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VEGETATION, LAND USE PATTERN AND SOIL SEED BANK COMPOSITION
ALONG ALTITUDINAL GRADIENT FROM LAKE TANA TO MOUNT GUNA,
SOUTH GONDAR, NORTHERN ETHIOPIA.

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BANK COMPOSITION ALONG ALTITUDINAL GRADIENT FROM LAKE
TANA TO MOUNT GUNA, SOUTH GONDAR, NORTHERN ETHIOPIA.**

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This is to certify that the thesis prepared by Birhanu Belay Telake, entitled: *Vegetation distribution, Land use pattern and soil seed bank composition along altitudinal gradients from Lake Tana to Mount Guna, South Gondar, Northern Ethiopia*, and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy (Biology: Botanical Science) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Birhanu Belay Telake

Addis Ababa University, 2018

Addis Ababa, Ethiopia

Dedicated

to

My late wonderful mother Hagnesh Abebe and Prof. Ensermu Kelbessa

ABSTRACT

Vegetation distribution, Land use pattern and soil seed bank composition along altitudinal gradients from Lake Tana to Mount Guna, South Gondar, Northern Ethiopia.

Birhanu Belay Telake, PhD Dissertation

Addis Ababa University, 2018

*The study area covers two watersheds (Rib and Gumara) occurring between Lake Tana and Mount Guna with elevation ranges between 1781 (near Lake Tana), and 4102 m asl (at Guna Mt.) which harbors different habitats. The study was conducted with the objectives of (i) investigating floristic composition, community types and vegetation structure, (ii) identifying the most important environmental predictors used to build habitat suitability Model for prioritized invasive species, (iii) evaluating soil seed bank composition, density and its implication for restoration, and (iv) determining the trend, rate and extent of LU/LC change for the period 1984-2017. Preferential sampling technique was used to establish 98 plots, 20 x 20 m each. The data was analyzed using R 3.4.2 software packages. In aboveground vegetation, a total of 342 plant species were identified, of which 97.53% were angiosperms, 5.84% endemic, 3.51% invasive and 52.05% were herbs. Asteraceae was the most dominant family with 47 (13.74%) species. Five community types were identified, of which *Cynodon dactylon* and *Eleusine indica* Community type I harbors 30.31% of the species. About 22.08% of the total IVI value calculated for *Chionanthus mildbraedii* (6.63%), *Juniperus procera* (5.89%), *Maytenus arbutifolia* (4.87%), and *Syzygium guineense* (4.69%). Maximum entropy (Maxent) indicates that the highest contribution to predict the spatial distribution of *Senna didymobotrya* was recorded from Classified Map (41%), and elevation (33.2%). Among 17 environmental parameters, only nine were significant at $p \leq 0.05$. In the soil seed bank, 12,896 individuals were extracted from 392 soil samples laid on 15 x 15 cm are represented by 140 species, 103 genera and 44 families. Poaceae was the most dominant family with 32 (22.86%) species. Seven LU/LC types were identified using ArcMap 10.3.1: Cropland, Forest, Grassland, Settlement, Shrubland, Water, and Wetlands. Cropland, Water and Settlement show an increasing pattern while Grassland, Shrubland and Wetlands continuously decrease with time series. But Forest showed an irregular pattern. It is hoped that this study will provide information for decision-makers and academicians on the vegetation status, long-term LU/LC changes, drivers and impacts of Rib and Gumara catchments in order to take appropriate measures.*

Key words/Phrases: *community, Lake Tana, structure, land use land cover, Mt. Guna, predictor, regeneration, soil seed bank.*

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TABLE OF CONTENTS

Contents	Pages
TABLE OF CONTENTS	VI
LIST OF ACRONYMS	XIV
CHAPTER ONE	1
1. INTRODUCTION.....	1
1.1. Background.....	1
1.2. Research questions, Hypotheses and Objectives	8
1.2.1. Research questions	8
1.2.2. Hypotheses.....	8
1.2.3. Objectives	9
1.2.3.1. General objective	9
1.2.3.2. Specific objectives	9
CHAPTER TWO	10
2. LITERATURE REVIEW	10
2.1. Agriculture in Ethiopia	10
2.2. Vegetation type of the study area.....	13
2.3. Soil seed bank and factors affecting its distribution	17
2.4. Vertical and horizontal distribution of seeds in the soil seed bank.....	18
2.5. Soil seed bank and area enclosure	21
2.6. Functional roles of soil seed banks	23
2.7. Land use land cover change and its cause	26
2.7.1. Causes of land cover change	27
2.7.2. Consequences of land use land cover change.....	29
CHAPTER THREE	31
3. MATERIALS AND METHODS	31
3.1. Description of the study area	31
3.1.1. Demographics	35
3.1.2. Geology and Soil	37
3.1.3. Climate and crops related with the livelihood of the community.....	38
3.1.4. Land use land cover and Vegetation types	40
3.2 Materials	41
3.3. Methods.....	42
3.3.1. Site selection, sampling design and plot establishment.....	42
3.3.2. Above ground vegetation.....	42
3.3.2.1. Structural data collection	44

3.3.2.2. Plant specimen collection and identification	44
3.3.3. Soil seed bank	46
3.3.3.1. Sampling method	46
3.3.4. Soil physical and chemical properties	48
3.3.5. Land use land cover change (LU/LC)	49
3.3.5.1. Description of land use land cover classes	49
3.4. Data analysis	51
3.4.1. Above ground vegetation.....	51
3.4.1.1. Vegetation data analysis	51
3.4.1.2. Structural data analysis	55
3.4.1.3. Environmental data analysis	56
3.4.2. Soil seed bank density and it's similarity with the above ground vegetation..	57
3.4.3. Data acquisition	59
3.4.3.1. Image and data processing	59
3.4.3.2. Land use and land cover image classification.....	60
3.4.4. Local ecological knowledge	61
CHAPTER FOUR.....	63
4. RESULTS	63
4.1. Above ground vegetation.....	63
4.1.1. Floristic composition	63
4.1.2. Distribution Model of <i>Senna didymobotrya</i>	70
4.1.3. Plant Community types	74
4.1.4. Community similarity	81
4.1.5. Species diversity	82
4.1.6. Population structure of woody species	84
4.1.6.1. DBH class	84
4.1.6.2. Height class.....	86
4.1.7. Natural regeneration potential of woody plant species	88
4.1.8. Basal area.....	90
4.1.9. The frequency, density and dominance of woody plant species	91
4.1.10. Importance value index (IVI)	94
4.1.11. Ordination	94
4.2. Soil Seed Bank Flora	101
4.2.1. Soil seed bank species composition.....	101
4.2.2. Frequency and density of the seed in the soil seed bank	105

4.2.3. The similarity of species composition among land uses	109
4.2.4. Species distribution across soil layers	110
4.3. Land use land cover change	115
4.3.1. Accuracy assessment	115
4.3.2. Area contribution of LU/LC types in three time periods.....	116
4.3.3. The affinity of LU/LC types to maintain their original state.....	117
4.3.4. Pattern and rate of change with time series	124
CHAPTER FIVE	126
5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS	126
5.1. DISCUSSION	126
5.1.1. Above ground vegetation.....	126
5.1.1.1. Floristic composition	126
5.1.1.2. Community types	128
5.1.1.3. Species diversity	133
5.1.1.4. The structure of woody species.....	135
5.1.1.5. Basal area.....	139
5.1.1.6. Density, frequency and IVI value	140
5.1.1.7. Natural regeneration potential of woody species.....	142
5.1.1.8. Endemic taxon	145
5.1.1.9. Invasive plant species	146
5.1.1.10. Impact of environmental variables on vegetation distribution	150
5.1.2. Soil seed bank.....	157
5.1.2.1. Species composition in the soil seed bank.....	157
5.1.2.2. Soil seed bank and LU/LC types	157
5.1.2.3. Soil seed bank frequency and density of species in the soil seed bank ..	164
5.1.2.4. Soil seed bank species and density distribution in different land uses ...	165
5.1.2.5. Depth distribution of soil seed bank composition and density	167
5.1.2.6. Comparison between above ground vegetation and soil seed bank.....	171
5.1.2.7. Implication and contribution of soil seed bank flora for rehabilitation ..	176
5.1.3. Land use land cover change.....	178
5.1.3.1. Accuracy assessment	178
5.1.3.2. Pattern, rate and extent of LU/LC and its implication.....	178
5.1.3.3. Conversion of LU/LC types between three time periods	185
5.2. CONCLUSION.....	188
5.3. RECOMMENDATIONS.....	192
6. REFERENCES.....	194
APPENDICES.....	220

LIST OF FIGURES

Figure 1: Acacia-Commiphora woodland and bushland at 1884 m asl	14
Figure 2: Overview of Afroalpine and sub Afroalpine vegetation (4102 m asl)	15
Figure 3: The source of Rib River from the starting point the catchment	15
Figure 4: Riverine vegetation <i>Phoenix reclinata</i> and <i>Syzygium guineense</i> at Adam	17
Figure 5: The conceptual model to show the complex pathways of seeds and their fate.	21
Figure 6: The experience of destocking to feed straw	23
Figure 7: Framework for analyzing proximate and underlying causes of LU/LC change	29
Figure 8: Map and location of the study area	33
Figure 9: Different geographic features of the study area.	34
Figure 10: The distribution of the three agro-ecological zones along the study area	35
Figure 11: Climate Diagram of the Study Area:	39
Figure 12: Sampling strategy: for trees and shrubs (a), herbs (b) and soil seed bank (c).	43
Figure 13: The process of soil seed bank germination at different periods.	57
Figure 14: Inhabitats involved as interviewee during fieldwork	62
Figure 15: The distribution of species along two major family classes.....	64
Figure 16: Plant habit of the study area	69
Figure 17: Area under the receiver-operating curve (AUC) of the training data.....	71
Figure 18: The response of <i>Senna didymobotrya</i> to different environmental predictors	72
Figure 19: The spatial distribution potential of <i>Senna didymobotrya</i>	73
Figure 20: The optimal number of clusters.....	74
Figure 21: Plant community types of Rib and Gumara watersheds.....	75
Figure 22: The species richness distribution Model using Boosted Regression Tree	83
Figure 23: DBH (cm) class distribution of woody plant species	85
Figure 24: Height (m) class distribution of woody plant species	87
Figure 25: Seedlings, saplings and matured woody plant species distribution pattern	88
Figure 26: Species and plot ordination diagram based on CCA, with nine variables	96
Figure 27: The affinity of altitude towards the spatial distribution of vegetation	97
Figure 28: Soil texture triangle using library soiltexture	100
Figure 29: Distribution of texture classes	100
Figure 30: Habit distribution in the soil seed bank	102

Figure 31: Distribution of species in the corresponding land use types	104
Figure 32: The distribution of habits among different land use types	105
Figure 33: Species unique to the corresponding land uses	108
Figure 34: Depth distribution of seeds/seedlings in the soil seed bank	111
Figure 35: Depth distribution of seeds in the corresponding sampling layers.....	111
Figure 36: The distribution of species unique to the corresponding sampling layers	112
Figure 37: Land use land cover Map of Rib and Gumara watersheds in 1984.....	119
Figure 38: Land use land cover Map of Rib and Gumara watersheds in 2000.....	121
Figure 39: Land use land cover Map of Rib and Gumara watersheds in 2017.....	123
Figure 40: Distribution pattern of LU/LC in Rib and Gumara watershed from 1984-2017	123
Figure 41: Inhabitants assembled at Kolay Mariam Church Forest as a memory for Saint Mary's flight from Nazareth of Galilee to Egypt	142

LIST OF TABLES

Table 1: Population by Urban-Rural Residence and Sex: 2007	36
Table 2: Population size, involved number of Kebeles and Agro-ecological zones	36
Table 3: Percentage distribution of Households by family size	36
Table 4: Land use type and the corresponding plot size	44
Table 5: The methods used to analyze the soil physical and chemical properties.....	56
Table 6: The date of acquisition and spatial resolution of the data set	59
Table 7: List of endemic plants species and their IUCN categories	64
Table 8: List of species considered as weeds by the local people (left) and recognized as invasive at a national level in Ethiopia (Right).....	66
Table 9: Plant families with their corresponding genera, species number and frequency	67
Table 10: Indicator plant species of the five community types significant at $P \leq 0.05$	76
Table 11: Matrix to show the possible comparison of communities using JCS	82
Table 12: The diversity, richness and evenness of the five Community types.....	82
Table 13: Distribution of species along an elevation.....	84
Table 14: Distribution of DBH, classes with species number, density and basal area	85
Table 15: Height class, distribution with species number, density and basal area	86
Table 16: Basal area, density and percent contribution of 17 species with a basal area ≥ 1	90
Table 17: Ten most frequent plant species	91
Table 18: Plant families with their genera, total species number and frequency	92
Table 19: The first 10 dominant families with a high number of individuals	94
Table 20: ANOVA test to check the level of significance for environmental variables ..	95
Table 21: Summary of the correlation coefficient of nine environmental variables	97
Table 22: The list of soil parameters and its minimum and maximum values	98
Table 23: Sample soil texture classes	99
Table 24: List of families in the SSB with its species and genus number	102
Table 25: Density distribution over different LU/LC types and habits	107
Table 26: The family, density and species number of five LU/LC types	109
Table 27: Similarity matrix among five LU/LC types.....	109

Table 28: The vertical distribution of seed's density with increasing depth.....	110
Table 29: Similarity value between sampling layers	113
Table 30: Species, population and density distribution of the four layers.....	113
Table 31: LU/LC types with their corresponding areas (Ha) in Rib and Gumara watershed in three different periods (1984, 2000 and 2017)	116
Table 32: LU/LC change matrix (Ha) and percent cover between 1984 and 2000	118
Table 33: LU/LC change matrix (Ha), and percent cover between 2000 and 2017	120
Table 34: LU/LC change matrix (Ha), and percent cover between 1984 and 2017	122
Table 35: Land use land cover change rate and extent in Rib and Gumara Watersheds in different time periods	125

LIST OF APPENDICES

Appendix 1: List of plants species with their family for the above ground vegetation ..	220
Appendix 2: Important value index (IVI value) of the woody species.....	234
Appendix 3: Synoptic table of the five community types with >0.2 value	239
Appendix 4: Incidence of species in the corresponding DBH and species number	245
Appendix 5: Incidence of species in the corresponding height class.....	250
Appendix 6: List of Seedlings and/or Saplings with their correspond family	255
Appendix 7: Soil chemistry test compared with standard soil fertility classes.....	258
Appendix 8: List of plants with the corresponding family in the soil seed bank	260
Appendix 9: List of families and its species number in the soil seed bank	265
Appendix 10: List of plant species unique to the corresponding layer of SSB	267
Appendix 11: Dominant families, species number and habit in the corresponding LU/LC of soil seed bank.....	269
Appendix 12: Semi-structured interview schedule for the inhabitants.....	270

LIST OF ACRONYMS

ABS	Access and Benefit Sharing
AGV	Above Ground Vegetation
AUC	Area under the Receiver Operating Curve
CCA	Canonical Correspondence Analysis
CEPF	Critical Ecosystem Partnership Fund
DAF	Dry evergreen Afromontane forest and grassland complex
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
EFAP	Ethiopian Forestry Action Program
EPA	Environmental Protection Authority
ETM+	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information Systems
IS	Invasive Species
IUCN	International Union for Conservation of Nature and Natural Resources
IVI	Importance Value Index
LU/LC	Land Use Land Cover
MAF	Moist evergreen Afromontane forest
NMA	National Meteorological Agency of Ethiopia
ORDA	Organization for Rehabilitation and Development in Amhara
RS	Remote Sensing
SDMs	Species distribution models
SSB	Soil seed bank
TaSBO	Tana Sub Basin
TM	Thematic Mapper
UNCED	United Nations Conference on Environment and Development
UNFAO	United Nation Food and Agriculture Organization of the United Nations.
USDA	United States Department of Agriculture

CHAPTER ONE

1. INTRODUCTION

1.1. Background

The topography of Ethiopia is composed of rugged mountains, flat topped plateaus, deep gorges, incised river valleys and rolling plains, which bring different climatic conditions (Zerihun Woldu, 1999). Such diversified range of environmental conditions enabled the country to possess very diverse plant and animal life (Demel Teketay, 1996). Because of these and other factors Ethiopia is known for its plant species which are ecologically and economically important and its vegetation has been described and classified based on climate and altitude as the most important environmental factors (Zerihun Woldu, 1985; Daniel Gamachu, 1977; FAO, 1996).

The higher parts of Ethiopian highlands are unique Afroalpine areas with diverse fauna and flora. The Afroalpine region covers more than 25,000 km² of land above 3,200 m asl, and more than 300,000 km² of land above 3000 m asl (Lisanework Nigatu, 1987; Tewoldeberhan Ghebregziabher, 1986; FAO, 1996; Hillman, 1986). Besides, their wonderful panorama, these highlands possess attractive, indigenous vegetation and home to endemic species.

The forest cover of Ethiopia used to be 35-40% of its total land area (EFAP, 1994). As a result of clearing of forests for cultivating crops and cutting trees and shrubs for various purposes, the natural forest cover has declined to 16% of the land area in the early 1950s, to 3.6% in the 1980s and to 2.7% in 1989 (EFAP, 1994; Kindu *et al.*, 2006). According to FAO (1981), Constable (1985), Assefa Kuru (1990) and Eshetu Yirdaw (1996), forest areas have been reduced from 40% a century ago to an estimated less than 3% with the current rate of deforestation estimated at 160,000 to 200,000 hectares, but according to the report of FAO (2010), today the forest area estimated to be 11%.

Rapid deforestation and degradation of land resources are taking place in Ethiopia on the account of high population increase have resulted in extensive forest clearing for agricultural use, exploitation of existing forests for fuelwood, fodder, construction materials, unsustainable exploitation of wood for timber, overgrazing and civil unrest are among the main anthropogenic causes of deforestation in Ethiopia. Deliberate fire and non-integrated investment activities are also becoming the major reasons for the reduction of forests. The rapidly growing population aggravates the causes and this has been argued by many studies (Christopher, 1981; Bongers *et al.*, 1988; Dowsett-Lemaire, 1988; Sebsebe Demissew, 1988; Tamrat Bekele, 1993; Demel Teketay, 1996; and FAO, 2001).

Degradation of the Environment followed by intensive agriculture in Tropical dry evergreen Afromontane forest and Shrubland complex (DAF) influence an endangered and native forest biodiversity, not only through the outright loss of habitat but also by declining the soil seed bank flora. The results showed that the contribution of woody species to the soil seed flora declined from 5.7% after 7 years to nil after 53 years of continuous cultivation. This ultimately affects the ecosystem through land degradation, which is defined as the process of progressive deterioration of biological (flora and fauna) and physical (soil, water, micro-climate, etc.) resources of the land, leading to declining productivity and unsustainable yields (Singh, 1995). In Ethiopia, consistent cropping jointly with the removal of harvest residues, absence of sufficient soil nutrients and recycling technologies has also its own contribution in aggravating land degradation (Bojo and Cassels, 1995; Sahlemedhin Sertsu, 1999).

In the highlands of Ethiopia which includes the northern part of Ethiopia (e.g. Rib and Guna watersheds), where intense population, high livestock density resulting high land degradation, known for its massive soil loss by water erosion ranging from 3.4 to 84.5 tons per ha per year

(El-Swaify, 1997). In these areas, land degradation has a long history, which was settled 5000 years ago (Hurni, 1987; El-Swaify, 1997).

One of the main concerns in ecological research has been identifying factors and understanding nature processes (Mueller-Dombois and Ellenberg, 1974), a special concern has been given to the relationship between biological dependent variables including an abundance of species, the structure of ecological communities and environmental factors, such as soil parameter, land use system and topography (Legendre *et al.*, 2002). The experience of many ecologists during their field time shows that living organisms and physical processes are distributed neither randomly nor uniformly, but they show spatial and temporal patterns (Legendre, 1993; Legendre and Legendre, 1998; Wagner and Fortin, 2005). The analyses of species-environment relationship have always been a central issue in ecology. The climate in combination with other environmental elements has been highly used to explain the fundamental vegetation patterns around the world (Humboldt and Bonpland, 1807; Good, 1953; de Candolle, 1855; Box, 1981; Walter, 1985; Woodward, 1987; Ellenberg, 1988).

Environmental variables including soil moisture, topographic position, slope, elevation and aspect are important controls on plant population structure at both local and landscape scales (Whittaker, 1967; Christensen and Peet, 1984; Allen *et al.*, 1990). These factors are also the most important determinants of the plant species abundance and its spatial distribution of vegetation as forest stands density, basal area and species composition varies according to these environmental variables (Taylor and Skinner, 1998; Taylor and Solem, 2001).

Different species may be adapted to specific site conditions or elevations and can hold a site by out-competing other, less adapted species (Ashton *et al.*, 1995; Oliver and Larsen, 1996;

Gunatilleke *et al.*, 1998; Singhakumara, 2000). For example, plants that dominate lower elevations are generally more drought tolerant than higher elevation species (Padien and Lajtha, 1992; Linton *et al.*, 1998). This ultimately has a direct impact on the Economy of local communities. That is why millions' of people in mountain areas depend on forests and plants as they effectively protect people against natural hazards such as rock fall, landslides, debris flows and floods (Brang *et al.*, 2001). Settlement and transportation center in alpine areas most of the time depending on the protective effect of the vegetation (Agliardi and Crosta, 2003). Therefore, understanding of distribution and patterns of vegetation growth along with the affecting factors in those areas are important and have been studied by many researchers (Oliver and Webster, 1986; Weiser *et al.*, 1986; Stephenson, 1990; Turner *et al.*, 1993; Henebry, 1993; Endress and China, 2001; Bai *et al.*, 2004).

Topography affects soil and climate in addition to affecting temperature and evapotranspiration (as elements of climate), makes deeper soil and higher content of organic matter. As a result, an intensive vegetation distribution has occurred (Jenny, 1980). Enright *et al.* (2005) showed that physical environmental factors likely to affect water availability were more important than soil chemicals, animal grazing and human impact factors for determining the distribution of major vegetation types and species richness patterns. Topography is thus a principal controlling factor in vegetation cover and that the type of soils and the amount of rainfalls play secondary roles at the scale of hill slopes (O'Longhlin, 1981; Wood *et al.*, 1988). Elevation, aspect and slope are the three main topographic factors that control the distribution and pattern of vegetation in mountain areas (Titshall *et al.*, 2000). Of these three variables, elevation is most critical (Day and Monk, 1974; Busing *et al.*, 1992). Elevation along with aspect and slope in many respects

determines the microclimate and thus large-scale spatial distribution and patterns of vegetation (Geiger, 1966; Day and Monk, 1974; Allen and Peet, 1990; Busing *et al.*, 1992).

Mountainous areas have steep gradients of moisture and temperature (Whittaker, 1975) and provide the opportunity to study biologically significant differences in an environment over a short distance. These gradients are caused by orographically induced precipitation patterns, adiabatically and topographically induced changes in temperature and hydrologic processes that redistribute water in steep terrain (Barry, 1992; Ambrose, 1995). The resulting vegetation pattern is typified by closely spaced ecotones, because of the overwhelming influence of environmental factors, may be especially sensitive to climate changes.

The composition, structure and dynamics vegetation is also affected by soil seed bank (Thompson *et al.*, 1997), which refers to dormant seeds that are present in the soil. Buried seeds of many species can retain their viability for long periods (Roberts, 1981; Telewski and Zeevaart, 2002). Soil seed bank flora is defined as the seeds that can remain dormant for a period of time in the soil until their germination is triggered by an environmental change (Simpson *et al.*, 1989). Furthermore, soil seed banks are considered as essential constituents of plant communities (Harper, 1997). Seed bank studies can provide important information for restoration and management purposes (Katharina *et al.*, 2009) and play a significant role in biodiversity maintenance, ecosystem restoration, management and conservation of genetic variability through replacing adult plants (Mulugeta Lemenih and Demel Teketay, 2006). Thus, it is acknowledged as a low cost restoration technique. According to Godefroid *et al.* (2009), the current and past above ground vegetation and the seed rain from adjacent areas identified as the main factors that determine the composition of the seed bank.

The soil seed bank represents the regeneration potential of the plant communities and it is regarded as a memory of the former plant community; thus, it could be important for conservation and restoration of species and plant communities (Bakker *et al.*, 1996) and play an important role in restoring former species diversity (Bakker *et al.*, 1996). Hence, according to McDonald *et al.* (1996) and Bekker *et al.*(1998), soil seed bank persistence is an important factor in the regeneration of plant communities and also for the assessment of the local extinction risk (Stöcklin and Fischer, 1999).

In general, the loss of vegetation cover is just one of several indicators of degradation. A combination of indicators may be used as a management level to assess the level of degradation of a particular site or landscape. List of indicators such as vital eco-system or landscape attributes, eco-system health assessment and landscape function indicator will be forwarded. At eco-system level, they may include attributes related to composition and structure, total plant cover, perennial species richness, the presence of keystone species, particular functional groups and functional attributes like; productivity, soil, organic matter content, rainfall efficiency are among the most active indicators. Therefore, it is important to know the type of land use pattern and current status of the spatial distributing of the vegetation to identify the threats and opportunities for the rehabilitation of the area. Therefore, the decision-making process can be initiated in order to make management interventions for biodiversity conservations and hydrological process.

The change in vegetation cover often leads to land degradation and consequently to problems in watershed management resulted from land use change stressed by high population growth. Failure in understanding the interactions between biodiversity, land use land cover and other physiographical environmental variables such as elevation, slope, aspect and others aggravate the

problem of biodiversity loss. Climate and land use change may affect the biodiversity in particular and functioning of the Earth's ecosystems in general (Hautier *et al.*, 2015). However, quantifying these dynamic relationships both in spatial and temporal pattern are compounded by challenges, specifically elucidating the impacts of land use land cover at the local to regional scales. Understanding the interactions between terrestrial ecosystems and the atmosphere are fundamental in addressing issues of climate change and environmental degradation.

Because Land Use Land Cover change study hereafter abbreviated as LU/LC is a significant section in understanding the connections of the human activities with the environment and thus it is important to be able to simulate changes. It is a major issue of global environmental change that is why, scientific research community called for a substantive study of land use changes during the 1972 Stockholm Conference on the Human Environment; at the 1992 United Nations Conference on Environment and Development (UNCED). Because, LU/LC change is the major threat to biodiversity.

Hence, understanding the driving forces of land use development in the past, managing the current situation with modern Geographic Information System (GIS) tools, Remote Sensing (RS) and modeling the future, one is able to develop plans for multiple uses of natural resources and nature conservation through efficient methods of analysis. The change in any form of land use is largely related with the problems of external forces and the pressure built up within the system (Bisht and Kothiyari, 2001) which has a direct contribution for runoff and sedimentation problems. Thus, this study aimed to answer the following research questions and attaining the corresponding objectives.

1.2. Research questions, Hypotheses and Objectives

1.2.1. Research questions

This study will provide answers to the following questions.

- What would be the floristic composition, density and vegetation structure of the study area?
- Which environmental predictors have a strong relationship to define the habitat suitability of selected invasive species?
- What is the potential for forest restoration if converted lands would be left alone?
- Which LU/LC type relatively show high rate and extent of change?

1.2.2. Hypotheses

- The diversity of the species increase with decreasing elevation;
- The distribution of invasive species is high in cropland use;
- The influence of all environmental variables on the species distribution and composition is the same;
- The future distribution potential of selected species would be limited along the main roads;
- The similarity in species composition in soil seed bank and above ground vegetation is the same;
- The number of species in the corresponding sampling layers increases with increasing soil depth.

1.2.3. Objectives

1.2.3.1. General objective

The general objective of this study is to investigate the relationships between vegetation cover, soil seed bank distribution from Lake Tana (1781 m asl), to Mount Guna (4102 m asl) and to understand the impact of environmental factors on land use land cover change (LU/LC) and plant species diversity in Gumara and Rib watersheds, South Gondar, Ethiopia.

1.2.3.2. Specific objectives

- To investigate the floristic composition, community types and vegetation structure in the study area;
- To identify the most important environmental predictors used to build habitat suitability Model for prioritized invasive species;
- To evaluate soil seed bank composition, density and its implication for restoration;
- To determine the trend, rate and extent of LU/LC change for the period 1984-2017.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Agriculture in Ethiopia

In Ethiopia notably in its highland parts, agricultural activities must have started about 5000 years ago (EPA, 1997). The Highlands of Ethiopia cover about 45% (FAO, 1986) of the land area; and are home to almost 90% of the entire population and 75% of livestock (Hawando, 1997; Mc Cann, 1995). The highland areas had fertile soil, less disease, relatively higher rainfall, adequate moisture for production and low evapotranspiration compared to lowland parts of Ethiopia (Hawando, 1997). These existing circumstances in these areas in turn create a healthy environment to live and work (FAO, 1986) and are responsible for 95% of cultivated land that accounts for 90% of the Ethiopian economy (Mc Cann, 1995).

Thus it is believed that the Ethiopian highlands have historically contributed for the early development of agriculture as these areas have been prime targets for human settlement (Hurni, 1990), which enabled the area for agricultural expansion and eventually cause the area to be more degraded (EI-Swaify and Hurni, 1996) compared to the lowlands of Ethiopia. Due to this high population concentration and the interest to expand agriculture in such areas, there were high activities of deforestation that started about 2500 years ago (Hurni, 1988), that caused environmental degradation and fertile soil loss occurring at alarming rates (Jijo, 2005). Thus, agricultural expansion has impacted land degradation and soil erosion.

The situation was aggravated by other related factors such as overgrazing, exploitation of existing forests for fuelwood, fodder, construction materials, timber production and civil war that are the main causes of deforestation. The study area is a part of such environment where the area is highly deforested, heavily eroded with nutrient deficient soils, hydrological instability, reduced

productivity and loss of biological diversity to the extent that different land use forms are created (Descorais *et al.*, 2008). In addition, poor land use and improper management systems and a lack of appropriate soil conservation practice have played a major role in land degradation in Ethiopia (Shimelis Setegn *et al.*, 2009). The problem of watershed management and land degradation is due to the failure of understanding on the interaction of the problem with other factors notably LU/LC change which has a direct impact on runoff, sedimentation load, vegetation cover and others which contributes to low agricultural production.

The extent of past forest cover on the Ethiopian highland is evident from the numerous isolated mature forest trees or small patches of forests (Alemayehu Wasse, 2005), which holds true for the study area with some remnant forests, forest patches and shrublands. This indicates that Land degradation has a long history in the northern highlands, which were settled 5000 years ago (Hurni, 1987; El-Swaify, 1997). For example, Carbon dating showed that forest burning in Welo and neighboring floristic regions began over 2460 years ago, which indicated that there is a long history of resources degradation (Hurni, 1987).

As a result, it was estimated that fertile topsoil loss through erosion was estimated at a rate of one billion m³/year (FAO, 1981; Constable, 1985; Assefa Kuru, 1990; Eshetu Yirdaw, 1996). The average annual soil loss rate estimate of the whole catchment in the study area was 0.5mm/year compared to the rate observed between 0.053 and 0.080 mm/year from 29 million years ago (Gani *et al.*, 2007; Garzanti *et al.*, 2006). The loss from newly cleared forest for crop production purposes was reported to be 130 t/ha/yr-1 (Solomon Abate, 1994), which caused massive environmental degradation and constituting a threat to sustainable agriculture. The degree of soil erosion is highly related to the interaction of land use land cover, soil type, slope, rainfall amount and its intensity and management may have played an important role in Ethiopia.

Due to an increase in agriculture, there is also an expansion of Invasive Plant Species. These days, the native flora in the study area is highly degraded and there is a gradual expansion of exotic plant species. Invasive species (IS) are the second most noteworthy cause for biodiversity loss next to habitat destruction through their rapid propagation and spreading potential which may displace ecologically important indigenous and endemic plant species (IUCN, 2014). The expansion of the invasive species also affects the farming activity negatively creating negative impacts on food security, health and economic development (McNeely *et al.*, 2001).

Modeling exercise on the potential distribution and habitat suitability is a fundamental knowledge for conservation planning and management of a prioritized species through the application of Maxent Modeling in the field of ecology and conservation (Graham *et al.*, 2004). For example, Maxent Modeling has been applied to study the spread of invasive species (Thuiller *et al.*, 2005) that affects the cropping system (agriculture) in Ethiopia, impacts of climate change (Thomas *et al.*, 2004) and spatial patterns of species diversity (Graham *et al.*, 2006). Species distribution models (SDMs) are increasingly applied as predictive tools for these purposes. Species distribute themselves based on defined niche, spaces and their probabilities of occurrence in accordance with environmental variables (Snyder and Chesson, 2003).

It is a very important approach in predicting species distribution based on presence data only jointly with predictor variables such as topographic, climatic, edaphic, biogeographic and remotely sensed predictors. Different techniques such as climatic envelopes, logistic regression, boosted regression tree, multivariate regression were employed and different predictions were observed (Pearson *et al.*, 2007). Recently, relatively a more accurate method called Maxent is established. Maxent has a unique feature in that it can fit more complex models from smaller datasets, with its explicit “regularization” mechanisms to prevent model complexity from

increasing beyond what is supported by the empirical data to optimize its predictive accuracy (Phillips *et al.*, 2006). Hence, it is more appropriate to apply with the current study on selected and prioritized invasive species and available environmental predictors.

2.2. Vegetation type of the study area

The spatial distribution of vegetation in Ethiopia is not uniform based on a number of natural factors such as elevation, slope, geology, climate, etc.; and anthropogenic factors including deforestation that resulted from high population growth. The classification and description of vegetation types in Ethiopia were started by foreign scholars such as Breitenbach (1963), Pichi-Sermolli (1957), who identified 23 vegetation types. Since then there have been studies on the vegetation types or on one of these by a number of Ethiopians (Tamrat Bekele, 1994; Sebsebe Demissew *et al.*, 1996; Kumilachew Yeshitela, 1997; Teshome Soromessa, 1997; Sebsebe Demissew, 1998; and Zerihun Woldu, 1999) to mention a few.

These vegetation types were grouped into eight (Friis and Sebsebe Demissew, 2001). Recently Friis *et al.*, (2011), identified and described twelve major vegetation. These are "i) Desert and semi-desert scrub land, ii) *Acacia-Commiphora* woodland and bushland, iii) Wooded grassland of the western Gambella region, iv) *Combretum-Terminalia* woodland and wooded grassland, v) Dry evergreen Afromontane forest and grassland complex, vi) Moist evergreen Afromontane forest, vii) Transitional rain forest, viii) Ericaceous belt, ix) Afroalpine belt, x) Riverine vegetation xi) Fresh water lake, lake shores, marshes, swamps and Flood plains vegetation, and xii) Salt-water lakes, lake shores, salt marshes and pan vegetation (Friis *et al.*, 2011)". In this study, there are also subtypes (Friis *et al.*, 2011).

In the current study area, there are five of the vegetation types and described below.

***Acacia-Commiphora* woodland and bushland (ACB):** It is dominated by various acacia species mixed with different grass and other herbaceous species (Fig. 1). This vegetation type has highly encroached for grazing and agriculture purpose.



Figure 1: *Acacia-Commiphora* woodland and bushland at 1884 m asl (Photo by Birhanu Belay, November 2015)

Afroalpine and sub-Afroalpine Vegetation: This type of vegetation found in areas where the average elevation is higher than 3200 meters above sea level (Hedberg, 1957). The area that represents this type of vegetation is Mount Guna found in the range from 3200-4102 m asl (Fig. 2), which comprise both Sub-Afroalpine in the range from 3200-3500 and Afroalpine which measures >3500 meters above sea level (Hedberg, 1957). Mt. Guna is the source of Rib and Gumara rivers which heading to Lake Tana, as a spring is originated under the mountain (Fig. 3). The summit of the mountain is the boundary for the three administrative Woredas such as Farta,

Gayint and Este and divides the watersheds as Tana (Blue Nile), Tekeze and Beshilo. The predominant plants for such vegetation types include *Lobelia rhynchopetalum*, *Helichrysum citrispinum*, *Dianthoseris schimperi*, *Alchemilla pedata* in which all of the species appeared in the study area. The bottom of the mountain is dominated by *Erica arborea* (Fig. 3) and some *Hypericum revolutum* and few *Echinops longisetus* are appeared.



Figure 2: Overview of Afroalpine and sub Afroalpine vegetation (4102 m asl), the left (Eastern part), and the right (Western part) of Mount Guna (Photo by Birhanu, November 2015)



Figure 3: The source of Rib River from the starting point the catchment (a), the bottom of mount Guna dominated by *Erica arborea* (b), and when the catchment water enter to the Lake Tana (c), (Photo by Birhanu, November 2015)

Dry evergreen Afromontane forest and grassland complex (DAF): This vegetation type represent more than 50% of the land of which DAF form the largest part (Tamrat Bekele, 1994), and occur in the range between 1500 m and 3000 m in altitude, with an average temperature and rainfall 14-45 °C and 700-1100 mm, respectively (Friis, 1992 and Zerihun Woldu, 1999). It is characterized by *Juniperus procera* and/or *Olea europaea* subsp. *cuspidata* as the main trees with *Acacia abyssinica*, *Podocarpus falcatus*, *Olea capensis* subsp. *hochstetteri*, *Prunus africana* and others as a tree layer. While the shrub layer is represented by *Calpurnia aurea*, *Myrsine africana* and *Olinia rochetiana* (Zerihun Woldu, 1999).

Freshwater marshes and swamps, floodplains and lakeshore vegetation (FLV/MFS): The study area include the wetlands of Lake Tana and Fogera plains that represent the vegetation type. It is dominated by *Eichornia crassipes*, *Ludwigia stolonifera*, *Nymphaea lotus*, *Nymphoides brevipedicellata*, *Cyperus dichroostachyus*, *Cyperus longus* and *Schoenoplectus articulatus*.

Riverine vegetation: This vegetation type includes the vegetation along the river within 20 meters range from both sides of the river, which has different structure and density (Fig. 4). The most pre-dominant and representative plants for riverine vegetation include *Phoenix reclinata*, *Celtis africana*, *Ficus sycomorus*, *Syzygium guineense* and *Mimusops kummel* (Friis *et al.*, 2011), in which most are appeared along the rivers of the recent study area. This type of vegetation is found almost in all parts of the country with permanent or temporary rivers and other streams below 1800 m. However, it is relatively rare to occur in the driest parts of Afar, Harerge and Sidama floristic regions.



Figure 4: Riverine vegetation *Phoenix reclinata* and *Syzygium guineense* at Adam River with an altitude of 1988 m asl (Photo by Birhanu Belay, November 2016)

2.3. Soil seed bank and factors affecting its distribution

Soil seed bank is defined as the mature viable seeds stock existing in the soil surface, or buried in the soil, litter, in a determinate moment and place capable of replacing the adult plants (Qiuyan *et al.*, 2011). It plays a vital role in vegetation composition and maintenance of future vegetation (Peco *et al.*, 1998), succession, ecosystem restoration, differential species management and conservation of genetic variability (Harper, 1977; Hills and Morris, 1992; Leck *et al.*, 1989; McGraw *et al.*, 1991; van der Valk and Pederson, 1989). It is acknowledged as a low-cost restoration technique through reducing resources, manpower and related problems that start during collection through propagation up to transplanting and growing to the field (van der Valk and Pederson, 1989). Seed banks are the potential source for the restoration of degraded lands

(Bakker *et al.*, 1996; Waldhardt *et al.*, 2001; Luzuriaga *et al.*, 2005; Dölle and Schmidt, 2009), and succession of bare habitats (Grandin and Rydin, 1998; Falińska, 1999; Bekker *et al.*, 2000).

The abundance of seeds as the soil seed bank vary according to seed proximity from the parent plant, seed persistence or state of dormancy (Walck *et al.*, 2005), and physiological state and dispersal units. Dispersal units affect the number of viable seeds through assisting the seeds to penetrate the soil structure (e.g using bracts); protecting the germination units from decomposers, seed predators and pests (e.g bracts, seed coats and spikes). For example, *Ranunculus arvensis* has a thick seed coat and spikes in which both decompose after a few years and leaving the germination units to be germinated. The distribution and the abundance of the seeds in the soil seed bank is also affected by other factors such as **duration** (Poschlod *et al.*, 1998); **season** (Milberg and Anderson, 1997); **depth** (Feyera Senbeta and Demel Teketay, 2002; Benvenuti, 2007); and **quantity** (Thompson *et al.*, 1997).

2.4. Vertical and horizontal distribution of seeds in the soil seed bank

The distribution of seeds in different LU/LC types (Horizontal distributions) and the distribution of the seeds in different soil layers (vertical distributions) in the soil seed bank show variations in space and time (Feyera Senbeta and Demel Teketay, 2002). The vertical and horizontal distributions of seeds is initially related to dispersal and its mechanism that determine the pattern and the distance from the parent to the surface. It is highly affected by the morphology of the seeds such as size and shape as gravity can move large and heavy seeds with a special structure (e.g awn) deeper into the soil column than small and lighter seeds, but if the physical structure of the soil is not suitable, the pore may not allow the seeds to pass through and reduce the chance (Harper, 1977).

However, the distribution and the dynamics of soil seed bank after dispersal are functions of inherent properties of seeds such as germination, local decay, seed movement in the soil and other factors (Chambers and MacMahon, 1994), dormancy, pathogens, viability and the environmental conditions where seeds land (Demel Teketay, 2005a).

Because, animals often forage according to their preference considering the size, food content of seeds and other factors. For example, rodents and birds prefer larger seeds, while ants prefer small seeds (Samson *et al.*, 1992; Guo *et al.*, 1995). Regardless of all these factors, successful regeneration depends upon the seeds being dispersed into safe sites where seeds can germinate and establish as seedlings (Schupp, 1995). When primary dispersal (from mother plant to the soil surface), followed by secondary dispersal (from the ground to elsewhere) via birds, rodents, ants and others agents which have a vital importance for disturbed areas through, providing seeds new opportunities to reach on favorable sites. However, it has generally received little attention much less than primary dispersal in the scientific literature (Chambers and McMahon, 1994).

The horizontal distribution of seeds determine the vertical distribution of the seeds although, the vertical distribution and the storage of the seeds in the soil column are also affected by different tillage systems (Cardina *et al.*, 1991), and burrowing activities (Chambers and MacMahon, 1994), by different animals through allowing seeds to move deeper. Soil conditions such as particle sizes, structure and soil chemistry are also among the factors, which determine the distribution of the seeds and its storage as a soil seed bank (Chambers and MacMahon, 1994).

In addition to several external factors such as seed coat, biochemical inhibitors, immature embryo (Alemayehu Wasse, 2007), and internal factors such as soil water content and temperature (Fernandez *et al.*, 1991), the longevity of the seeds depends on burial depth, plant

species and soil moisture (Bekker *et al.*, 1997). Seeds in the soil last longer with the deeper layers (Qi *et al.*, 1996), notably with impermeable coats (Owen, 1950). But if the soil type is coarse textured it allows the seeds to move deeper by ants and worms (Kebrom Tekle and Tesfaye Bekele, 2000). This is the main reason why seed densities vary considerably over small distances, observed as dense or comparatively without any seeds (Thompson, 1986; Benoit *et al.*, 1989; Dessaint *et al.*, 1991).

The viability of the seed in the soil bank is affected by different factors notably intensive grazing and deforestation. These activities determine the seeds return as a soil seed bank (O'Connor *et al.*, 1992). The study area is identified as one of the areas that experience intensive grazing and high deforestation. Both the vertical and horizontal distributions of the seeds in different microhabitat and soil depths are very important in promoting the diversity of above ground vegetation.

The complex pathways of populations of seeds from seed production (primary and secondary dispersal) to seed establishment are shown using different models since 1970s (Harper, 1977; Fenner, 1985; Chambers and McMahon, 1994; Baskin and Baskin, 1998; Vander Wall *et al.*, 2002). On the basis of these models, a new model is developed and illustrated by a figure (5).

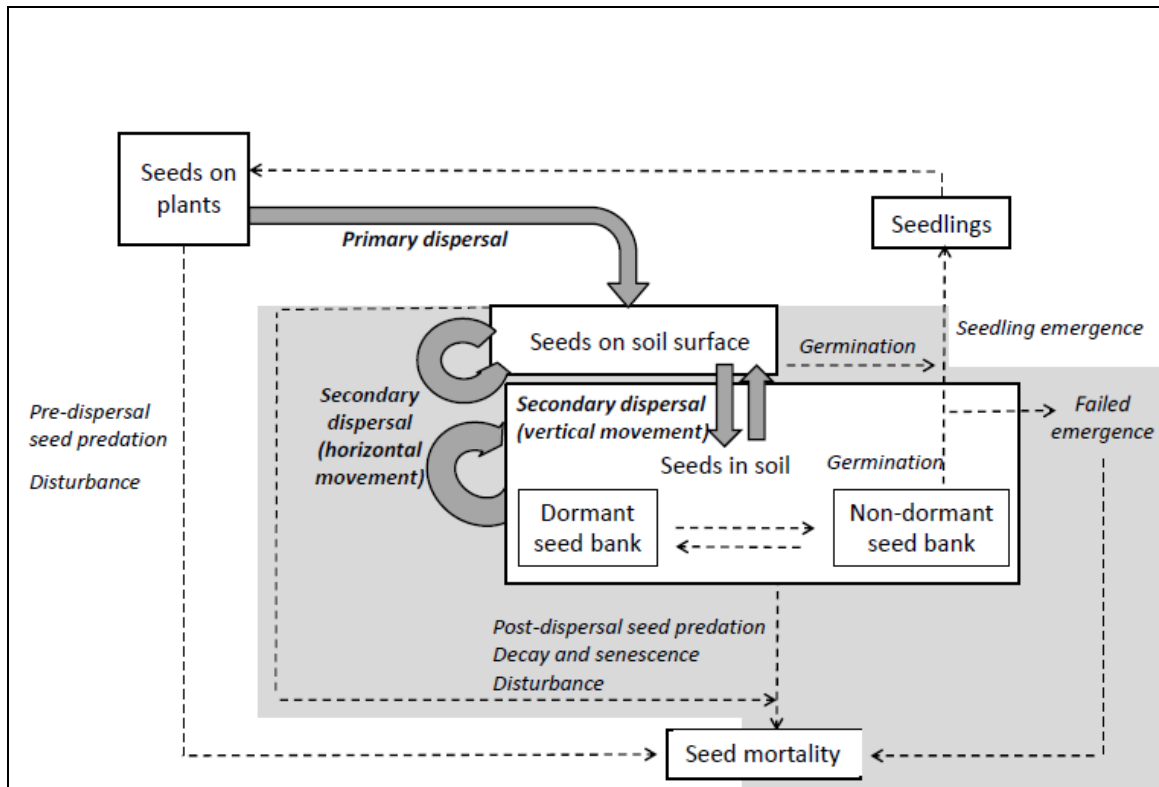


Figure 5: The conceptual model to show the complex pathways of seeds and their fate: the arrows show seed movement while the process related to the movement is indicated by bold, Adopted from Van der Wall *et al.* (2002).

According to Demel Teketay and Granström (1995), the soil seed bank in Dry evergreen Afromontane Forests and grassland complex (DAF), of Ethiopia shows that higher densities are recorded in the upper 3 cm of soil and gradually decrease with increasing depth.

2.5. Soil seed bank and area enclosure

Area enclosure and/or enclosure is the act of exclusion of livestock and human from open access to an area notably characterized by severe degradation (Aerts *et al.*, 2009; Demel Teketay *et al.*, 2010). Enclosure is area selected for natural regeneration of the native flora as a means of land reclamation through protection of the areas from human and animal interferences (Bendz, 1986; Dejene Alemneh, 1992).

Some pastoralists and agro-pastoralists, such as the Gogo and Maasai (Tanzania), the Himba (Namibia), and Borana (Ethiopia), use traditional ways by avoiding grazing on specific grazing lands during the rainy season. This allows the recovery of palatable feed reserves (Solomon Tefera *et al.*, 2007; Mwilawa *et al.*, 2008).

Due to the absence of comprehensive land use system and failure to enforce the law such as Rural Land Administration and Land use Proclamation (Proclamation No. 456/2005) in many parts of Ethiopia, grazing lands are being converted to croplands. During the Military (Derg) Regime (1974-1991), farmers were forced to reduce the number of cattle they owned in order to minimize free grazing. Following this action, hillsides were protected and rehabilitated to maintain the balance of grazing land shortage (Hussein Ali, 2009).

As a result, farmers started collecting straw (Fig. 6a) and other byproducts to provide animal feed. Farmers were also using cow dung with straw to substitute the firewood (Fig. 6c), to reduce pressure on forest degradation. These activities provided opportunities to local kids to be sent to school as the cows and oxen were managed by elders as they have to be tied with ropes to limit their movement within a given radius.



Figure 6: The experience of destocking to feed straw (a), Bore hall to drink their cattle (b), the byproducts used as a source of energy (c), and the local kids back from their school (d)

The diversity and dynamics of above ground plant species, population and communities maintained by the soil seed banks (Kemp, 1989; Harrod and Halpern, 2005), as native plant communities restored from it (Graham and Hutchings, 1988; van der Valk and Pederson, 1989).

2.6. Functional roles of soil seed banks

Soil seed banks are the source of regeneration for the floristic and structural diversity of the above ground vegetation (Fekadu Debushe *et al.*, 2010). It is classified as transient for species that have viable seeds present for less than 1 year and persistent for species seeds that remain for more than 1 year which further divided as short-term persistent (1–5 years) and long-term

persistent with > 5 years (Thompson and Grime, 1979; Maas, 1987; Bakker, 1989; Thompson and Fenner, 1992; Thompson *et al.*, 1997).

The spatial distribution of soil seed bank varies in its species composition and density as a result of different natural and anthropogenic factors that affect the germination and growth of species. Human activities have resulted in loss or degradation of plant communities. The seed bank can contribute towards restoration through a regeneration process. In Ethiopia, natural regeneration depends on the soil seed bank (Wang *et al.*, 2009), and an important subject in both conservation biology and management (Du X *et al.*, 2007). It is affected by the removal of trees, land disturbance (for example, the collection of firewood, intensive cultivation of lands and uncontrolled grazing) that severely reduce the plant species density and regeneration (Demel Teketay, 2005a). The distribution of seedlings and saplings are also affected by topography through its effect on drainage, moisture and nutrient disparity (Mamo Kebede *et al.*, 2012).

Soil seed banks produced in the most recent reproductive period or over previous years (Dekker, 1999), are important reserves of viable seeds in the soil or on its surface (Roberts, 1981), Seed banks thus represent a '**memory**' of the past and recent vegetation (Templeton and Levin, 1979). Thus, they are considered to be an important source of plant diversity (Fenner, 1985; Chesson *et al.*, 2004), because they play a central role in species' recruitment and establishment (Harper, 1977). Moreover, seed banks may facilitate the coexistence of potentially competing species and mitigate the effects of inter and intra-specific competition (Rees and Long, 1992; Pake and Venable, 1995). This role has also been described as the '**storage effect**' (Chesson, 1994, Chesson *et al.*, 2004).

Soil seed banks are also important to maintain the balance of ecological functions through different mechanisms notably through the restoration of degraded lands accompanied by exclosure and/or enclosure (Bakker *et al.*, 1996; Bossuyt and Honnay, 2008; Fourie, 2008; Gaertner *et al.*, 2009). However, the abundance of invasive soil seed bank flora might be a significant factor of their invasiveness at a given locality (Richardson and Kluge, 2008), and used as a source of information about invasive species, for example, *Acacia* spp. in Ethiopia and South African fynbos.

The degree of the impacts of plant invasions on the soil seed bank composition depends on the identity of the invading species and characteristics of invaded communities. Significant changes in species composition, abundance and species richness were reported in several ecosystems, such as **fynbos** (Fourie, 2008; Gaertner *et al.*, 2011), **coastal dunes** (French *et al.*, 2011), ***Banksia* woodlands** (Fisher *et al.*, 2009), **river banks** (Vosse *et al.*, 2008), **wet meadows**, **coastal cliffs and grasslands** (Gioria *et al.*, 2011), **roadsides** like *Senna didymobotrya* and *Argemone mexicana* (Personal observation, 2016), in Ethiopia. Changes in the structure of standing vegetation such as species abundance, diversity and composition associated with invasion (Hejda *et al.*, 2009; Gaertner *et al.*, 2011) inevitably result in changes in the seed rain.

These changes caused by the exotic plant species affect the balance between seed input and output by limiting the dispersal efficacy of native species (Zobel *et al.*, 2000; French *et al.*, 2011). Increased production of litter also affects the dispersal efficacy of native species (Xiong *et al.*, 2003), and may prevent seeds of native species from reaching the soil (Facelli and Pickett, 1991), rather exposed to the attack of predators (Cintra, 1997).

2.7. Land use land cover change and its cause

According to Meyer (1999), each landscape on the surface of the Earth possesses a unique cover. Land use and land cover are different but are closely related features of the Earth's surface in which one affects the other. **Land use** is the human use of land or immediate activities modifying or converting the land use (Sherbinin, 2002; FAO, 2006), such as agriculture, grazing, urban development, logging and mining to mention a few. While **land cover** categories referred to the physical characteristics of the land surface including Forest, Grassland, cropland, wetland and pasture cover among others (Meyer, 1995). Land use affects land cover and vice versa. A change in either, however, is not necessarily the product of the other. Because, shifting of the land use patterns also appeared by the complex interaction between different biophysical and socio-economic conditions (Reid *et al.*, 2000), which internally affect the spatial distribution of biodiversity and other processes at a different time (Meyer and Turner, 1994).

With the rapid increase in agriculture, there are also changes in LU/LC. In addition to the land degradation and expansion of invasive species associated with agricultural practices, the introduction of cultivated rice into Fogera Woreda can be cited as one of the significant factors that induced a change in LU/LC from a Wetland that was used for grazing land into cropland. Rice production started in 1993 by 30 households in an area of 6 ha and produced ca. 16 tonnes. This production expanded to around 6,871 ha with a production of about 28,877 tonnes in 2005 (Tilahun Gebey *et al.*, 2012).

Besides anthropogenic causes, the change and modifications also initiated by natural events such as weather change, flooding, fire (wild) and ecosystem dynamics. As indicated by Moore (1986), land cover changes such as deforestation are activities through the direct use of land by humans for intensive agriculture, livestock raising, forest harvesting, urbanization, charcoal production,

etc. These changes ultimately affect the spatial distribution and abundance of underground and above ground vegetation, The change also affects the health of the ecosystem in different forms and levels such as high runoff, sedimentation to the extent to affect hydrological processes, irrigation, fishery, navigation and extinction of species as well (Thomas R. Loveland, 1999). The consequences of the change also affect the soil seed bank.

2.7.1. Causes of land cover change

The cause of land use change is the most complex concept and change eventually. For example, Malthusian hypothesis believes that population growth causes land degradation and deforestation as it causes the land to change from one land use to another notably from forest to agriculture and fuel (Allen and Barnes, 1985; UNFAO, 1993). According to Von Thunen (1960), distance and access to the market has also a direct effect for the land use system, while others (Geoghegan *et al.*, 2001; Liverman and Cuesta, 2008), labour availability considered as a major factor, others view that as the change is driven by individuals who maximize their profit.

Keeping in mind the diverse causes of the LULC change and its impact at different scales and regions, researchers from various experiences and disciplines attempted to generalize and group a dozen cluster of factors as proximate and underline causes (Turner *et al.*, 1993; Meyer and Turner, 1994; Geist and Lambin, 2002; Mather, 2002), as it is important to consider synthesis theories instead of relying on a single crucial point. Mather (2002) added actors such as individuals, agencies and institutions representing the whole range of organizational scales (Bürge *et al.*, 2004), that is in a position to make a decision and execute those actions considered as a driving force that influences the change though affecting both proximate and underlying driving causes.

Proximate causes the change directly (Geist and Lambin, 2002), through the direct action of infrastructure, agricultural extension and wood extraction (Fig. 7) and others factors. "Other factors" include environmental conditions, fire, floods, soil quality and topography, which are considered as intermediate factors. Proximate factors can be quantifiable, related to the smallest territorial units such as plots and have a direct relation to land use change (Mather, 2002). Because the direction and intensity of proximate factors change over time and depend on or driven by intermediate and underlying factors. However, the causal relationship is complex as they are context specific and changing over time and region to region (Chowdhury, 2006; Bawa *et al.*, 2007).

Underlying causes are driving forces that indirectly affecting land use change (Geist and Lambin, 2002), though: Demographic, Economic, Technological, Policy and Institutional; and Cultural factors used by human to alter the environment (Fig. 7). It has a qualitative character and related to large scaled areas such as national and global levels (Bürgi *et al.*, 2004).

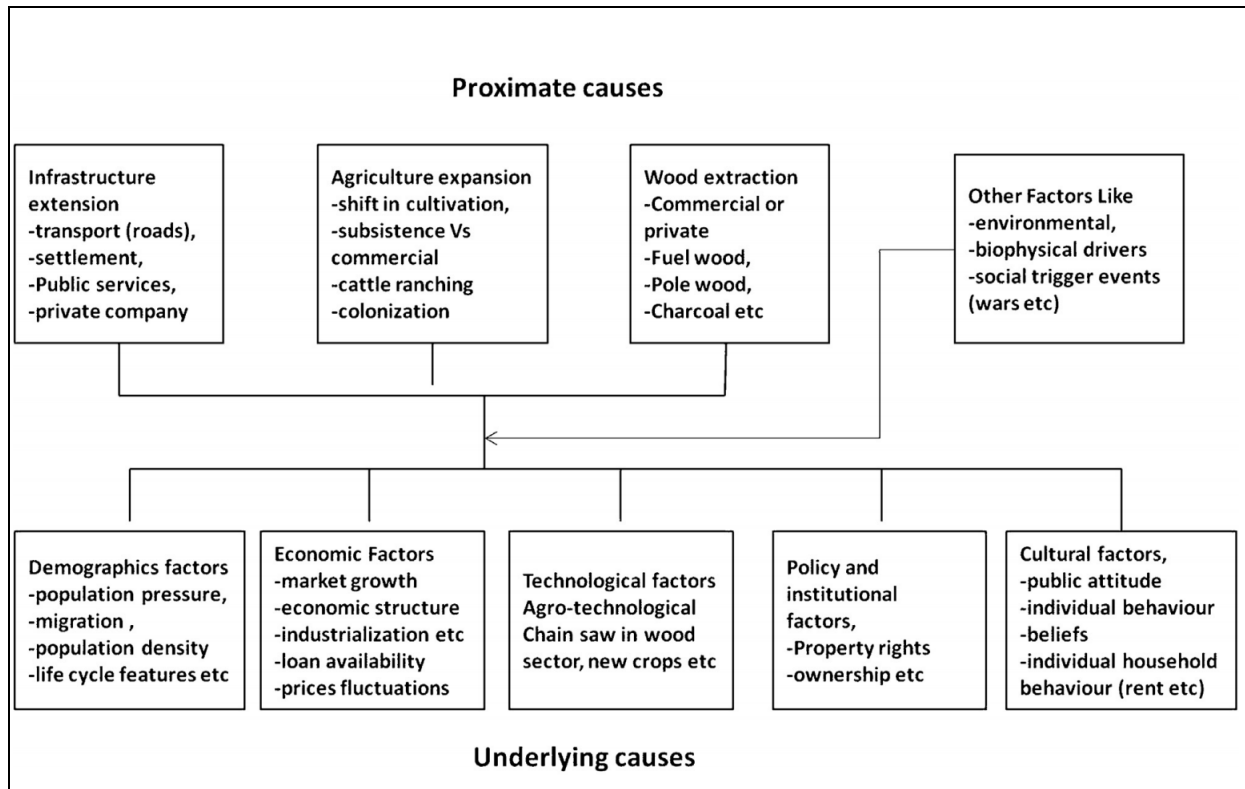


Figure 7: Framework for analyzing proximate and underlying causes of land use change

Source: Meyer and Turner (1992), and Geist and Lambin (2002).

2.7.2. Consequences of land use land cover change

Understanding the causes and consequences of land use land change is one of the primary goals of global change research (Geist and Lambin, 2002; Rindfuss *et al.*, 2004). Land use and land cover have important consequences through their impacts on a wide variety of global environmental issues such as emission of greenhouse gases and global climate change, loss of biodiversity both for underground and above ground vegetation, loss of soil resources and impacts on soil and water quality. Therefore, it has been recognized as one of the most serious problems faced by the global community (Meyer and Turner, 1992; Boissière *et al.*, 2009).

Change in climate at global regional and local scale influence the atmospheric temperature trend (Mahmood *et al.*, 2010) and rainfall pattern accordingly. Global warming caused by increasing

the release of carbon dioxide to the atmosphere resulted from the disturbance of soils and vegetation. The change in climate and land use also affect the ground and surface water regimes and availability (Piao *et al.*, 2007; Sherwood and Fu, 2014; Wang *et al.*, 2014).

The consequence is not limited to environmental issue as its impact on economic and social aspect is also significant. Thus, land use pattern has a direct impact on the quality and quantity of agricultural productivity, social benefits and ecological services. Some other socioeconomic impacts of the change include: reduction in the amount of land available for food and timber production, reduction in the amount of open space and environmental amenities for local residents, affect the lives of individuals and the way in which society is organized (e.g urban development pattern) and economic disparities among communities, etc.

In general, Land use land cover change play an important role in global environmental change and is one of the major factors affecting sustainable development and human responses to global change. The extent and rates of change in land cover and some land uses are known with some certainty (Meyer and Turner, 1994). In the case of Ethiopia, studies on LU/LC changes are few, except limited studies focused on Northern Ethiopian highlands in areas with early settled agriculture and with a relatively high population pressure (Belay Tegene, 2002). This being the case, accurate information on LU/LC changes are believed to be critical for resource analysis (Solomon Abate, 1994). Hence, this aspect is considered in the current study.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

The study area is located in Tana Sub Basin (TaSBO), at the headwater of the Abay (Blue-Nile), basin and its geographical location lies between 10.95°N to 12.78°N latitude and from 36.89°E to 38.25°E longitude (Fig. 8). It is found 650 km NW of, Addis Ababa. The study area is delineated based on the two watersheds called Rib (2,184 km²) and Gumara (1,557 km²), together covering a total area of 3741 km² (Fig. 8 and 9) East of Lake Tana. The study area covers the two watersheds occurring between Lake Tana and Mount Guna with elevation range between 1781 (near Lake Tana) and 4102 (at Guna Mt.) m asl. Mount Guna and parts of Fogera plain have been also recognized as Key Biodiversity Areas (Critical Ecosystem Partnership Fund, 2012). Due to differences in altitudes between the lower parts close to Lake Tana and the Guna summit coupled with other environmental factors, the study area harbors different habitats such as wetland, grassland, Afroalpine and sub Afroalpine vegetation, riverine vegetation, Shrubland, forest and croplands.

The Rib and Gumara watersheds are adjacent to each other and include five Woredas in South Gondar zone, Amhara Regional State (Dera, Este, Farta, Fogera and Libokemkem) and with two major permanent rivers named after the catchments that originate in Mount Guna and drain to Lake Tana. These rivers have many tributaries (Fig. 8).

Ethiopia has five agro-ecological zones classified based on elevation such as Bereha, Kola, Woyna-Dega, Dega and Wurch with elevation ranges below 500, 500-1500, 1500-2300, 2300-3200 and above 3200 m asl respectively (Daniel Gamachu, 1977). Each has its own pre-dominant representative flora, fauna, landscape, vernacular house and crop. The recent study

area include the three agro-ecological zones include Woyna-Dega (Cool sub-humid), Dega (cool and humid) and Wurch (moist) with the actual elevation range between 1781-2300, 2300-3200 and 3200-4102 m asl., respectively (Belay Simane *et al.*, 2013). The area coverage of the corresponding agro-ecological zones include Woyna-Dega (51.65%), Dega (34.05%) and Wurch with 14.30% (Fig. 8, 9 and 10).

The two catchments also cover three different agroecological zones: Woyna-Dega, Dega and Wurch (Fig. 8). Physiographically the catchments are similarly dominated by a dissected with high level plateau remnants separated by deeply incised river valleys with steep slopes.

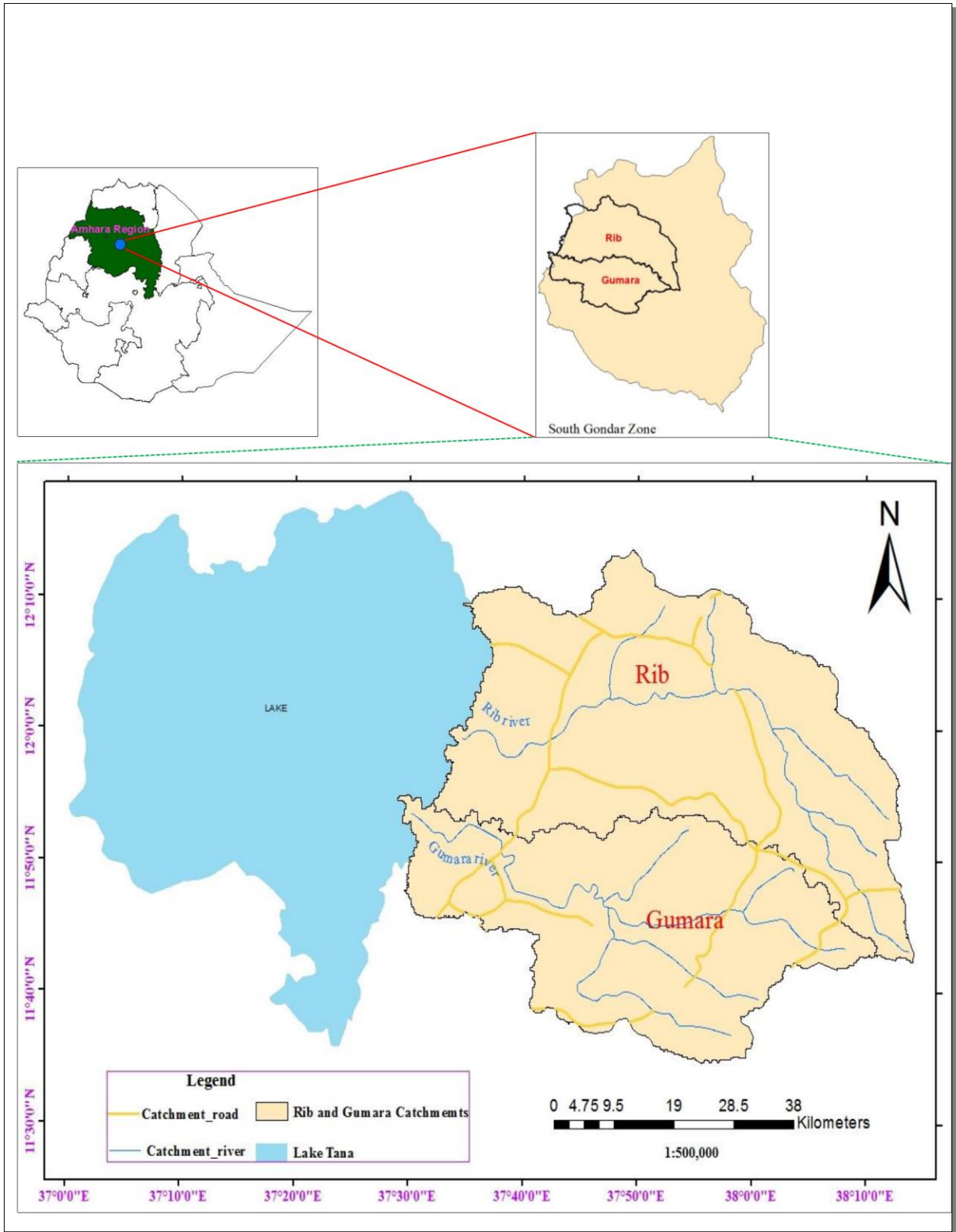


Figure 8: Map and location of the study area



Figure 9: Different geographic features of the study area. A. Gumara River (1800 m asl); B. Alemsaga Forest (2259 m asl); C. Panoramic view of Fogera plain and Lake Tana from Arsema Church side (1951 m asl); D. Part of the Guna range of mountains (4102 m asl.)

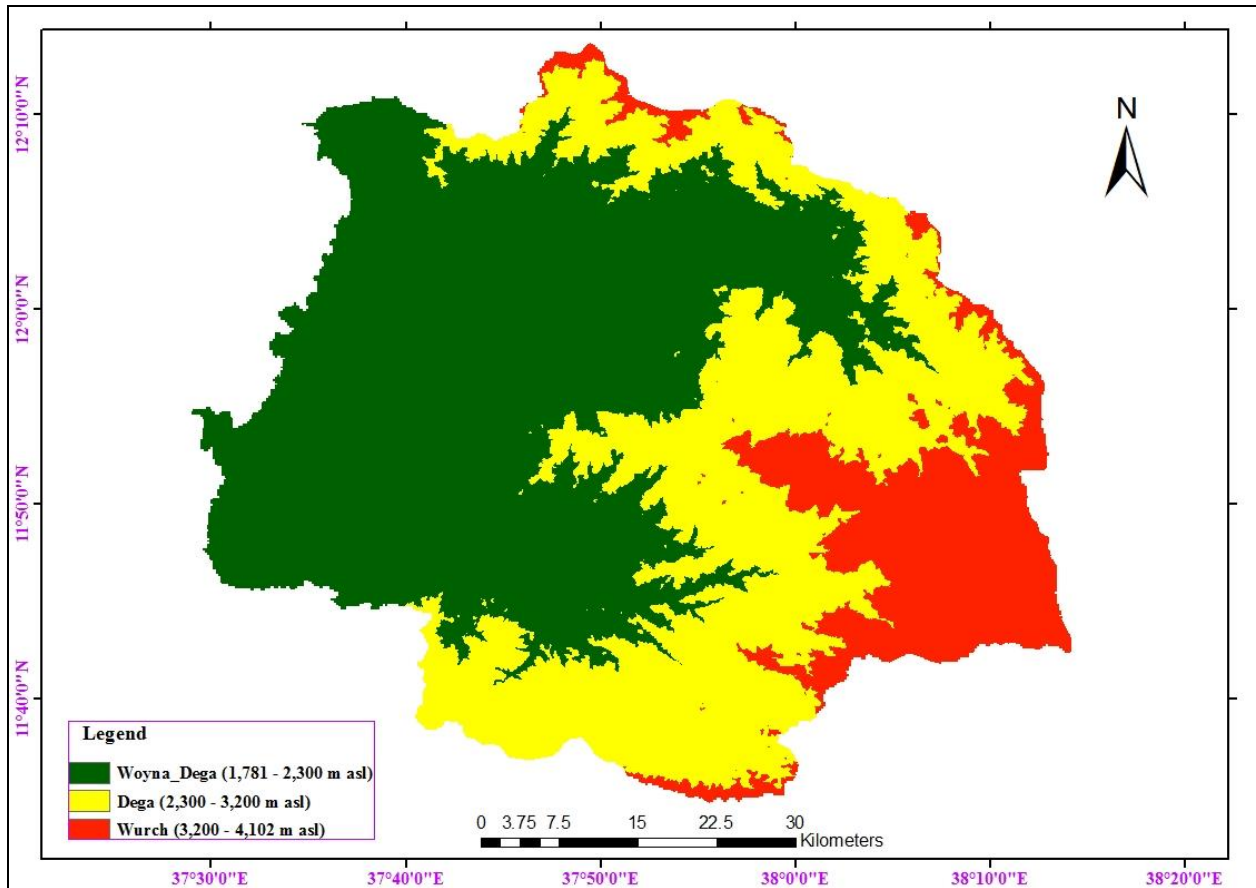


Figure 10: The distribution of the three agro-ecological zones along the study area (Map by Birhanu Belay, November 2016)

3.1.1. Demographics

According to the National Census in 2007 a total population of 1,294,835 was reported for the five Woredas, of which 660,146 (50.98%), are men and 634,689 (49.02%), women. Most of the population accounted for 1,294,835 (89%), are living in rural areas, while the remaining 142,488 (11%), people live in urban areas (Table 1, 2 and 3). The average family size of households in all sub-watersheds is greater than 5.2 person. The people living in the range of these Woredas belong to the Amhara ethnic group and speak only Amharic language (Table 4).

Table 1: Population by Urban-Rural Residence and Sex: 2007

Geographical Area	Urban + Rural			Urban			Rural		
	Total	Female	Male	Total	Female	Male	Total	Female	Male
South Gondar Zone	2,051,738	1,010,677	1,041,061	195,619	99,770	95,849	1,856,119	910,907	945,212
Libokemkem woreda	198,435	97,448	100,987	22,054	11,105	10,949	176,381	86,343	90,038
Fogera Woreda	228,449	111,984	116,465	25,190	12,845	12,345	203,259	99,139	104,120
Farta Woreda	232,181	113,668	118,513	6,783	3,340	3,443	225,398	110,328	115,070
Misrak Este Woreda	210,825	103,270	107,555	13,901	6,888	7,013	196,924	96,382	100,542
Mirab Este Woreda	120,885	58,864	62,021	2,192	1,092	1,100	118,693	57,772	60,921
Dera Woreda	248,464	121,503	126,961	16,772	8,826	7,946	231,692	112,677	119,015
Debretabor Town	55,596	27,952	27,644	55,596	27,952	27,644	0	0	0
Sum	1,294,835	634,689	660,146	142,488	72,048	70,440	1,152,347	562,641	589,706
Distribution in (%)	63.11	62.80	63.41	72.84	72.21	73.49	62.08	61.77	62.39

Table 2: Population size, involved number of Kebeles and Agro-ecological zones of Gumara and Rib watersheds. Where: M.A = mean altitude, No. K = Number of Kebeles, Pop/ha = population per hectare. Source: Integrated Watershed Management (Ethiopia) Watershed Project (2007) volume 1 main report.

Catchment	Components to be considered for each watersheds				
	Population No.	Pop/ha	M.A (m)	No. K.	Agro-ecological zones
Gumara	50,126	2.22	2675	13	Moist Woyna-Dega, Moist Dega, Wurch
Rib	64,066	1.96	2315	12	Moist Woyna-Dega, Dega, Wurch

Table 3: Percentage distribution of Households by family size in Rib and Gumara watersheds
Source: Tana-Beles Integrated Water Resource Development Project (2010)

Watershed	Family Size										
	1	2	3	4	5	6	7	8	9	10	above 10
Gumara	4	5	14	17	16	16	14	8.1	3	3	0
Rib	2	6	12	13	18	18	11	11	5	3	2

According to the report by Tana-Beles WME (2011), the distribution of the livestock is different and rated as oxen (21.4%), Cows (21.4%), Sheep (17.42%), Goats (5.33%), Horses (4.73%), Donkeys (8.71%), Mules (3.09%), while poultry (15.48%) and Beehives (2.74%).

3.1.2. Geology and Soil

Rock and soil type

The soils of the recent study area have developed from variable parent materials including basic volcanic rocks, intrusive rocks, alluvium (deposited by water) and colluvium (deposited by gravity), coarse grained clastics, non-carbonate meta sediments, meta volcanic rocks, laterite, sandstone, gabbros etc, (FAO, 2006).

Luvisols: Luvisols are widely distributed in the Ginde Atamim (East Este) and Dera Woredas and are classified as Eutric Luvisols and Chromic Luvisols. This soil type is developed in well-drained areas at higher altitude. They are mainly developed in variable parent materials such as basalts, alkali Trachyte and Rhyolite, which is predominantly heavy clay with good permeability (Ayalew Wondie *et al.*, 2011).

Nitisols: These soils have developed in well-drained areas with good permeability and a favorable structure. They are found dominantly on flat to rolling topography. They are characterized by their very thick, (greater than 150 cm) more or less uniform clay distribution. The soils are reddish in color, derived from different parent materials, where Tertiary Basal derived materials are found (Ayalew Wondie *et al.*, 2011).

Alisols: It is the most dominant soil class which is intensively cultivated on the account of its good drainage and till characteristics. These soils are well known on its yellowish brown color, very deep to deep, clay to clay loam (Ayalew Wondie *et al.*, 2011).

Leptosols: Leptosols are very shallow soils limited in depth by continuous hard rock. They occur mainly on steep side slopes; mountains and hills are prominent in the Amhara Region. The soils are generally young and are limited by their topsoil horizon or directly over altered parent rocks from which they have developed (Ayalew Wondie *et al.*, 2011).

3.1.3. Climate and crops related with the livelihood of the community

In the Ethiopian highlands, subsistence farming which involves oxen driven plow is practiced. The major annual crops are teff, wheat and barley. However, these annual crops are constrained by a unimodal type of rainfall pattern with the higher between the months of June to September, but the growing periods for those crops range from 90 to 180 days (Ayalew Wondie *et al.*, 2011). The dominant land use throughout the study area is farmland, encompassing more than half of the study area and the farming systems range from teff, wheat-pulse system in the lower elevations (1781-2300 m asl), through wheat-barley-pulses systems in the middle elevations (2300-3200 m asl) to one dominated by barley and potato in the higher elevations (>3200-4102 m asl) of both (Rib and Gumara) catchments (Ayalew Wondie *et al.*, 2011).

Based on the rainfall pattern, the year is divided into three seasons: Kiremt (main rainy season) mainly centered on the months of June to September, Bega (dry season) from October to January and Belg (small rainy season) from February to May (Amare Babu, 2009). In the highland parts of the basin the months of April and May are an intermediate season where minor rains often occur. On the account of this, rainfall ranges from 1295 mm to over 1313 mm per year characterized by unimodal rain fall pattern with a corresponding single secure cropping season which lasts from the middle of May to the middle of October (Ayalew Wondie *et al.*, 2011), and the 16 years mean minimum temperature is 4.7 °C recorded in December while the mean maximum temperature is 29.5 °C recorded in February (Fig. 11).

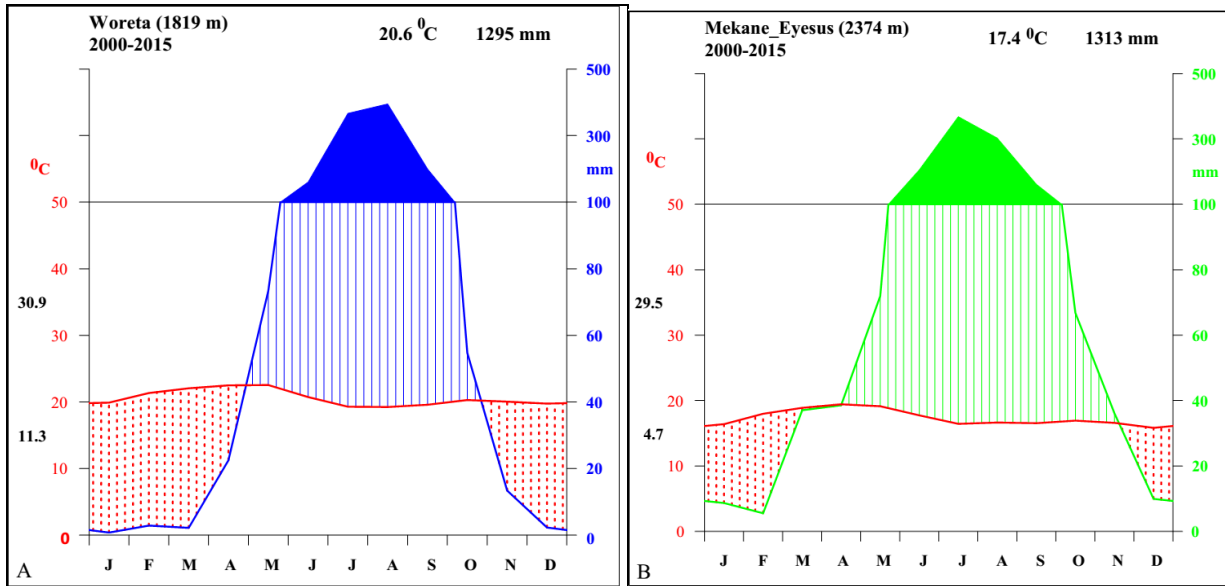


Figure 11: Climate Diagram of the Study Area: (A) Woreta Station, (B) Mekane_Eyesus Station

The rainfall and the temperature condition of the study area was described based on the data collected from 2000-2015 by the National Meteorological Agency of Ethiopia (NMA), from Woreta and Mekane_Eyesus meteorological Stations to represent the lower (1819 m asl) and the higher elevations (2374 m asl) of the study area respectively (Fig. 11).

According to the data from NMA the result of the analysis showed that the mean annual average temperature of the study area is about 19.0 °C. The range of mean monthly minimum and maximum temperatures of the study area is 7.98 and 29.94 °C observed in December and March respectively. The average mean annual rainfall of the study area over 16 years is 1304 mm per year and show unimodal type of rainy season. The short rainy season is observed in January, February and December and the long rainy season starts from June up to September (Fig. 11). When the precipitation curve undercuts the temperature curve, the area between them is dotted with 2 mm distance, indicating dry season. When the precipitation curve supersedes the

temperature curve, the area in between is hatched with a distance of 2 mm indicating, moist and rainy seasons.

3.1.4. Land use land cover and Vegetation types

Due to elevation differences in the study area, the study area displays various land use-land cover and vegetation types. The LU/LC types in the study area along vertical altitudinal variations include: woodlands, shrublands, croplands, settlements and natural forests and plantations.

The vegetation types (based on Friis *et al.*, 2010), that occur in the area include: Riverine forest, Freshwater marshes and swamps, floodplains and lake shore vegetation, Dry evergreen Afromontane forest and grassland complex and Afroalpine and sub Afroalpine vegetation. Most of the highlands in the study area have Dry evergreen Afromontane forest and grassland complex type, which have been subjected to severe deforestation, fragmentation and biodiversity loss. All of these influence the species composition and abundance which may be limiting the restoration possibilities (Mulugeta Lemenih and Demel Teketay, 2006).

These days, the forest is largely dominated by bushy shrubs such as *Dodonea angustifolia*, *Carissa spinarum*, *Rosa abyssinica* and *Capparis tomentosa*, it is also possible to find different trees and shrubs as a homesteads, along water courses and near churches. For example, *Cordia africana*, *Calpurnia aurea*, *Rhamnus prinoides*, *Olea europaea* subsp. *cuspidata*, *Croton macrostachyus*, *Euphorbia abyssinica*, *Apodytes dimidiata*, *Juniperus procera*, *Brucea antidysenterica*, *Clusia abyssinica*, *Erythrina abyssinica*, *Ficus vasta* and *Maytenus undata*.

The Afroalpine and sub Afroalpine part of the study area which covers 14.30%, is predominantly cultivated and interspersed with grassland complex. However, *Erica arborea*, *Lobelia rhynchopetalum*, *Festuca macrophylla* and *Alchemilla abyssinica* are observed. There are small

areas of natural woodland and eucalyptus plantations, being more extensive in the Rib catchment (Ayalew Wondie *et al.*, 2011).

3. 2 Materials

The equipments used during the fieldwork include:

GPS: The Global Positioning System used to navigate in looking for places of interest and to mark the plots and take reference points during the survey to rectify the changes.

Video camera: Used for electronic motion picture acquisition of plants which are not appropriate for digital photo camera for further identification and interpretation. It also used to record the discussions held with the inhabitants.

Tape Recorder: Used to record and play back discussions and interviews with the inhabitants to validate the changes on land use types for further analysis.

Auger: An apparatus used for soil sample collection.

Hand trowel: It is a tool with a pointed, scoop-shaped metal blade with a handle. It is used for clearing the surface, break up earth, digging small holes and mixing the soil sample.

Clinometers: Used to measure the slope of each plot.

Compass: Used to show the aspect of each plot and to maintain the bearing of each plot.

Thermometer: Used to check the temperature of the greenhouse.

Hygrometer: Used to measure the humidity of the greenhouse chamber where the seedlings keep growing.

3.3. Methods

3.3.1. Site selection, sampling design and plot establishment

Field observation and reconnaissance survey was conducted from 30 June 2013 to 15 July 2013 to obtain an impression on the general vegetation cover, landscape, land use types and identify sampling sites. The actual fieldwork was undertaken during peak vegetation periods (with flowers and fruits), from September to November 2013-2016 and revisited during the dry (December-January) and small rainy seasons (February to March).

3.3.2. Above ground vegetation

The study area is part of the Ethiopian highlands in which farming activity has been taking place since 5000 years (EPA, 1997). On account of high population growth followed by agricultural expansion, the study area is highly degraded and fragmented which result in patchy distribution of vegetation. Because of the ragged topography and the land use pattern transect method may not capture the natural vegetation and other land uses of the study area. Hence, preferential sampling method was used to select the sampling sites while the plots were established systematically against gradient by maintaining the bearings.

The main road from Woreta to Debretabor which divide Rib (northern side) and Gumara (southern side) were used to access the sampling sites. Following Kent and Coker (1992), 98 (39, 200 m²), main plots measuring 20 m x 20 m for trees and shrubs, 490 subplots (1 m x 1 m), for herbs were established to represent the above ground vegetation (Fig. 12). The corresponding environmental parameters such as Altitude, Aspect and Slope were also recorded using Garmin_GPSmap_62, Suunto compass and Suunto clinometers, respectively.

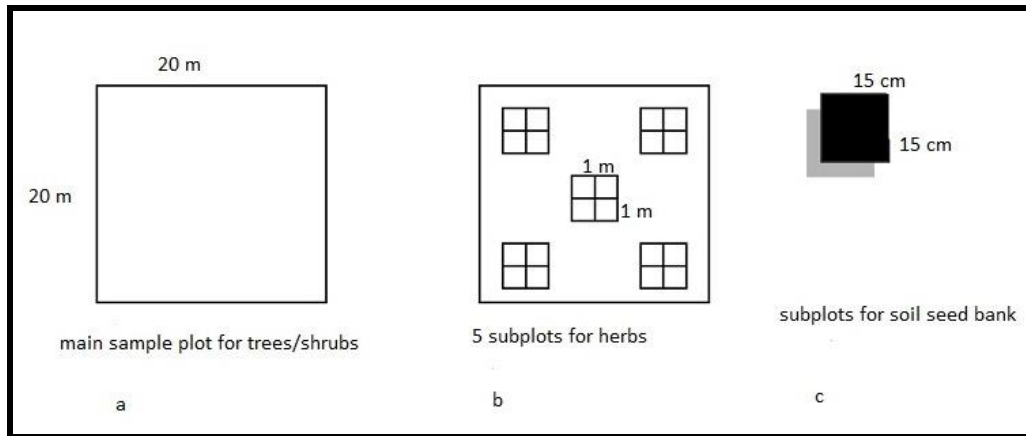


Figure 12: Sampling strategy: for trees and shrubs (a), herbs (b) and soil seed bank (c).

For the wetland part of the study area where there is no main road (from Bahir-Dar to Debretabor through Woreta), the sampling sites were accessed using footpaths to ensure sufficient representation of the Wetland. In addition, plots were established following the shore of Lake Tana adjacent Rib and Gumara watersheds to record the aquatic flora such as *Azolla nilotica*, *Eichornia crassipes*, *Nymphoides brevipedicellata* and *Nymphaea lotus* to mention a few.

The locations of each sample stand were recorded using Garmin GPS-62. When plantations, settlements and active croplands encountered, it was recorded and passed to the next plot. While the cropland which has been left uncultivated for two and more growing seasons were considered, as it is needed to check its soil seed bank status.

The plots were stratified by LU/LC type (Table 4) and environmental variables such as slope, aspect and elevation using topographic maps, digital elevation model, shapefiles of the study area, Google earth and field reconnaissance.

Table 4: Land use type and the corresponding plot size

LU/LC type	Cropland	Forest	Grassl and	Shrubland	Water	Wetland	Settlement	Total
No. of plots	12	22	12	27	0	25	0	98

3.3.2.1. Structural data collection

The height (≥ 2.5 m) and diameter of all woody species with DBH ≥ 2.5 cm were measured in each plot using caliper (Isikhuemen, 2005) and calibrated stick respectively. When the DBH of the trees and shrubs were beyond the size of the caliper, meter tap was used to measure the circumference which was later converted to diameter using a formula, $DBH = C/\pi$ to compute the basal area and dominance of woody species. When topographic feature and high density of trees preclude using Clinometer, height of the trees was also estimated using a combination of measuring stick and visual estimation. The number of all seedlings (<1 m height) and saplings (1 - 2.5 m height) were recorded in each plot to evaluate the regeneration status of selected woody species (Feyera Senbeta and Demel Teketay, 2001). In the meanwhile, the land use type and percent cover of the canopy was recorded for each plot to support LU/LC classification by taking the geographic position system (gps) as the ground control point to rectify the process.

3.3.2.2. Plant specimen collection and identification

Plant specimens were collected from the different plots provided with collection number, pressed and dried. Every plant species outside the plots, having special feature was recorded. The dried specimen were identified by using *Flora of Ethiopia and Eritrea* and herbarium specimens and further confirmation by was made by taxonomists.

Once identification was made the status of each species was known for further analysis. Notably, relatively the most invasive species were selected based on its occurrences and their extent to

challenge the farmers validated by semi-structured interview to build habitat suitability model. Direct matrix ranking was employed to identify the most difficult invasive plant species in the sense of degree of invasiveness and its impact on grazing and cropping systems. The respondents were provided with invasive species and requested to assign one of the following values: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree. Finally, by summing up the value given by all respondents, overall score was obtained.

3.3.3. Soil seed bank

3.3.3.1. Sampling method

In order to assess the seed bank composition that was collected considering seasons when germination had ended and before new seeds were dispersed (Baskin and Baskin, 1998). In each plot, five subplots measuring 15 cm x 15 cm (225 cm²): 4 at the corner and one at the center were chosen. Using a labeled metal rod and spoon, soil samples were collected from four separate layers Litter (0 cm), first layer (0-3 cm), second layer (3-6 cm), third layer (6-9 cm), following Tefera Mengistu (2001), Feyera Senbeta and Demel Teketay (2001, 2002), Mulugeta Lemenih (2004), Tefera Mengistu *et al.* (2005), and Mulugeta Lemenih and Demel Teketay (2006).

The samples were taken carefully so as not to mix with the next layers. Samples of the corresponding layers from the five sub-plots (Fig. 12c), were mixed thoroughly to form a soil composite so as to reduce variability within the plots and to represent the layers and later divided into three equal parts (Emiru Birhane, 2002 and Tefera Mengistu *et al.*, 2005). To identify the seeds two major methods such as seed count (physical extraction) and germination method were used. Seed count method is applied using different sizes of sieves (Mulugeta Lemenih, 2004). The soil samples were kept in a plastic bag for 10 days to kill the propagules and sieved to recover seeds using four sieve sizes, i.e. 1 mm, 1.6 mm, 2 mm (to remove coarse debris and propagules) and 3.15 mm, were selected assuming that the seed sizes of different species were within these diameter ranges.

Some of the seeds recovered by seed count method were *Cordia africana*, *Acacia* sp, *Olea europaea* subsp. *cuspidata* and *Chionanthus mildbraedii*. These seeds were taken back to the study site for identification through group discussion among the local people and then by

comparing with the seeds of the parent plant. Once preliminary identification is carried out the seeds were checked for their viability and germinated for further identification. The viability of the seeds were determined by dissecting tests (Demel Teketay and Granström, 1995). Seeds with firm and white contents were considered viable (Demel Teketay, 1996).

Germination method (seedling emergence methods) which rely on direct assessment of seedlings that emerged from the samples (Roberts, 1981). This method was the most frequently used and the more reliable method, in soil seed bank studies (Baskin and Baskin, 1998). Soil samples were transported to the greenhouse of Addis Ababa University and spread on plastic trays to induce germination.

While the emerged seedlings reached a certain size preliminary identification was done and later specimens were collected, pressed and identified using Flora of Ethiopia and Eritrea (FEE) volumes and by comparing with voucher specimens in a National Herbarium, Addis Ababa University. The seed trays were kept continuously moist by watering them as necessary and to avoid differences in light exposure, the position of the trays were changed every 2 weeks following the method used by Esmailzadeh *et al.* (2011). All plastic trays were perforated at the bottom and plugged by cotton to facilitate proper drainage without losing soil. To control and detect contamination of external seed rain, thin transparent plastic was stretched over the sample trays following Eyob Tenkir (2006). Every week, all seed trays were checked for seedlings and the first emerged seedling within two weeks was *Senna didymobotrya*.

Newly emerging seedlings notably herbs were identified, counted, recorded and removed from the trays every week before fruiting in order to reduce the possibility of germination suppression of other seeds due to competition. The germination tests for herbs proceeded until no new

seedlings emerged for 4 weeks (Wang *et al.*, 2009), as there is no universally accepted maximum duration for a germination test. Those trays, which were free from any germinant, were stirred to expose the seeds resided at the bottom of the tray to light in order to give the possibility for some hampered seeds to germinate.

When the seedlings were difficult to identify, these were transplanted to continue their growth by transferring and maintaining them at Gullele Botanic Garden Greenhouse until the seedlings reach a flowering stage (when necessary) and are identified (Diaz-Villa *et al.*, 2003). Those plants are donated to the garden with full collected data information and will be planted in the corresponding agro-ecological zones. This exercise was considered a good one as it allowed the germination and seedling for a longer period compared to the shorter period that could have resulted in an underestimation of the persistent seed bank (Baskin and Baskin, 1998).

This method enabled the determination of the species composition in the soil seed bank, assuming that the number of seedlings detected by this method represent the number of buried viable seeds, which would indicate the number of a readily germinal seeds in the soil bank.

3.3.4. Soil physical and chemical properties

Soil samples were collected in five replicates using hand trowel at five subplots measuring 40 cm x 40 cm: four at the corners and one at the center from 0-30 cm depth (Canadian Society of Soil Science, 2006; Shazia *et al.*, 2014), forming composite sample. The soil samples were air-dried, mixed well and passed through a 2 mm sieve for chemical analysis. The soil sample were taken to Amhara Design and Supervision Works Enterprise Soil Chemistry and Water Quality Section at Bahir-Dar to analyze the soil physical properties (Texture) and soil chemical properties for selected parameters such as Electrical conductivity (EC), Exchangeable bases (Ca, Mg, Na and

K), Cation exchange capacity (CEC), Organic Carbon (OC), Organic matter content (OMC), Total Nitrogen (N), Available phosphorous (P) and soil pH.

3.3.5. Land use land cover change (LU/LC)

3.3.5.1. Description of land use land cover classes

Landsat imageries with <10% of cloud percent were used to identify the LU/LC types and detect the changes. GIS and RS used to classify LU/LC types. The process was supported by the intensive observation during field visits and data collection on vegetation, soil seed bank and general background information on the catchments. Thus, seven major LU/LC were observed and described below:

- **Forest:** It includes both open and closed canopy forests which described based on their canopy. Represented by government and private and church forests. It also include plantation and riverine vegetation.
- **Shrubland:** Represented by plants which fall below five meters and most of the time known for plants with two and more than two number of balls from the ground in which it include some wood lands which are mostly dominated by shrubs.
- **Cropland:** It represents the land available for the cultivation of various crops, for example, teff, wheat, pulses, barley, potato, grass pea, chickpea, rice and others in the catchment. Some croplands managed through a fallow system that allows the land to rehabilitate or restore for one growing season were also considered a cropland.
- **Grassland:** It is represented by small and fragmented grazing lands and other related open spaces enclosed and available for cattle feed and grasses for roof thatching.

- **Wetland:** It is defined as the area which is flooded mainly during the rainy season and used as water reservoir for Lake Tana. This land use type include marshes of the lake and pocket of the rivers and ponds observed fragmentally.
- **Settlement:** This include small villages, schools, towns notably Debretabor, Woreta, Addis Zemen, Hamusit which are established before the first time period (1984).
- **Water:** The water include the ponds, shores of Lake Tana, Rib dam, Rib River; Gumara and other rivers included in the current study area.

3.4. Data analysis

3.4.1. Above ground vegetation

3.4.1.1. Vegetation data analysis

The list herbs, shrubs, climbers and trees were made in each plot and the cover value estimated 1-100% which was later converted to 1-9 modified Braun-Blanquet scale (van der Maarel, 1979)

Scale 1: Rare, generally one individual;

2: Sporadic, with less than 5% cover of the total area;

3: Abundant, with less than 5% cover of the total area;

4: Very abundant, with less than 5% cover of the total area;

5: 5-12% covers of the total area;

6: 12-25% covers of the total area;

7: 25-50% covers of the total area;

8: 50-75% covers of the total area;

9: 75-100% covers of the total area;

The vegetation information was ordinarily collected in mixed formats and customized to the Braun-Blanquet 1-9 scale to make it ready for use in R software. This data was later transformed by a suitable scale utilizing R statistical package of with a version of R x64 3.4.2, accomplished utilizing `vegtrans` function given in library (`labdsv`) as indicated by Roberts (2010). Community types were determined by applying **Hierarchical Agglomerative Clustering Method** with **Similarity Ratio** on the basis of "**Ward Linkage**".

The packages in R were also used to determine: Indicator species (`indicspecies`), optimal number of clusters, the correlation between species distribution and environmental variables, the

statistical significance of environmental variables and to show species accumulation curve (**vegan**) through importing the data organized using excel spread sheet.

The relative Importance Value Index (IVI) was computed from the sum of ecological parameters such as relative percentage of frequency, density and dominance to determine the ecological importance of the species (Lamprecht, 1989), as used by Oyun *et al.* (2009) and Mueller-Dombois and Ellenberg (1974).

Percent frequency of a species (%F): it is the frequency of plots occupied by a given species and calculated by a formula:

$$F = \frac{\text{Number of plots in which a species occur}}{\text{Total number of plots}} \times 100$$

Relative frequency (RF): Frequency of species A/total frequency of all species X 100. Having a high frequency value indicates the plant is widely distributed through the study area, the same is not necessarily true for a high abundance value, because abundance is not always an indicator of the importance of a plant in a community.

$$\text{Density of a species (D)} = \frac{\text{the number of individuals of that species}}{\text{Area sampled}}$$

It is closely related to abundance but more important in estimating of the number of species.

$$\text{Relative density (RD)} = \frac{\text{Density of species A} \times 100}{\text{Total density of all species}}$$

$$\text{Basal area (m}^2\text{) (BA)} = \frac{\text{DBH}^2 \pi}{4}$$

Where: DBH is the Diameter (m) at Breast Height, $\pi = 3.14$

$$\text{Dominance (DO)} = \frac{\text{Total of Basal area of each species}}{\text{Area sampled}}$$

$$\text{Relative dominance (RDO)} = \frac{\text{Dominance of species A} \times 100}{\text{Total dominance of all species}}$$

Importance Value Index (IVI): Relative density + Relative frequency + Relative dominance.

Basal areas and densities were determined on per hectare basis (Addo-Fordjour *et al.*, 2009). The basal areas of the trees in each plot were summed up and converted to basal area per hectare. The densities of the trees were calculated on per hectare basis for each plot and used to calculate mean number of individuals/ha for the entire stand. The structure of the selected woody species were determined by diameter at breast height (Adam and EK. 1974) and height classes.

Detrended correspondence ordination Analysis (DCA) was used to analyze floristic data. The diversity indices of the communities such as Richness and Evenness were calculated following Kent and Cooker (1992). The species richness and its diversity of the communities was computed by using Shannon-wiener (1949), diversity index represented by $-\sum p_i \ln p_i$ where p_i is the proportional cover of a species to the total species in a community. While the richness of species in the corresponding plots were modeled by using the application of Boosted Regression Tree (BRT), Model validated by Random Forest (RF), using R_{x64} 3.4.2. The R program was also used to carry out one-way analysis of variance (ANOVA), to evaluate the significance variance among environmental factors and the communities as well.

Shannon-Wiener diversity index was used to compute the overall biological diversity (Equation 1). The species richness and Shannon's evenness were calculated to describe species diversity of the plant community types (Kent and Coker, 1992). The Shannon-Wiener diversity index was computed as follows:-

$$H' = - [\sum_{i=1}^s p_i \ln p_i] \dots\dots\dots\text{Equation 1}$$

Where:

H' = Shannon diversity index,

S = the number of species,

P_i = the proportion of individuals or the abundance of the ith species expressed as a proportion of total cover

ln = logbasen

Evenness (Equitability) coded by $J = H'/H' \text{ max}$, where;

J = Evenness,

H' = Shannon-Wiener diversity index

H' max = ln s, where s is number of species

The spatial distribution of the plant species in the study area was computed using the application of Boosted Regression Tree (BRT) Model with a modified code from Elith *et al.* (2008). This application uses a combination of remote sense data (Landsat images of 2017) and GIS environmental layers. The model determines the scientific connections, relationship between physical attributes of a landscape (i.e., environmental layers) and species count data collected at geo-referenced field plots (i.e., response variable) to make spatial predictions across the entire study area. Environmental layer refers to all environmental variables considered during data analysis such as heat load index (HLI), linear aspect, roughness, mean slope, Compound topographic index (CTI) and elevation extracted from DEM, with a scale of 30 m x 30 m using ArcMap tool **Geomorphometry and Gradient Metrics** (version 2.0). While classified map, Normalized Difference Vegetation Index (NDVI), tasseled cape wetness (1= brightness, 2 = greenness and 3 = wetness) were generated from Landsat images of 2017. Species count, a data refers to the number of species (Richness) in the corresponding plots were also considered. The environmental variables were organized with an extension of coma delimited (.csv) format which later changed to ascii format to develop a Model.

Rx64 3.4.2 was used to run the process with Generalized Boosted Regression Models (gbm) and BRT source code (function) in Rstudio. A Map of BRT model was generated by running a raster environmental data using "raster" and "rgdal" libraries. Finally, the model was predicted using `"predict (raster.stack, fit.step.simp, ilename='BiodiversityModel', progress='text', n.trees=fit.step.simp$n.tree, type='response', format='GTiff')"` programme then opened using ArcMap to display and visualized the model.

Maximum entropy or “MaxEnt” model (Phillips *et al.*, 2006) was run to generate habitat suitability (Species distribution) modeling of *Senna didymobotrya* as an invasive species. This species was selected among other invasive as it occurs frequently (12x) compared to others, its extent to cause problems for the farmers and its fast germination period as shown in the soil seed bank experiment. The challenge of *Senna didymobotrya* for the farmers was rated by using direct matrix ranking and the result was computed using excel spreadsheet. All the environmental predictors considered in BRT model were also considered to build Maxent Model. All the 11 environmental predictors and a presence data were changed with ascii extension before running Maxent with the following setting: Regularization (1.5), maximum number of background points (10,000) and Replicates (10).

3.4.1.2. Structural data analysis

All the measurement taken for height was changed into meter and DBH were computed from the circumference measured in centimeters (Equation 2), with the application of excel spreadsheet.

$D = C / \pi$ Equation 2

3.4.1.3. Environmental data analysis

The soil tests were conducted for Electrical conductivity (EC), Texture, Exchangeable bases (Ca, Mg, Na and K), Cation exchange capacity (CEC), Organic Carbon (OC), Organic Matter Content (OMC), Total Nitrogen, Available phosphorous and soil pH (Table 5).

Table 5: The methods used to analyze the soil physical and chemical properties

Soil physical/chemical parameters		Methods used
Texture class	Sand	Bouyoucos Hydrometer
	Clay	
	Silt	
Exchangeable bases	Ca	Flame atomic absorption spectrophotometer (AAS)
	Mg	Flame atomic absorption spectrophotometer (AAS)
	Na	Flame emission spectrophotometer (FES)
	K	Flame emission spectrophotometer (FES)
Electrical conductivity		Conductivity meter using soil saturation paste
Cation exchange capacity		NH ₄ 0ac (Ammonium acetate)
Organic Carbon		Titration
Organic matter content		
Total Nitrogen		Kjeldhal procedure
Available phosphorous		Olson method
soil pH		pH meter using soil saturated paste

Ordination technique using Canonical Correspondence Analysis was used to analysis the relationship or correlation of plots, species and environmental variables as triplot. Canonical Correspondence Analysis (CCA) with library (vegan) was selected due to the following major reasons: i) high species turn over indicated by high beta diversity (>3.5) and ii) better visualization of the graph.

In addition, according to (David, 2013), fuzzy set ordination (FSO) which helps to compute a set of samples along environmental gradients based on sample similarities and gradient values to determine the relationship between two environmental variables. One-Way ANOVA test was run to check the level of significance for different environmental variables at a permutation of 999.

3.4.2. Soil seed bank density and it's similarity with the above ground vegetation

The seedlings that emerged from the soil seed bank were allowed to grow to various degrees at different periods (Fig. 13). The species composition and the density of the soil seed bank among soil depths and the study sites were analyzed using the excel spreadsheet.

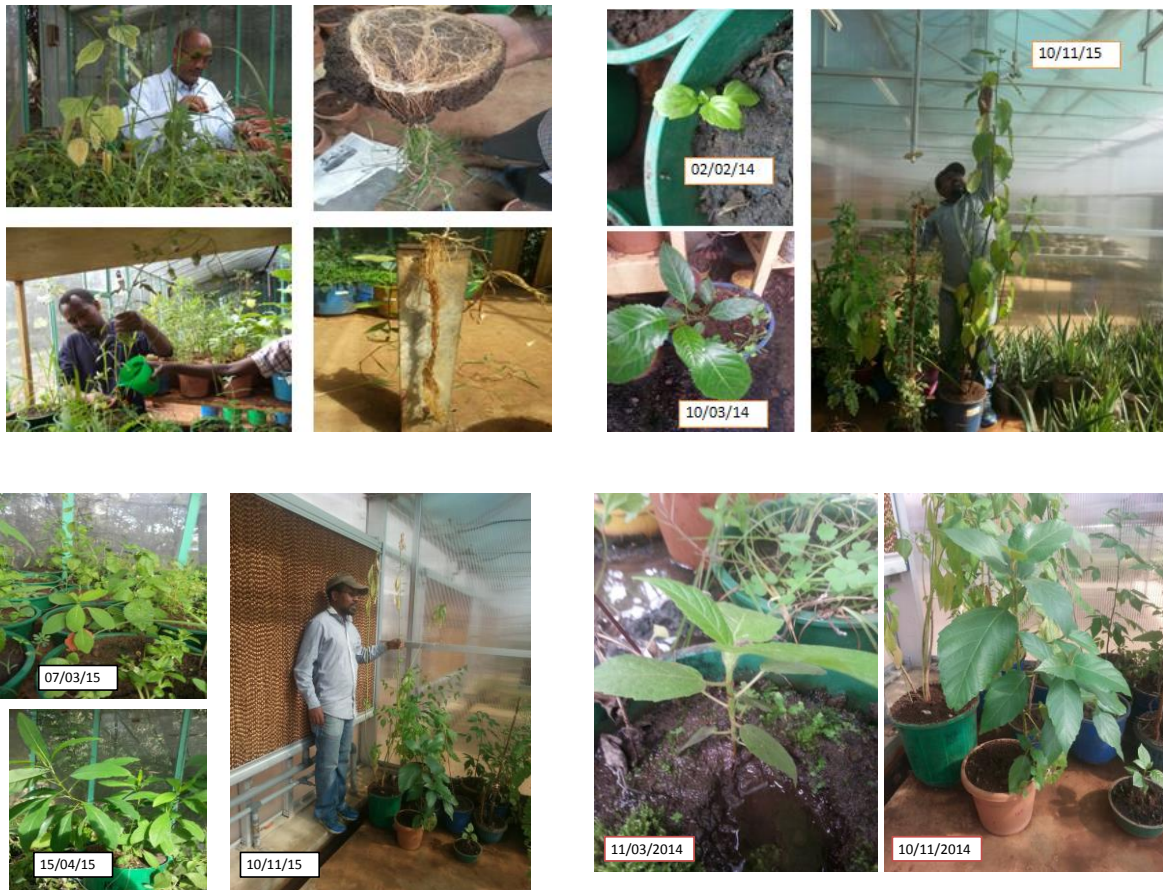


Figure 13: The process of soil seed bank germination at different periods.

Moreover, the degree of similarity between the seed bank and the above ground vegetation was determined using Jaccard's Coefficient of Similarity (Krebs, 1989). This coefficient has been also identified as unbiased when compared with other similarity indices, even with small sample sizes (Ludwig and Reynolds, 1988).

The Jaccard's Coefficient of Similarity (JCS) which is expressed in equation (3) is also used to compute the similarity of the soil samples among each layer. It is calculated based on the presence-absence relationship between the number of species common to the two layers and the total number of species from the two layers. This means that the coefficient expresses the ratio of the common species to all species found on the two layers:

$$S_j = \frac{a}{a + b + c} \dots\dots\dots\text{Equation 3}$$

Where S_j = Jaccard similarity coefficient

a= Number of species common to both layers

b= Number of species unique to layer b

c= Number of species unique to layer c. The coefficient has a value from one to zero, where one indicates complete similarity and zero complete dissimilarity. This method was also used to determine the similarity of the species of the soil seed bank across different LU/LC. Minitab 17 was used to check the statistical significance of species number and density among soil seed bank sampling layers. In addition excel spread sheet was used to produce different graphs.

3.4.3. Data acquisition

To identify and trace back the trend of LU/LC for the catchments, the source data was extracted from satellite imageries of land sat archive. The data sets include Land sat TM, ETM+ and TIROS for 1984, 2000 and 2017 respectively. The data set were accessed from different options such as **Global Land Cover Facilities**; **Earth Explore** and **Glovis** as appropriate, finally an image with a better quality was accessed at Earth Explore engine (<http://earthexplorer.usgs.gov>). The images were selected in light of the accessibility of the data and cloud cover percentage, which were zero percent (0%) for 1984 and 2000 and 1.49% for 2017. Two scenes were used with path number 169 and row number 052 for the first scene and path number 170 and row number 052 for the second scene (Table 6).

Table 6: The date of acquisition and spatial resolution of the data set

Where: P = path; r = Row

Data set	Date/year of acquisition	Band No.	Spatial Resolution	Band Combination	Path and Row	
					Scene 1	Scene 2
TM	1984	7	30 m x 30 m	4,3,2	P169_r52	P170_r52
ETM+	2000	8	30 m x 30 m	4,3,2	P169_r52	P170_r52
TIROS	2017	10	30 m x 30 m	5,4,3	P169_r52	P170_r52

3.4.3.1. Image and data processing

For the land use land cover change, remote sensing (RS) and GIS techniques were used. Digital satellite image was extracted, processed, classified and analyzed using ArcGIS 10.3.1. The satellite image was also extracted based on the study area boundary. Terrain data such as elevation, slope and aspect were generated from SRTM data after being patched for the anomalies using 3DEM visual software and further processed by using spatial analyst tool of

ArcGIS 10.3.1. To fit geometrically, all the layers and points were projected as Adindan_UTM_Zone_37N.

Satellite imagery of three time periods (1984, 2000 and 2017) were used as a data source to detect the land cover dynamics. Different LU/LC classes were distinguished from visual and digital interpretations of imageries extracted from different data sets. Based on the appropriate year satellite imagery, the LU/LC classes analyzed for changes. During data processing, different tools in ArcMap10.3.1 was employed to make mosaic the raster data and convert it to polygon or vector data, to form composite, to dissolve, classify, reclassify, to create attribute data and calculate routine mathematical processes. Google earth engine's historical imagery tab was also used to visualize the changes over time.

3.4.3.2. Land use and land cover image classification

Image classification was performed by using both unsupervised and supervised classification procedures. Unsupervised classification procedure was applied to test and visualized the trend of LU/LC types through automated method to cluster reflectance values in order to drive a required number of classes and their corresponding spectral signatures (Tudor *et al.*, 1998). Supervised classification is achieved with maximum likelihood classifier decision rule (Lillesand and Kiefer, 1999), using the following three stages: Assigning training sites (signature) and running **Maximum Likelihood Classification Method** and interpreting the corresponding outputs. Using this approach the major land cover types were indicated manually through visual observation unlike unsupervised before classifying the image electronically.

The time range was divided into 3 periods (1984, 2000 and 2017). Change analysis was made using post classification comparison in GIS. Using confusion matrix comparisons were made

between 1984 and 2000, 1984 with 2017 and 2000 with 2017. Finally, a map was produced on the basis of reflectance characteristics of false color composites at a scale of 1:40, 000 for the corresponding years.

The quality of the map extracted from remotely sensed data followed by classification was determined by performing the accuracy assessment tools of ERDAS software by using the representative points after classification was made. The ground information was taken from 300 points generated from each class (Sherbinin, 2002), visual interpretation of the raw images with the help of personal knowledge of the study area and from high resolution imageries such as Google Earth and Sentinel 2.

3.4.4. Local ecological knowledge

Following, the field observation a survey was administered to farmers living in the study area and the researcher together with the local field guides gather the information using the semi-structured questionnaires and interviews (Appendix 12). Through a series of fieldworks, purposive sampling method was used to select the respondents. The interviewees were asked and their response recorded via oral interviews using their own local language and later translated to English to assess the ecological knowledge of the community, the history of the vegetation and land use experience. It was also helpful to identify the major cause of the change and the extent of the impact both on soil seed bank and above ground vegetation.

In the field assessment where questionnaires and interviews were carried out to gather information from farm households, both males and females were involved. There were 90 informants identified from 3 agro-ecological zones (30 each), with their age ranging from 56 and above (Fig. 14). During vegetation and environmental data collection, encountered farm

households were participated by considering their willingness to sit for an interview. The information gathered from individuals were qualified and validated by group discussion.



Figure 14: Inhabitats involved as interviewee during fieldwork

CHAPTER FOUR

4. RESULTS

4.1. Above ground vegetation

4.1.1. Floristic composition

The total number of plant species documented in the Gumara and Rib watersheds was **342** in 246 genera and 90 families in 98 plots (Appendix 1). About 97.53% of the recorded species were angiosperms while the remaining (2.47%) were non-flowering seed-bearing plants (gymnosperms), for example, *Juniperus procera* (Cupressaceae) and *Podocarpus falcatus* (Podocarpaceae) and seedless vascular plants such as *Adiantum poiretii* (Adiantaceae), *Azolla nilotica* (Azollaceae), *Dryopteris schimperiana* (Dryopteridaceae) and *Pteridium aquilinum* (Hypolepidaceae) recorded as Pteridophyta while *Selaginella goudotiana* (Selaginellaceae) recorded as Lycopodiophyta. The number of species in the corresponding plots increases with increasing elevation up to 3200 m asl and then decrease beyond this point.

The most dominant families in species richness in decreasing order are Asteraceae, Poaceae, Fabaceae and Lamiaceae with 47 (13.74%), 35 (10.23%), 35 (10.23%) and 18 (5.26%) species respectively all together contributed to about 135 (39.47%) of the total number of species. Families, which had ≥ 9 species include Cyperaceae (4.39%), Acanthaceae (2.92%), Euphorbiaceae (2.92%) and Solanaceae (2.62%) which represent 179 (52.34%) species of the totality (Fig. 15).

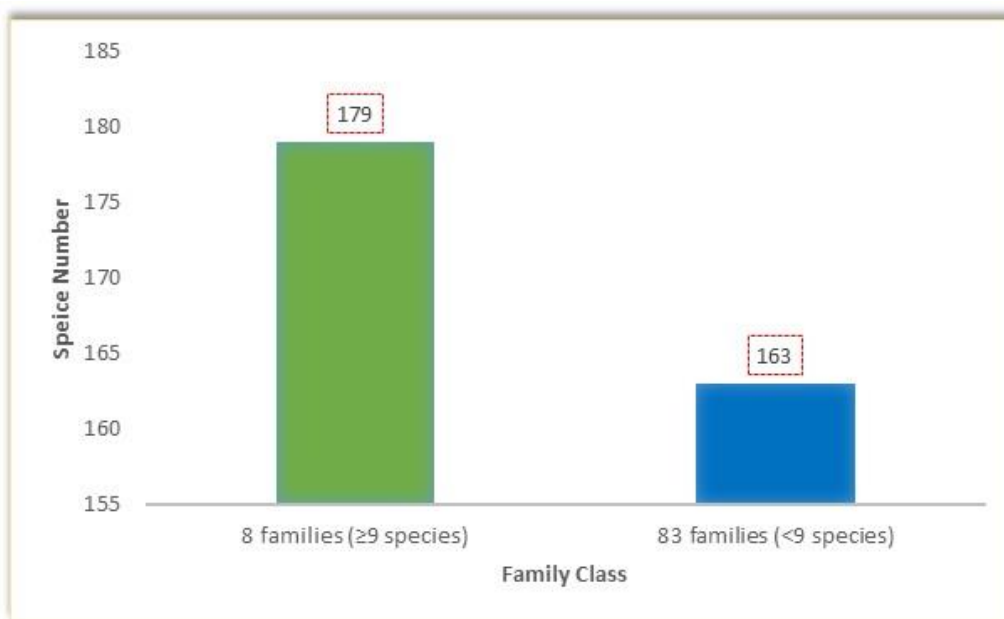


Figure 15: The distribution of species along two major family classes

From a total number of species, 20 (5.84%) were endemic to Ethiopia (Table 7); and 12 (3.51%) were considered as weeds by the inhabitants of which 91.67% were herbs (Table 8).

Table 7: List of endemic plants species and their IUCN categories

Key: T = tree, S = shrub, H = herb, NT= Nearly Threatened, LC= Least, SU = Shewa, IL = Ilubabor, WG = Wollega, AR= Arsi, KF= Kefa, GG = Gammogofa, SD = Sidamo, GD = Gondar, GJ = Gojam, Wu = Welo, BA = Bale, HA = Harar, TU = Tigray, EW= Eritrea West, FE = Flora of Ethiopia and IUCN = International Union for Conservation of Nature and Natural Resources.

Endemic species	Family	Habit	IUCN category	Distribution (FE)
<i>Acanthus sennii</i> Chiov.	Acanthaceae	Sh	NT	GD GJ WU SU AR WG KF GG SD BA HA
<i>Bothriocline schimperi</i> Oliv. and Hiern ex Benth.	Asteraceae	Sh	LC	GD GJ SU AR WG IL KF GG SD BA
<i>Chiliocephalum tegetum</i> Mesfin	Asteraceae	H	NE	GD GJ SD BA
<i>Crassocephalum macropappum</i> (Sch.	Asteraceae	H	LC	GD GJ WU SU WG IL KF GG SD BA HA

Endemic species	Family	Habit	IUCN category	Distribution (FE)
Bip. ex A. Rich.) S. Moore				
<i>Echinops ellenbeckii</i> O. Hoffm.	Asteraceae	Sh	EN	SU AR HA
<i>Echinops longisetus</i> A. Rich.	Asteraceae	Sh	LC	GD GJ WU SU AR WG KF GG SD BA HA
<i>Festuca macrophylla</i> Hochst. ex A. Rich.	Poaceae	H	NE	GO SU
<i>Laggera tomentosa</i> (Sch. Bip. ex A. Rich.) Oliv. and Hiem	Asteraceae	H	NT	TU GD GJ WU SU HA
<i>Leucas aequistylosa</i> Sebald	Lamiaceae	H	NE	KF
<i>Leucas stachydiformis</i> (Hochst. ex Benth.) Briq.	Lamiaceae	H/Sh	NT	TU GD GJ WU SU AR SD BA HA
<i>Lobelia rhynchopetalum</i> Hemsl.	Lobeliaceae	H	NE	GD GJ SU AR BA HA
<i>Mikaniopsis clematoides</i> (Sch. Bip. ex A. Rich.) Milne-Redh.	Asteraceae	Cl	LC	TU/GD WU AR KF BA HA
<i>Milletia ferruginea</i> (Hochst.) Bak. subsp. ferruginea	Fabaceae	T	LC	TU GD GJ SU WG HA
<i>Rutya speciosa</i> (Hochst.) Engl.	Acanthaceae	Sh	NE	TU GD GJ
<i>Senecio myriocephalus</i> Sch. Bip. ex A. Rich.	Asteraceae	H	LC	TU/GD GD WU SU AR KF SD BA HA
<i>Senecio unionis</i> Sch. Bip. ex A. Rich.	Asteraceae	H	NE	GD SU AR BA
<i>Solanecio gigas</i> (Vatke) C. Jeffrey	Asteraceae	T	LC	GD GJ WU SU AR SD IL KF BA HA
<i>Trifolium schimperi</i> A. Rich.	Fabaceae	H	NE	TU GD GJ WG WU SU AR KF
<i>Urtica simensis</i> Steud.	Urticaceae	H	LC	TU GD GJ SU AR BA SD
<i>Vernonia leopoldi</i> (Sch. Bip. ex Walp.) Vatke	Asteraceae	Sh	LC	TU GD GJ WU SU WG KF HA GG

Table 8: List of species considered as weeds by the local people (left) and recognized as invasive at a national level in Ethiopia (Right)

Weeds recognized by the inhabitants					Prioritized invasive recognized at national level		
No	Species Name	Habit	No	Family	Species Name	Habit	Family
1	<i>Ageratum conyzoides</i>	H	1	Asteraceae	<i>Parthenium hysterophorus</i>	H	Asteraceae
2	<i>Amaranthus spinosus</i>	H	2	Amaranthaceae	<i>Eichornia crassipes</i>	H	Pontederiaceae
3	<i>Argemone mexicana</i>	H	3	Papaveraceae	<i>Lantana camara</i>	Sh	Lamiaceae
4	<i>Azolla nilotica</i>	H	4	Azollaceae	<i>Mimosa pigra</i>	Sh	Fabaceae
5	<i>Datura stramonium</i>	H	5	Solanaceae	<i>Nymphoides brevipedicellata</i>	H	Nymphaeaceae
6	<i>Echinochloa pyramidalis</i>	H	6	Poaceae	<i>Argemone mexicana</i>	H	Papaveraceae
7	<i>Eichornia crassipes</i>	H	7	Pontederiaceae	<i>Acacia seyal</i>	T	Fabaceae
8	<i>Galinsoga quadriradiata</i>	H	8	Asteraceae	<i>Amaranthus spinosus</i>	H	Amaranthaceae
9	<i>Guizotia scabra</i>	H	9	Asteraceae	<i>Xanthium spinosum</i>	H	Asteraceae
10	<i>Senna didymobotrya</i>	Sh	10	Fabaceae	<i>Xanthium strumarium</i>	H	Asteraceae
11	<i>Xanthium spinosum</i>	H	11	Asteraceae	<i>Datura stramonium</i>	H	Solanaceae
12	<i>Xanthium strumarium</i>	H	12	Asteraceae	<i>Senna didymobotrya</i>	Sh	Fabaceae

However, the number of families represented by one species only were 49 (53.85%). Examples include Adiantaceae (*Adiantum poiretii*), Aloaceae (*Aloe macrocarpa*), Amaryllidaceae (*Scadoxus multiflorus*), Araceae (*Arisaema schimperianum*), Azollaceae (*Azolla nilotica*), Bignoniaceae (*Stereospermum kunthianum*), Dioscoreaceae (*Dioscorea quartiniana*), Ericaceae (*Erica arborea*), Lobeliaceae (*Lobelia rhynchopetalum*), Lythraceae (*Ammannia baccifera*),

Menispermaceae (*Stephania abyssinica*), Onagraceae (*Ludwigia stolonifera*), Papaveraceae (*Argemone mexicana*), Proteaceae (*Protea gaguedi*), Resedaceae (*Caylusea abyssinica*), Santalaceae (*Osyris quadripartita*), Sterculiaceae (*Dombeya torrida*), Thymelaeaceae (*Gnidia glauca*) and Ulmaceae (*Celtis africana*) to mention a few (Table 9).

Table 9: Plant families with their corresponding genera, species number and frequency

No	Family name	Number		Frequency		No	Family name	Number		Frequency	
		Genera	Species	Freq.	%			Genera	Species	Freq.	%
1	Acanthaceae	7	10	57	4.78	46	Lythraceae	1	1	1	0.08
2	Adiantaceae	1	1	7	0.59	47	Malvaceae	5	7	27	2.26
3	Aloaceae	1	1	3	0.25	48	Meliaceae	2	2	11	0.92
4	Amaranthaceae	3	3	39	3.27	49	Meliantaceae	1	1	14	1.17
5	Amaryllidaceae	1	1	1	0.08	50	Menispermaceae	1	1	3	0.25
6	Anacardiaceae	2	4	24	2.01	51	Molluginaceae	1	1	1	0.08
7	Apiaceae	6	6	20	1.68	52	Moraceae	1	4	14	1.17
8	Apocynaceae	2	2	39	3.27	53	Myrsinaceae	3	3	16	1.34
9	Araceae	1	1	2	0.17	54	Myrtaceae	2	2	13	1.09
10	Araliaceae	1	1	3	0.25	55	Nymphaeaceae	2	2	3	0.25
11	Arecaceae	1	1	9	0.75	56	Olacaceae	1	1	6	0.50
12	Asclepiadaceae	3	3	3	0.25	57	Oleaceae	4	5	29	2.43
13	Asparagaceae	1	1	5	0.42	58	Onagraceae	1	1	3	0.25
14	Asteraceae	34	47	85	7.12	59	Oxalidaceae	1	1	2	0.17
15	Azollaceae	1	1	2	0.17	60	Papaveraceae	1	1	6	0.50
16	Bignoniaceae	1	1	9	0.75	61	Phytolaccaceae	1	1	4	0.34
17	Boraginaceae	4	4	18	1.51	62	Pittosporaceae	1	1	9	0.75
18	Brassicaceae	1	2	2	0.17	63	Plantaginaceae	1	1	5	0.42
19	Capparidaceae	1	1	16	1.34	64	Plumbaceae	1	1	2	0.17
20	Celastraceae	1	5	47	3.94	65	Poaceae	25	35	78	6.54
21	Chenopodiaceae	1	1	1	0.08	66	Podocarpaceae	1	1	2	0.17
22	Combretaceae	2	3	9	0.75	67	Polygonaceae	2	5	15	1.26

No	Family name	Number		Frequency		No	Family name	Number		Frequency	
		Genera	Species	Freq.	%			Genera	Species	Freq.	%
23	Commelinaceae	1	2	5	0.42	68	Pontederiaceae	1	1	3	0.25
24	Convolvulaceae	1	3	5	0.42	69	Proteaceae	1	1	1	0.08
25	Crassulaceae	2	2	11	0.92	70	Ranunculaceae	4	5	9	0.75
26	Cucurbitaceae	1	1	1	0.08	71	Resedaceae	1	1	2	0.17
27	Cupressaceae	1	1	5	0.42	72	Rhamnaceae	1	2	2	0.17
28	Cyperaceae	3	15	29	2.43	73	Rosaceae	4	5	19	1.59
29	Dioscoreaceae	1	1	1	0.08	74	Rubiaceae	5	7	24	2.01
30	Dipsacaceae	3	3	3	0.25	75	Rutaceae	2	2	26	2.18
31	Dracaenaceae	1	1	1	0.08	76	Salicaceae	1	1	1	0.08
32	Dryopteridaceae	1	1	3	0.25	77	Santalaceae	1	1	11	0.92
33	Ebenaceae	2	2	4	0.34	78	Sapindaceae	2	2	19	1.59
34	Ericaceae	1	1	2	0.17	79	Sapotaceae	1	1	1	0.08
35	Euphorbiaceae	7	10	58	4.86	80	Scrophulariaceae	1	1	1	0.08
36	Fabaceae	20	35	81	6.79	81	Selaginellaceae	1	1	1	0.08
37	Flacourtiaceae	3	3	8	0.67	82	Simaroubaceae	1	1	7	0.59
38	Geraniaceae	1	1	8	0.67	83	Solanaceae	4	9	17	1.42
39	Hypericaceae	1	3	6	0.50	84	Sterculiaceae	1	1	4	0.34
40	Hypolepidaceae	1	1	1	0.08	85	Thymelaeaceae	1	1	1	0.08
41	Icacinaceae	1	1	4	0.34	86	Tiliaceae	2	2	29	2.43
42	Lamiaceae	11	18	43	3.60	87	Ulmaceae	1	1	1	0.08
43	Lobeliaceae	1	1	2	0.17	88	Urticaceae	3	3	13	1.09
44	Loganiaceae	2	3	8	0.67	89	Verbenaceae	3	3	32	2.68
45	Loranthaceae	1	1	1	0.08	90	Vitaceae	2	2	14	1.17
Total								246	342	1193	100

All the growth forms (Climber, Herb, Shrub, Shrub/Tree and Tree) were observed and represented by different proportions of species such as 17 (4.97%), 178 (52.05%), 87 (25.44%),

11 (3.22%) and 49 (14.33%) respectively (Fig. 16). The maximum number of species were recorded for Herbs while the least were for both Shrubs and Trees (T/Sh)

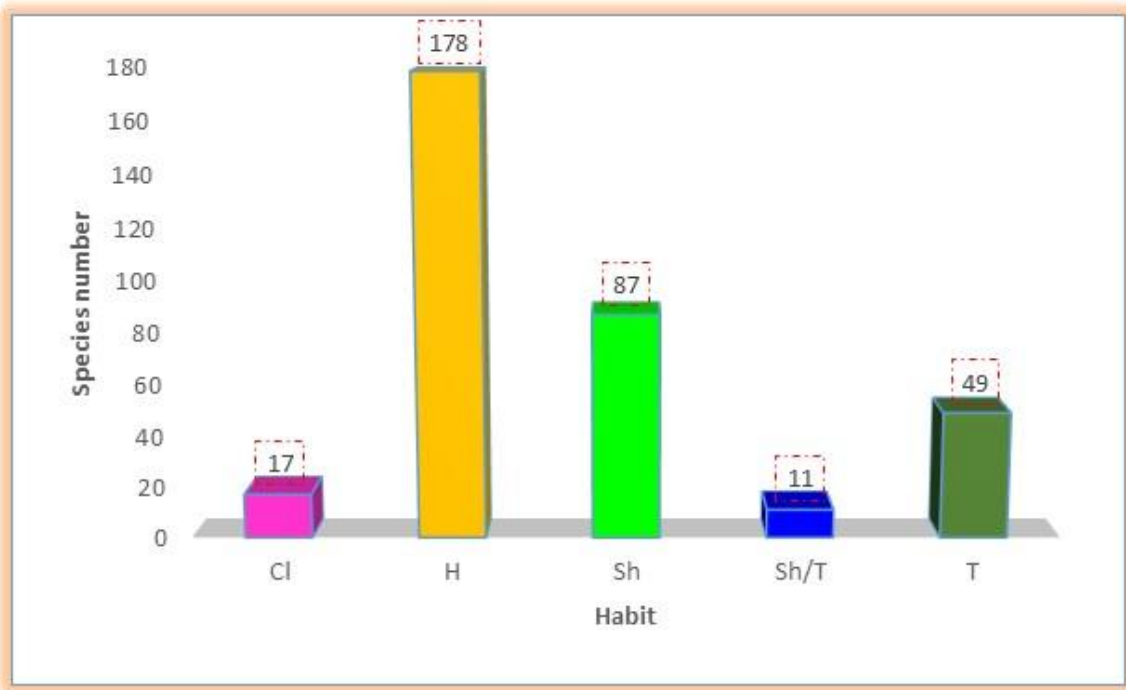


Figure 16: Plant habit of the study area

Key: Cl = Climber, H = Herb, Sh = Shrub, Sh/T = Shrub or Tree & T = Tree

A total of 35 established and emerging invasive plant species recognized by a manual entitled "Environmental Policy of Ethiopia (EPE) and the Biodiversity Strategy and Action Plan as posing a major threat to biodiversity and economic well-being of the population" at a national level, Ethiopia (Rezene Fessehaie *et al.*, 2005). Of which 12 (3.51%) were observed in a recent study area. About 83.33% of the invasive including *Eichornia crassipes*, *Nymphoides brevipedicellata* and *Mimosa pigra* to mention some are limited to the Wetland of Fogera plain, located at the lower elevation of the study area.

4.1.2. Distribution Model of *Senna didymobotrya*

Of the 12 (3.51%) identified invasive plant species by the local people, the most frequently observed one was *Senna didymobotrya*. According to the result, the relative contributions of the environmental variables (predictors) to build the Maximum Entropy (Maxent), model was different. The highest average contribution was recorded from Classified Map (41%), followed by elevation (33.2%), roughness (16.3%), mean_slope (8.9%), heat_load (0.5%), while the least was contributed from Compound topographic index (CTI), with 0.1 percent contribution. While the rest of the environmental factors such as linear aspect, Normalized Difference Vegetation Index (NDVI) and tasseled cape wetness (1= brightness, 2 = greenness and 3 = wetness), remained non-significant in their contribution to building the model.

The process was repeated (re-run), until the average value of test AUC either similar to or greater than the average value of training AUC by avoiding the least percent contributor variable observed at the output of each run. Finally, the average replicate run value of test AUC (0.879) became greater than the corresponding training AUC with a value of 0.867 which convey the final output (Fig. 17).

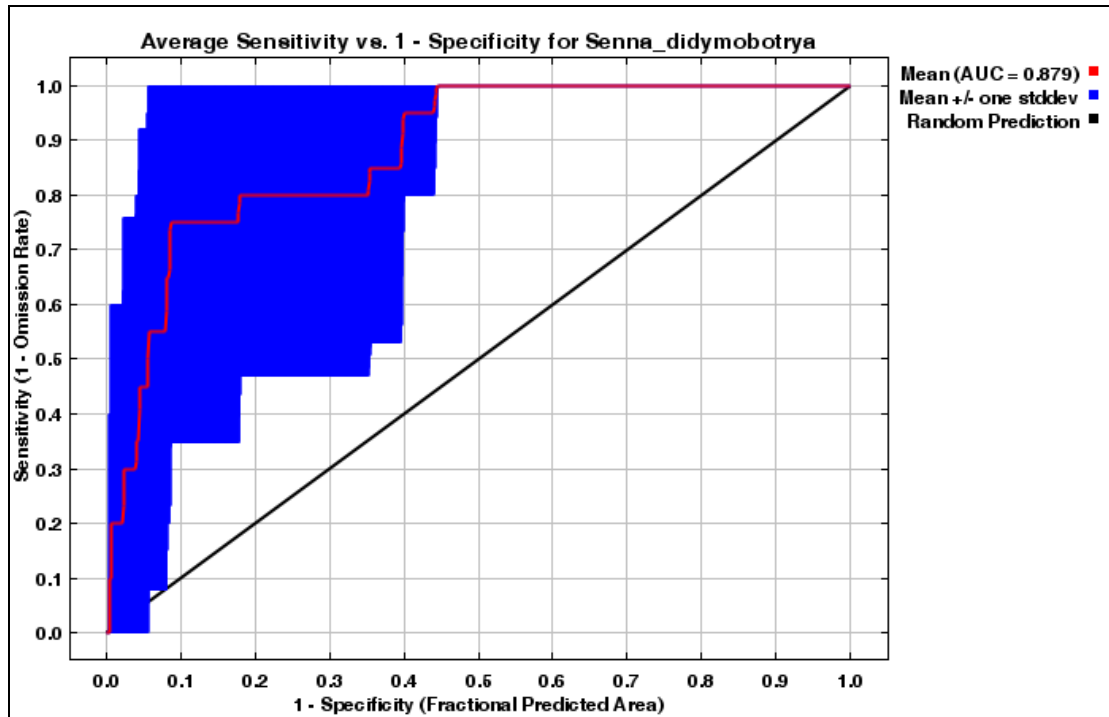


Figure 17: Area under the receiver-operating curve (AUC) of the training data

The response of each variable to *Senna didymobotrya* was indicated by curves to the predicted probability of the presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value (Figure 18). The classified map has five classes represented by 1 (Water), 7 (Cropland), 15 (Wetland), 18 (Settlement), 24 (Grassland), 30 (Shrubland) and 34 (Forest). The distribution potential of *Senna didymobotrya* ranged between 0 and 1 (Fig. 19), 1 represents the highest habitat suitability while 0 represents the unsuitability of the habitat for the spatial distribution of *Senna didymobotrya*.

According to the result in the classified map, Shrubland was the most suitable habitat for *Senna didymobotrya* followed by Settlement. The response to mean slope was also high with ~ 75.5% observed in a range between -0.6 and 0 (zero). The response of *Senna didymobotrya* to elevation was constant (66%), in the range between 1781-1800 m asl and then followed a decreasing

pattern with increasing elevation. While the response to roughness was just above 73.6% up to zero value of roughness and remain constant at 73% with increasing roughness. The response to heat load remained constant as it was observed between 73.0% and 73.2%. Similarly, the distribution potential of *Senna didymobotrya* was constant in compound topographic index (CTI) at a corresponding CTI value of 73.0% up to a CTI value reaches 20 and then decrease with increasing cti value.

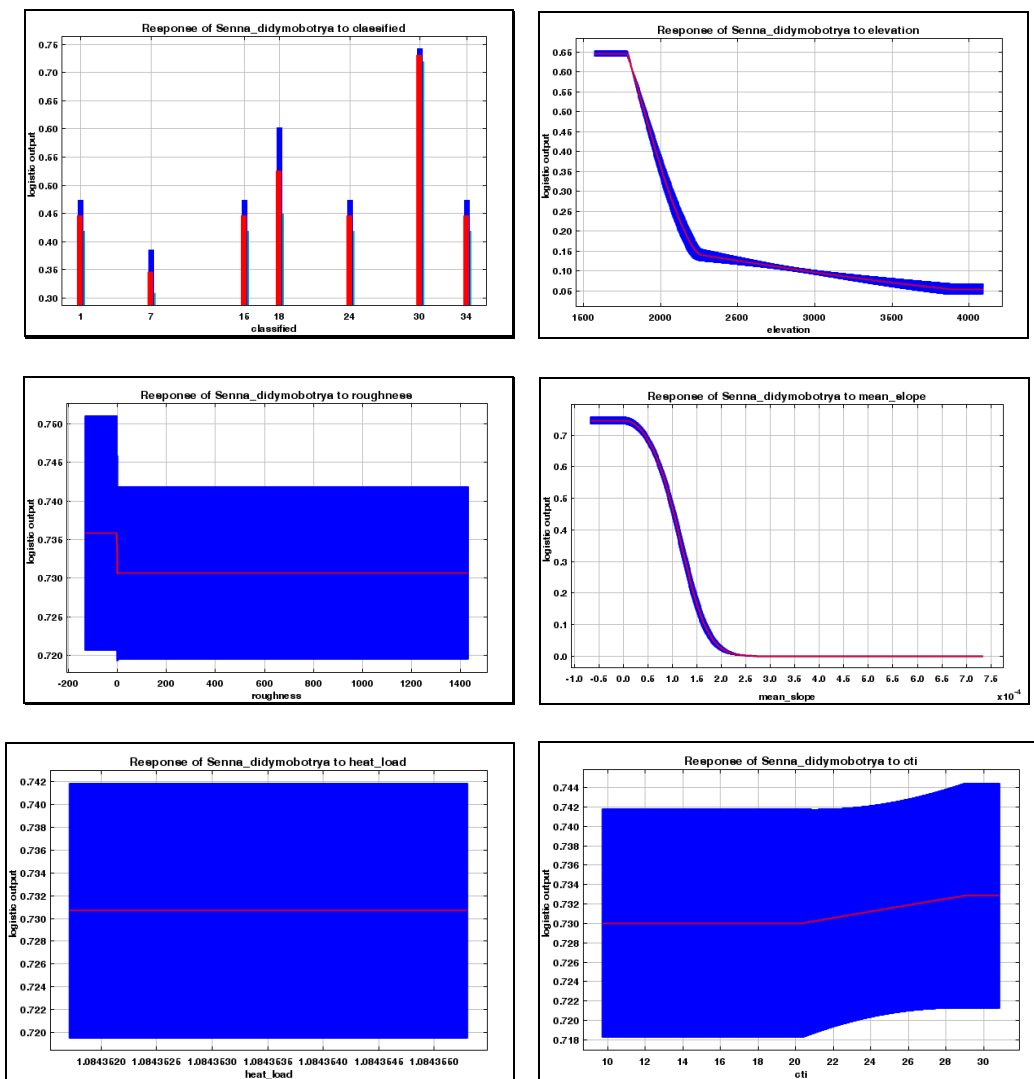


Figure 18: The response of *Senna didymobotrya* to different environmental predictors

The distribution pattern observed in the model was a good representative (fit) of the ground truth as it covers similar extent.

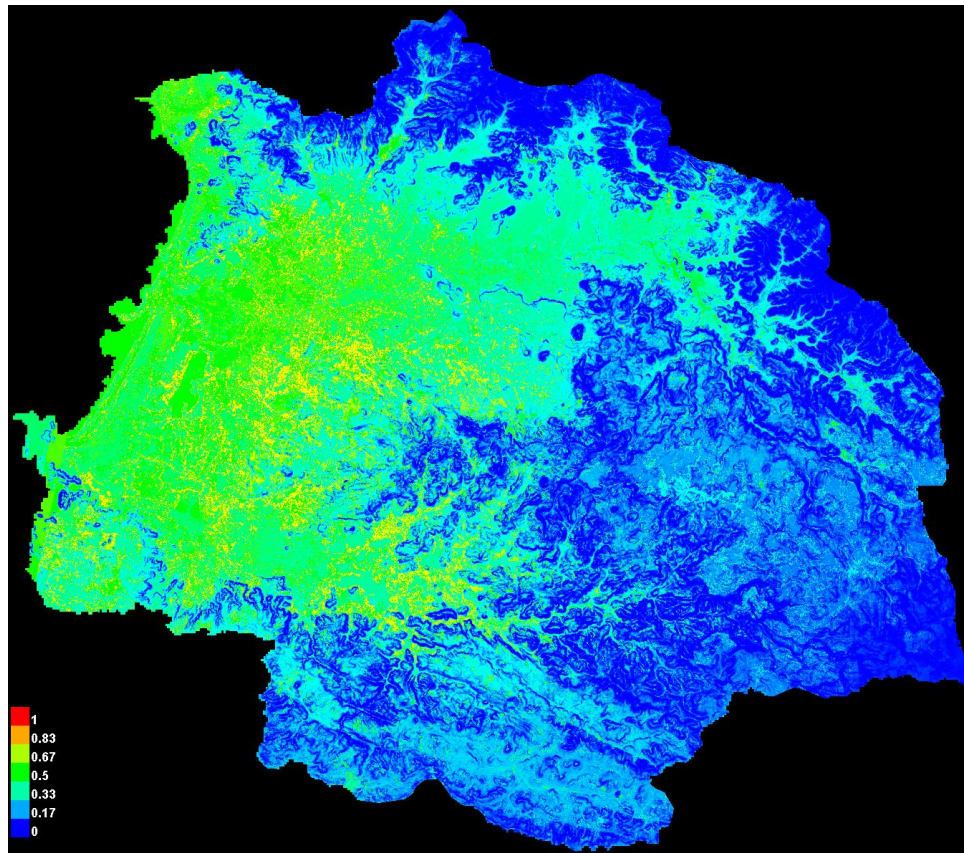


Figure 19: The spatial distribution potential of *Senna didymobotrya*

Where: (1) indicates the highest area suitability, while (0) indicates area unsuitability for the growth of *Senna didymobotrya*

4.1.3. Plant Community types

Based on the corresponding synoptic cover values five types of clusters were generated and named after two dominant species with the highest mean cover/abundance or importance value index (Appendix 3) that appeared within the corresponding clusters. The five clusters (Fig. 21) designated as community types were *Cynodon dactylon* and *Eleusine indica* Community type I, *Syzygium guineense* and *Phoenix reclinata* Community type II, *Croton macrostachyus* and *Grewia ferruginea* Community type III, *Dodonea angustifolia* and *Premna schimperi* Community type IV and *Chionanthus mildbraedii* and *Maytenus arbutifolia* Community type V. It was identified based on its ecological similarity and relative magnitude of mean cover abundance.

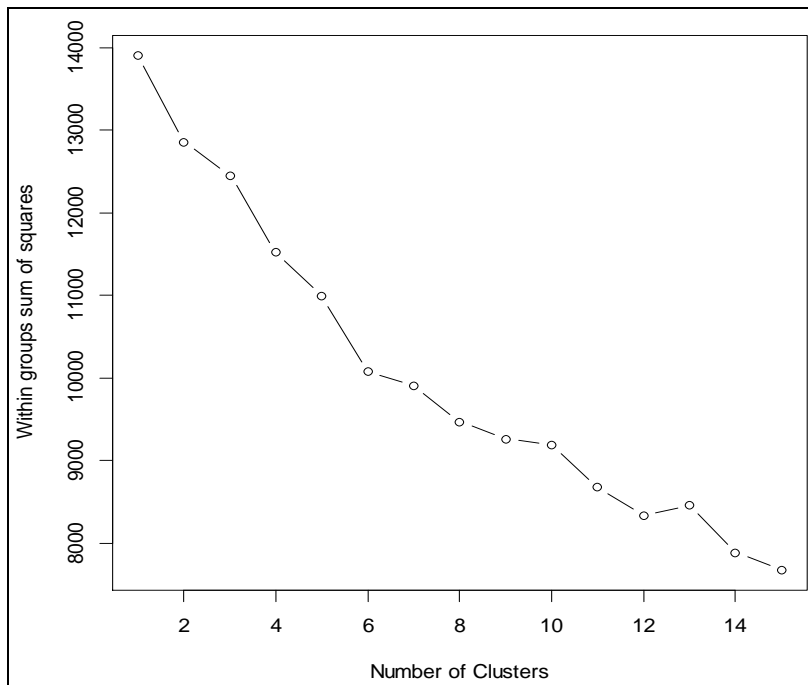


Figure 20: The optimal number of clusters

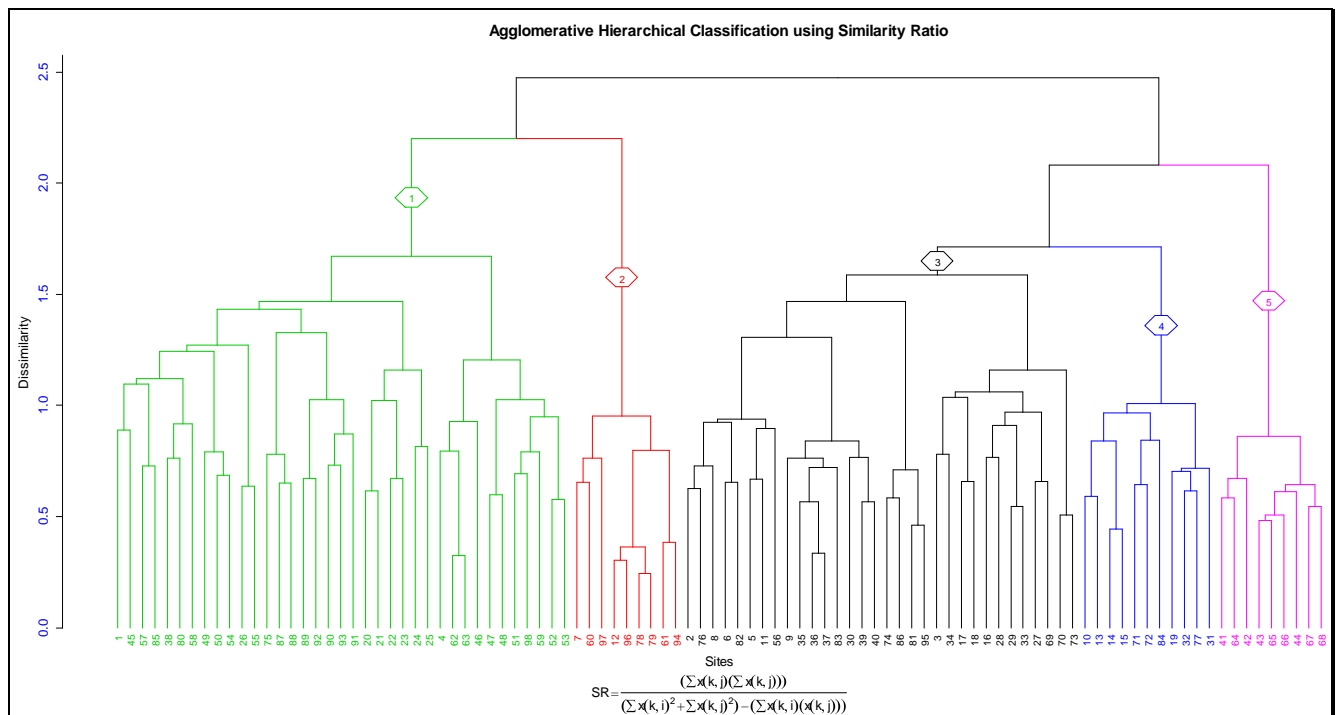


Figure 21: Plant community types of Rib and Gumara watersheds

Community type I had maximum number of plots (37) followed by Community type III and IV with plot numbers of 32 and 11 respectively (Table 9). While Community type II and V had, the least with 9 plots each. The number of plant species in the corresponding community types were 194 (30.31%), 70 (10.94%), 176 (27.5%), 123 (19.22%) and 77 (12.03%) for Community type I, II, III, IV and V respectively. The number of species in the corresponding communities range between 70 and 194 where the maximum plant species was observed in *Cynodon dactylon* and *Eleusine indica* Community type I, while the least plant species number relatively, was observed in *Syzygium guineense* and *Phoenix reclinata* Community type II.

Out of the total number of plant species about 7.02% (24), were identified as an indicator species for the identified five community types with a distribution of: 1, 12, 1, 3 and 7 for the corresponding Community type I, II, III, IV and V respectively (Table 10). The habit of the indicators were composed of 58.33% (14), Herbs, 20.83% (5), Shrubs and Trees each and it was

represented by 21 families such as Acanthaceae, Aloaceae, Amaranthaceae, Apiaceae, Araliaceae, Asteraceae, Boraginaceae, Cyperaceae, Fabaceae, Geraniaceae, Lamiaceae, Meliaceae, Melianthaceae, Moraceae, Oleaceae, Onagraceae, Papaveraceae, Rosaceae, Rubiaceae, Simaroubaceae and Sterculiaceae. Each family were represented by one species with the exceptions in Acanthaceae, Asteraceae and Fabaceae represented by two species.

Table 10: Indicator plant species of the five community types significant at $P \leq 0.05$

Community Name and its corresponding community type	Indicator species	P.value	Significant code
<i>Cynodon dactylon</i> and <i>Eleusine indica</i> (Community type I)	<i>Leucas martinicensis</i>	0.044	*
<i>Syzygium guineense</i> and <i>Phoenix reclinata</i> (Community type II)	<i>Galiniera saxifraga</i>	0.001	***
	<i>Hypoestes triflora</i>	0.005	**
	<i>Chionanthus mildbraedii</i>	0.002	**
	<i>Ekebergia capensis</i>	0.003	**
	<i>Bersama abyssinica</i>	0.018	*
	<i>Geranium arabicum</i>	0.011	*
	<i>Brucea antidysenterica</i>	0.007	**
	<i>Crotalaria quartiniana</i>	0.016	*
	<i>Schefflera abyssinica</i>	0.013	*
	<i>Agrocharis melanantha</i>	0.018	*
	<i>Rubus apetalus</i>	0.043	*
<i>Dombeya torrida</i>	0.031	*	
<i>Croton macrostachyus</i> and <i>Grewia ferruginea</i> (Community type III)	<i>Hypoestest forskoolii</i>	0.014	*
<i>Dodonea angustifolia</i> and <i>Premna schimperi</i> (Community type IV)	<i>Cyperus macrostachyos</i>	0.029	*
	<i>Ficus thonningii</i>	0.02	*
	<i>Ludwigia stolonifera</i>	0.05	*
<i>Chionanthus mildbraedii</i> and <i>Maytenus arbutifolia</i>	<i>Argemone mexicana</i>	0.001	***
	<i>Heliotropium supinum</i>	0.001	***

Community Name and its corresponding community type	Indicator species	P.value	Significant code
(Community type V)	<i>Amaranthus spinosus</i>	0.001	***
	<i>Senna didymobotrya</i>	0.029	*
	<i>Aloe macrocarpa</i>	0.013	*
	<i>Parthenium hysterophorus</i>	0.019	*
	<i>Xanthium spinosum</i>	0.035	*

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

Community type II has the highest number of indicator species (12) followed by Community type V and Community type IV with 7 and 3 indicator plant species respectively, while Community type I and III have 1 species each to define the environment for the corresponding communities (Table 10).

The plant communities which grouped, based on their affinity and associations are described below:

i. *Cynodon dactylon* and *Eleusine indica* community type I

The number of plots and plant species in this community type were 37 and 194 respectively. The synoptic value of this community type was in the range between 0.03 and 1.38. This community type was named after *Cynodon dactylon* and *Eleusine indica* because of their relatively high synoptic value (SV) with 1.38 and 0.54, followed by *Hygrophila schulli* and *Guizotia scabra* with a synoptic value of 0.54 and 0.49 respectively as a herb layer. The least synoptic value was represented by *Acanthus polystachius*, *Astragalus aremophilus*, *Capparis tomentosa*, *Caylusea abyssinica*, *Chloris pycnothrix* and *Cirsium vulgare* with recorded value of 0.03 each. Some of the species which form Tree layer of the community include *Cordia africana*, *Acacia seyal* and *Juniperus procera* with a synoptic value of 0.51, 0.46 and 0.44 respectively. Some of the plant

species which form the shrub layer of this community type were *Vernonia myriantha*, *Erica arborea* and *Buddleja polystachya* with a synoptic value of 0.51, 0.41 and 0.33 respectively. This shows that the presence of all growth forms including climbers such as *Jasminum grandiflorum* and *Stephania abyssinica* in this community.

The distribution of the plant species under this community type was found in the range between 2600 and 4102 m asl. The species of this community distributed into different landuse types such as in Cropland, Forest, Shrubland, Grassland and Wetlands.

ii. *Syzygium guineense* and *Phoenix reclinata* community type II

The number of plant species in this community type was 70 appearing in 9 plots. The synoptic value of this community was in the range between 0.11 and 7.22. The highest value was represented by *Syzygium guineense* and the lowest was by *Acokanthera schimperi*, *Andropogon abyssinicus*, *Bidens prestinaria*, *Cyperus rigidifolius* and *Stephania abyssinica*.

This community was named after *Syzygium guineense* and *Phoenix reclinata* on account of their relatively high synoptic value of 7.22 and 2.44 followed by *Maytenus arbutifolia* and *Croton macrostachyus* with a synoptic value of 2.33 and 1.78 respectively. The plant species named after the community were riverine plants which also represent riverine vegetation.

Some of the species, which form tree layers of the community, include *Syzygium guineense*, *Phoenix reclinata* and *Croton macrostachyus*. *Maytenus arbutifolia*, *Calpurnia aurea*, *Pterolobium stellatum*, *Carissa spinarum* and *Sida schimperiana* were some of the species which form the Shrub layer while the Herb layer was composed of *Persicaria senegalensis*, *Cynodon dactylon*, *Ageratum conyzoides* and *Xanthium strumarium* with a synoptic value of 0.67 each.

The distribution of the plant species under this community type was found in the range between 1797 and 2005 m asl.

iii. *Croton macrostachyus* and *Grewia ferruginea* community type III

The number of plots and plant species in this community type were 32 and 176 respectively. The minimum and maximum synoptic values of the community were between 0.03 and 2.72 in which the highest value was represented by *Maytenus arbutifolia* followed by *Croton macrostachyus*, *Calpurnia aurea* and *Grewia ferruginea* with a synoptic value of 2.72, 2.60, 2.48 and 1.9 respectively. However, the name of the community was given after ***Croton macrostachyus* and *Grewia ferruginea***. Because *Maytenus arbutifolia* was the most dominant in other community type than its value in this community type. The lowest synoptic value was represented by *Nicandra physaloides*, *Poa annua*, *Laggera tomentosa*, *Caesalpinia decapetala*, *Sida rhombifolia* and *Verbena officinalis* to mention a few with 0.03 each.

Some of the species which form a Tree layer of the community include *Croton macrostachyus*, *Acacia albida* and *Albizia schimperiana*. The Shrub layer was represented by *Maytenus arbutifolia*, *Calpurnia aurea*, *Grewia ferruginea*, *Carissa spinarum*, *Pterolobium stellatum*, while the Herb layer (ground cover) was represented by *Guizotia scabra*, *Achyranthes aspera* and *Cynodon dactylon* as examples. The distribution of the plant species under this community type was found in the range between 1910 and 2446 m asl and most observed in forests' of Fogera Woreda which include Church and Community Forests, as well as Shrublands.

iv. *Dodonea angustifolia* and *Premna schimperii* community type IV

The number of plant species in this community type was 123 appearing in 11 plots. The synoptic value of this community was in the range between 0.08 and 5.33. The highest value was

computed from *Dodonea angustifolia* whereas the lowest was from *Asparagus africanus*, *Bidens pilosa*, *Brucea antidysenterica*, *Crepis rueppellii*, *Dryopteris schimperiana*, *Momordica foetida*, *Rubia cordifolia*, *Phytolacca dodecandra*, *Senna singueana* and *Stylosanthes fruticosa* to mention some with a recorded value of 0.08 each. The community was named after ***Dodonea angustifolia* and *Premna schimperi*** as they had the highest synoptic value relatively with 5.33 and 2.92 followed by *Carissa spinarum* and *Rhus vulgaris* with 2.58 and 2.33 respectively.

The Tree layer of the community was composed of *Combretum molle*, *Acacia albida* and *Pittosporum viridiflorum* with a synoptic value of 1.33, 1.17 and 1.08 respectively. The Shrub layer included *Dodonea angustifolia*, *Premna schimperi*, *Carissa spinarum*, *Rhus vulgaris*, *Osyris quadripartita*, *Calpurnia aurea*, *Grewia ferruginea* and *Pterolobium stellatum* with a synoptic value of 5.33, 2.92, 2.58, 2.33, 2.08, 1.67, 1.67 and 1.58 respectively. While the ground layer composed of *Hyparrhenia rufa*, *Guizotia scabra*, *Bidens prestinaria* and *Andropogon abyssinicus* to list a few with a synoptic value of 1.42, 1.33, 0.92 and 0.33 in a logical order.

v. ***Chionanthus mildbraedii* and *Maytenus arbutifolia* community type V**

The number of plots and plant species in this Community type was 9 and 77 respectively. The maximum synoptic values of the community were represented by *Chionanthus mildbraedii* (7.44) while the minimum synoptic value was represented by *Cardamine africana*, *Caylusea abyssinica*, *Cyathula cylindrica*, *Dryopteris schimperiana*, *Euphorbia schimperiana*, *Kalanchoe petitiana* and 6 others with 0.11 each.

The community was named after ***Chionanthus mildbraedii* and *Maytenus arbutifolia*** as they had the highest synoptic value of 7.44 and 4.44 respectively. Tree layer of the community was composed of *Chionanthus mildbraedii*, *Ekebergia capensis*, *Lepidotrichilia volkensis* and *Prunus*

africana with a synoptic value of 7.44, 3.67, 2.44 and 2.11 respectively. *Calpurnia aurea*, *Carissa spinarum*, *Clausena anisata* and *Bridelia micrantha* to list a few with a synoptic value of 3.56, 2.22, 2.0 and 1.89 respectively form the Shrub layer of the community. The ground cover was represented by *Oplismenus hirtellus*, *Hypoestes forskalii*, *Guizotia scabra*, *Hypoestes triflora*, *Pimpinella hirtella* and *Cyperus fischerianus* with a synoptic value of 2.11, 1.67, 0.89, 0.89, 0.78 and 0.67 respectively. The distribution of the plant species under this community type was found in the range between 2413 and 2513 m asl which had a low elevation difference compared to others. This community was composed of nine plots established in a community forest called Yifara.

4.1.4. Community similarity

There were 12 plant species common to all (five) community types. However, there were species unique to the corresponding community types with a recorded value of 83, 13, 37, 24 and 18 for Community type I, II, III, IV and V respectively. Similarly, each community type had unique endemic plant species with an observed value of 6, 0, 1, 0 and 3 respectively.

The similarity was indicated by Jaccard's coefficient similarity index evaluating whether the similarity of the species composition was relatively slightly or strongly varied among communities. The similarity between Community III and IV was the highest-with a value of 0.39 followed by Community I and III with 0.33 while, Community type II and IV, III and V and IV and V had the same value of 0.23 each (Tables 11). The similarities between I and V and II and V were the least, with 0.15 each.

Table 11: Matrix to show the possible comparison of communities using JCS

Community Types	C-I	C-II	C-III	C-IV
C-I				
C-II	0.18			
C-III	0.33	0.21		
C-IV	0.21	0.23	0.39	
C-V	0.15	0.15	0.23	0.23

4.1.5. Species diversity

The diversity of a forest ecosystem depends on the number of the species within a given area (**Richness**), the number of species per unit area (**Density**) and the number of individual species present (**Evenness**). The observed species richness, evenness (equitability) and diversity among communities was between 78 and 200, 0.84 and 0.93 and 3.58 and 4.94 respectively (Table 12).

While the overall diversity of the recent study area was 4.73.

Table 12: The diversity, richness and evenness of the five Community types

Community Type	Richness	H' (Diversity Index)	H'-max	Evenness (J) = H'/H-max	Altitudinal range
I	200	4.94	5.31	0.93	2600-4102
II	70	3.58	4.26	0.84	1797-2005
III	181	4.59	5.22	0.88	1910-2446
IV	126	4.27	4.85	0.88	1888-2052
V	78	3.80	4.37	0.87	2413-2513

Relatively the lowest richness value 70 (3.58%), was observed in Community type II while the highest was 200 (30.53%), observed in Community type I followed by Community type III and IV with a richness of 181 (27.63%) and 126 (19.24%), in logical order. Similarly, the diversity within the community groups that appeared in the range between 3.58 and 4.94 was different as

observed in Community II and I respectively. Community type I was characterized by high evenness with a recorded value of 0.93 followed by Community type III and IV with 0.88 each. Community type II was characterized by the least evenness with a recorded value of 0.84.

According to the result from Boosted Regression Tree (BRT) Model, the spatial floral diversity (response count) was between 7 and 30 (Fig. 22). Relatively in Woyna-Dega (1781-2999 masl), Dega (2300-3200 masl) and Wurch (>3200 masl) the average number of species per plot was 17.50, 21.05 and 13.50 respectively (Table 13).

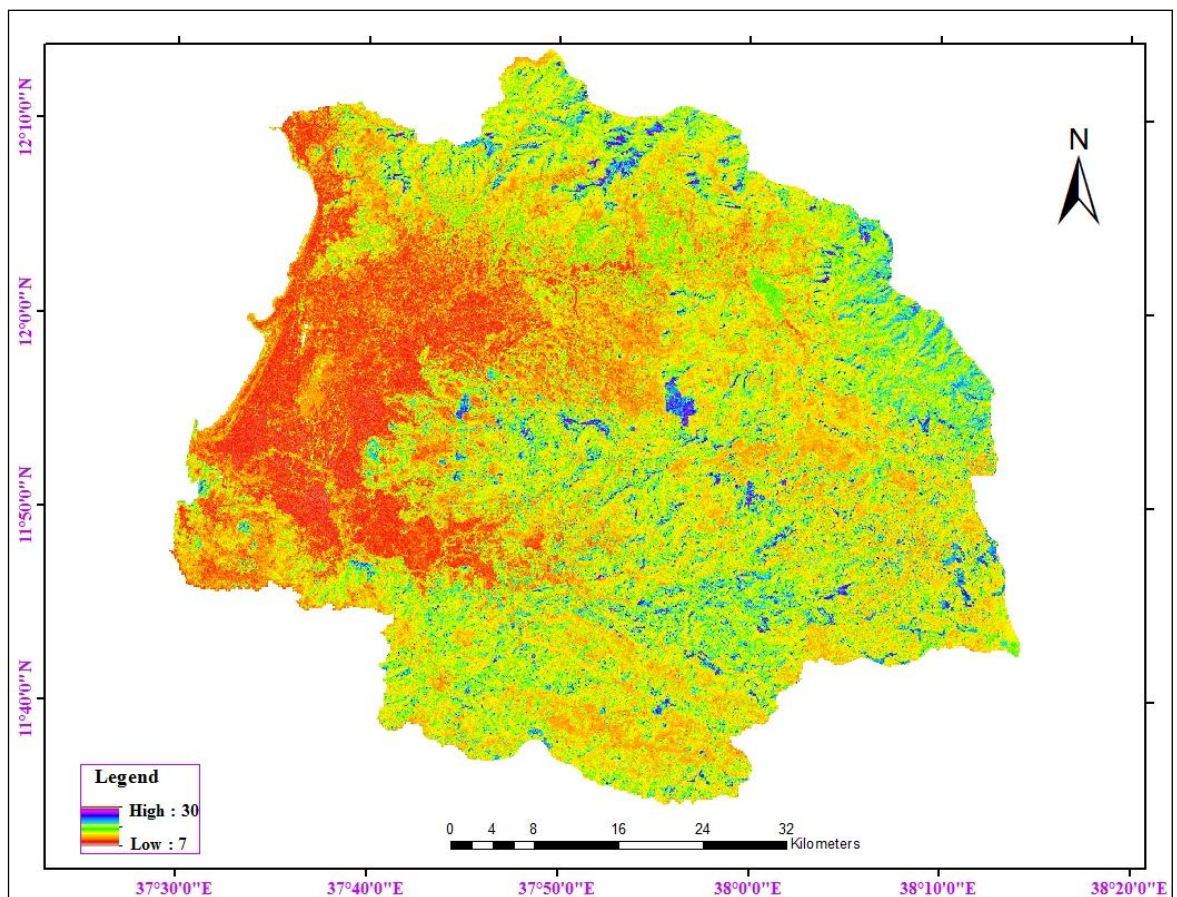


Figure 22: The species richness distribution Model using Boosted Regression Tree in Rib and Gumara catchments

Table 13: Distribution of species along an elevation

Altitude (m)	Agro_ecology	No. of Plots	Average richness/plot
1788-2299	Woyna-Dega (Mid Humid)	49	17.5
2300-3200	Dega (Humid)	34	21.05
3200-4102	Wurch (Afroalpine and sub-Afroalpine)	15	13.5

4.1.6. Population structure of woody species

4.1.6.1. DBH class

A total of 5321 individuals of woody plants which measure ≥ 2.5 cm in diameter at breast height (DBH) were represented by 125 species. The DBH class was conventionally (Adane Girma and Mosandl, 2012) grouped into 11 classes with class boundaries: 2.51-12.5, 12.51-22.5, 22.51-32.5, 32.51-42.5, 42.51-52.5, 52.51-62.5, 62.51-72.5, 72.51-82.5, 82.51-92.5, 92.51-102.5 and >102.5 represented by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11, respectively (Table 15).

The general pattern indicates that as diameter class size increases, the number of species, individuals, density and the number of plots where the species belong to, decreases, whereas the value of the basal area increases. The highest number of individuals and species was in the range between 2.51 and 12.5 DBH class which decreased in logical order up to the 6th DBH class. The remaining DBH classes show irregular patterns (Fig. 23, Table 14 and Appendix 4). The lowest number of individuals was in the range of 82.51-92.5 (cm), whereas the lowest number of species was found at a value greater than 102.5 (102.5-163.06 cm), represented by *Juniperus procera*, *Schefflera abyssinica* and *Ficus thonningii*.

Table 14: Distribution of DBH (cm), classes with species number, density and basal area

Code	DBH class	No. of species	Density/Ha	Basal_Area (M ²)	No. of Plot
1	2.51-12.5	113	1176.79	9.54	79
2	12.51-22.5	55	77.04	6.03	61
3	22.51-32.5	35	44.13	9.87	49
4	32.51-42.5	24	15.82	6.78	31
5	42.51-52.5	12	6.89	4.92	16
6	52.51-62.5	10	5.87	5.84	12
7	62.51-72.5	14	11.48	15.19	22
8	72.51-82.5	6	2.81	5.18	7
9	82.51-92.5	4	1.53	3.63	5
10	92.51-102.5	10	4.34	12.76	11
11	>102.5	3	3.57	16.98	5
Total		286	1357.4	96.88	298

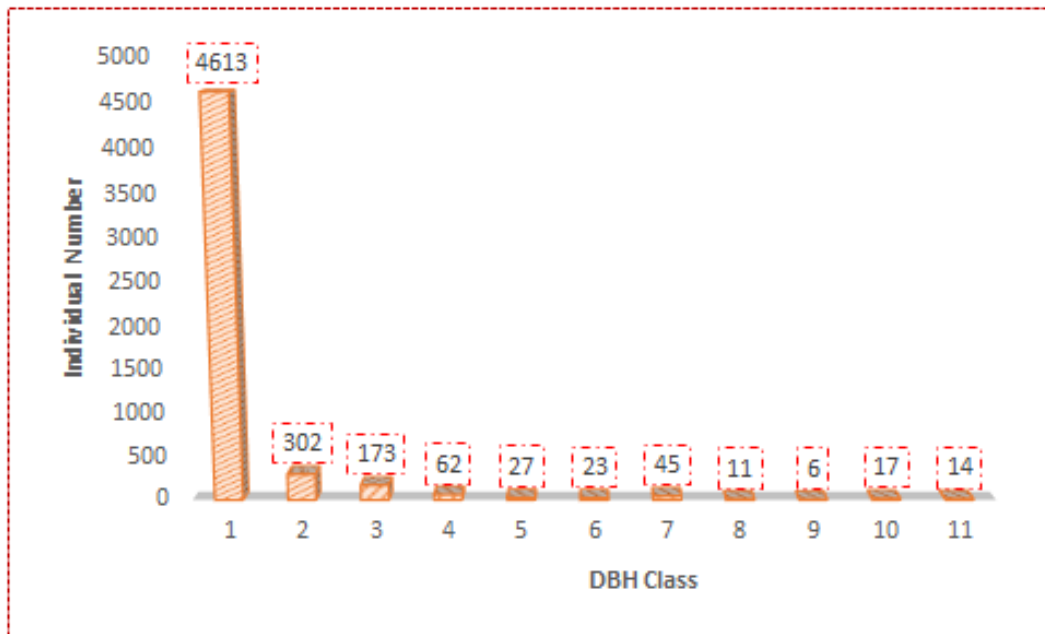


Figure 23: DBH (cm) class distribution of woody plant species in Guna and Rib watersheds
 Key: (1) = 2.51-12.5, (2) = 12.51-22.5, (3) = 22.51-32.5, (4) = 32.51-42.5, (5) = 42.51-52.5, (6) = 52.51-62.5, (7) = 62.51-72.5, (8) = 72.51-82.5, (9) = 82.51-92.5, (10) = 92.51-102.5 and (11) = >102.5.

4.1.6.2. Height class

The total number of individuals for woody plant species (5,321) which measure ≥ 2.5 m in height was conventionally (Adane Girma and Mosandl, 2012) grouped into 10 classes as: 2.5-5.5, 5.51-8.5, 8.51-11.5, 11.51-14.5, 14.51-17.5, 17.51-20.5, 20.51-23.5, 23.51-26.5, 26.51-29.5 and >29.5 symbolized by 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 respectively (Table 15). The first height class interval was composed of 114 (35.08%), plant species followed by the second and the third height classes with 69 (21.23%) and 40 (12.31%) respectively where some of the species appeared in three of the classes. For example, *Acacia albida*, *Bersama abyssinica*, *Combretum molle*, *Grewia ferruginea* and *Prunus africana* to mention a few. The ninth height class was represented by the least number of species (7); even less than by four from the highest (>29.5 m) height class. In general, as the height class size increases the number of species representing the corresponding class size decreases sharply from height class one to five while others showed irregular patterns.

Table 15: Height class (m), distribution with species number, density and basal area

Code	Height-Class	species No.	Aggregate Basal Area (m2)	Basal_Area/Ha	Density/ha
1	2.5-5.5	114	9.54	2.43	1104.34
2	5.51-8.5	69	11.68	2.98	151.53
3	8.51-11.5	40	11.76	3	41.33
4	11.51-14.5	29	10.73	2.74	17.86
5	14.51-17.5	17	8.9	2.27	11.73
6	17.51-20.5	21	15.27	3.89	13.78
7	20.51-23.5	9	6.09	1.55	3.83
8	23.51-26.5	8	11.02	2.81	5.87
9	26.51-29.5	7	4.27	1.09	2.3
10	>29.5	11	7.63	1.95	4.85
Total		325	96.89	24.71	1357.42

The distribution of the individuals in the corresponding height class show almost the same pattern as the distribution of DBH class did. The first height class was represented by 4329 individuals (1104.34 density/ha or 0.26 density/ha/individual), followed by the second and third height classes with 594 and 162 individuals (Table 16, Fig. 24 and Appendix 5).

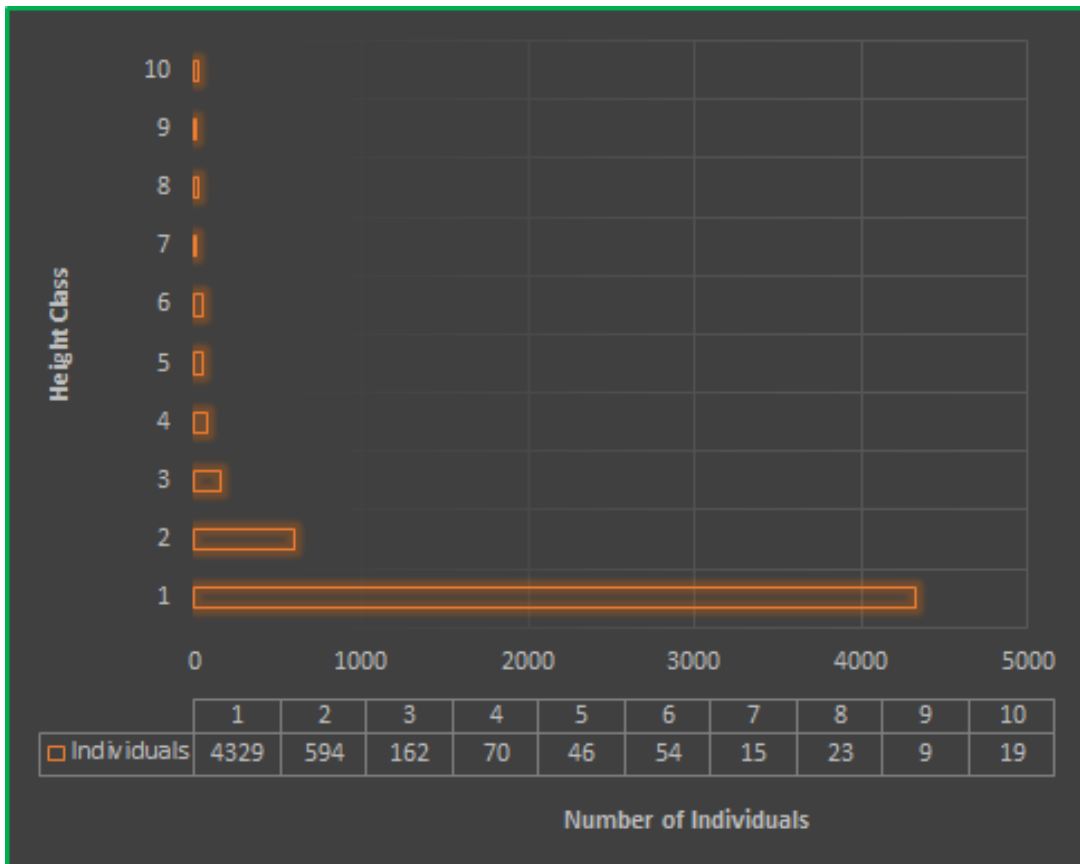


Figure 24: Height (m) class distribution of woody plant species in Gumara and Rib catchments

Key: (1) = 2.5-5.5, (2) = 5.51-8.5, (3) = 8.51-11.5, (4) = 11.51-14.5, (5) = 14.51-17.5, (6) = 17.51-20.5, (7) = 20.51-23.5, (8) = 23.51-26.5, (9) = 26.51-29.5 and (10) = >29.5

4.1.7. Natural regeneration potential of woody plant species

As indicated by Dhaukhandi *et al.* (2008) and Tiwari *et al.* (2010), the regeneration status of the forest is analyzed by comparing seedlings and saplings with the mother plant stated that: if seedlings > saplings > adults (**good**). If seedlings > or ≤ saplings ≤ adults (**fair**) and if the species survives only in sapling stage or saplings may be ≤ or ≥ adults (**poor**). If, however, a species is present only in adult form, it is considered as **not regenerating**. In light of these, the general pattern of the regeneration status is fair but fails to represent the individual species with good and poor recovery potential.

The distribution of the natural regeneration potential of the woody species shows four different patterns such as J_shape, U_shape, Inverted J_shape and Gauss types (Fig. 25). The highest number of species (37) depict J_shape patterns followed by 16 species which belongs to the U_shape, while the least number of species (7) belong to inverted J_shape.

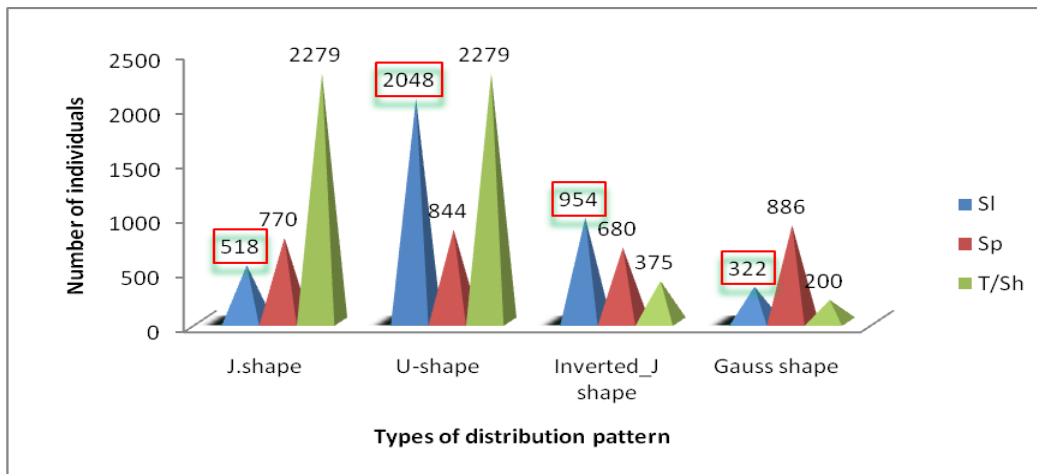


Figure 25: Seedlings, saplings and matured woody plant species distribution pattern

Key: SL = Seedling, Sp = Sapling, T/Sh = either Tree or Shrub, T = Tree and Sh = Shrub

J_shape distribution pattern (Poor regeneration potential): This type of pattern represents lower numbers of seedlings and high number of matured Trees/Shrubs (Fig. 25). The species

which depict this type of distribution pattern include *Calpurnia aurea* with the highest number of seedlings and saplings, followed by *Grewia ferruginea*, *Pittosporum viridiflorum*, *Croton macrostachyus*, *Galiniera saxifraga*, *Millettia ferruginea*, *Olea europaea* subsp. *cuspidata*, *Prunus africana* and *Sapium ellipticum* to mention only a few (Fig. 25).

U_shape distribution pattern (Fair regeneration potential): This type of pattern depicts high numbers of seedlings and matured Trees/Shrubs compared to saplings (Fig. 25). The species with the highest number of seedlings and matured Trees/Shrubs are *Maytenus arbutifolia*, *Chionanthus mildbraedii*, *Pterolobium stellatum*, *Teclea nobilis*, *Syzygium guineense*, *Phoenix reclinata* and *Lobelia rhynchopetalum*, which comprise 89.01% of the seedling and 87.44% of the sapling individuals, out of 16 total plant species belonging to this category.

Inverted J_shape distribution pattern (Good regeneration potential): The distribution pattern characterized by high numbers of seedlings decreasing down saplings and matured woody species in logical order. A total of seven species were represented by this distribution pattern such as *Clausena anisata*, *Dodonea angustifolia*, *Myrsine africana*, *Salix subserrata*, *Entada abyssinica*, *Urera hypselodendron* and *Calotropis procera*. Out of these, 91.3% of individual seedlings and 92.35% of saplings are represented by *Clausena anisata* and *Dodonea angustifolia*. This type of pattern is an indicator of good reproduction and healthy regeneration as indicated by (Tamrat Bekele, 1993; Dhaukhandi *et al.*, 2008; and Tiwari *et al.*, 2010).

Gauss distribution pattern (Poor regeneration potential): This type of distribution has a relatively high number of individuals of saplings compared to seedlings and matured woody plant species. It is composed of eight species such as *Erica arborea*, *Rhamnus staddo*, *Hypericum revolutum*, *Maytenus gracilipes*, *Bersama abyssinica*, *Clerodendrum myricoides*,

Juniperus procera and *Ficus thonningii*. Out of these, 69.57% of the individual seedlings and 67.83% of saplings were made up of *Erica arborea* and *Rhamnus staddo*. Some of the mother plants such as *Albizia malacophylla* and *Acacia venosa* have neither seedlings nor saplings and considered as **not regenerating**.

4.1.8. Basal area

The total DBH was found to be 403.03 m which was equivalent to 96.88 m² basal area (24.71 m²/ha), of which the highest value contributed about 11.09 m²/ha (44.88%), was observed in *Chionanthus mildbraedii*, *Juniperus procera* and *Syzygium guineense* with a recorded value of 4.29 (17.36%), 4.04 (16.35%) and 2.76 (11.17%) basal area per hectare. The lowest value was computed for *Justicia schimperiana*, *Lantana viburnoides*, *Mimosa pigra* and *Rhus glutinosa* subsp. *neoglutinosa* with 0.0035 m²/ha (0.014%) each. The highest portion (81.19%) of the basal area was computed from 17 species (Table 16).

Table 16: Basal area, density and percent contribution of 17 species with a basal area ≥ 1 .

No	Species name	Basal_Area (m ²)		Density/ha	
		Value	%	value	%
1	<i>Acacia albida</i>	2.26	2.33	23.72	1.757031
2	<i>Albizia schimperiana</i>	1.85	1.91	13.27	0.982426
3	<i>Apodytes dimidiata</i>	1.05	1.08	3.32	0.245607
4	<i>Celtis africana</i>	1.48	1.53	0.51	0.037786
5	<i>Chionanthus mildbraedii</i>	16.81	17.38	18.88	1.398068
6	<i>Cordia africana</i>	1.03	1.06	6.12	0.453427
7	<i>Croton macrostachyus</i>	2.58	2.67	32.91	2.437172
8	<i>Ekebergia capensis</i>	3.11	3.22	7.40	0.547891
9	<i>Ficus sycomorus</i>	2.49	2.57	2.55	0.188928
10	<i>Ficus thonningii</i>	3.31	3.43	1.53	0.113357
11	<i>Ficus vasta</i>	1.00	1.04	1.02	0.075571

No	Species name	Basal_Area (m ²)		Density/ha	
		Value	%	value	%
12	<i>Juniperus procera</i>	15.84	16.38	9.18	0.680141
13	<i>Olea europaea</i> subsp. <i>cuspidata</i>	3.75	3.88	6.63	0.491213
14	<i>Prunus africana</i>	1.25	1.30	3.83	0.283392
15	<i>Sapium ellipticum</i>	4.42	4.57	6.12	0.453427
16	<i>Schefflera abyssinica</i>	5.45	5.63	2.04	0.151142
17	<i>Syzygium guineense</i>	10.83	11.20	20.15	1.492532
Total		78.51	81.19	159.18	11.79

4.1.9. The frequency, density and dominance of woody plant species

A total of 778 frequencies were recorded for a woody plant species which had a DBH and height measure. It was represented by 53 families, 99 genera and 125 species. The most frequent plant species include *Calpurnia aurea* 40 (5.14%), *Maytenus arbutifolia* 37 (4.76%), *Carissa spinarum* 36 (4.63%), *Croton macrostachyus* 34 (4.37%) and *Grewia ferruginea* 28 (3.6%) which contributed 175 (22.5%), in total (Table 17 and Appendix 4).

Table 17: Ten most frequent plant species

Species Name	Family	Frequency	Relative Frequency
<i>Calpurnia aurea</i>	Fabaceae	40	5.14
<i>Carissa spinarum</i>	Apocynaceae	36	4.63
<i>Clausena anisata</i>	Rutaceae	24	3.08
<i>Croton macrostachyus</i>	Euphorbiaceae	34	4.37
<i>Grewia ferruginea</i>	Tiliaceae	28	3.60
<i>Maytenus arbutifolia</i>	Celastraceae	37	4.76
<i>Premna schimperi</i>	Verbenaceae	22	2.83
<i>Pterolobium stellatum</i>	Fabaceae	27	3.47
<i>Rhus vulgaris</i>	Anacardiaceae	19	2.44
<i>Vernonia myriantha</i>	Asteraceae	21	2.70

The most frequent plant families were Fabaceae 63(10.08%) followed by Euphorbiaceae 52 (8.32%), Celastraceae 42 (6.72%), Apocynaceae 39 (6.24%) and Oleaceae 29 (4.64%), which contributed 36% of the family frequency (Table 18). While, Sapotaceae represented by one individual, after Proteaceae and Ulmaceae with two individuals each; and Asclepiadaceae, Rhamnaceae, Salicaceae with 3 each.

Table 18: Plant families with their genera, total species number and frequency

No	Family	Genera	species No.	Frequency	R. Frequency (%)	No	Family	Genera	species No.	Frequency	R. Frequency (%)
1	Acanthaceae	2	2	4	0.64	28	Myrsinaceae	3	3	15	2.4
2	Anacardiaceae	2	4	22	3.52	29	Myrtaceae	2	2	13	2.08
3	Apiaceae	1	1	2	0.32	30	Olacaceae	1	1	6	0.96
4	Apocynaceae	2	2	39	6.24	31	Oleaceae	4	5	29	4.64
5	Araliaceae	1	1	3	0.48	32	Phytolaccaceae	1	1	4	0.64
6	Arecaceae	1	1	10	1.6	33	Pittosporaceae	1	1	9	1.44
7	Asclepiadaceae	1	1	1	0.16	34	Poaceae	1	1	1	0.16
8	Asteraceae	4	6	27	4.32	35	Podocarpaceae	1	1	2	0.32
9	Bignoniaceae	1	1	9	1.44	36	Proteaceae	1	1	1	0.16
10	Boraginaceae	1	1	8	1.28	37	Rhamnaceae	1	1	1	0.16
11	Capparidaceae	1	1	16	2.56	38	Rosaceae	3	3	12	1.92
12	Celastraceae	1	5	42	6.72	39	Rubiaceae	5	5	18	2.88
13	Combretaceae	2	3	9	1.44	40	Rutaceae	2	2	26	4.16
14	Cupressaceae	1	1	5	0.8	41	Salicaceae	1	1	1	0.16
15	Ebenaceae	2	3	5	0.8	42	Santalaceae	1	1	11	1.76
16	Ericaceae	1	1	2	0.32	43	Sapindaceae	2	2	19	3.04
17	Euphorbiaceae	7	7	52	8.32	44	Sapotaceae	1	1	1	0.16
18	Fabaceae	11	22	63	10.08	45	Simaroubaceae	1	1	5	0.8
19	Flacourtiaceae	3	3	8	1.28	46	Solanaceae	2	2	4	0.64
20	Hypericaceae	1	2	5	0.8	47	Sterculiaceae	1	1	4	0.64

No	Family	Genera	species No.	Frequency	R. Frequency (%)	No	Family	Genera	species No.	Frequency	R. Frequency (%)
21	Icacinaceae	1	1	4	0.64	48	Thymelaeaceae	1	1	1	0.16
22	Lamiaceae	3	3	8	1.28	49	Tiliaceae	1	1	28	4.48
23	Lobeliaceae	1	1	2	0.32	50	Ulmaceae	1	1	1	0.16
24	Loganiaceae	2	2	1	0.16	51	Urticaceae	1	1	2	0.32
25	Meliaceae	2	2	11	1.76	52	Verbenaceae	1	1	22	3.52
26	Melanthaceae	1	1	10	1.6	53	Vitaceae	2	2	7	1.12
27	Moraceae	1	4	14	2.24	Total	53	99	125	625	

The species with the highest cover abundance include *Calpurnia aurea* (20.29%), *Maytenus arbutifolia* (19.76%), *Dodonea angustifolia* (19.58), *Albizia schimperiana* (17.50%) and *Croton macrostachyus* (15.83%).

A total of 5321 individuals of woody plant species which had DBH and height was result in 1357.4 density. The density of the woody plant species was between 0.23 and 129.34 computed for *Mimusops kummel* and *Maytenus arbutifolia* respectively. Of this 31.37% was contributed by five species such as *Maytenus arbutifolia* 9.53%, *Calpurnia aurea* 6.33%, *Bersama abyssinica* 5.54%, *Carissa spinarum* 5.34% and *Grewia ferruginea* 4.60% (Appendix 4). The number of individuals in the corresponding species also contributed highly to the dominance/richness of the corresponding families (Table 10). The first 10 families contributed for about 69.52% of the total density of which the most dominant family was Fabaceae with a density of 211.73 followed by Celastraceae, Euphorbiaceae, Apocynaceae and Asteraceae with a density of 177.30, 85.71, 80.36 and 78.83 respectively (Table 19).

Table 19: The first 10 dominant families with a high number of individuals

No	Family	Individual No.	Density/ha
1	Apocynaceae	315	80.36
2	Asteraceae	309	78.83
3	Celastraceae	695	177.30
4	Euphorbiaceae	336	85.71
5	Fabaceae	830	211.73
6	Melianthaceae	295	75.26
7	Oleaceae	196	50.00
8	Rutaceae	240	61.22
9	Sapindaceae	238	60.71
10	Tiliaceae	245	62.50
Total		3699	943.62

4.1.10. Importance value index (IVI)

The sum of the three parameters such as Relative Frequency, Relative Density and Relative Dominance gave the **IVI** which measures the ecological importance of the species or the leading dominant species. The recorded value was between 0.15 (*Schinus molle*) and 19.9 (*Chionanthus mildbraedii*). About 22.08% of the total IVI was calculated for *Chionanthus mildbraedii* (6.63%), *Juniperus procera* (5.89%), *Maytenus arbutifolia* (4.87%) and *Syzygium guineense* (4.69%). However, of 125 plant species, 46.4% have an IVI value of below one (Appendix 2). Example are *Albizia malacophylla* (0.17), *Euclea racemosa* Murr. subsp. *schimperi* (0.16), *Protea gagedi* (0.18) and *Rytigynia neglecta* (0.17) to mention a few.

4.1.11. Ordination

As shown from Ordination diagram (Fig. 26) by CCA the principal axes represent 48.03% of the variance of which the first principal axis (x-axis) represents 28.05% and the second principal

axis (y-axis) representing 19.98%. According to the result using Analysis of Variance (ANOVA) conducted in conjunction with Canonical Correspondence Analysis (CCA), among 17 parameters considered for the recent study, only nine such as altitude, Slope, Sand, Clay, Silt, Ca, OC, available phosphorus and pH were significant $p \leq 0.05$, while EC remains less significant and other remained as non-significant (Table 20).

Table 20: ANOVA test to check the level of significance for environmental variables

Key: Df (Degree of freedom), Pr (Probability)

Variables	Df	Sum of square	Mean_Square	F.Model	R2	Pr (>F)	Significant code
Altitude	1	1.776	1.77555	5.0366	0.04403	0.001	***
Aspect	1	0.424	0.42386	1.2023	0.01051	0.197	
Slope	1	1.021	1.02087	2.8958	0.02531	0.001	***
pH	1	0.767	0.76694	2.1755	0.01902	0.003	**
EC	1	0.486	0.48645	1.3799	0.01206	0.077	.
sand	1	2.438	2.43769	6.9148	0.06045	0.001	***
clay	1	0.544	0.54407	1.5433	0.01349	0.022	*
silt	1	0.551	0.55126	1.5637	0.01367	0.01367	*
Ca	1	0.516	0.51566	1.4627	0.01279	0.043	*
Mg	1	0.373	0.37299	1.058	0.00925	0.36	
Na	1	0.349	0.34924	0.9907	0.00866	0.447	
K	1	0.308	0.30832	0.8746	0.00765	0.67	
CEC	1	0.433	0.43324	1.2289	0.01074	0.158	
OC	1	0.794	0.79381	2.2517	0.01968	0.003	**
OMT	1	0.348	0.34751	0.9858	0.00862	0.491	
Total N	1	0.368	0.36804	1.044	0.00913	0.391	
Av. P	1	0.63	0.63002	1.7871	0.01562	0.007	**
Residuals	80	28.202	0.35253		0.69933		
Total	97	40.328			1.00000		
Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 at a permutation of 999							

Canonical Correspondence Analysis (CCA) was used to determine the relationship between significant environmental variables with the plots and the corresponding species as tri-plot (Fig. 26).

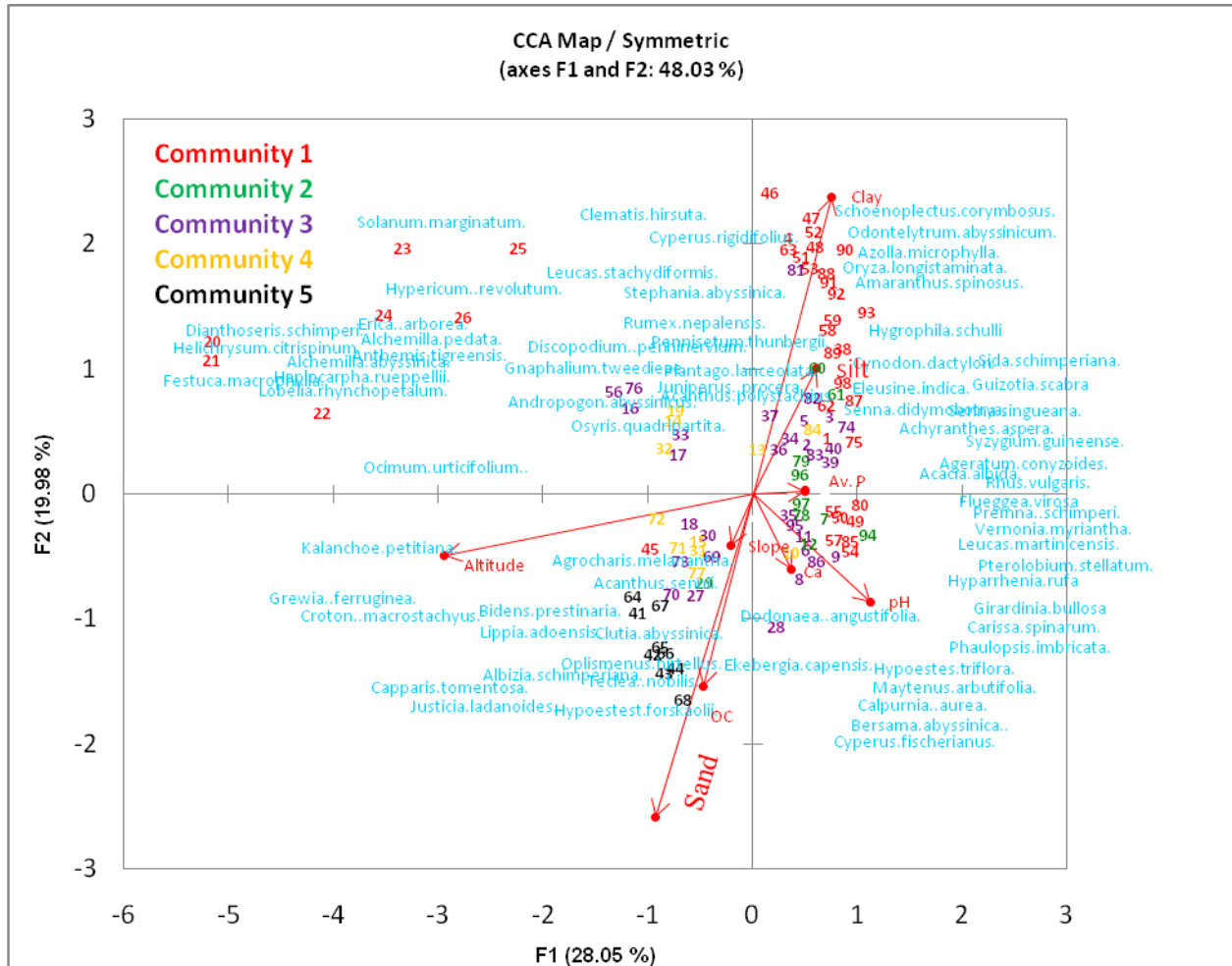


Figure 26: Species and plot ordination diagram based on CCA, with nine variables

The relationship of vegetation represented by plots, communities and the corresponding species on the recent study area to environmental factors were indicated by the length (magnitude) and the direction of rows (direction) representing environmental variables (Fig. 26).

Clay, Silt and available Phosphorous were positively correlated with axis one (X-axis) and two (Y-axis) while Altitude, Slope, Sand and OC were negatively correlated with the two axes. pH

and Ca were positively correlated with axis one and negatively correlated with axis two with different gradient length. Community I was negatively correlated with slope, OC, Sand, Altitude while it was positively correlated with Clay, Silt and available P. The reverse was true for other Community types II, III, IV and V.

The result indicated that, Altitude, Slope and Sand had almost similar effect on the spatial distribution and species composition as they had nearly equal length at $P \leq 0.05$ but according to fuzzy set ordination altitude had much more effect on the distribution of vegetation through demonstrating difference in species composition as elevation is changed (Table 21 and Fig. 27).

Table 21: Summary of the correlation coefficient of nine environmental variables

Variables	Altitude	Slope	pH	Sand	Clay	Silt	Ca	OC	Av.P
FSO (Corr.coef)	0.83	0.42	0.49	0.73	0.67	0.42	0.3	0.53	0.42

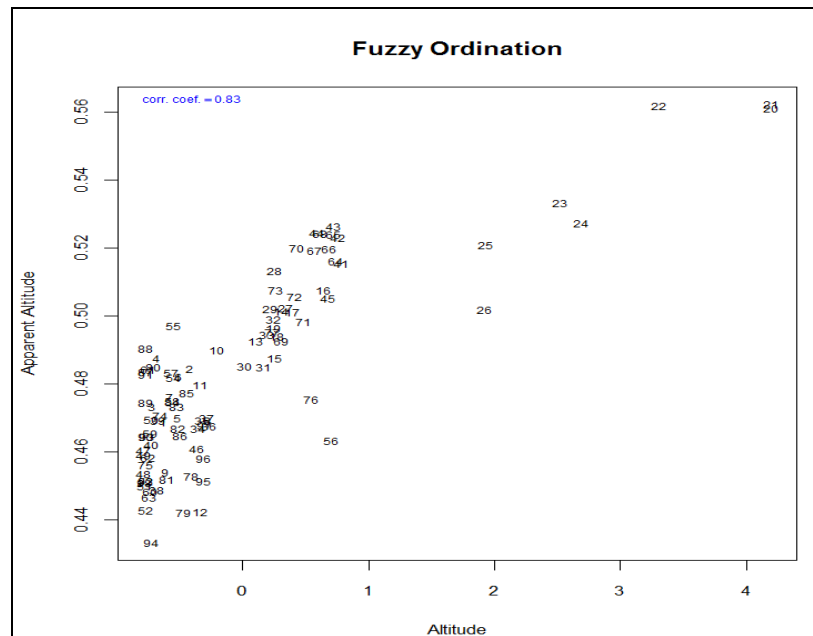


Figure 27: The affinity of altitude towards the spatial distribution of vegetation

Species with frequency ≥ 10 were prioritized to display on ordination diagram to avoid where it congestion with the exception of the species such as *Lobelia rhynchopetalum*, *Erica arborea*, *Helichrysum citrispinum*, *Alchemilla pedata*, *Dianthoseris schimperi* and *Festuca macrophylla* where distinctively located at the negative end of x-axis. The affinity of the above environmental variables towards the spatial distribution of plant species (e.g *Senna didymobotrya*) was also validated by the application of Maxent Modeling.

Table 22: The list of soil parameters and its minimum and maximum values

Soil Parameters		Minimum Value	Maximum Value
pH		5.5	6.92
Texture	Sandy	15	84
	Clay	5	69
	Silt	9	51
Electrical Conductivity		0.03	0.72
Exchange Capacity	Ca	2.34	67.44
	Mg	0.09	2.11
	Na	0.08	1.67
	K	0.1	7.42
Cation Exchange Capacity		13.6	53.8
Organic Carbon		0.9	7.4
Organic Matter		1.48	12.77
Total Nitrogen		0.07	0.64
Available phosphorous		2.87	77.13

Among 13 expected texture classes (FAO, 2006) composed from different proportions of soil texture such as Sand, Silt and Clay only 8 were observed (Appendix 7, Table 22 and 23).

Table 23: Sample soil texture classes

Plot No.	Soil Texture (%)			Class
	<i>Sand</i>	<i>Clay</i>	<i>Silt</i>	
3	39	26	35	Loamy (Lo)
7	73	16	11	Sandy loam (SaLo)
13	51	22	27	Sandy clay loam (SaClLo)
22	79	8	13	Loamy sand (LoSa)
38	22	69	9	Heavy clay (HCL)
47	14	35	51	Silty clay loam (SiClLo)
59	24	55	21	Clay (Cl)
82	40	33	27	Clay loam (ClLo)

As the relationship between basic textural classes and the percentages of the soil texture (Clay, Sand and Silt) about 40.82% of the texture class was observed under Sandy Loam followed by Loamy Sand (Fig. 28). It was represented by plots such as 5, 7, 10, 11, 20, 28, 29, 36, 49, 50, 54, 65, 72 and 73 to mention a few. While relatively Silty Clay Loam represent the smallest occurrence (2.04%) as it is observed in plot number 47 and 48 (Fig. 28 and 29).

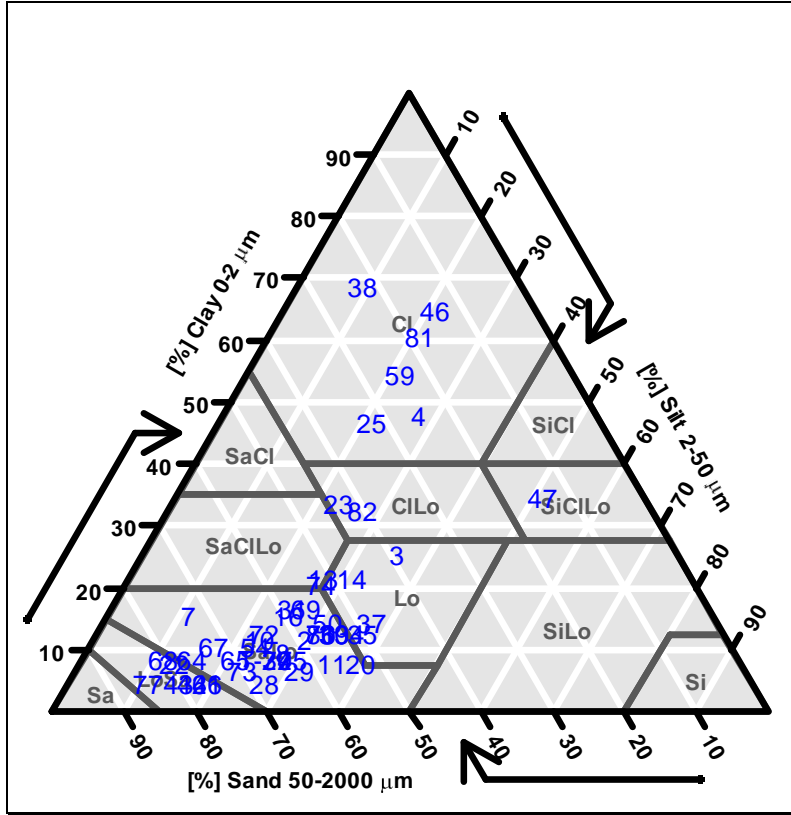


Figure 28: Soil texture triangle using library soiltexture

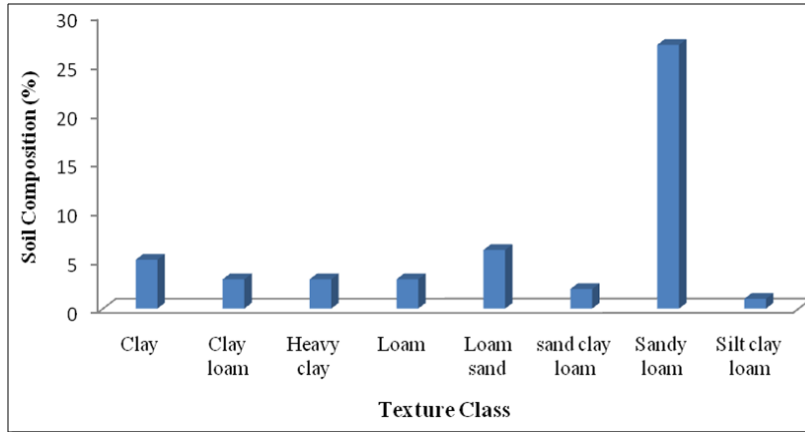


Figure 29: Distribution of texture classes

4.2. Soil Seed Bank Flora

4.2.1. Soil seed bank species composition

A total of 12,896 germinants and seeds were recorded within 2.205 m² total sampling area from both manual extraction (seeds) and experimental methods (germinants), in 392 seed bank samples. It was represented by 140, 103 and 44 species, genera and families respectively (Appendix 8). Out of the total number of species, *Festuca macrophylla*, *Leucas aequistylosa* and *Trifolium schimperi* were endemic (2.14%), while *Argemone mexicana*, *Datura stramonium* and *Senna didymobotrya* were invasive.

The families with the highest number of species were Poaceae, Asteraceae and Fabaceae with 32 (22.86%), 15 (10.71%) and 13 (9.29%) respectively and represent 60 (42.86%) of the total recorded plant species. This relative order of percentage holds true at the generic level too (Table 24). Out of 140 total species recorded in the soil seed bank, 138 (98.57%) were taxonomically identified at the species level and 2 at the generic level by comparing with authenticated specimens at the National Herbarium (ETH), Addis Ababa University. Most of the species, which accounts for 137 (97.86%) were identified from seedling emergence method. The remaining three: *Chionanthus mildbraedii*, *Olea europaea* subsp. *cuspidata* and *Acacia* sp., were identified from direct seed count by comparing with the seeds of the parent trees through the help of the local people. From a total of 392 samples, only 10 samples (2.55%) observed in sampling layer one (4) and three (6) remained without any seed and/or germinants.

All habit types such as Cl, H, Sh, Sh/T and T were observed and represented by 2 (1.43%), 114 (81.43%), 16 (11.43%), 2 (1.43%) and 6 (4.29%) species respectively (Fig. 30).

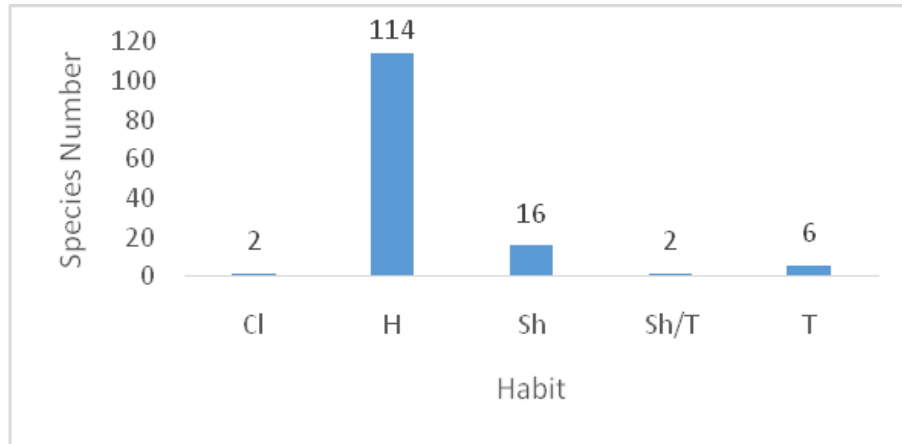


Figure 30: Habit distribution in the soil seed bank

Table 24: List of families in the SSB with its species and genus number

No.	Family	Genus No.	%	Species No.	%
1	Acanthaceae	2	1.94	2	1.43
2	Adiantaceae	1	0.97	1	0.71
3	Amaranthaceae	2	1.94	3	2.14
4	Apiaceae	1	0.97	1	0.71
5	Asteraceae	12	11.65	15	10.71
6	Balsaminaceae	1	0.97	2	1.43
7	Boraginaceae	2	1.94	2	1.43
8	Brassicaceae	3	2.91	5	3.57
9	Caryophyllaceae	2	1.94	2	1.43
10	Commelinaceae	2	1.94	4	2.86
11	Convolvulaceae	1	0.97	1	0.71
12	Crassulaceae	2	1.94	2	1.43
13	Cyperaceae	1	0.97	5	3.57
14	Ericaceae	1	0.97	1	0.71
15	Euphorbiaceae	2	1.94	2	1.43
16	Fabaceae	8	7.77	13	9.29
17	Hypericaceae	1	0.97	2	1.43
18	Juncaceae	1	0.97	1	0.71
19	Lamiaceae	3	2.91	4	2.86

No.	Family	Genus No.	%	Species No.	%
20	Loganiaceae	1	0.97	1	0.71
21	Malvaceae	1	0.97	2	1.43
22	Molluginaceae	2	1.94	2	1.43
23	Moraceae	1	0.97	1	0.71
24	Myrsinaceae	1	0.97	1	0.71
25	Oleaceae	2	1.94	2	1.43
26	Oxalidaceae	1	0.97	1	0.71
27	Papaveraceae	1	0.97	1	0.71
28	Phytolaccaceae	1	0.97	1	0.71
29	Plantaginaceae	1	0.97	2	1.43
30	Poaceae	22	21.36	32	22.86
31	Polygonaceae	2	1.94	4	2.86
32	Portulacaceae	1	0.97	1	0.71
33	Primulaceae	1	0.97	1	0.71
34	Ranunculaceae	1	0.97	1	0.71
35	Rosaceae	2	1.94	2	1.43
36	Rubiaceae	2	1.94	2	1.43
37	Sapindaceae	2	1.94	2	1.43
38	Scrophulariaceae	2	1.94	2	1.43
39	Selaginellaceae	1	0.97	1	0.71
40	Sinopteridaceae	1	0.97	1	0.71
41	Solanaceae	2	1.94	5	3.57
42	Tiliaceae	1	0.97	1	0.71
43	Urticaceae	2	1.94	2	1.43
44	Violaceae	1	0.97	1	0.71
Total		103	100.00	140	100.00

Out of 12,896 total number of individuals about 44.88% (5,788), were represented by four plant species such as *Galinsoga quadriradiata*, *Oxalis corniculata*, *Ageratum conyzoides* and

Trifolium rueppellianum with 3056 (23.70 %), 1648 (12.78%), 544 (4.22%) and 540 (4.19%), individual germinants respectively.

The composition of the species along different land use types ranges between 32 and 94 plant species in which the maximum number were represented by Shrubland (94) followed by Forest (74), Grassland (49) and Cropland (40). The least representation was made by Wetland use type with 32 species (Fig. 31).

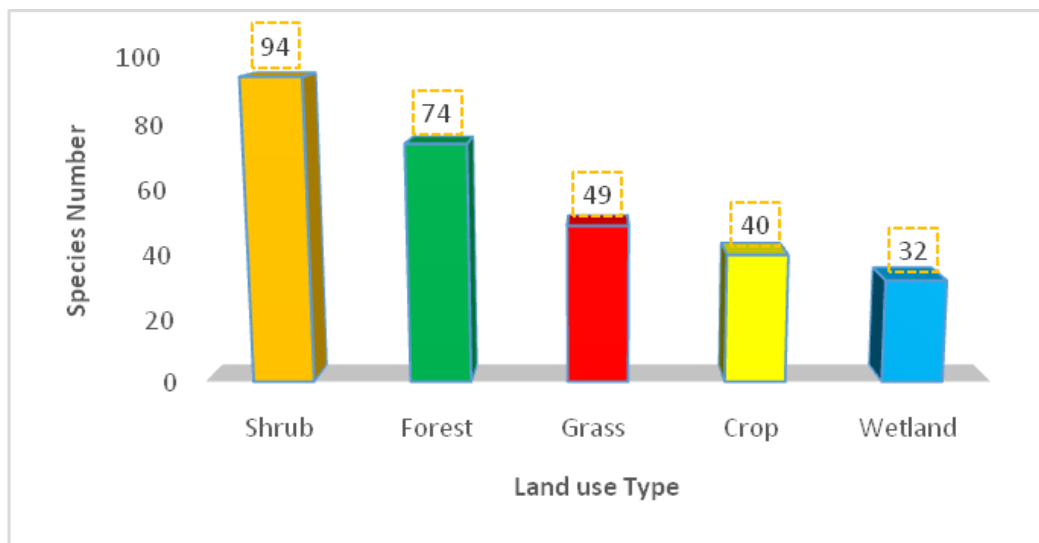


Figure 31: Distribution of species in the corresponding land use types

The distribution of the habits was also different among different land use types. Herbs were the most dominant in all land use types, followed by shrubs. However, Shrubs were not observed in croplands. The forest contains all the possible five habits while the rest such as Cropland, Grassland and Shrubland contain 3 habit types each, while the Wetland had only 2 habit types such as herb and shrub (Fig. 32).

Out of 289 aggregate plant species considered in all land use types, Herbs contributed 255 (88.24%), of which 82 (28.38%) were contributed from Shrubland. Similarly, Forest contributed 62 (21.45%), while Climber was the least contributor with two (0.69%) species (Table 26).

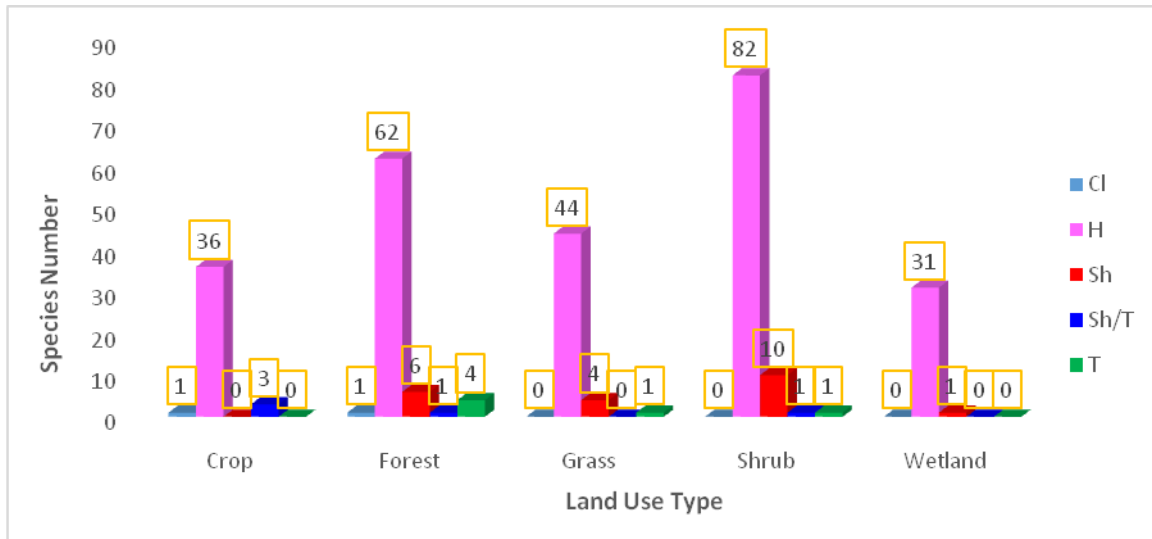


Figure 32: The distribution of habits among different land use types

Key: Cl = Climber, H = Herb, Sh = Shrub and T = Tree

About 88.24% (255), Herbs were distributed in different LU/LC types such as Cropland (36), Forest (62), Grassland (44), Shrubland (82) and Wetland (31), while Climbers were limited to Cropland (1) and Forest (1). The remaining (11.07%) were woody species which appeared as Shrub, Tree or both forms were observed in all land uses except Wetland. In all LU/LC types Poaceae was the first dominant family followed by Asteraceae and Fabaceae with the exception that Cyperaceae was the second dominant family in wetlands (Appendix 11).

4.2.2. Frequency and density of the seed in the soil seed bank

Galinsoga quadriradiata, *Oxalis corniculata*, *Ageratum conyzoides* and *Trifolium rueppellianum* were the first four most frequent and dominant species observed in 120 (30.61%), 90 (22.96%), 50 (12.76%) and 41(10.46%) of 392 sampling layers; and 70 (71.43%), 65 (66.33%), 29

(29.59%) and 29 (29.59%) of 98 plots respectively. While 22 (15.7%) species including *Allophylus abyssinicus*, *Arabis alpina*, *Chionanthus mildbraedii*, *Erica arborea* and *Ficus sur* to mention a few, only appeared in one sampling layer. Poaceae was the most dominant family followed by Asteraceae and Fabaceae with 32, 15 and 13 species respectively (Appendix 9).

The total density was 5,848.53 seeds m⁻² of which 2,624.94 seed m⁻² (44.88%) was computed from four species such as *Galinsoga quadriradiata*, *Oxalis corniculata*, *Ageratum conyzoides* and *Trifolium rueppellianum* with an observed value of 1385.94 (23.70%), 747.39 (12.78%), 246.71 (4.22%) and 244.90 (4.19%) seeds m⁻² of the totality in logical order. The density of the seed bank was decreasing as 404.54 (Litter), 365.08 (0-3 cm), 349.66 (3-6 cm) and 342.86 m⁻² (6-9 cm) with increasing depth.

The distribution of the density in land use types was also observed in different proportions as it was observed in the range between 3,889 (17%) and 5,346 (23%). The highest density was observed in Shrubland use followed by Forest (21%), Grassland (21%) and Cropland (18%), land use types while the least was observed in Wetland use type (Table 25). *Galinsoga quadriradiata*, *Oxalis corniculata* and *Ageratum conyzoides* were the most abundant plant species of the soil seed bank which contribute 30.36%, 16.37 % and 5.40% of the density as observed in all land use types.

The result indicated that all the habits such as Climber, Herb, Shrub and Tree were contributed in different proportion in its species density. About 98.70% of the plant species density was contributed from Herbs which was observed in Croplands (17.82%), Forest (20.69), Grassland (20.94%), Shrubland (23.33%) and Wetland use type (17.22%). Relatively, the highest number

was indicated from Shrubland while the lowest was observed in Wetland use types. On the other hand, Climber was the least contributor among other land use types (Table 25).

Table 25: Density distribution over different LU/LC types and habits

Key: D = Density in percent (%), Ind = Individuals

LU/LC	Habit											
	Climber		Herb		Shrub		Shrub/Tree		Tree		Total	
	Ind	D	Ind	D	Ind	D	Ind	D	Ind	D	Ind	D
Cropland	4	12.5	8852	17.82	52	11.02	0	0	0	0	8908	17.7
Forest	28	87.5	10276	20.69	156	33.05	16	33.4	100	96.2	10576	21
Grassland	0	0	10400	20.94	52	11.02	24	50	0	0	10476	20.8
Shrubland	0	0	11588	23.33	188	39.83	8	16.7	4	3.85	11788	23.4
Wetland	0	0	8552	17.22	24	5.09	0	0	0	0	8576	17
Total	32	100	49668	100	472	100	48	100	104	100	50324	100
%	0.1		98.7		0.9		0.1		0.2	0	100	

Sixty-four (45.71%), plant species were unique to one of the LU/LC types such as Cropland (5%), Forest (15.71%), Grassland (2.14%), Shrubland (21.43%) and Wetlands with 1.43% (Fig. 33). Example of unique plant species in the corresponding land use type: *Achyranthes aspera*, *Parthenium hysterophorus* and *Juncus bufonius* to mention some, were limited to cropland; *Allophylus abyssinicus*, *Cardamine africana*, *Chionanthus mildbraedii*, *Clematis simensis*, *Ficus sur*, *Nelsonia canescens*, *Olea europaea* subsp. *cuspidata* and *Sida ternata* to mention a few were unique to forests; *Acacia* Sp., *Arabis alpina* and *Vernonia wollastonii* were unique to grassland; *Anagallis arvensis*, *Calpurnia aurea*, *Cordia africana*, *Cyanotis barbata*, *Dodonea angustifolia*, *Erica arborea*, *Hypericum revolutum*, *Portulaca oleracea* and *Uebelinia abyssinica* to mention a few, were limited to Shrubland LU/LC types; and *Cyperus* sp., and *Digitaria ternate* were limited to Wetland. While, the remaining 76 (54.29%), plant species were shared by two or more land use types (Table 26).

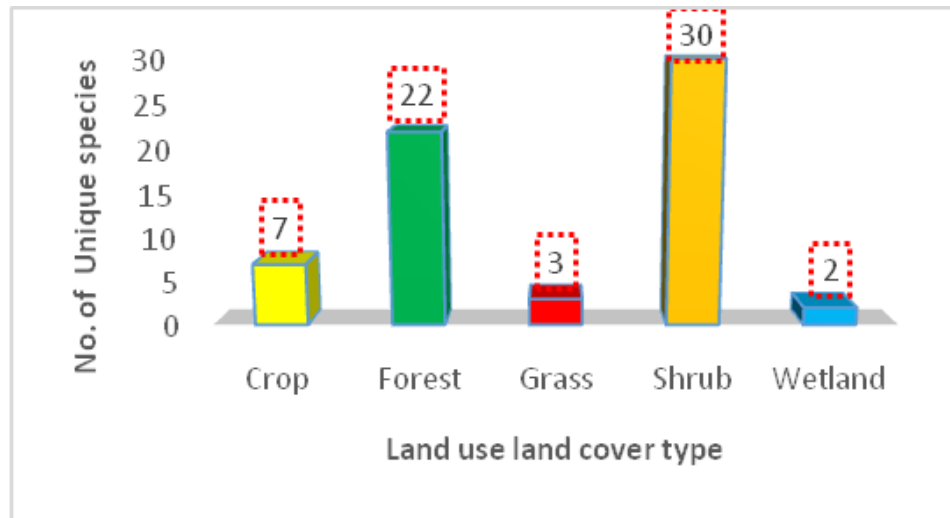


Figure 33: Species unique to the corresponding land uses

Alternatively, nine plant species such as *Ageratum conyzoides*, *Cynodon dactylon*, *Datura stramonium*, *Eleusine indica*, *Galinsoga quadriradiata*, *Guizotia scabra*, *Oxalis corniculata*, *Trifolium rueppellianum* and *T. schimperi* were common for all land use types. The aggregate number of species recorded in different land uses was in the range between 32 (11.07%) and 94 (32.53%), in which the maximum species number was observed in Shrublands followed by Forest, Grassland and Croplands with an observed value of 74 (25.61%), 49 (16.96%) and 40 (13.84%) respectively. The lowest number was observed in Wetlands.

Families were distributed in different land use types such as Cropland, Forest, Grassland, Shrubland and Wetland with 17 (14.66%), 34 (29.31%), 18 (15.52), 37 (31.90%) and 10 (8.62%) families respectively. The maximum number of families was observed in Shrubland while the lowest number was observed in Wetland use type. Poaceae was the most species-rich (dominant) family in all land use types followed by Asteraceae and Fabaceae with the exception of Wetlands, followed by Cyperaceae and Fabaceae (Table 28).

Table 26: The family, density and species number of five LU/LC types

Key: No. = Species number, Pop_No = Population number, D/m² = density in square meter

LU/LC	Family		Species		Pop_No.	Density	
	No.	%)	No	%		D/m ²	%
Cropland	17	14.66	40	13.84	8,908	4,040	18
Forest	34	29.31	74	25.61	10,576	4,796	21
Grassland	18	15.52	49	16.96	10,476	4,751	21
Shrubland	37	31.9	94	32.53	11,788	5,346	23
Wetland	10	8.621	32	11.07	8,576	3,889	17
Total	116	100	289	100.01	50324	22,823	100

4.2.3. The similarity of species composition among land uses

The similarity value computed from JCS was different among different land uses in the range between 0.20 and 0.47 as indicated by * and ** to indicate the least and the highest observed values respectively. The highest value was computed from Grassland and Wetland. This was followed by 0.41, 0.40 and 0.39 values of similarity computed from Forest and Shrubland; Grassland and Shrubland; and Cropland and Grassland respectively. While the least was computed from Forest and Wetland with 0.20 similarity value of each (Table 27).

Table 27: Similarity matrix among five LU/LC types

<i>Jaccard Similarity</i>	Cropland	Forest	Grassland	Shrubland
Cropland				
Forest	<i>0.24</i>			
Grassland	<i>0.39</i>	<i>0.31</i>		
Shrubland	<i>0.22</i>	<i>0.41</i>	<i>0.40</i>	
Wetland	<i>0.26</i>	<i>0.20*</i>	<i>0.47 **</i>	<i>0.24</i>

4.2.4. Species distribution across soil layers

The distribution pattern of habits in the corresponding layers was shown in different proportions.

Herbs were dominant in all sampling layers followed by Shrub and Trees (Table 28 & Fig. 34).

Table 28: The vertical distribution of seed's density with increasing depth

Hab it	Layers														
	Litter (surface)			A (0-3 cm)			B (3-6 cm)			C (6-9 cm)			Total		
	Species Number	Unique species number	Density/m ²	Species Number	Unique species number	Density/m ²	Species Number	Unique species number	Density/m ²	Species Number	Unique species number	Density/m ²	Species Number	Unique species number	Density/m ²
Cl	1	0	5.44	1	0	3.63	1	0	0	1	1	5.44	4	1	14.51
H	76	3	1507.48	77	5	1411.34	79	7	1362.36	72	10	1353.29	30	4	5634.47
Sh	6	0	54.42	11	2	36.28	8	2	29.02	5	1	10.88	30	5	130.61
Sh/ T	1	0	5.44	1	0	1.81	1	1	36.28	0	0	0.00	3	1	43.54
T	2	0	54.42	3	2	7.26	2	1	3.63	1	1	1.81	8	4	67.12
Su m	86	0	1627.21	93	9	1460.32	91	11	1431.29	79	13	1371.43	34	9	5890.25

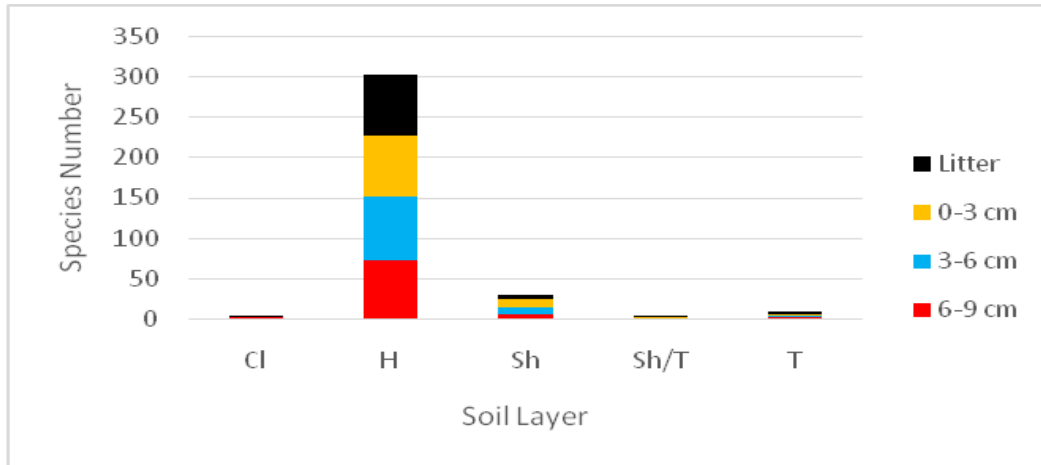


Figure 34: Depth distribution of seeds/seedlings in the soil seed bank

The number of individuals of viable seeds were 12,896 observed in four sampling layers such as Litter (0 cm), A (0-3 cm), B (3-6 cm) and C (6-9 cm) with an observed value of 3568, 3220, 3084 and 3024 represented by 89, 92, 87 and 81 species respectively (Fig. 35).

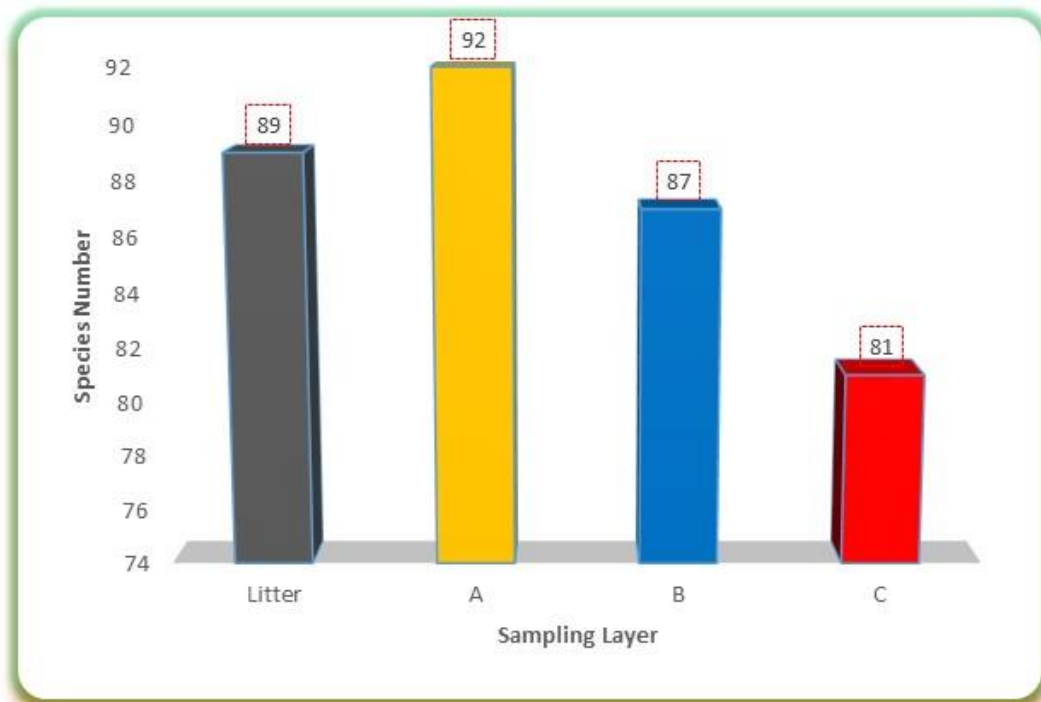


Figure 35: Depth distribution of seeds in the corresponding sampling layers

Key: Litter = 0 cm, A = 0-3 cm, B = 3-6 cm and C = 6-9 cm

There were 39 (27.86%) seeds shared by four layers such as *Achyranthes aspera*, *Ageratum conyzoides*, *Bidens pilosa*, *Dichondra repens*, *Girardinia bullosa*, *Hypericum peplidifolium*, *Setaria pumila*, *Trifolium rueppellianum* and *Triumfetta rhomboidea*. However, there were species locally unique to one sampling layer such as 3 (2.14%) Litter, 9 (6.43%) A, 11 (7.86%) B and 13 (9.29%) C of 140 total plant species (Fig. 36). The first layer had the least observed unique species while sampling layer C had relatively the highest observed value. Example *Andropogon chrysostachyus*, *Commelina reptans* and *Galium aparinoides* were limited to litter sampling layer. *Allophylus abyssinicus*, *Bromus leptoclados*, *Dodonea angustifolia*, *Olea europaea* subsp. *cuspidata*, *Erica arborea* and *Phytolacca dodecandra* were unique to sampling layer A. Sampling layer B included unique plant species such as *Calpurnia aurea*, *Cheilanthes farinosa*, *Cordia africana* and *Ocimum urticifolium*. Similarly, sampling layer C include *Arabis alpina*, *Ficus sur*, *Pterolobium stellatum* and *Viola abyssinica* to mention a few.

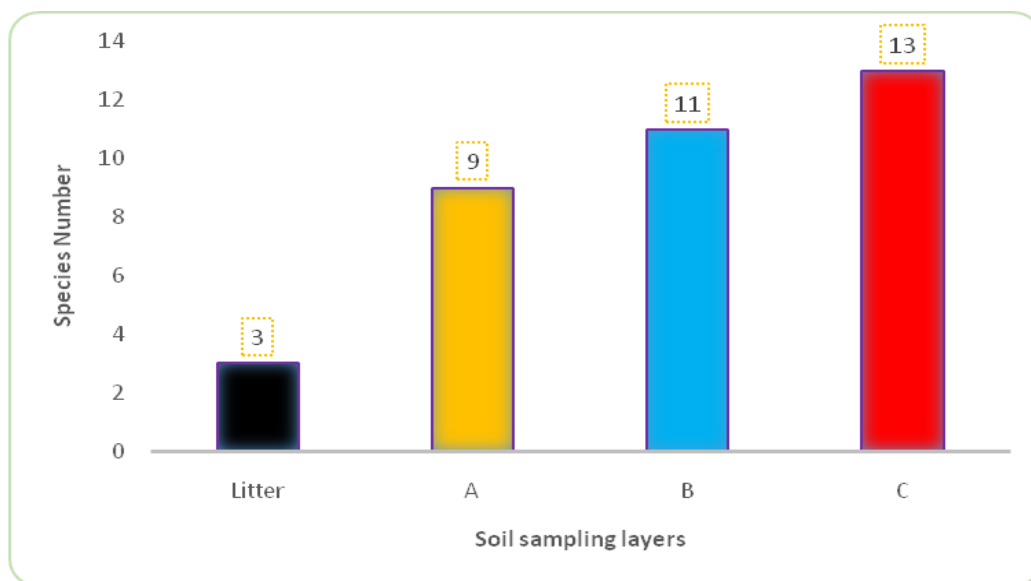


Figure 36: The distribution of species unique to the corresponding sampling layers

Key: Litter = 0, A = 0-3 cm, B = 3-6 cm, C = 6-9 cm

The remaining 65 (46.43%) seeds and/or seedlings were shared by greater than or equal to two and less than four sampling layers. The degree of similarity among layers was in the range between 0.24 and 0.28. Relatively the highest similarity was observed between litters and A (0.28), while the lowest value was observed between litter and C, A and B, A and C; and B and C with a similarity value of 0.24 each (Table 29).

Table 29: Similarity value between sampling layers

Similarity	Litter	A	B
Litter			
A	0.28		
B	0.27	0.24	
C	0.24	0.24	0.24

The distribution pattern of families was irregular with 33, 36, 34 and 31 in litter, A, B and C sampling layers respectively (Table 30). The first three species-rich families were Poaceae, Asteraceae and Fabaceae from litter to B sampling layers with an **average** recorded species number of 24, 11 and 7 respectively. But in sampling layer C, the 2nd dominant families were Asteraceae and Fabaceae with 8 species each; while the 3rd dominant families were Brassicaceae, Cyperaceae, Polygonaceae and Solanaceae with 3 species each.

Table 30: Species, population and density distribution of the four layers

Sampling Layer	Family		Species		Density	
	No.	%)	No	%	Pop/m ²	%
Litter	33	24.63	89	25.50	1618.14	27.67
A	36	26.87	92	26.36	1460.32	24.97
B	34	25.37	87	24.93	1398.64	23.91
C	31	23.13	81	23.21	1371.43	23.45
Total	134	100	349	100	5848.53	100

In the study area (Rib and Gumara watersheds) 68 different seedlings and saplings of woody species were encountered in the above ground vegetation, of which 12 (17.65%) were also appeared in the soil seed bank. The total density of the woody species in the soil seed bank was 128.80 seedlings m^{-2} while, the total density of the seedlings and saplings from the standing vegetation were 980.10 ha^{-1} and 811.22 ha^{-1} respectively.

4.3. Land use land cover change

4.3.1. Accuracy assessment

The overall accuracy of the classified images from 1984, 2000 and 2017 were 91.6%, 88.4% and 87.7%; while, the kappa coefficient were 0.9, 0.85 and 0.83 respectively. Relatively, the highest Kappa value was observed in 1984 while the smallest value was in 2017. This shows that the classification was accurate as it provides specified target level indicated by (Campbell, 1996; Smits *et al.*, 1999), to justify the degree to which the classified image agrees with reality on the ground. Producer's accuracy of the individual classes of the three classified maps ranged from 77.4% in 2000 to 100% observed in Settlement LU/LC types over the three time periods, respectively. The user accuracy was lowest for the crop classification (80%), in 2000 and the highest for the settlement (100%), in all time periods.

For each of the classified images, the producer accuracy was lowest in Crop LU/LC classification with 80.64%, 77.4% and 77.5% for 1984, 2000 and 2017, respectively. This might be due to the observation of the same reflectance with grassland. However, it is in the range as Scean (1999), mapped in his recommendation range between 40% to 100%.

Croplands had a reflectance similar to Grasslands, therefore the statistics showed that there were omissions and commission errors as Cropland grouped with Grasslands due to the observation of reflectance confusion. However, the two land uses were classified carefully and correctly. The second lowest accuracy was performed with Wetlands as a Grassland shared similar reflectance during a dry season. On the other hand, in some places, Grassland becomes barren and the reflectance becomes similar to Croplands. Settlement LU/LC classes had a 100% user and producer accuracy because before an accuracy assessment was conducted, the area was masked and replaced by correctly classified shape files.

4.3.2. Area contribution of LU/LC types in three time periods

According to the result processed by supervised classification supported by ground truth seven types of classes such as Cropland, Forest, Grassland, Settlement, Shrubland, Water and Wetland were identified (Table 31). The major land use types for the three time periods of 1984 (Fig. 37, Table 31 and 35), 2000 (Fig.38, Table 32 and 36) and 2017 (Fig. 39, Table 33 and 37) were represented by Cropland and Grassland contributing 46.91%, 66.03%, 66.78%; and 28.71%, 18.53% and 18.10% respectively. Shrubland was the 3rd contributor in the first and second time periods with 7.90% (1984) and 5.71% (2000), but in 2017 Forest was the 3rd contributor with 5.56 (Fig. 40 and Table 33). While Settlement was the least contributor with 0.03% (1984), 0.07% (2000) and 0.39% (2017). Cropland, Water and Settlement LU/LC types increased with increasing periods while Grassland, Shrubland and Wetlands continuously decrease with increasing periods. But Forest showed an irregular pattern as it decreases between 1984 and 2000 and increased between 2000 and 2017.

Table 31: LU/LC types with their corresponding areas (Ha) in Rib and Gumara watershed in three different periods (1984, 2000 and 2017)

No.	LU/LC type	Time periods and their corresponding area (Ha)					
		1984		2000		2017	
		Area	%	Area	%	Area	%
1	Cropland	175392	46.91	246902	66.03	249429	66.78
2	Forest	29380	7.86	16003	4.28	20772	5.56
3	Grassland	107364	28.71	69279	18.53	67619	18.10
4	Shrubland	29541	7.90	21336	5.71	16058	4.30
5	Water	2889	0.77	3762	1.01	4343	1.16
6	Wetland	29218	7.81	16363	4.38	13818	3.70
7	Settlement	122	0.03	261	0.07	1466	0.39
Total		373,905	100	373,905	100	373,905	100

4.3.3. The affinity of LU/LC types to maintain their original state

As the values indicated by diagonals with the corresponding percent area contribution (Table 31-33) all the identified classes maintained their original state (remain unchanged) with different observed values. In 1984 and 2000, the value to maintain its original state was between 87.97% and 30.62%. The highest was observed in Water (87.97%) followed by Settlement (86.09%), Cropland (78.42%) and Forest (40.17%). While the least was observed in Shrublands with 30.62%. However, the remaining percentage of the corresponding classes converted from one LU/LC type to another. For example, the remaining percentage of the Water (13.03%) was merely converted to Wetland (8.89%) and Cropland (3.13%). The remaining portion of the Settlement (13.95%) was distributed to Cropland (8.78%), Shrubland (3.25%) Forestland (1.40%), Grassland (0.37%) and Wetland (0.15%), while it remains zero (0%) in Water (Table 32). Forest (40.17%, unchanged) were converted to Cropland (49.79%), Shrubland (8.26%), Grassland (1.73%), Settlement (0.06%), but it was not changed into Water and Wetland. Shrubland was changed to Cropland (48.99%), Grassland (16.12%), Forest (4.20%) and Settlement with 0.07%.

During, transformation the probability of converting one class to another was different. Cropland was the highest to be changed into all (6) classes. While, Forest, Grassland and Shrublands were not changed to Water and Wetland. Conversely, Water and Wetlands were not converted to Forest, Grassland and Shrubland. Similarly, Settlement was not changed to Grassland, Water and Wetland.

Table 32: LU/LC change matrix (Ha) and percent cover between 1984 and 2000

LU/LC type	Cropland	Forest	Grassland	Shrubland	Water	Wetland	Settlement	Year/1984
Cropland	137551	2457	23852	4987	226	6236	82	175392
<i>Contribution (%)</i>	78.42	<i>1.40</i>	<i>13.60</i>	<i>2.84</i>	<i>0.13</i>	<i>3.56</i>	<i>0.05</i>	100
Forest	14629	11801	507	2426	0	0	16	29380
<i>Contribution (%)</i>	<i>49.79</i>	40.17	<i>1.73</i>	<i>8.26</i>	<i>0.00</i>	<i>0.00</i>	<i>0.06</i>	<i>100.00</i>
Grassland	61806	502	40158	4875	0	0	23	107364
<i>Contribution (%)</i>	<i>57.57</i>	<i>0.47</i>	37.40	<i>4.54</i>	<i>0.00</i>	<i>0.00</i>	<i>0.02</i>	<i>100</i>
Shrubland	14473	1241	4761	9045	0	0	21	29541
<i>Contribution (%)</i>	<i>48.99</i>	<i>4.20</i>	<i>16.12</i>	30.62	<i>0.00</i>	<i>0.00</i>	<i>0.07</i>	<i>100</i>
Water	90	0	0	0	2541	258	0	2889
<i>Contribution (%)</i>	<i>3.13</i>	<i>0.00</i>	<i>0.00</i>	<i>0.00</i>	87.97	<i>8.92</i>	<i>0.00</i>	<i>100</i>
Wetland	18343	0	0	0	994	9868	13	29218
<i>Contribution (%)</i>	<i>62.78</i>	<i>0.00</i>	<i>0.00</i>	<i>0.00</i>	<i>3.40</i>	33.77	<i>0.04</i>	<i>100</i>
Settlement	11	2	0	4	0	0	105	122
<i>Contribution (%)</i>	<i>8.78</i>	<i>1.40</i>	<i>0.37</i>	<i>3.25</i>	<i>0.00</i>	<i>0.15</i>	86.09	<i>100</i>
year/2000	246902	16003	69279	21336	3762	16363	261	X

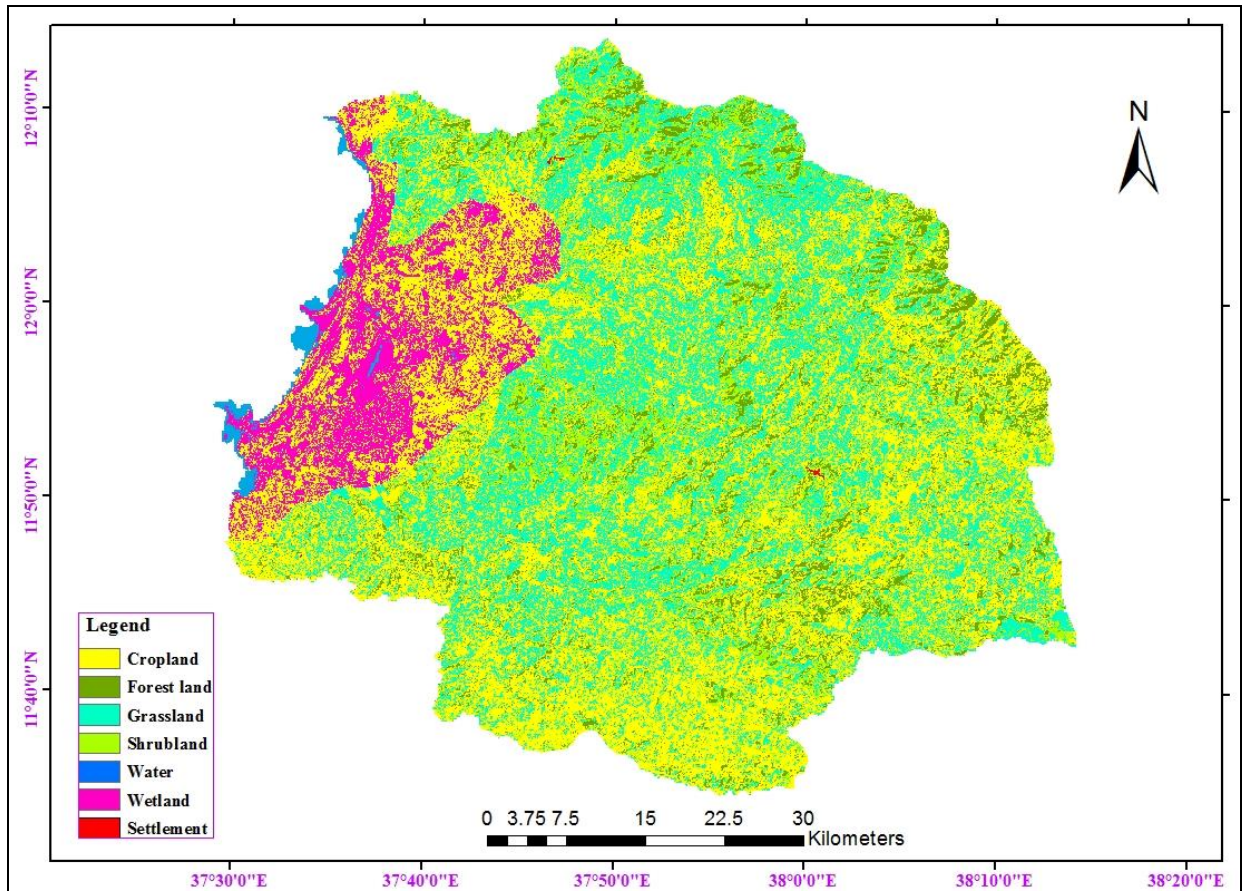


Figure 37: Land use land cover Map of Rib and Gumara watersheds in 1984

Between 2000 and 2017 time periods, the affinity to remain unchanged was between 97.41% and 5.22%. The highest was observed in Settlement with 97.41% followed by Water, Cropland and Wetland with 76.16%, 74.84% and 37.92% respectively. The smallest value was observed in Shrublands with 5.22%. Even though, the remaining percentage of the corresponding classes converted from one LU/LC type to another. For example, the remaining 2.59% of the Settlement was converted to Cropland, Shrubland, Forest and Grassland with 1.79%, 0.31%, 0.24% and 0.21% respectively. The remaining percentage of the Water was converted to Wetland, Cropland and Grassland with 17.56%, 4.03% and 0.05% respectively. Cropland was converted to Grassland (14.73%), Forest (4.02%), Shrubland (3.02%), Wetland (2.82%), Settlement (0.26%) and Water with 0.21%. Wetland was converted to Cropland, Water, Grassland and Settlement

with 54.44%, 4.03%, 3.00% and 0.56% respectively. Shrubland which was the least in maintaining its original state was changed to Cropland (43.52%), Grassland (26.06%), Forest (23.34%), Settlement (0.75%) and Water with 0.08% (Table 33).

In the process of conversion, the maximum change was observed in Cropland as it was converted into all (6) classes. While Forest, Grassland and Shrublands were not changed to Wetland. Conversely, Wetlands was not converted to Forest. Similarly, Settlement was not changed into Water and Wetland (Table 33).

Table 33: LU/LC change matrix (Ha), and percent cover between 2000 and 2017

LU/LC type	Crop	Forest	Grass	Shrub	Water	Wetland	Settlement	Year/2000
Cropland	184786	9925	36358	7451	527	6952	647	246902
<i>Contribution (%)</i>	74.84	4.02	14.73	3.02	0.21	2.82	0.26	100
Forest	5760	2476	897	6510	218	0	135	16003
<i>Contribution (%)</i>	35.99	15.47	5.60	40.68	1.36	0.00	0.84	100
Grassland	40532	3178	24310	982	56	0	178	69279
<i>Contribution (%)</i>	58.51	4.59	35.09	1.42	0.08	0.00	0.26	100
Shrubland	9286	5193	5561	1113	17	0	160	21336
<i>Contribution (%)</i>	43.52	24.34	26.06	5.22	0.08	0.00	0.75	100
Water	152	0	2	0	2865	660	0	3762
<i>Contribution (%)</i>	4.03	0.00	0.05	0.00	76.16	17.56	0.00	100
Wetland	8908	0	491	1	660	6205	91	16363
<i>Contribution (%)</i>	54.44	0.00	3.00	0.00	4.03	37.92	0.56	100
Settlement	5	1	1	1	0	0	254	261
<i>Contribution (%)</i>	1.79	0.24	0.21	0.31	0.00	0.00	97.41	100
Year/2017	249521	20777	67642	16067	4361	13822	1466	X

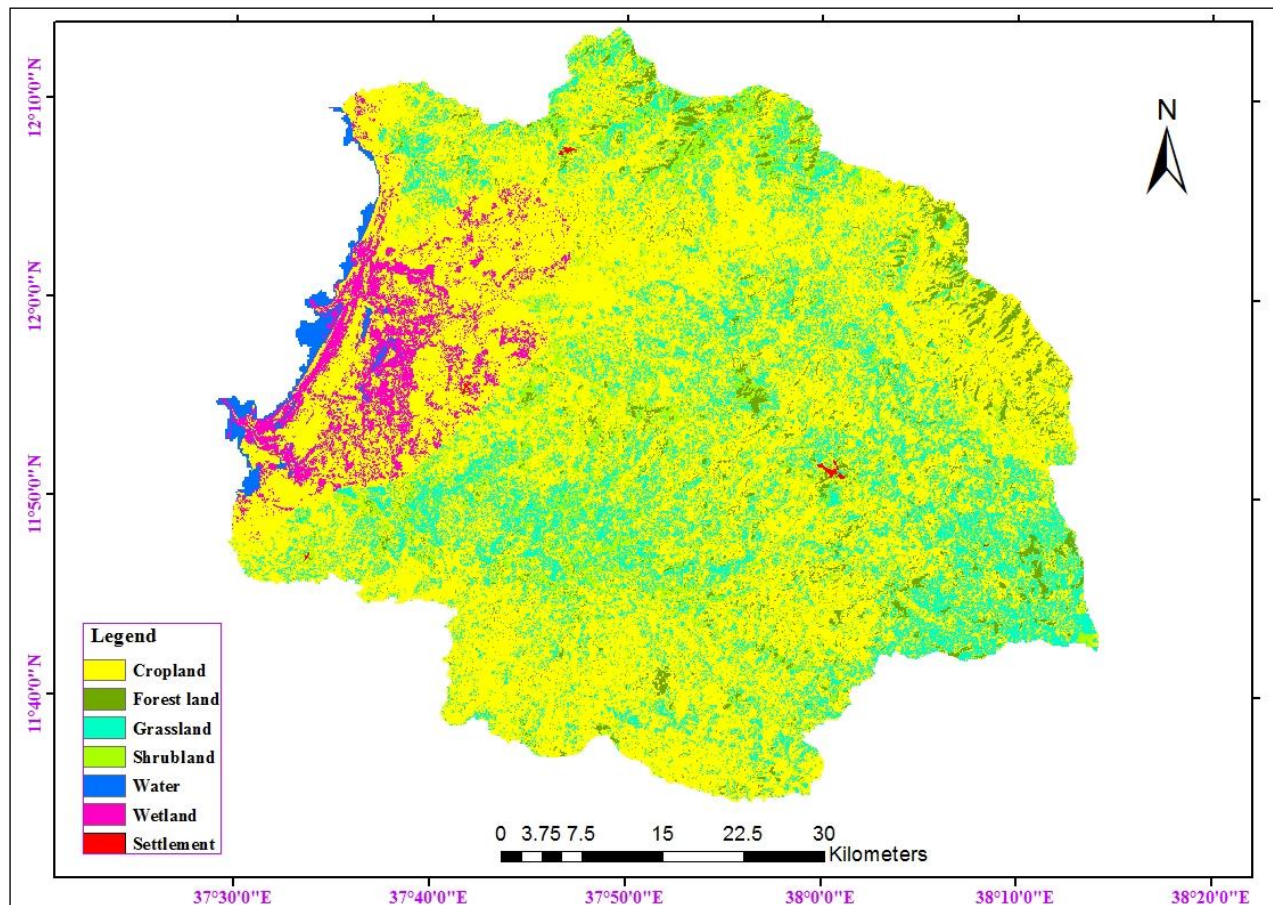


Figure 38: Land use land cover Map of Rib and Gumara watersheds in 2000

According to the result indicated between 1984 and 2017 (Table, 34), the maximum value to remain unchanged was observed in Settlement with 96.05% followed by Water and Croplands with 82.86% and 73.41% respectively. While, the minimum was observed in Shrublands with 4.14%. Even if, the remaining portion of the land in the corresponding classes were changed and distributed into different classes. For example, Settlement was converted to Cropland and Shrubland with 2.95% and 0.89% respectively. Water to Wetland (10.19%), Cropland (3.23%) and Grassland with 0.11%; Cropland to Grassland (14.73%), Forest (4.63%) and Shrubland with 3.13% of the area.

Shrubland which represents the minimum unchanged value (4.14%), for the corresponding and other time periods was converted to Cropland (56.13%), Grassland (23.95%), Forest (15.15%), Settlement (0.48%) and Water with 0.11% (Table 34).

In the process of LU/LC conversion, the maximum change was observed in Cropland as it was converted into all (6) classes. While, Forest, Grassland and Shrublands were not changed to Wetland. Conversely, Wetlands was not converted to Forest. Settlement was not changed into Forest, Grassland and Wetland. While Water was not changed into Forest, Shrubland and Settlement (Table 34).

Table 34: LU/LC change matrix (Ha), and percent cover between 1984 and 2017

LU/LC type	Crop	Forest	Grass	Shrub	Water	Wetland	Settlement	Year/1984
Cropland	128747	8117	25842	5498	474	6073	625	175392
<i>Contribution (%)</i>	73.41	4.63	14.73	3.13	0.27	3.46	0.36	100
Forest	15789	3332	1945	7940	226	0	134	29380
<i>Contribution (%)</i>	53.74	11.34	6.62	27.02	0.77	0.00	0.46	100
Grassland	69649	4852	30908	1403	150	1	321	107364
<i>Contribution (%)</i>	64.87	4.52	28.79	1.31	0.14	0.00	0.30	100
Shrubland	16580	4476	7075	1224	31	1	143	29541
<i>Contribution (%)</i>	56.13	15.15	23.95	4.14	0.11	0.00	0.48	100
Water	93	0	3	0	2394	294	0	2889
<i>Contribution (%)</i>	3.23	0.00	0.11	0.00	82.86	10.19	0.00	100
Wetland	18659	0	1868	0	1086	7453	125	29218
<i>Contribution (%)</i>	63.86	0.00	6.39	0.00	3.72	25.51	0.43	100
Settlement	4	0	0	1	0	0	117	122
<i>Contribution (%)</i>	2.95	0.00	0.00	0.89	0.00	0.00	96.05	100
Year/2017	249521	20777	67642	16067	4361	13822	1466	X

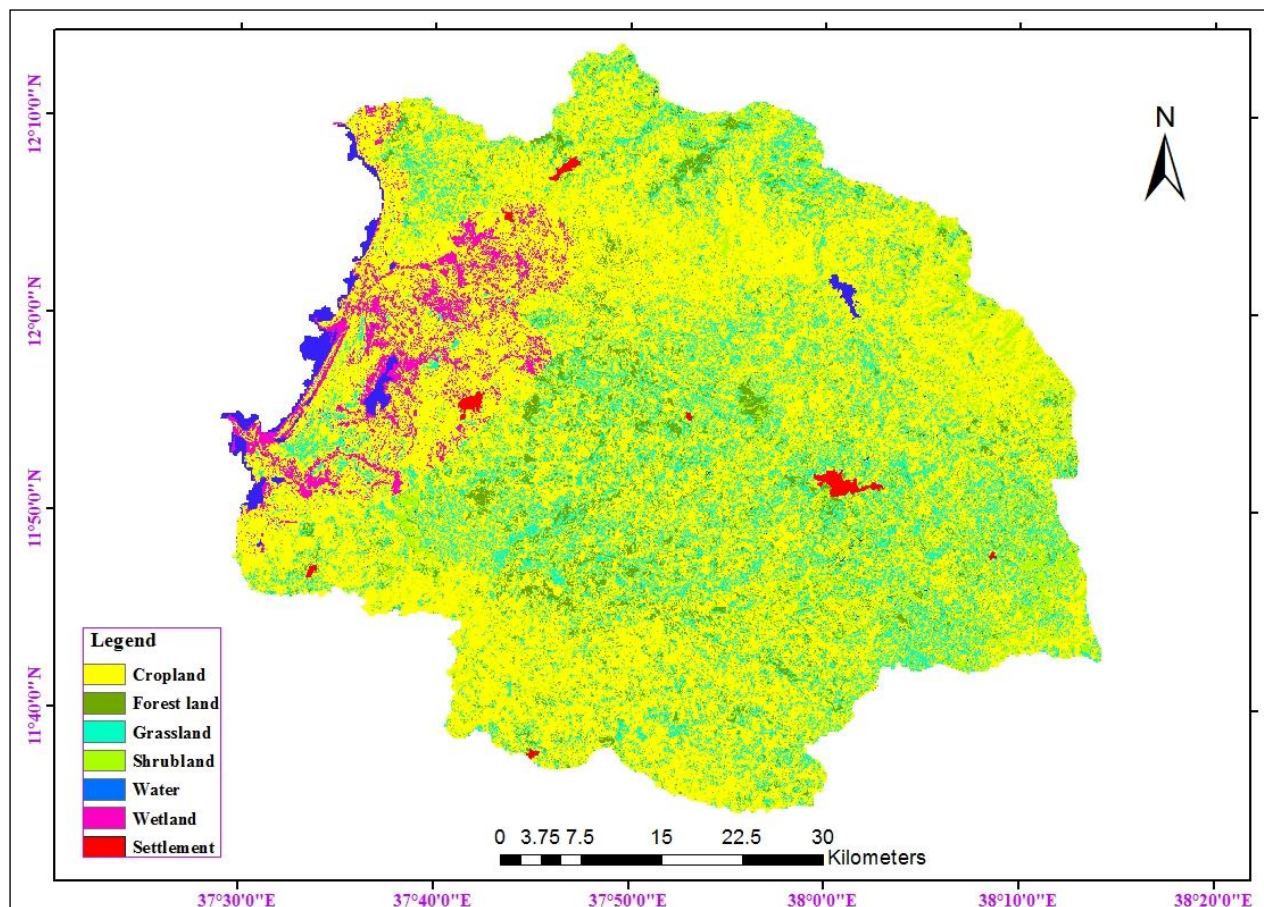


Figure 39: Land use land cover Map of Rib and Gumara watersheds in 2017

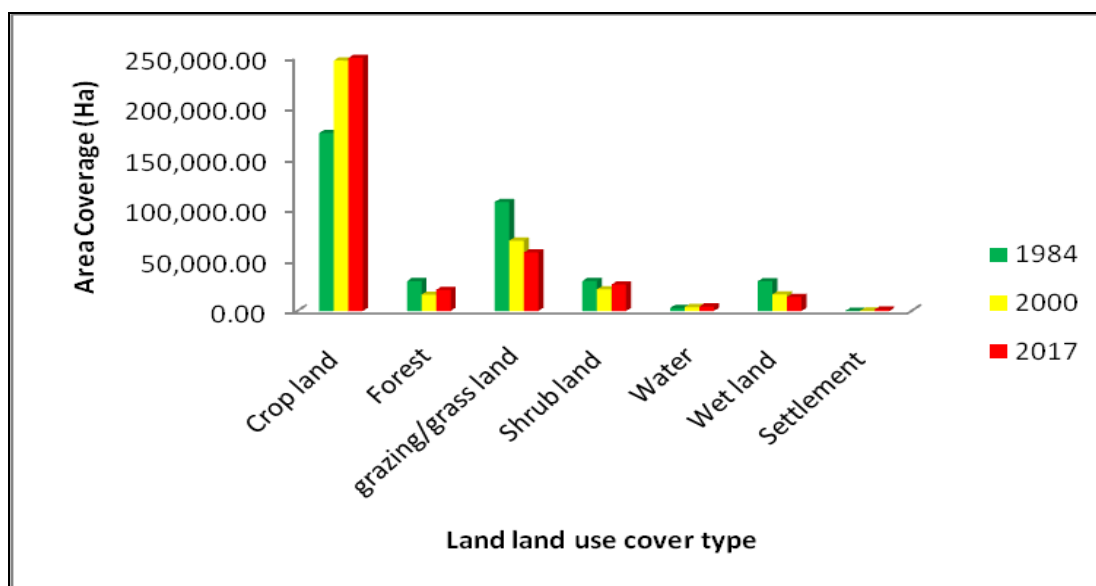


Figure 40: Distribution pattern of LU/LC in Rib and Gumara watershed from 1984-2017

4.3.4. Pattern and rate of change with time series

According to the result, the change was made both in increasing (gain) and decreasing (loss) trend. The highest gain was made by Cropland compared with all classes, patterns (gain and loss) and overall time periods with 2,103 ha/year rate of increasing observed between 1984 and 2000, followed by Forest with 140 ha/year rate of increasing observed in 2000 and 2017, Cropland with 74 ha/year in 2000 and 2017. While the least value over all classes, pattern (gain and loss) and time periods was represented by Settlement with 4 ha/year rate of increase observed in 1984 and 2000, followed by Water with 17 ha/year in 2000 and 2017.

On the other hand, for those showing a decreasing pattern the maximum rate was observed in Grassland, Forest and Shrubland with a decreasing rate of 1120, 393 and 241 ha/year (1984-2000) while Wetland with 453 ha/year (1984-2017). Grassland, Wetland and Shrublands show continuous decreasing pattern, While Forest shows an irregular pattern as it increases between 2000 and 2017 with 140 ha/year. While the minimum decreasing rate was observed in Grassland and Wetland with a decreasing rate of 49 and 75 ha/year (2000 and 2017) respectively.

Relatively the highest percent of increment was observed in Settlement LU/LC with 1101.1% (1984-2017), 461.81% (2000-2017) and 113.90% (1984-2000), followed by Water with 50.29% (1984-2017) and Cropland use with 42.21% (1984-2017) and 40.77% (1984-2000). While, the smallest change was observed in Cropland use with 1.02% (2000-2017), followed by Water with 15.44% (2000-2017).

The land uses which show a decreasing pattern, the highest percent of decline was observed in Wetland with 52.71% (1984 and 2017) followed by Shrubland with 45.64% (1984 and 2017),

Forest with 45.53% (1984 and 2000) and Wetland with 44.00% between 1984 and 2000 (Table 35).

Table 35: Land use land cover change rate and extent in Rib and Gumara Watersheds in different time periods

LU/LC type	Change in land use area (ha and %) coverage; gain (+) or loss (-)								
	2000-1984			2017-2000			2017-1984		
	Area	%	Rate/year	Area	%	Rate/year	Area	%	Rate/year
Crop	71510	40.77	2103	2527	1.02	74	74037	42.21	2178
Forest	-13377	-45.53	-393	4770	29.81	140	-8607	-29.3	-253
Grass	-38085	-35.47	-1120	-1660	-2.4	-49	-39745	-37.02	-1169
Shrub	-8204	-27.77	-241	-5279	-24.74	-155	-13483	-45.64	-397
Water	872	30.19	26	581	15.44	17	1453	50.29	43
Wetland	-12855	-44	-378	-2545	-15.55	-75	-15400	-52.71	-453
Settlement	139	113.79	4	1205	461.81	35	1344	1101.11	40

CHAPTER FIVE

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. DISCUSSION

5.1.1. Above ground vegetation

5.1.1.1. Floristic composition

The dominance of these families is in line with the relative number of species recorded in the Flora of Ethiopia and Eritrea with Asteraceae (473), Fabaceae (447) and Poaceae (444) species. Similar results, notably with Asteraceae and Fabaceae were reported by Motuma Didita *et al.* (2010), Leul Kidane *et al.* (2010), Tamene Yohannes *et al.* (2013), Gideon Woldemariam *et al.* (2016) as the species rich (dominant) families. The number of species in corresponding plots increase with increasing elevation and reaches its maximum average value of 21 species per plot between 1788 and 3200 and then shows a decreasing pattern as elevation increases beyond 3200 m asl. This distribution pattern is approved by Boosted Regression Tree Model. This pattern of plant species distribution is in line with the result reported by Abiyot Berhanu *et al.* (2016).

According to Teshome Soromessa *et al.* (2004), Fabaceae and Poaceae were the most represented families with 33 and 22 species respectively. While Asteraceae was rated as a 4th dominant species-rich family with 10 species. According to Ensermu Kelbessa and Teshome Soromessa (2008), Fabaceae and Asteraceae are dominant due to their efficient and successful dispersal mechanism and a wide range of ecological adaptation. The dominance is also due to the adaptation potential and high ecological range of the corresponding families.

According to the result reported by Kumilachew Yeshitela and Tamrat Bekele (2002), the dominant families were Euphorbiaceae and Moraceae from the Afromontane and Transitional Rainforest vegetation types in southwestern Ethiopia. According to Getaneh Belachew (2006),

the most dominant family was Poaceae reported from Beschillo and Abay (Blue Nile), Riverine Vegetation type in North East Ethiopia. Lamiaceae which was rated as 4th with 18 species, was not common to see both in the study of others and in the flora of Ethiopia and Eritrea. Though according to Abyot Dibaba *et al.* (2014), it was observed as 5th level with the observed value of six (genera) and eight (species).

All Plant habits were observed of which 52.05% were recorded as Herbs followed by Shrubs and Trees with an observed value of 25.44% and 14.33% respectively. The difference in the distribution of habits may be due to various factors notably: land use practice, dispersal factors and altitudinal difference. Herbs are dominant due to their short reproduction season, persistent soil seed bank and an advantage during seed dispersal. However, some of the herbs for example, *Eichornia crassipes*, *Cotula cryptocephala*, *Chiliocephalum tegetum*, *Cyperus articulatus*, *C. assimilis*, *C. dichroostachyus*, *C. distans*, *C. fischerianus* are limited to the Wetland parts.

Most (81.51%) of the woody plant species were observed in Forest and Shrublands between 2300 and 3200 m asl. The Alpine and Afroalpine vegetation (>3200 m asl) part of the study area was represented by a dominance of herbs with the exception of *Helichrysum citrispinum* and *Lobelia rhynchopetalum* which were observed as shrubs. *Festuca macrophylla*, *Trifolium acaule*, *Trifolium rueppellianum*, *Andropogon abyssinicus*, *Digitaria abyssinica*, *Eleusine indica*, *Sporobolus africanus* and *Guizotia scabra* to mention few were the dominant Herbs.

5.1.1.2. Community types

Community I had relatively the wider range of elevation compared to other communities which observed between 2600 m asl and 4102 m asl (the highest elevation observed at Mount Guna). The presence of wide ecological ranges allowed the communities to have diversified plant species observed from different specialized habitats. However species some of the species *Lobelia rhynchopetalum*, *Erica arborea*, *Helichrysum schimperi* and *H. citrispinum* are limited to the Afroalpine and sub Afroalpine of Mount Guna. The assembled species in the corresponding plot into one community (Community I) from different habitats might be due to species abundance relation as indicated by Wilson (1999).

Community IV: The distribution of the plant species under this community type was found in altitudinal ranges between 1888 and 2052 m asl and most in Shrubland and some in Forest land use type. The community was represented by *Dodonea angustifolia* and *Premna schimperi* its tree layer is represented by *Combretum molle*, *Acacia albida* and *Pittosporum viridiflorum*; shrub layer by *Dodonea angustifolia*, *Premna schimperi*, *Carissa spinarum*, *Rhus vulgaris*, *Osyris quadripartita*, *Calpurnia aurea*, *Grewia ferruginea* and *Pterolobium stellatum* while the ground layer composed of *Hyparrhenia rufa*, *Guizotia scabra*, *Bidens prestinaria* and *Andropogon abyssinicus* to mention some.

Community type V had the smallest elevation difference (2413-2513 m asl) and the highest synoptic value with 67.37 (25.67%) of which 11.88 (17.63%) was contributed by *Chionanthus mildbraedii* with a synoptic value of 7.44 (11.04%) and *Maytenus arbutifolia* with a synoptic value of 4.44 (6.59%) which represents the name of the community type. It is followed by **Community type IV** with a synoptic value of 67.15, which is almost of similar recorded value to **Community type V**. It is by far greater than Community type I, with a synoptic value of 29.43.

Community type I has 30.31% (194) of observed species compared to Community type V which is composed of 12.03% (77 species) of the species totality. This might be due to the high number of individuals (abundance) in the corresponding species as appearing in Community type V. For example, *Chionanthus mildbraedii*, *Teclea nobilis*, *Albizia schimperiana*, *Bersama abyssinica*, *Bridelia micrantha*, *Clausena anisata*, *Ekebergia capensis* and *Dombeya torrida* of **Community type V** appeared in relatively specialized dense forest habitat where encroachment and degradation is comparatively less. That is why such species become more dominant and contributed a lot to the synoptic value of Community type V. The species under the corresponding plots of Community type I were located in degraded land; and in Afroalpine and sub-Afroalpine regions of the study area, where species abundance is limited on the account of existing natural factors such as extreme cold weather conditions at mount Guna (4102 m asl).

On one hand, high altitudinal difference (in Community type I) allows for the growth of different species which in turn increases the diversity, whilst on the other hand this affects the abundance of the species at higher altitudes such as the mount Guna area where its altitudinal range is low due to different reasons. One of the probable reason is eco-physiological constraint such as low temperature and low ecosystem productivity (Körner, 1998). Because, as elevation increases temperature decreases which reduces the activities of micro-organisms in the soil used to increase organic matter content (OMC). In addition, the heavy rain in the highlands removes the surface soil which is rich in organic matter.

Less abundant of species in higher elevation elevations is might be also due to the presence of inherent edge (boundary) effects such as topographic difference, soil types, presence of open water (e.g Lake Tana and permanent rivers) and geomorphic (landform factors); and induced factors (man-made) such as flooding, erosion and uncontrolled grazing (Thomas *et al.*, 1979,

Gerytnes and Vetaas, 2002) as well as over-expansion of settlement. The impact of over-grazing on the spatial distribution of vegetation is also high as documented by Belay Simane *et al.* (2012) in relation to the vegetation of Choke Mountain.

The identified plant communities have both unique and common species. The composition and distribution of the plant species in the corresponding communities show their relationship based on their similarity among themselves and with their environment better than other parameters (Fikadu Erenso *et al.*, 2014, Gemedo Dalle *et al.*, 2005). Conventionally, the degree of similarity is in the range between **1** (completely similar) and **0** (Completely different). As Jaccard's coefficient of similarity implies, the similarity value of the communities is in the range between 0.15 and 0.39. The highest relative association (least heterogeneity) is observed between **C-III and C-IV** with a recorded value of 0.39. Community type III shared more species (33.73%) with Community type IV and the vice versa. This shows that the two communities are floristically similar as they shared more species. This might be due to having related altitudinal range, habitat and soil type. The highest recorded value of similarity in the recent study area is low compared to the result reported by Fekadu Erenso *et al.* (2014) with the highest similarity of 43%.

Relatively high heterogeneity was detected between Community I and V and II and V with an observed similarity value of 0.15 each. This shows that the communities have relatively different floristic composition as they shared a small number of species (12.92%). Possible reasons may be variation in conservation and disturbance status resulting from anthropogenic activities in which Community type I is highly protected as a community forest and Community type V is highly degraded due to overgrazing.

There are 12 plant species common to all community types, including *Achyranthes aspera*, *Andropogon abyssinicus*, *Bidens prestinaria* and *Calpurnia aurea* to mention some. This is represented by 33.33% Herb and 66.66% is Woody species. This reveals that such species have a wide range of ecological adaptation. However, unique plant species are observed in different communities in different proportions. The maximum number of unique species is observed in Community type I while the least number of species is observed in Community II with a recorded value of 83 and 13 respectively.

Those species unique to the corresponding community types are also might be considered as characteristic species to reflect the current and future status of that environment. About 55.56% of the plant species are unique to one of the community types of which 10 are endemic to Ethiopia. For example; *Chiliocephalum tegetum*, *Echinops longisetus*, *Festuca macrophylla*, *Lobelia rhynchopetalum*, *Senecio unionis* and *Urtica simensis* are endemic species unique to Community type I. This might be expected to as Community I is composed of a plant species observed in a unique habitat of the study area such as Afroalpine and sub Afroalpine which is result in a wide difference in climate that may bring a limited geographical and ecological range unique to those plant species. *Ruttya speciosa* are unique to Community type III; and *Bothriocline schimperi*, *Mikaniopsis clematoides* and *Solanecio gigas* are unique to Community type V. However, Community type II and IV have no unique endemic plant species.

The presence of a relatively high number of indicator species represented by community type II implies that the sensitivity of the community and the corresponding area compared to others known for their less number of indicator species.

About 75.28% of the invasive species were observed in a Wetland use type. The remaining 24.72% were distributed in different land uses. About 68.02% of the invasive species are observed in Wetlands. Because, the orientation of the wetlands are appropriate to support the species to grow and establish themselves through: (i) facilitating nutrients entering through runoff from Rib and Gumara catchments, along with water transported the seeds and seedlings, (ii) allowing the seeds, propagules and seedlings of the aquatic invasive species from Lake Tana to take the opportunity to continue growing when lake water overflow to the wetlands. While the remaining 31.98% were distributed in other community types. This may be due to different reasons such as habitat specificity and different climatic conditions.

Community type IV is rich in Shrub and Tree layer while Community type I is rich in Herb layer. Most of the species that are frequently used for household implements, fences, firewood and medicine are *Acacia venosa*, *Albizia schimperiana*, *Calpurnia aurea*, *Canthium oligocarpum*. These are dominantly observed in Community type III while, *Maytenus arbutifolia* and *Phytolacca dodecandra* are the most frequently observed in Community type IV.

Community type I is characterized by high species richness while, Community type V is characterized by relatively poor species richness. The highest species richness indicates that the area has relatively less disturbance and the presence of optimum ecological stability. Similarly, the diversity of the community groups is also different and appears in the range between 3.58 and 4.94 observed in Community II and I respectively. This implies that Community type I has more diversity compared to others. This is not in agreement with the result reported by Teshome Soromessa *et al.* (2004) with a maximum of (4.37) and a minimum of (2.71) diversity of the plant species in the community of Gamo Gofa zone. However, the minimum recorded value of

the diversity in Community II (3.58) is still higher than the maximum value of the diversity of the community (1.79) reported by Fekadu Erenso *et al.* (2014) in Boda DAF.

Community I has more even distribution of plant species than Community type II. The higher value of evenness indicates the greater evenness in individuals in the corresponding species in their distribution within the community (Kent and Coker, 1992; Kent, 2012). Lower evenness indicates the dominance of a few species and is attributed to excessive environmental disturbances; variable conditions for regeneration and selective exploitation of the plant species (Alemayehu wasse and Demel Teketay, 2006; Feyera Senbeta, 2006).

5.1.1.3. Species diversity

The current study on 3.92 ha sampling plots as characterized by a relatively high number of species (342 species), with a distribution of 87.24 species ha⁻¹ compared to the result of other studies such as 174 species (Abate Ayalew *et al.*, 2006) in undifferentiated Afromontane forest of Denkoro, 230 plant species (Haile Yineger *et al.*, 2008) in Dry Afromontane Forest at Bale Mountain National park, 102 species (Luel Kidane *et al.*, 2010) in Hugumbirda-Gratkhasu National Forest Priority Area, 213 species (Teshome Soromessa and Ensermu Kelbessa, 2013) in Chilimo Forest and 157 species (Kflay Gebrehiwot and Kitessa Hundera, 2014) in Belete moist evergreen Montane forest.

According to Feyera Senbeta *et al.* (2007), in order to understand the ecological process, considering the pattern of species diversity in very important in prioritizing conservation and management activities. The diversity of a forest ecosystem depends on the number of species within the target area which is further dependent Richness and the number of individual species per unit area present (Evenness).

The composition, richness, evenness and the diversity of the species decreased with increasing elevation. As altitude increases temperature decreases and precipitation increases which causes mineral leaching and soil organic matter erosion. In addition, when altitude increases isolation of the habitats occurs as observed at the top of the mountain (Körner, 1998). As its habitat area decreases with increasing altitude, this ultimately affects the dispersal of plant species (Lomolino, 2001). This result is in line with the findings by (Brown and Lomolino 1998; Desalegn Wana, 2005; Neduvoto *et al.*, 2015).

The overall diversity of the recent study area is 4.73; indicating that the diversity is relatively high and higher than the commonly recorded index value observed between 1.5 and 3.5. Although, according to Kent and Coker (1992) and Kent (2012), it rarely exceeds 4.5. This high species diversity may be due to the high elevation difference observed between 1781 - 4102 m asl and habitat specificity. This is evident for the relatively high Shannon-Wiener Diversity Index ($H = 4.73$) of the recent study compared with similar DAF such as Zegie peninsula ($H = 3.72$) reported by Alemnew Alelign *et al.*, (2007) and Chilimo Forest ($H = 2.72$) reported by Tadesse Woldemariam *et al.* (2000).

The overall Shannon Evenness Index (E) is relatively high ($E = 0.88$), compared to similar Dry Afro-Montane Forests such as Chilimo forest ($E = 0.68$) reported by Tadesse Wodemariam *et al.* (2000) and Zegie peninsula ($E = 0.84$) reported by Alemnew Alelign *et al.* (2007). This implies that the distribution of individuals in the corresponding species is fair compared to others characterized by the dominance of few species, indicated by relatively low even distribution.

5.1.1.4. The structure of woody species

One of the morphological characteristics of vegetation is the structure of woody species. The analyses of DBH and height class (population structure), show the age of the trees and reveal the relatively large numbers of individuals in the lowest DBH class followed by either a gradual or sharp decline in the next higher diameter classes, forming a more or less reversed "J" type of distribution. The trend showed that the lower diameter classes exhibited higher diversity values, indicating that the sites are at an early stage of succession (Silvertown, 1982).

The general pattern of individuals in the corresponding DBH class decreases considerably as the DBH class size increases. However, the number of individuals in DBH class 7 (62.51-72.50 cm), is greater than the number of individuals in class number 5 (42.51-52.5 cm), 6 (52.51- 62.5 cm), while the rest show an irregular distribution pattern. This may be due to selective cutting and the absence of effective reproductive and/or germplasm dispersal ability. This suggests that the forest has good regeneration potential as it is characterized by a higher number of individuals in the lower class. This result is consistent with the report by Abate Ayalew *et al.* (2006), undifferentiated Afromontane Forest of Denkoro in the Central Highland of Ethiopia, Alemnew Alelign *et al.* (2007), on the peninsula of Zegie and Luel Kidane *et al.* (2010) in Hugumbirda-Gratkhasu National Forest Priority Area.

About 87.15% of the individuals represented by 113 (90.40%) species appeared in the first DBH class (2.5-12.5 cm), while the remaining 12.85% were distributed in the rest of the DBH classes. This may be due to the presence of large numbers of small trees with notable exceptions of a few individuals with relatively **large size and thick balls**; notably *Chionanthus mildbraedii* (96.18 cm), *Syzygium guineense* (101.91 cm), *Ficus thonningii* (141.72 cm), *Schefflera abyssinica* (146.50 cm) and *Juniperus procera* (163.06 cm).

The representation of individuals of the species is different in the corresponding DBH classes. For example, the most dominant represented species in the first class includes *Maytenus arbutifolia*, *Calpurnia aurea*, *Bersama abyssinica*, *Carissa spinarum*, *Vernonia myriantha*, *Dodonea angustifolia* and *Grewia ferruginea* with individuals of 497 (9.39%), 335 (6.33%), 292 (5.52%), 282 (5.33%), 240 (4.53%), 236 (4.46%) and 215 (4.06%) respectively, which also contribute to about 534.94 (39.41%), to the total density. *Acacia sieberiana*, *Chionanthus mildbraedii*, *Podocarpus falcatus*, *Scolopia theifolia* and *Syzygium guineense* are some of the species most poorly represented in the first DBH class with 1 individual each. Species with the highest number of individuals also contribute to the highest density.

The highest number of individuals also contribute to the highest density. Sixty-seven plant species (53.60%), was observed only in one class, of which 61 (91.04%), were unique to the first (2.5-12.5 cm) class, with 3 (4.48%), plant species such as *Albizia gummifera*, *A. malacophylla* and *Entada abyssinica* in the second DBH class; 2 (2.99%), such as *Maytenus obscura* and *Mimusops kummel* in the 3rd class; and 1 (1.49%), such as *Celtis africana* were unique to DBH class ten. The rest of the DBH classes have no unique species as they shared with other classes.

However, other species (46.40%) observed in at least two DBH classes notably *Chionanthus mildbraedii* was observed in 10 classes, with the exception of the 11th class, while *Sapium ellipticum* and *Syzygium guineense* were dominantly represented in 9 different classes with the exceptions of 8th, 11th; and 9th, 11th class respectively. Similarly, *Juniperus procera* and *Olea europaea* subsp. *cuspidata* appeared in 8 different classes with the exceptions of 4th, 6th, 9th; and 8th, 9th, 11th classes respectively. This suggests that these plants are well protected by the local people. Plant species discontinue notably at the 11th (>102.5 cm) DBH class; this is due to selective cutting for mortar production. Though, *Ficus thonningii*, *Juniperus procera* and

Schefflera abyssinica are dominantly represented in the 11th DBH class. The main reason is they were not available for mortar production and other household equipment due to various reasons. As an example, *Ficus thonningii* has an inappropriate stem structure, *Juniperus procera* is considered a sacred plant and in the case of *Schefflera abyssinica*, its stem is not strong enough for mortar production. The presence of such old plant species is an indicator of the age of that particular species and used to estimate the relative age of the forest.

The distribution pattern of individuals in the corresponding height class decreases as the height class size increases with increasing of DBH class. However, the number of individuals in the height class 11 (>29.5 m), is greater than the number of individuals in class numbers 7 (20.51-23.5 m), 8 (23.51-26.5 m) and 9 (26.51-29.5 m). About 81.79% of the individuals represented by 114 (91.2%), species appeared in the first height class (2.5-5.5 m), while the remaining 18.21% was distributed in the rest of the height classes. The general pattern showed that, when height increases, the corresponding number of individuals decreases up to the 7th height class; while the remaining three height classes showed an irregular pattern.

The representation of individuals of the species was different in the corresponding height classes. For example, the most dominantly represented species of the first class includes *Maytenus arbutifolia*, *Calpurnia aurea*, *Bersama abyssinica*, *Carissa spinarum*, *Vernonia myriantha* and *Dodonea angustifolia* with 506 (9.56%), 331 (6.25%), 292 (5.52%), 269 (5.08%), 240 (4.53%) and 217 (4.10%) individuals respectively which also represents about 473.40 (34.86%) of the total density. The distribution of *Dodonea angustifolia* and *Vernonia myriantha* is limited to the 1st class size while others are poorly represented in the 2nd height class (5.51-8.5 m) and not observed at all in classes 4 to 10 with the exception of *Bersama abyssinica* and *Carissa spinarum* observed in the 3rd class (8.51-11.5).

This may be due to the height of most shrubs being low compared to some trees which can grow up to 30 meters and above as observed in the largest height class (>29.5 m); example being *Chionanthus mildbraedii*, *Ekebergia capensis*, *Ficus sycomorus*, *Sapium ellipticum*, *Schefflera abyssinica* and *Urera hypselodendron*. In this category (>29.5 m), unexpected height was recorded for *Capparis tomentosa*, *Ficus thonningii* and *Pterolobium stellatum* greater than the height recorded in the Flora of Ethiopia and Eritrea.

The highest height class (>29.5 m), is composed of 19 (0.36%) individuals composed of 11 species such as *Ekebergia capensis* and *Sapium ellipticum* with individual values of 3 each; *Chionanthus mildbraedii*, *Pterolobium stellatum* and *Capparis tomentosa*, each with an individual value of 2; *Ficus sycomorus*, *F. thonningii*, *Olea europaea* subsp. *cuspidata*, *Schefflera abyssinica* and *Urera hypselodendron* with an individual value of 1 each. This class (>29.5 m), indicated the presence of very large and old species commonly found around Ethiopian Orthodox Churches which indicate the presence of remnant forests; notably in northern Ethiopia, including the recent study area.

Out of 125 plant species, 53 (42.4%), are unique to either of the height classes of which 50 (94.34%) are observed in the 1st class while the remaining were observed in the 2nd height class. This shows that 57.6% of the species are observed in at least two height classes. Those species which occur five times and above are 22 (17.6%), of which *Albizia schimperiana* was observed in 8 classes with the exception of class number 7 and 10, *Sapium ellipticum* observed in 9 classes with the exception of class 5. *Chionanthus mildbraedii* and *Olea europaea* subsp. *cuspidata* are the only species which occur in all (10), height classes. This indicates that the species are well protected and that special attention was given to them as they are considered as sacred plants.

The number of species in the corresponding height class from 1st to 5th class sizes decrease sharply while other classes show irregular patterns corresponding to the number of individuals. This may be due to the species being too small and young to be harvested for construction, farm implements, firewood and other purposes.

5.1.1.5. Basal area

About 87.15% of the individuals are observed in the lower DBH class and contributed about 9.86% of the basal area compared to 14 individuals of 3 species such as *Schefflera abyssinica*, *Juniperus procera* and *Ficus thonningii* which represent the 11th diameter class (>102.5 cm), contributing 17.56% of the aggregate basal area. As the number of individuals in the same class increases, its contribution to density value becomes higher. For example, the contribution of the first DBH class (2.51-12.5 cm) to the density is 1176.79 ha⁻¹ whereas the contribution of the plant species with thick balls under the highest DBH class (102.5 to 163.06 cm) is 3.57%.

This implies that the presence of large numbers of small trees except few with very large size with thick balls; notably *Chionanthus mildbraedii*, *Juniperus procera* and *Syzygium guineense*, *Schefflera abyssinica* and *Ficus thonningii* with a basal area of 16.81 (4.29 m²/ha), 15.84 (4.04 m²/ha), 10.83 (2.76 m²/ha), 5.45 (1.39 m²/ha) and 3.31 (0.84 m²/ha) respectively; contributed 44.96% of the aggregate basal area and 17.22% of IVI. This indicates that these species have a relatively higher contribution to maintain the ecosystem of the recent study area. These plants are mostly observed around Ethiopian Orthodox Churches and reserved community-based forests in the study area.

But, as their size increases their number decrease. Because of this only 3.55%, density ha⁻¹ was computed from three species such as *Chionanthus mildbraedii* (1.39%), *Juniperus procera*

(0.68%) and *Syzygium guineense* (1.48%) as compared to the most dominant species which contributed 290.57 density ha⁻¹ (21.41%) from *Maytenus arbutifolia*, *Calpurnia aurea* and *Bersama abyssinica* with an aggregate density of 9.53% (129.34), 6.30% (85.97) and 5.54% (75.26), respectively. This value is relatively higher compared to other studies reported by (Adane Girma and Mosandl, 2012), in degraded secondary forests in Munessa-Shashemene forest with 9.5 m² ha⁻¹. It is pointed out that the probability of some plant species to attain its maximum growth and age is less due to selective cutting for various purposes such as house construction, firewood, farm and household implements to mention some.

Most of the woody species with thick stems were observed between 2300 to 3200 m asl altitudinal range and Forest LU/LC while the study area between 1800-2000 m asl was wetland represented by herbs such as *Cyperus articulatus*, *C. assimilis*, *C. distans*, *C. rotundus*, *Eichornia crassipes*, *Nymphoides brevipedicellata* and *Nymphaea lotus*; and Acacia-Commiphora woodland and bushland dominated by Herbs and small Shrubs such as *Acacia abyssinica*, *A. albida*, *A. lahai*, *A. seyal*, *Flueggea virosa*, *Calpurnia aurea* and *Cynodon dactylon* to mention a few. In addition, part of the catchment above 3200 m asl was Afroalpine and sub Afroalpine vegetation type dominated by small Shrubs and Herbs such as *Chiliocephalum tegetum*, *Cotula cryptocephala*, *Erica arborea*, *Helichrysum citrispinum* and *Lobelia rhynchopetalum*.

5.1.1.6. Density, frequency and IVI value

The total density (Ha) which accounted for 1,357.4 is lower than the result reported by other researchers such as Alemnew Alelign *et al.* (2007) with 3318 on Zegie peninsula, Gideon Woldemariam *et al.* (2016) with 7791 in Kumuli and Feyera Senbeta and Demel Teketay (2003) with 3059 stems ha⁻¹ at Kimphee DAF. It is higher compared to the density of Adelle forest with

898 and Boditi Forest with 498 reported by Haile Yineger *et al.* (2008) and 1218 stems per hectare reported by Ermias Aynekulu (2011) in fragmented landscapes of northern Ethiopia.

Regarding the frequency of the recent study, the most frequent plant species is *Calpurnia aurea* with a recorded value of frequency (40) and relative frequency (5.14%) which is equivalent to the plant species which appeared only once, such as *Albizia malacophylla*, *Celtis africana*, *Gnidia glauca*, *Mimusops kummel*, *Protea gaguedi* and *Scolopia theifolia* to mention a few among 40 different plant species. This indicates that these species have a wide range of adaptation and are relatively dominant compared to other plant species limited in 1 and 2 plots.

The high relative frequency, density and dominance attribute to the presence of high IVI value which used to measure the ecological adaptation and abundance of the species. This suggests that these plants relatively with high IVI value have the ability to establish themselves over an array of habitats. In addition, it is considered as a characteristic species of the study area distributed throughout all community types and thus considered as dominant species as well. Example, *Calpurnia aurea* and *Maytenus arbutifolia* are the most dominant species and have similar population structures. Species with the similar IVI value have similar population structure (Lamprecht, 1989).

The most prioritized woody plant species which have been protected and respected by the local communities through local rules and regulations and have been saved from local extinctions. That is why most of the species which has high contribution to the IVI value are found in sacred (Church and Mosque) forests where spiritual ceremonies, worshiping and funeral ceremonies are performed (Figure 41).



Figure 41: Inhabitants assembled at Kolay Mariam Church Forest as a memory for Saint Mary's flight from Nazareth of Galilee to Egypt (Photo by Birhanu Belay, 15 November 2015)

5.1.1.7. Natural regeneration potential of woody species

The total number of individuals of the seedlings, saplings and Trees/Shrubs is 3,842 (980.12 ha^{-1}), 3,180 (811.22 ha^{-1}) and 5,133 (1309.44 ha^{-1}) respectively. The seedlings and/or saplings are represented by 7022 individuals, 68 species, 60 genera and 40 families (Appendix 6). The total density of the seedlings and saplings (1791.34) are relatively low compared to Dodola Forest as reported by Eyob Tenkir (2006) with 41,092, Birhanu Kebede *et al.* (2014), with 1905.72 ($1,068.21$ seedling and 837.51 sapling) of Gedo forest and Birhanu Woldie *et al.* (2015) with a total of 2061.29 seedlings and saplings of Sesa Mariam Monastery, though their species number is relatively lower compared to the result of the recent study.

However, it is greater than the result reported by Alemnew Alelign *et al.* (2007) with 5674 ($1075 \text{ density ha}^{-1}$) on Zegie peninsula. The distribution in some moist forests is reversed (Yohannis Teklu, 2014) as the number of seedlings is relatively low due to the closed canopy which limits the light to reach the soil in order to initiate the soil seed bank to germinate.

Most of the regenerating species that appeared in Forest and Shrubland use and cover types observed with the mother plant. But some of the species such as *Acacia abyssinica*, *Ekebergia capensis*, *Grewia ferruginea*, *Maytenus arbutifolia* and *Steganotaenia araliacea* which also appeared in Grassland-cover types in the absence of the corresponding mother plants. This shows that the land changed from either Shrub or Forest as validated by the semi-structured interview, soil seed bank experiment and change detection matrix.

The seedlings and/or saplings common to both in the above ground vegetation and soil seed bank include *Allophylus abyssinicus*, *Calpurnia aurea*, *Dodonea angustifolia*, *Erica arborea* and *Ficus sur*. While, *Vernonia wollastonii* was grown as a soil seed bank but had not been appeared in the above ground vegetation. *Clausena anisata*, *Maytenus arbutifolia*, *Grewia ferruginea* and *Rhamnus staddo* were the dominant seedling and sapling appearing in the above ground vegetation, but not in the soil seed bank. This dynamism may be due to a number of factors such as predation, lack of optimum weather conditions to germinate in the greenhouse, lack of germination treatment, the availability of seed during sample collection and swift germination before the experiment started.

The seedlings and saplings of *Chionanthus mildbraedii* were dominant in the above ground vegetation which failed to grow as a soil seed bank, although collected as a soil seed bank sample and checked for its viability in the laboratory. This might be due to lack of optimum condition to induce its germination.

Out of 40 families, the most frequent and species-rich families are Fabaceae with 13.24% and Oleaceae, Celastraceae, Euphorbiaceae with 5.88% each and Rubiaceae with 4.41% compute a totality of 35.29%. The ratio of seedlings to saplings, seedlings to matured woody species and sapling to mature woody species are 1.21, 0.75 and 0.62 respectively. The highest value obtained

from seedlings to saplings compared to the other pairings, indicates that the area has a good regeneration and recruitment potential.

The highest density of seedlings and saplings is found in species such as *Maytenus arbutifolia* (306.12 and 142.09), *Clausena anisata* (117.86 and 71.17), *Dodonea angustifolia* (104.34 and 89.03), *Chionanthus mildbraedii* (86.48 and 8.42) and *Calpurnia aurea* (52.81 and 55.61) which contributed 667.6 (68.12%) and 366.32 (45.16%) of the aggregate density of the seedlings and saplings respectively. *Calpurnia aurea* is also among the most dominant with the highest in its seedling density and *Dodonea angustifolia* in its sapling density, in the soil seed bank study by Mamo Kebede *et al.* (2012). Similarly, it is also the second most dominant species in the study of Tinsae Assefa and Berhanu Abraha (2014), as it is justified as a widely distributed, fast-growing species in harsh conditions, even up to -5°C (Zorloni, 2007). The dominance of these species, notably *Maytenus arbutifolia* is an indicator of disturbed area beginning to rehabilitate.

Most of the species with the highest seedling count also have a high number of saplings and appeared as both forms except some of the species limited to only seedlings such as *Dombeya torrida*, *Ficus sur* and *Senna petersiana*; and sapling such as *Diospyros abyssinica*, *Schefflera abyssinica* and *Steganotaenia araliacea* to mention some.

Some plant species have limited numbers of seedlings/or saplings such as *Dombeya torrida*, *Hypericum quartinianum*, one each; *Diospyros abyssinica*, *Entada abyssinica* and *Ficus sur*, two each; and *Sapium ellipticum*, *Schefflera abyssinica* and *Steganotaenia araliacea*, three individuals each. These are examples of plant species characterized by small numbers of individuals compared to plant species with relatively high numbers of individuals of seedlings

and samplings such as *Maytenus arbutifolia* (1757), *Dodonea angustifolia* (758) and *Clausena anisata* (741).

5.1.1.8. Endemic taxon

According to the Flora of Ethiopia and Eritrea, the recent study area had 27 endemic plant species for Ethiopia and Eritrea out of 342 plant species of which 20 (74.07%) being solely endemic to Ethiopia. Seven species (25.93%), such as *Acacia venosa*, *Albizia malacophylla*, *Bidens macroptera*, *Kalanchoe petitiiana*, *Rhus glutinosa* subsp. *neoglutinosa*, *Lippia adoënsis* and *Thymus schimperi* are shared with Eritrea and so are not considered endemic to Ethiopia as Eritrea is now an independent country. *Festuca macrophylla* was the only plant species observed both in the above ground vegetation and soil seed bank while *Leucas aequistylosa* and *Trifolium schimperi* were unique to the soil seed bank.

All the 20 endemic plant species registered in the IUCN red data list of Ethiopia and Eritrea (Vivero et al., 2005), and distributed to Near threatened (15%), Least concern (45%), Endangered (5%) and Not evaluated (35%). This implies that 45% of the endemic species are at the lowest risk that does not qualify for a more at risk category while 5% represent species with extremely high risk of extinction from its natural habitat. Some of these plant species such as *Lippia adoensis*, *Lobelia rhynchopetalum*, *Solanecio gigas* and *Vernonia leopoldi* were used by the local people for the preparation of traditional medicine. Similarly, most of these endemic species are used for household equipment and farm implements, notably *Acacia venosa* which has only one remnant specimen at Addis Ababa National Herbarium. It is used for farm implements such as yokes (Kenber), pulling bar (Mofer), wing (Digir), handle (Erif) and rows (Manekia) for plowing on the account that it is very strong and durable and is not attacked by insects. This pressure may cause the plant species to become locally rare.

This result is in line with the research by Ensermu Kelbessa *et al.* (1992), which justified that, DAF as a center of endemism; notably of threatened endemic plant species. The presence of the high level of floristic composition and endemism at the local level may be due to the presence of the high elevation difference (1781-4102 m asl), which may cause geographical and ecological isolation (Kruckeberg and Rabinowitz, 1985), of the endemic species populations. Most of the endemic plant species are distributed in different floristic regions, while *Mikaniopsis clematoides* is limited to GD/GJ. According to the Flora of Ethiopia and Eritrea *Leucas aequistylosa* is only observed in KF floristic regions but according to the recent study, it is a new record for GD floristic region.

5.1.1.9. Invasive plant species

Invasive species (IS), are the second most noteworthy cause for biodiversity loss next to habitat destruction through their high propagation and spreading potential to displace and kill ecologically important and endemic plants through generating negative impacts on the local ecosystem and species (IUCN, 2014). Similarly, it affects the farming activity in negative ways. It has also a negative impact on food security, health and economic development (McNeely *et al.*, 2001). Example, *Eichornia crassipes* and *Nymphoides brevipedicellata* are forming thick mats that reduce sunlight and oxygen from reaching the water column and submerged plants which ultimately affects biodiversity (Downey *et al.*, 2010) and other hydrological process such as navigation, swimming traffic and fishing. These invasive plants affect not only biodiversity and ecosystem functioning, but also the human health of the community through facilitating mosquito breeding which causes malaria (Personal communication, 2015).

High distribution of invasive species in the soil seed bank is also observed in Fogera plain where the wetland is located. This might be due to three main reasons: (i) The Fogera plain is the last

destination of the watershed where run-off becomes stable before it enters Lake Tana allowing the seeds to settle in the sediment and form a seed bank (ii) During the rainy season; the Lake over-flows on to the plain and remains for about three month before it goes back to its regular bank; allowing the seeds of the invasive plant species from different sources of the Lake watershed, to stay buried and germinate later as validated by the soil seed bank experiment (iii) The presence of urbanization and disturbance has increase the degree of invasion.

This is supported by Hopkins and Graham (1983), as seeds are easily transported by running water. Similarly, Looney *et al.* (1995), described water carrying viable seeds to a place where they can remain dormant for a long period of time and establishing a soil seed bank. Due to different resources such as debris, sediments, water and nutrients, the landscape sink of the Wetland facilitates the invasion and growth of invasive plant species. This was validated by the results of the current study of the invasive species such as *Argemone mexicana*, *Datura stramonium* and *Senna didymobotrya* which emerged from the soil seed bank. The result is also supported by Galatowitsch *et al.* (1999) as Wetlands fed by surface water from the corresponding watersheds would increase the probability to have invasive species.

The inhabitants tried to eradicate exotic water plants remarkably, *Eichornia crassipes* by physical methods. They have collected this plant species and permit the biomass to dry as 94% its biomass is water and burnt. Sometimes used for cattle feed in times of drought but the farmers discovered that the plant species caused health disorders for their cattle. All methods to manage the exotics in a sustainable manner failed. Recently, the **Ministry of Environment, Forest and Climate change of Ethiopia** in a joint effort with Bahir-Dar and Gondar Universities, are working together to apply new strategies such as biological controls and machinery which entail the application of fungus and charcoal production (Ethiopian News Agency, personal

communication, 2017). Remarkably, the weed harvesting machine designed by Gondar University is the best and promising strategy.

In like manner, *Argemone mexicana*, *Xanthium strumarium*, *Amaranthus spinosus*, *Datura stramonium* and others also attacked different parts of the Wetland known for its high production of rice (*Oryza sativa*), chickpea (*Cicer arietinum*) and other crops. As per the information from the inhabitants and Woreta Woreda Agriculture Office (WWAO) the yields decrease year after year. The crops were out-competed by invasive; by taking advantage of their fast growth, high reproduction rate and its ability to expand. This has caused great anxiety for lakeside farmers.

The local people are quick to identify agricultural weeds which affect the growth and production of their crops and its products. According to their report (Personal communication, 2015), they have recognized 12 (3.51%) weeds such as *Ageratum conyzoides*, *Amaranthus spinosus*, *Argemone mexicana* and *Azolla nilotica*. They have also recognized the invasive species such as *Amaranthus spinosus*, *Argemone mexicana*, *Datura stramonium*, *Eichornia crassipes*, *Senna didymobotrya*, *Xanthium spinosum* and *X. strumarium* as agricultural weeds influencing the quality and quantity of their crop production, resulting in the price penalty.

Parthenium hysterophorus and *Calotropis procera* were observed along the main road between Woreta and Addis Zemen; a new record for Gondar Floristic Region. Their occurrence is far less than in the Awash Basin. This showed that the species appeared recently as a new species which had not established itself as a self-sustaining mechanism but which has the potential to invade and spread across broad areas of the recent study area. Due to this, the local people recognize the species as neither invasive nor weed. These species will soon proliferate (Richardson *et al.*, 2000b; Richardson and Pyšek 2006, Blackburn *et al.*, 2011), due to its ability to overcome

dispersal and ecological barriers, which in turn depends upon its reproductive and dispersal characteristics (Richardson *et al.*, 2000b, Moravcová *et al.*, 2010).

According to Gaertner *et al.* (2009), and Catford *et al.* (2012), the introduction of invasive species to new localities is the characteristic for ecosystem disturbance. The local people noticed that these plant species come from other areas and call it "Metē" in Amharic, which means newcomer. This name is particularly given for *Nymphoides brevipedicellata*.

According to the recent study *Senna didymobotrya*, *Eichornia crassipes*, *Nymphoides brevipedicellata*, *Amaranthus spinosus*, *Datura stramonium* and *Argemone mexicana* were the dominant invasive plant species and of the most threat to farmers as they are difficult to avoid once established themselves.

The general pattern of the response of *Senna didymobotrya* to elevation, roughness and mean slope followed a decreasing pattern while compound topographic index showed an increasing pattern. Classified map followed an irregular pattern while heat load remained constant with ~73.1% of contribution with increasing the value of the corresponding predictor values. In a classified map, Shrubland was the most suitable habitat for the species followed by Settlement. The response to mean slope was also high with ~75.5% observed in a range between -0.6 and 0 (zero), while it shows a gradual decrease between 0 and 2.3. The response of *Senna didymobotrya* to classified map (Shrubland) with nearly 76% of habitat attribute to its spatial distribution followed by mean slope (~75%) and roughness with ~73.7%. The response of *Senna didymobotrya* to elevation was constant (66%) in the range between 1781-1800 masl., but it decreased drastically between 1800 m asl and 2300 m asl and then continue with a gradual decrease from 2300 m asl up the summit of the study area (4102 m asl). This might be due the

interaction of other factors with elevation. The pattern and the corresponding range of the response for elevation and slope were almost similar. This shows that the two predictors have a similar impact on the spatial distribution of *Senna didymobotrya*.

Thus, the distribution of *Senna didymobotrya* decreases even to the extent of zero with increasing altitude. That is why this invasive species was not observed in the Afroalpine and sub-Afroalpine parts of the recent study area (Mt. Guna). But still, there is a potential to invade areas up to 3200 m asl with different degree of invasion.

5.1.1.10. Impact of environmental variables on vegetation distribution

On the account complex topography and set up, the spatial distribution of vegetation is different (Zerihun Woldu *et al.*, 1989) which also affect the related environmental variables notably the soil structure and soil chemistry. According to Andreucci *et al.* (2000), a single species is less informative compared to the combination of species and their response to a given environment, as there is co-existence factor among different species.

The degree of contribution of environmental variables for vegetation distribution is different when Fuzzy set of ordination software run with single environmental variables. Even, the contribution of one environmental variable when it is considered alone and with other variables is also different, for example, the impact of altitude represented by x-axis (actual elevation) and y-axis (apparent elevation) is high when considered alone (unconstrained) as it is indicated by a relatively high correlation coefficient (0.83), followed by sand and clay with a correlation coefficient value of 0.73 and 0.67 respectively. This shows that the contribution of altitude is high compared with other variables and considered as the most important factor influencing species composition and distribution. In addition, the pattern of the plots appeared as linear

which is also a good indicator of strong affinity to elevation. While the rest relatively remained as lower impact compared to altitude as it appeared as low coefficient value and nonlinear plot distribution. Calcium was the least contributor to affect the spatial distribution of vegetation with a correlation coefficient of 0.3. While in ordination, run multiple variables at the same time the reverse will be true as sand and clay become the most determining factors over elevation as their corresponding length of the arrow is relatively longer than others.

This result is supported by Zerihun Woldu *et al.* (1989) as an altitude has a high contribution in both cases to determine the spatial distribution of the vegetation than other environmental variables such as aspect, slope and soil physical and chemical properties considered during the recent study. According to Zerihun Woldu *et al.* (1989) most of the environmental variables are indirectly controlled by altitude. This might be due to most variables are a function of altitude. For example, altitude is inversely correlated to temperature and directly related with precipitation. This shows altitudinal gradient has a distinctive opportunity to study the pattern of vegetation distribution as it represents the natural slope of temperature and precipitation, which ultimately affect the distribution of vegetation and floristic composition.

All the five communities types represented from 98 plots have appeared with their corresponding plots. With respect to axis two, Community type I was negatively correlated with 66.67% of the variables such as Slope, OC, Sand, Altitude, pH and Ca while it was positively associated with Clay, Silt and available P. This shows that the corresponding species in Community I such as *Plantago lanceolata*, *Juniperus procera*, *Pennisetum thunbergii*, *Azolla nilotica*, *Amaranthus spinosus* and *Hygrophila schulli* to mention a few have a negative correlation with respect to axis I. All the Afroalpine and sub Afroalpine species of the recent study area including *Erica*

arborea, *Lobelia rhynchopetalum*, *Trifolium acaule*, *Alchemilla pedata*, *Helichrysum citrispinum* and *Dianthoseris schimperi* also mark the same pattern in its relationship.

With respect to the first and the second axis, Community I is highly influenced by Clay followed by Silt. While Community type II by Calcium and pH, Community type III by Silt, Community type V by OC and Sand as they show a positive relationship. While IV did not show a distinct pattern of distribution and correlation with environmental variables as it appeared in different locations. It might be correlated with other environmental variables which were not considered during the recent study.

Teclea nobilis, *Clusia abyssinica*, *Oplismenus hirtellus*, *Lippia adoensis* and *Bidens prestinaria* to mention a few show a gradient separation along the negative side of the x-axis. *Capparis tomentosa*, *Croton macrostachyus*, *Grewia ferruginea*, *Albezia schimperiana*, *Premna schimperi*, *Achyranthes aspera*, *Osyris quadripartita*, *Senna singueana*, *Kalanchoe petitiana*, *Sida schimperiana* and *Acacia albida* to mention a few appeared at the origin of the both x and y-axes. This shows that the habitat preference of the species to grow with optimum values of all considered environmental variables.

While some of the species locally unique to mount Guna such as *Lobelia rhynchopetalum*, *Erica arborea*, *Helichrysum citrispinum*, *Alchemilla pedata*, *A. abyssinica*, *Dianthoseris schimperi*, *Haplocarpha rueppellii* and *Festuca macrophylla* were appeared at the extreme negative end of x-axis as isolated from other species distinctively. This implied that these species have unique habitat selection as it is observed in the Alpine and Afro-alpine regions of the recent study area.

Schoenoplectus articulatus, *Amaranthus spinosus* and *Oryza longistaminata* were distributed at the positive end of y-axis. *Cyperus fischerianus*, *Bersama abyssinica*, *Calpurnia aurea*,

Maytenus arbutifolia and *Hypoestes triflora* observed at the negative end of y-axis. The observation of different species at a different location of the ordination diagram with respect to x and y-axis indicates that the requirement of the species for habitat selection and the way environmental variables affect the distribution of the species is different.

Aspect refers the orientation of plot which affects the precipitation and temperature level (Barbour *et al.*, 1987), and the influence of wind is coded using different symbols such as N (North), E (East), S (South), W (West) and others in between (FAO, 2006). Example, in Bale mountains different vegetation types at southwest and northeast aspects (azimuth) was noticed by Uhlig (1988), in which the former received relatively high moisture from Atlantic Ocean than the latter influenced by the offshore trade winds (Daniel Gamachu, 1977). But in the recent study, the impact of aspect is not significant. That is why it was not observed in ordination diagram. This might be due to, as it is in the tropics where all the landscapes share almost similar day length and angle of the sun.

Slope indicates the steepness or the degree of incline of a surface. Example, steep slopes aggravate the movement of surface water and cause the resource available for plants to be washed. Ordination diagram indicates that slope is one of the influencing factors which affect the distribution of the species observed in different plots and the corresponding community types. It is negatively correlated with Community types I and III while it is positively associated with Community type V and its corresponding plots such as 41, 43, 44, 64, 65, 66, 67, 68 and 70; and the corresponding species such as *Acanthus sennii*, *Agrocharis melanantha* and *Clutia abyssinica* to mention a few. Though according to FAO (2006), high slope areas particularly: strongly sloping (10-15°), moderately steep (15-30°), steep (30-60°) and very steep (>60°) levels are not

suitable for agriculture as it is difficult to access. But in the recent study area such areas are accessed manually for crop production as there is a scarcity of farmland.

The activity of hydrogen ions in the soil solution is represented by soil pH which determines the availability of nutrients (e.g minerals) to plants (FAO, 2006). With respect to x-axis Community I and the corresponding species such as *Girardinia bullosa*, *Hypoestes triflora*, *Calpurnia aurea* and *Pterolobium stellatum* observed both in standing vegetation and soil seed bank show a positive relationship (Negative with respect to x-axis). The result shows the importance of pH to maintain the longevity of the seeds as a soil seed bank is reported by Solomon Tefera (2011).

The average soil pH (H₂O) ranges from 4-8 for the normal growth of plants (FAO, 2006). The distribution of pH is rated as: low (94.23%) and medium (5.77%) level following the standard set by B. Frank (1990), as low is between 4 and 6.6 while medium is between 6.6 and 7.3. This show that the recent study area is represented by acidic soil, because all the pH values are below 7. This might be due to the result of soil acidification which is the process of increasing the concentration of hydrogen ions in the soil through time. It is slightly decreasing with increasing altitude in an irregular pattern. It might be due to relatively low temperature and high rainfall which cause mineral leaching. It might be also caused by the application of fertilizers (ammonium) in which ultimately increase legume growth and organic matter. It is validated by the recent study as 59.59% of the plots rated as very high (>6), content of pH while the rest rated as medium (21.28%) and high (19.15%). This would be a good opportunity for the plants which love acidic soil to grow. While it will be a challenge for the plants which love an alkaline media to thrive. This problem might be minimized through a liming process (e.g Pulverized limestone) to raise the soil pH. The presence of one parameter affects the other. Example, available P is one of nutrient which is strongly dependent on a soil pH.

Available phosphorous is one of the primary macronutrients heading away from the origination to the positive side of the x-axis. It was the least in its contribution to affect both the species distribution and composition as its arrow length is shorter than the other environmental variables. Though it has a positive relationship with Community type I and the corresponding species notably with *Ageratum conyzoides*, *Acacia albida* and *Rhus vulgaris* to mention a few. According to the standard set by B. Frank (1990), about 68.42% of the plots belonged to high (18.42%) and very high (50%), level while the rest (31.58%) lay on medium (13.16%), low (10.53%) and very low (7.89%).

The distribution of available phosphorous rated as medium, low and very low level in 31.58% of the plots, might be resulted from the washing process of the mineral by the running water to Lake. The distribution of available phosphorous rated as medium and below to a level of low and very low accounts about 31.58% of the plots. This small value might have resulted from the washing process of the mineral by the running water to Lake Tana and ultimately cause invasive species to grow and propagate in alarming rate notably for *Eichornia crassipes*.

All exchangeable bases such as Mg, K and Na were not significant except Ca. It was observed in the negative direction Community IV and marks a negative response for the community, while in a positive direction of Community III and the corresponding plots and species. While Organic matter (OC), is negatively correlated with Community type I and positively correlated with Community type IV and its corresponding plot and species as it is extending to the negative side of x and y-axis like that of altitude, sand and slope with their corresponding gradient strength.

Soil texture refers to the proportion of the different particle-size classes (fractions) in a given soil volume and is described as soil textural class. According to FAO (2006), the names for the

particle-size classes correspond closely with commonly used standard terminology, including that of the system used by the United States Department of Agriculture (USDA).

Among 13 expected texture classes (FAO, 2006), eight texture classes made out of the relative proportion of sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) and characterize the physical properties of the soil, about 40.82% is represented by Sandy Loam. This demonstrates that a large proportion of the plots (40.82%) represented by this texture classes. For example, the majority of the plots of this class type are observed under Community type III. While relatively Silty Clay Loam represent the smallest occurrence (2.04%) as it is observed only in plot numbers 47 and 48 observed in Community type one. This indicates that the recent study area might be characterized by low soil fertility due to the fact that the presence of significant proportion of sand (73%) to drain water and nutrient which has an implication on soil water and availability of nutrients for plants.

So, the nutrients washed away by the running water to Lake Tana together with other contents of the soil ultimately may affect Lake Tana in different ways: i) hydrological instability ii) reduced primary productivity iii) increase siltation iv) increase the incidence of invasive species and its growth and propagation. Mineral leaching may also take place in very sandy soils because sandy soils do not contain enough clay which has a tendency to hold positively charged nutrients such as Ca^{++} , Mg^{++} , Na^+ and NH_4 in which ultimately increase the CEC of the soil.

5.1.2. Soil seed bank

5.1.2.1. Species composition in the soil seed bank

The composition of the seed bank depends on seed longevity and viability, burial depth, soil moisture, temperature and soil water content (Fernandez *et al.*, 1991). The growth performance of all emerged seedlings has been good except for *Cordia africana* which dried at the early stage. About 98.86% of the species emerged as seedlings. However, according to Demel Teketay (2005a), more seeds are recorded from seed count than from seedling emergence method as there could be a lack of suitable weather conditions compared to that of their natural habitat for germination.

5.1.2.2. Soil seed bank and LU/LC types

About 42.86% of the species in the seed bank were mainly members of the family Poaceae with 32 species (22.86%), followed by Asteraceae and Fabaceae with 15 (10.71%) and 13 (9.29%). Similarly, these families were also dominant in the corresponding sampling layers, A and B. But, in sampling layer C the 2nd species-rich (dominant), families were Asteraceae and Fabaceae with the same observed species number. Poaceae, Asteraceae and Fabaceae were also dominant in five of the LU/LC types except for the Wetland that was dominated by Poaceae that might be due to the dominance of the families in the above ground vegetation. The success of these families are also due a number of attributes: For example According to White (1983), Poaceae is found from hyperarid Sahara to the coldest Antarctica (e.g *Deschampsia antarctica*), due to its ability to disperse itself in a wide ecological range, tolerate persistent harsh conditions and to establish itself with other populations (Levick *et al.*, 2015). In Wetland use types, Cyperaceae became the second species-rich family after Poaceae which indicated that more species are observed in the Cyperaceae family compared to other families. This might be due to habitat

suitability on the one hand, as Asteraceae; which was the first in the above ground vegetation and the second species-rich family in the aggregate soil seed bank, rated 3rd. This indicated that the growth performance of species in Asteraceae family is relatively less in Wetlands compared to other land use types.

The number of species and distribution of seeds found in the soil samples varied significantly among the LU/LC types ranging from low of 32 (Wetland) to a high of 94 (Shrubland). The presence of less number of species in Wetlands is might be due to the reduce persistence of the seed and increased mortality as the seed is in a water-logged soil which causes oxygen deficiency. While, relatively high number of species observed in Shrublands might be due to the presence of optimum condition which increases the probability of most of the seeds to germinate in the soil seed bank, the relative fertility of the soil and vegetation cover in Shrubland and Forest LU/LC types support seed persistence (Wagner and Mitschunas, 2008; Koprdoва *et al.*, 2010; Saatkamp *et al.*, 2011a).

With a similar pattern of distribution, the number of seeds and/or seedlings per meter square also varied from low (17%) recorded in Wetlands to high (23%) recorded in shrublands. Shrublands become dominant due to the presence of a large number of herbs such as *Galinsoga quadriradiata*, *Oxalis corniculata* and *Ageratum conyzoides* which contributed to about 52.13% of the density. This shows that the Shrubland is dominated by herbs and it is at the state of succession. The large densities of these weeds in the soil seed bank indicate that there will be threats of high infestation in the future.

Even though all types of habits were observed, Herbs were the most dominant in all land use types in different proportions, with the highest recorded value in the Shrublands (32.16%),

followed by Shrub habit, although it remained absent in Croplands. The presence of high proportion of herbs is an indicator that the forest type in the recent study area is not high. Because dense canopy forest closure doesn't allow herbs to grow under its canopy due to lack of direct sunlight to enhance germination. Because of this, the density of viable seeds in the soil seed bank of the forest with closed canopy is characterized by relatively less seed number compared to other LU/LC types (Demel Teketay, 1996). The dominance of herbs over other habits is also indicated by different researchers (Demel Teketay, 1996; Mekuria Argaw *et al.*, 1999; Kebrom Tekle and Tesfaye Bekele, 2000; Feyera Senbeta and Demel Teketay, 2001 and Alemayehu Wassie and Demel Teketay, 2006).

This indicates that a relatively high density of seeds are observed in degraded open canopy areas compared to that of high forests as herbs colonize degraded areas and forest in the process of restoration as observed in the recent study area. This study confirmed that the status of the soil bank, notably, for herbs, is relatively higher than MAF vegetation types (Yohannis Teklu, 2014). This is also an indicator of species predominance observed in the range of the recent study area as compared to undisturbed habitats such as woodland and pasture which have generally lower seed persistence (Poschlod, 1993; Thompson *et al.*, 1997).

In Croplands, there was no seed in the seed bank of species with Tree life forms. The probable reason may be the complete removal of mother trees which serve as the source of soil seed bank. Despite the fact that there were no tree seeds in the seed bank during the life of the project. Farmers were observed allowing the growth of some selected Tree species such as *Cordia africana*, *Ficus sur*, *Croton macrostachyus* and *Syzygium guineense* to maintain either for the purpose of shelter or fodder but they do not appear in the soil seed bank. However, some the plant species such as *Calpurnia aurea* and *Solanum giganteum*, were found as seedlings and had

a seed bank. Forest land use type has all the possible habit types due to the presence of relatively conducive environmental factor such as reasonable shade, moisture, organic content and other related factors.

Of 140 seeds/seedlings extracted from the soil seed bank species, 24.27% represents the standing vegetation. The number of emerged seedlings from the soil seed bank may not be limited to 140, as there might be others which did not appear on account of different factors such as optimum temperature, light and treatments. It is to be noted that those seedlings which need additional treatments such as soaking in boiled water, scarification, burning with fire and chemical application to break their dormancy would be absent among the seedlings. In the recent study, *Calpurnia aurea* germinated without any additional treatment, although it was indicated that it requires mechanical scarification to break its dormancy (Demel Teketay and Granström, 1995; Demel Teketay, 1998 b and c). This might be due to the fact that its dormancy was broken by disturbance.

The total number of species in the seed bank (140), is less than that reported by Demel Teketay and Granström (1995) in dry Afromontane forests of Ethiopia where at least 167 plants species were identified in the range between 0 to 9 cm soil layers. However, it is much greater than what was reported by Yohannis Teklu (2014), in Gera Moist evergreen Afromontane forest, Mulugeta Lemenh and Demel Teketay (2006) in tropical dry Afromontane forest of Ethiopia with 66 species each, and by Tinsae Assefa and Berhanu Abraha (2014), in Bezawit Forest with 48 species, and Demel Teketay and Granström (1995) in Munessa-Shashemene and Gara Ades forests, with 58 and 92 species respectively.

Galinsoga quadriradiata, *Oxalis corniculata*, *Ageratum conyzoides* and *Trifolium rueppellianum* were relatively the most important plant species as they were observed as the most frequent and dominant plant species resulting in high density compared to the other plant species. This might be due to the high adaptation potential of their seeds viable in a wide ecological range. This implies that these dominant species become a threat for the catchment and the farmers through affecting the cropping system.

This dominance may be due to the high number of viable seeds; the potential to germinate and to its relatively high abundance. Similarly, having high frequency indicates that the ecological range of these specific plant species to grow and perpetuate under harsh conditions. Most of the species including *Helichrysum forskoolii*, *Leucas aequistylosa*, *Sida ternata*, *Vigna heterophylla* and *Viola abyssinica* to mention a few, are represented by a very small number of individuals, limited to one sampling layer and one plot. These species are exposed to local extinction. This might be due to the pressure of dominant weeds and other invasive plants species competing in many various ways such as for a resource, high reproduction rate and dispersal ability.

As it is observed from most of the studies (Demel Teketay and Granström, 1995; Alemayehu Wassie and Demel Teketay, 2006; Eyob Tenkir, 2006), all the possible growth forms such as Climbers, Herbs, Shrubs, Shrubs/Trees and Trees were observed in the recent study. Of the total number of species, 114 (81.43%), were Herbs in which 26% appeared from 2nd (3-6 cm), sampling layer due to their relatively high ability to withstand harsh environmental conditions and remain dormant for a long period of time (Demel Teketay and Granström, 1995; Demel Teketay, 1996). The remaining 18.57% were represented by seeds of woody and climber species which were distributed in different sampling layers notably at the 1st (0-3 cm) with 35.56% followed by the 2nd (3-6 cm) and litter (0 cm) sampling layers with 26.67% and 22.22% in

descending order. While the least number of woody species was observed in the 3rd (6-9 cm) sampling layers with 15.56% of all relative species. This may be due to decreased of woody plant species with calcitrant seeds, to reach the lowest layer (6-9 cm).

In general, the disparity in distribution of habits and the predominance of Herbs in different land use types- and altitudinal gradients is explained by a combination of different factors: (i) they are generally less likely to be predated on or damaged by micro-organisms, (ii) seed size and its longevity which is indirectly related the seed size (Wang *et al.*, 2009), (iii) resistance to harsh conditions such as extreme low and high temperature, humidity and variation in oxygen supply (Demel Teketay, 2005b), (iv) persistence in certain areas resulting from their great numbers, long term viability, continuous germination, and phenotypic and genotypic elasticity (Christoffoleti and Caetano, 1998). For example, *Portulaca oleracea* is one of the seed identified in the recent study area which remain viable in the soil for up to 40 years (Freitas, 1990).

This finding of the dominance of Herbs is supported by the reports of different researchers where a similar trend was observed in the findings of other researchers (Demel Teketay and Granström, 1995; Demel Teketay, 1996; Kebrom Tekle and Tesfaye Bekele, 2000; Tefera Mengistu *et al.*, 2005; Alemayehu Wassie and Demel Teketay, 2006; Eyob Tenkir, 2006; Degafi Sileshi and Berhanu Abraha, 2014).

In most cases, the abundance and distribution of the Shrubs and Trees were represented by large seeds, whereas this was relatively low in comparison to the Herbs; known for their small seeds. According to Eyob Tenkir (2006), one of the probable reasons the seeds of most woody plant species appear in the above ground vegetation known for their transient seeds is that seeds and germinate immediately or within a few days after dispersal, rather than being stored as a soil

seed bank for a long period of time as with the Herbs. Herbs with small seeds have their seeds more frequently dispersed and more broadly distributed over space in any particular season via different mechanisms, whereas plant species with large seeds are present in fewer seasons, with restricted spatial distribution in any of those seasons.

In general, the distribution of the seeds of woody species demonstrated an irregular pattern identified with increasing depth. The lowest number is observed in the 3rd (6-9 cm) sampling layer. This might be on account of either the seeds germinating promptly after primary dispersal by using their large size (seed), as a good opportunity to provide them the endosperm as immediate source of food, or the strategy accompanied by with high moisture content or even in light of the fact that they were attacked by pathogens and predators before they reached this layer. For instance, *Chionanthus mildbraedii* was the most populated tree in Yifara forest with high numbers of saplings, seedlings and seeds lying on the surface of the soil which appeared as a viable when tested in the laboratory (GBG), but which failed to grow as a soil seed bank germinant when allowed to grow in a modified environment.

Some of the woody plant species observed in the soil seed bank include *Calpurnia aurea*, *Clutia abyssinica*, *Dodonea angustifolia*, *Erica arborea*, *Ficus sur*, *Hypericum revolutum*, *Maesa lanceolata*, *Solanum giganteum* and *Chionanthus mildbraedii*. The presence of small numbers of Trees and/or Shrubs was not surprising compared to Herbs as it is consistent with observations made in other studies such as Feyera Senbeta and Demel Teketay (2002), Getachew Tesfaye *et al.* (2004), Mulugeta Lemenih and Demel Teketay (2006), undertaken in other Ethiopian Afromontane forests. Most of them reported rare woody species due to the relatively short lifespan of the woody species (Demel Teketay, 2005b). Though the recorded, 26 woody plant species of the recent study is greater than the findings by Degafi Sileshi and Berhanu Abraha

(2014) and Feyera Senbeta and Demel Teketay (2002) with a recorded value of 19 and 15 species respectively.

5.1.2.3. Soil seed bank frequency and density of species in the soil seed bank

The total density was 5,848.53 seeds m^{-2} of which 2,624.94 seed m^{-2} (44.88%) was computed from four major and the most frequent species such as 1385.94 (23.70%) *Galinsoga quadriradiata*, 747.39 (12.78%) *Oxalis corniculata*, 246.71 (4.22%) *Ageratum conyzoides* and 244.90 seeds m^{-2} (4.19%) *Trifolium rueppellianum*. This may be due to the wide ecological range of the species and their high prolific seed amount produced in one reproductive season. The total density of the recent study is by far less than the result reported by Feyera Senbeta and Demel Teketay (2002), Eyob Tenkir (2006) and Degafi Sileshi and Berhanu Abraha (2014), with a density of 27,200; 30,267 and 12,344.4 seeds m^{-2} at Menagesha-Suba, Dodola Forest and Hgumbirda National Priority Area respectively.

While it is higher than the result reported by Feyera Senbeta and Demel Teketay (2002), at Munessa-Shashemene forest in the 9 years of old stand of *Cupressus lusitanica*, with a density of 4,500 seeds m^{-2} . The aggregate density of the recent study area did not lie within the range of the report by Demel Teketay and Granström (1995), in DAF of Ethiopia. The expected density at the 0 to 9 cm soil sampling layer was in the range of 12,300 seeds m^{-2} of Menagesha-Suba state forest and 24,000 seeds m^{-2} of Wolf-washa forest.

The result indicated that the density was lower in the lower layer (6-9 cm), compared to other sampling layers. The highest densities of seeds are observed in the litter layer, with decreasing seed density with increasing depth. This result agrees with the findings by Eyob Tenkir (2006), and Degafi Sileshi and Berhanu Abraha (2014).

The spatial variability in composition and density was relatively high among different land use types and altitudinal ranges. About 58.13% of the species were observed in Forest and Shrubland LU/LC types. Poaceae was the most dominant family in all land use types, followed by Asteraceae and Fabaceae, except in Wetland where Cyperaceae was the second dominant family. While, in the above ground vegetation, the first species-rich (dominant) family was Asteraceae followed by Poaceae and Fabaceae. This shows that there is a possibility for Poaceae to become the most dominant family in the above ground vegetation and that there will be a tendency for the recent study area to be changed to Grasslands as it is validated by change detection matrix that shows the dropping of its decreasing pattern from 35.47% (1984 and 2000) to 2.40% (2000 and 2017). The dominance of Poaceae is anticipated as grasses do not require light for germination and thus are able to germinate at any layer by taking this advantage over others (Rice, 1989). That is why the number of species of this family (Poaceae) in the litter layer, is equal to the sampling C (6-9 cm).

5.1.2.4. Soil seed bank species and density distribution in different land uses

Out of 140 plant species only 9 species *Ageratum conyzoides*, *Galinsoga quadriradiata*, *Oxalis corniculata*, *Trifolium rueppellianum*, *Cynodon dactylon*, *Datura stramonium*, *Eleusine indica*, *Guizotia scabra* and *Trifolium schimperii* appeared in all land use types. The preponderance of such agricultural weeds may be due to their ability to resist different harsh environmental conditions (Halfiges, 1990). The local inhabitants in the semi-structure interview also attested the fact that the above species are weeds and also affect the productivity of their crops and additional cost incurred to harvest. This is validated by the name given to one of the weed, *Galinsoga quadriradiata* which is called Diha Nekay (Amharic), translated as “uprooting the poor”.

The distribution of density in different land use types was different. The highest density was contributed by Shrubland, Forest and Grasslands with a relative density of 23%, 21% and 21% respectively, followed by Cropland (18%) and Wetland (17%). This may be due to Shrublands and Forest which are in the process of restoration. The succession of herbs has the potential to produce more seeds which increases its chance to store more seeds as a soil seed bank.

A total of 64 plant species was unique in either of the land uses types. As soil seed persistence for a given species may vary from site to site (Thompson *et al.*, 1997), Shrubland use type had contributed 30 plant species followed by Forest (22) and Cropland (7). The result revealed that Shrubland had more unique species compared to other land uses while, Wetland and Grassland LU/LC types had relatively the least with 3 and 2 unique species respectively.

The presence of more unique species in Shrubland and Forest due to the presence of high aggregate number of species which increase the probability of unique species. It might be also due to the presence of optimum condition which increase the probability of most of the seeds to germinate in the soil seed bank which increases the presence of more unique species, the relative fertility of the soil and vegetation cover in Shrubland and Forest land use types which supports seed persistence (Wagner and Mitschunas, 2008; Koprdoва *et al.*, 2010; Saatkamp *et al.*, 2011a), to ensure its successional state.

Wetland contributed only two species (3.13%). This may be due to the reduce persistence of the seed and increased mortality as the seed is in a water-logged soil which causes oxygen deficiency. This suggests that Wetland species may require specific adaptations to survive in water-logged environments.

5.1.2.5. Depth distribution of soil seed bank composition and density

The general pattern of plant species (composition), distribution decreased with increasing depth. Although, the litter layer had shown the second in its species number. Because, most of the seeds require light to germinate (Silvertown, 1981), and other probable factors such as burial depth, oxygen supply, seed density, soil fertility, vegetation cover, fungal activity (Wagner and Mitschunas, 2008; Saatkamp *et al.*, 2011a). In addition, the viability of the seeds and the probability of the seeds to reach the next layer decrease due to different factors such as predation and rotting. However, the number of unique species related to the corresponding land use increases with depth. Although, it shows a significance different in seed number among different land use types. This indicates that there is a relatively high degree of floristic similarity among sampling layers and a low degree of similarity among land use types. The recent finding is in line with the studies by Demel Teketay (2005a), and Abdella Mekonnen *et al.* (2007).

Jaccard's coefficient of similarity implied that the degree of floristic similarity between the litter and other sampling layers such as A (0-3 cm), B (3-6 cm) and C (6-9 cm), was decreasing with increasing depth. Possibly, as depth increases the probability of the layers being mixed through disturbance decreases, which results in the decreased probability of adjacent sampling layers to share seeds. The nature and degree of disturbances inflicted on a site are major determining factors not only in the number of species and density of soil seed banks but also in the realization of the existing potential of the seed bank (Granström, 1986). That is why, the highest similarity was observed between litter and sampling layer A (0.28), followed by litter and sampling layer B (0.27), while, the other possible pairings remained with the same observed value (0.24), of similarity.

The plant species common to all (4), sampling layers were 39 composed of 100% Herbs which showed the wide range of their distribution in the soil column. The number of unique plant species increases with increasing depth as 3 (8.33%), 9 (25.00%), 11 (30.56%) and 13 (36.11%), in litter, A, B and C sampling layers, show in contrast to the pattern of distribution of species and individual numbers which decrease with increasing depth from 0 to 9 cm. This indicates that sampling layer C had the highest number of unique species. The probable reason is that as the depth increases, the species require a special adaptation in order to survive.

But, the number of unique woody species decrease with increasing soil depth due to other possible reasons: **i)** Due to its large size, woody species seeds are less able to penetrate down the soil column (Mulugeta Lemenih and Demel Teketay, 2005). Rather the seed will remain on the surface and its flesh attract predators for predation (Mekuria Argaw *et al.*, 1999), **ii)** its delay in reproductive cycle (Harper, 1977), **iii)** it is not able to maintain its viability for a long period of time to reach the lower layer as most of the seeds of the trees in Afromontane forest germinate within a few days after dispersal (Demel Teketay, 1996; Hulme, 1998b; Thompson, 2000), and **iv)** its relatively large size and heavy weight, the seeds limit the primary dispersal ability of being carried away from the mother plant.

However, *Ficus sur* and *Pterolobium stellatum* appeared only in the last sampling layer (6-9 cm). This may be due to their relatively small seed size (*Ficus sur*), to gravity and good physical soil structure which allows the seeds to pass down to the bottom. In addition, there is no predation as these particular seed predators do not forage on fruit below 7 cm in diameter (Reichman, 1979). This justification also applies to the distribution of woody species in terms of density, as the number of individuals of the woody plants decreases at a similar rate.

Similarly, the soil seed bank density at the first sampling layer (litter) was slightly higher than the rest of the three sampling layers on account of the abundance of individuals of Herbs on the litter sampling layer as validated by Yohannis Teklu (2014). This might be due to its small size enabling the seeds to move at ease both horizontally and vertically as they are easily carried by dispersal agents. They are less likely to be predated on and their ability to maintain a dormancy period, withstanding environmentally harsh conditions (Benvenuti, 2007), is great.

Seeds with higher longevity (persistent seeds) are also found in deeper soil layers (Bekker *et al.*, 1998). Because the seed movement in the soil is slow, this causes short-lived seeds to die or germinate before reaching greater (next) depths by maintaining its required quantity and quality. It is understood that viable seeds in the lower soil layer are older than the seeds at the soil surface (Leck, 1989 and Bakker *et al.*, 1991). That is why 98.68% of the density of the last sampling layer (6-9 cm) was composed of Herbs of which 44.18% of the density was contributed by *Galinsoga quadriradiata* (20.24%), *Oxalis corniculata* (12.83%), *Ageratum conyzoides* (7.28%) and *Trifolium rueppellianum* (3.84%). The remaining 1.32% was composed of woody species and climbers. This indicates that the contribution of woody species and climbers in "C" sampling layer was less, compared to its contribution to other layers. The number of individuals belonging to Herbs decreased with increasing depth. The percentage of Herbs contribution increased as the number of individuals of woody species and climbers decreased.

According to the result of the recent study, the number of species of Herbs increased with increasing depth from litter layer to sampling layer "B", but decreased in sampling layer "C" compared to other layers. Most (36.59%) of the woody species germinated from sampling layer "A" followed by sampling layer "B", "litter" and "C" with 26.83%, 21.95% and 14.63% respectively. This is very different to the findings in other ecosystems where; for example, seeds

of many desert annual species cannot germinate from depths >1 cm (Freas and Kemp, 1983) and the seeds of desert shrubs cannot emerge from below 4 cm (Williams *et al.*, 1974).

Regardless of their density, some of the Herbs which were unique to the last sampling layer (6-9 cm) included: *Arabis alpina*, *Crepis rueppellii*, *Viola abyssinica* to mention some while, *Andropogon chrysostachyus*, *Commelina reptans* and *Galium aparinoides* are unique to the litter layer. However; *Ageratum conyzoides*, *Galinsoga quadriradiata*, *Oxalis corniculata* and *Trifolium rueppellianum* were the most dominant species appearing in all (4) sampling layers among 39 plant species (Appendix 10).

Most of the plant species (20.63%), from the litter sampling layer, also appeared at sampling layer A (0-3 cm), as it is difficult to separate them as explained by (Christoffoleti and Caetano, 1998), from the rest of the adjacent layers. This might be due to its proximity to the first layer to be mixed by external factors.

The density of the seed was decreasing as litter layer (1,627.21), A (1,460.32), B (1,431.00) and C (1,371.43), seeds m⁻² with increasing depth. The average seed density (1,472.56 seeds m⁻²), of the recent study, is relatively less compared to the study by Mulugeta Lemenih and Demel Teketay (2006), in Munessa-Shashemene forest which appeared as a mean density of 912, 278 seeds m⁻² sampled along 0-3, 3-6 and 6-9 cm. Similarly, the result of the recent study was greater compared to the study by Mamo Kebede *et al.* (2012), in Wondogenet moist evergreen Afromontane Forest which appeared at 375, 180 seeds m⁻².

The trend in decreasing of the seed density with increasing depth is consistent with the results found in other studies (Demel Teketay, 2005a; Abdella Mekonnen *et al.*, 2007; Anderson *et al.*, 2012; Tessema Z.K. *et al.*, 2012). But the number of species appeared in the sampling layer such

as Litter (surface), was less than sampling layer A (0-3 cm), but greater than other sampling layers which consistently decreased with depth. The likely reason might be, some plant species rely upon light for germination and their seeds do not germinate when buried at adequate depth (Woolley and Stoller, 1978). This implies some seeds remain un-germinated in deeper sampling layers.

While the number of individuals and density show decreasing pattern from the surface (litter) with increasing depth. This indicates that relatively the number of individuals in litter layer was high while the number of species was less than in the sampling layer A (0-3 cm). This showed that most of the species growing in layers A, B and C also appeared in the litter sampling layer.

5.1.2.6. Comparison between above ground vegetation and soil seed bank

The plant species common to above and soil seed bank flora was 83 while the species unique to them were 259 and 57 respectively. The similarity between soil seed bank and above ground vegetation was computed using Jaccard coefficient similarity. When we compare the number of species/richness in the soil seed bank, it was much lower than the above ground vegetation (Equation1) as it shares only 21% of the species. It shows that low representation of the soil seed bank compared with the findings by Tinsae Assefa and Berhanu Abraha (2014), and slightly similar with Eyob Tenkir (2006) with 31% and 22% of similarity respectively. This association between above ground vegetation and soil seed bank flora was less significant in woody species compared to the overall similarity.

The similarity of plant species particularly the woody is most of the time is less as it shared only 15% of the species. It might be due to: i) seeds of the woody species germinate within a short time before it established as a soil seed bank ii) optimum conditions of germination may not be

maintained, iii) some of them will require treatment to germinate, iv) the probability of the seeds to be predated before it is germinated, v) limited dispersal mechanism which affects horizontal distribution. In addition, seed size, shape and its depth distribution may also contribute in determining the longevity of the corresponding seeds which ultimately affect its germination potential (Bekker *et al.*, 1998), vi) According to Popay and Roberts (1970), and Hendricks and Taylorson (1974), environmental gradients also affect the distribution of soil seed bank. For example, the availability of Nitrogen in nitrite form used to induce the germination of many species. Though, according to the standard set by B. Frank (1990), the availability of total nitrogen in the recent study rated as medium (31.25%), high (10.42%) and very high (58.33%), the probability to change Nitrogen to a usable form (nitrite) might be less. In general, the association between above ground vegetation and soil seed bank is less compared with others.

The floristic composition between above ground vegetation and soil seed bank are reported as very different for different habitats (Davies and Waite, 1998; Bekker *et al.*, 2000; Dölle and Schmidt, 2009), due to the ability of seeds to survive in the soil for many years without being appeared in the recent vegetation (Thompson and Grime, 1979; Hill and Stevens, 1981). Notably, weed seeds in agricultural soils are able to survive long periods and germinate when conditions are suitable again (Brown and Oosterhuis, 1981; Bakker *et al.*, 1996) due to the presence of special chemical and physical defense mechanisms to maintain themselves viable for a long time. Predation, germination requirements, dormancy mechanisms, seed shape and resistance to pathogens are factors which affect the persistent of the seeds in soil seed banks (Thompson *et al.*, 1993). Seed dormancy has resulted from embryo dormancy and/or impermeable seed coat which is commonly important to the species of **DAF** areas where the

recent study is undertaken which is known for its pronounced dry and unpredictable rainy seasons.

Out of the 140 plant species in the soil seed bank 83 (59.29%) also occurred in the recent standing vegetation. But, out of 125 woody plant species observed at the above ground vegetation only 25 (20%) such as *Allophylus abyssinicus*, *Chionanthus mildbraedii*, *Cordia africana*, *Dodonea angustifolia* and *Olea europaea* subsp. *cuspidata* are some of the species observed in the soil seed bank.

Thus the trend having less number of species particularly woody ones in the soil seed bank compared with the above ground vegetation is in agreement with the findings by Granström (1982); Demel Teketay and Granström (1995); Demel Teketay (1996); Demel Teketay (1998a); Mekuria Argaw *et al.* (1999); Kebrom Tekle and Tesfaye Bekele (2000); Feyera Senbeta and Demel Teketay (2001); Feyera Senbeta and Demel Teketay (2001, 2002); De Villiers *et al.* (2003); Tefera Mengistu *et al.* (2005); Alemayehu wassie and Demel Teketay (2006), and Abdella Mekonnen *et al.* (2007).

Because, can be due to different reasons notably, as seeds buried or lost by being washed down, especially in coarse-textured soils, transported into deep parts of the soil by dispersal agents such as ants and worms or may die from genetically controlled physiological responses to environmental factors (Kebrom Tekle and Tesfaye Bekele, 2000). This implies that dependence on the SSB for the recovery of native woody flora on other land uses abandoned after certain years of continuous cultivation may not be successful and call for a restoration of the study area.

Generally, this weak association, it might be due to the presence of high human population growth which drives forest clearance and encroachment followed by vegetation and soil

degradation. In addition, the mortality of the seeds caused by human disturbance, erosion, shade, drought, herbivory and disease.

This value indicated that even though, there are emerged germinants unique to the soil seed bank, the unique seedlings occurred in the above ground vegetation is much greater than the seedlings which appeared only in the soil seed bank. The most abundant plant species prominent to the above ground vegetation include: *Clausena anisata* and *Maytenus arbutifolia* which contributed 2,498 (35.57%) of individuals, have not appeared as emergent/seeds in the soil seed bank.

While seeds such as *Agrostis quinqueseta*, *Amaranthus dubius*, *Amaranthus hybridus*, *Anagallis arvensis* and *Coronopus didymus* to mention some were not observed in the above ground vegetation, might be on the account of different factors notably climatic and competitive factors (Espeland *et al.*, 2010), and the chance of most of the seeds were not likely to germinate and appeared as a standing vegetation.

Among 259 (75.73%) species unique to the above ground vegetation; *Maytenus arbutifolia*, *Flueggea virosa*, *Myrsine africana* and *Grewia ferruginea* are the most common woody plant species whereas *Calpurnia aurea*, *Allophylus abyssinicus*, *Chionanthus mildbraedii*, *Clematis simensis*, *Clutia abyssinica* and *Dodonea angustifolia* are among the 83 plant species shared by above ground vegetation and soil seed bank. This less number of plant species shared by the two flora cause weak association of the woody species as well.

Some woody plants species such as *Acacia venosa*, *Albizia malacophylla*, *Celtis africana*, *Combretum collinum*, *Euclea racemosa* and others which appeared only in one plot (1.02%), with a limited number of individuals and considered as locally rare. This might be due to the

pressure experienced by the local people for different uses such as household material, farm implement and fuelwood. These plants are on the verge of **local extinction** notably *A. venosa* to the extent has only limited number of individuals at its natural habitat and one type specimen in the National Herbarium of Addis Ababa University. Because, the tree is preferably used by local inhabitants for farm household implements due to its high quality, strength and durability followed by *Albezia schimperiana*. This indicates that the species may disappear throughout Ethiopia unless conservation measure is taken.

These days, the local people are trying to grow another species of woody plants such as *Cordia africana* and *Eucalyptus camaldulensis* to get the access for farm and household implements through applying their yearly accumulated local ecological knowledge. Their local ecological knowledge is not limited to grow and adapt such plants but also extend to know when it is planted, cut and how it is treated to use the material for a long period of time.

The Awuramba Community goes beyond this, in addition to growing plants around their village they minimize wood and wood products instead they build their bed, seat and cooking material from mud and straw. This experience would rescue the rare plant species growing in their natural habitat. Moreover, they organize a plantation campaign to grow selective plants. It is also getting to be noticeably common to build houses from corrugated sheets instead of mud thatched house which has its own contribution to minimizing the pressure on the Grass and Cyperus used for this purpose.

Enclosure activities practiced by local institutions, for example, Organization for Rehabilitation Development in Amhara (ORDA), Tana Sub-basin Organization and others are working groups to restore on the catchment which has shown promising indicators as 21% of the underground

plant species to be seen as a standing vegetation. This would happen if conducive environment exists through natural succession to a more natural state. Because, the persistence of the seeds and its germination in soil is related to the conditions of the micro sites (Reuss et al., 2001).

5.1.2.7. Implication and contribution of soil seed bank flora for rehabilitation

Understanding the major source of natural regeneration such as seed rain, soil seed bank and copies (Getachew Tesfaye *et al.*, 2004), potential (Demel Teketay, 2005a), and regeneration mechanisms of persistent soil seed banks is an important first-step and an opportunity for the rehabilitation and characterization of the upcoming vegetation of degraded tropical forest that depend much on natural regeneration which holds true for the recent study area.

Out of 125 recorded woody species from the above ground vegetation 68 (54.4%), of them, had seedling and or saplings. From the total seedling and sapling about 3881 (55.27%), individuals are computed from 1757 (25.02%), *Maytenus arbutifolia*, 768 (10.80%), *Dodonea angustifolia*, 741 (10.55%), *Clausena anisata* and 625 (8.90%), *Erica arborea* of the above ground vegetation. The highest density is also contributed by the seedlings and/or samplings of these dominant species.

However, the above ground vegetation affects the distribution of the soil seed bank (Rice, 1989), and vegetation around (Godefroid *et al.* 2006); and then the abundance of the seedlings and saplings in standing vegetation had predictive value for abundance in the persistence seed bank. The seeds of corresponding dominant plant species were not observed as a soil seed bank. This might be due to, the seeds of the woody species germinate within a short time before it established as a soil seed bank.

In general, however, a species disappears from the standing vegetation, its presence as a soil seed bank in a dormant state guarantees its availability and promising to grow as a standing vegetation if an enclosure is made. Yet, in some local areas, the species which have been earlier however at present was not observed as a standing vegetation (Appendix 12) and also as soil seed bank represents a permanent change. This might be due to overutilization of the species and climate change.

5.1.3. Land use land cover change

5.1.3.1. Accuracy assessment

The overall accuracy of the classified images from 1984, 2000 and 2017 were 91.6%, 88.4% and 87.7% respectively. It is in line with the result set by Anderson *et al.* (1976) >85% as a minimum threshold and the result reported by Gessesse Dessie and Kleman (2007), Menale Wondie *et al.* (2011), Abate Shiferaw (2011) with 87% (TM), 88% (ETM+) and 86.1% (ETM+) respectively.

5.1.3.2. Pattern, rate and extent of LU/LC and its implication

Cropland, Water and Settlement LU/LC types increase with increasing time periods while Grassland, Shrubland and Wetlands continuously decrease with time serious. But Forest showed an irregular pattern as it was decreased between 1984 and 2000 and then increased between 2000 and 2017. However, the rate of increasing and decreasing was different. Crop was the most contributor of the total percent area of the recent study area with 46.91% (1984), 66.03% (2000) and 66.78% (2017), followed by Grassland with 28.71% (1984), 18.53% (2000) and 18.10% (2017), compared with Settlement LU/LC observed as a least contributor with 0.03% (1984), 0.07% (2000) and 0.39% (2017). Conversely, relatively the highest percent of increment was detected in Settlement LU/LC as it sharply increased with 1101.1% (1984 and 2017), 461.81% (2000 and 2017) and 113.90% (1984 and 2000). This might be due to the outbreak of population growth followed by globalization and urbanization. These days the number of people are moving from the rural part of the country to the nearby towns to find a job opportunity, as they do not have enough space to undertake agriculture. Similarly, this increasing of settlement is also connected with the resettlement program organized during Derg Regim. The expansion of Settlement was at the average expense of Cropland (4.51%), Forest (0.60%), Grassland (0.19%), Shrubland (1.48%) and Wetland with 0.05% over 34 years together with its affinity to stay

unchanged with an average of 93.18% area contribution. This pattern is in accordance with the report by Kebrom Tekle and Hedlund (2000).

While, the smallest change was recognized in Cropland with 1.02% (2000 and 2017) followed by Water land use with 15.44% (2000 and 2017). Relatively, the most elevated declining was observed in Wetland with 52.71% area (1984 and 2017) followed by Shrubland with 45.64% (1984 and 2017), Forest with 45.53% (1984 and 2000) and Wetland with 44.00% (1984 and 2000). Wetland was declining at alarming rate remarkably, the change was high in 1984 and 2000 with a rate of 1,112% compared to 220% observed in 2000 and 2017. It was decreased due to changing of Wetland to Cropland with 60.40% of an average area over 34 year mainly for the cultivation of Muddy-rice.

When the average loss and gain compared to the corresponding paired time periods, high loss was observed between 1984 and 2017 with 41.12% followed by 1984 and 2000 with 38.20%, while high average gain was observed between 1984 and 2017 with 397.87% followed by 127.02% observed between 2000 and 2017. Relatively the presence of small average loss (-14.23%) between 2000 and 2017, indicates that the intervention on the rehabilitation program and the enforcement of the laws such as Rural Land Administration and Land use Proclamation No. 456/2005) and Forest Development, Conservation and Utilization Proclamation No. 542/2000 which protect the expansion of Agricultural land from Grassland, Shrubland, Forest and Wetland. That is why the percent area change for Cropland between 2000 and 2017 becomes relatively the smallest of all land use types and overall time periods with 1.02%, while the area percent change becomes 461.81% between 2000 and 2017.

Ultimately, all land use types which show either increasing or decreasing pattern show a negative implication except Forest which shows 29.81% gain between 2000 and 2017. For example, as a Cropland and Settlement area increase (gain), with increasing time period will cause deforestation and other land uses to be changed from their original state while Grassland, Shrubland and Wetlands continuously decrease (loss), with increasing time serious. This shows that Cropland is expanded at the expense of these LU/LC types.

According to the result, the change was made both in increasing (gain) and decreasing (loss), pattern. The highest gain was made by Cropland compared to all classes, patterns and over the three time periods with 2,103 ha/year rate of increase observed between 1984 and 2000, followed by Forest with 140 ha/year rate of increase observed in 2000 and 2017. This amount (2,103 ha/year), was high due to the starting of Muddy-rice cultivation in 1986 and its expansion between 2001 and 2005 into a large scale on flooded plains of Fogera, Dera and Libokemkem Woredas. During this period (1984 and 2000) most of the Wetland (62.78%) and Grassland (57.57%) were changed into Cropland. But, this rate of expansion (2,103 ha/year) was not continued as it was dropped to 74 ha/year between 2000 and 2017 due to different reasons (i) its affinity to maintain its original state dropped from 78.42% to 74.84% (ii) the probability of changing Wetland to Cropland decrease from 62.78% to 54.44% (iii) the probability of changing Forest to Cropland decrease from 49.79% to 35.99% (iv) the probability of changing Shrubland to Cropland decrease from 48.99% to 43.52% and (v) better enforcement of the laws such as Forest Development, Conservation and Utilization Proclamation No. 542/2000 and Rural Land Administration and Land use Proclamation No. 456/2005 that protect the changing of Grassland, Forest, Shrubland, Wetland and other land uses to agriculture (Cropland). However, according to the result from 2017 classified map, most of the recent study area is Cropland as it has

contributed about 66.78%. Settlement was representing the least value of all classes, patterns and overall time periods with 4 ha/year rate of increase observed in 1984 and 2000.

These days, these areas are known for its three times cropping within a year. Because, in addition to rice cultivation during the rainy season, it is also known to grow grass pea (*Lathyrus sativus*) and chickpea (*Cicer arietinum*), from residual moisture and during the dry season tomato (*Solanum lycopersicum*) and onion (*Allium Sp.*), using the irrigation system from permanent rivers notably using Rib and Gumara. In addition to 60.45% its average percent area which continues as a Cropland and 6.16% of the average Wetland changed to Cropland, the expansion were also at the expense of natural vegetation computed from Grassland (23.06%), Forest (4.85%) and Shrubland with 5.41% of the average gain over 34 years. This pattern of contribution was in line with result indicated by (Solomon Abate 1994; Gete Zeleke and Hurni, 2001; Belay Tegene, 2002; Girmay Kassa, 2003; Selamyihun Kidanu, 2004).

The water had shown an increasing pattern over the three time periods. Notably, it had demonstrated that, it was expanded by 872 ha with a rate of 26 ha/year (75%), between 1984 and 2000. During this period Forest, Grassland and Shrubland cover had shown a significant decreasing pattern with 45.53%, 35.47% and 27.77% of area respectively. This might expose the area for high soil erosion followed by siltation which increases the volume of the Lake to flood over other land uses. Similarly, the waterway of permanent rivers such as Rib was changed, on the account of high siltation which allows the water to overflow in a different direction and later stored as a permanent pond. On the other hand, the coverage of forest was increased in the last time period (2017), which might contribute to decrease runoff and ultimately contribute to the decreasing of siltation. Additionally, rehabilitation program was had its own contribution. These might be the reasons why, the addition moved towards becoming reduction with 581 ha with a

rate of 17 ha/year (50%), observed in 2000 and 2017, of which 370 ha (63.68%), was contributed from RIB Dam, showed up in images of 2017. This demonstrated the example of expanding moved toward becoming dropped contrasted with the first time period (1984 and 2000). In 34 years, the increment was of the Water at the expense of Wetland (22.15%), Cropland (9.65%), Forest (3.39%), Grassland (1.58%) and Shrubland with an average percent area of 0.37% together with an average of 62.71% unchanged Water. While the contribution of Settlement to establish a water was zero.

Grassland, Wetland and Shrublands show a continuous decrease, while Forest shows an irregular pattern as it increases between 2000 and 2017 with 140 ha/year. However, the rate of decreasing or loss (393 ha/year) observed in 1984 and 2000 is not equivalent to the rate of increase (140 ha/year) observed in 2000 and 2017.

In the case of Forest and Shrublands, as the result showed there was a decrease between 1984 and 2000 because of the impact of the drought observed on the recent study area by 1980s and the negative impact of resettlement program organized by the Military Government (Derg). Similarly, Ethiopian Civil War, extensive use of plants for different purposes such as firewood, charcoal production, used for farm and household implements were also the major cause of the deforestation. Due to this, the Forest were changed to Cropland (46.50%), Shrubland (25.32%), Grassland (4.66%), Water (0.71%) and Settlement with 0.45% of an average area over 34 years to supplement an average of 22.33% unchanged. While it was not changed into Wetland. Similarly, Shrublands were converted to Cropland (49.55%), Grassland (22.04%), Forest (14.56%), Settlement (0.43%) and Water (0.06%), to supplement an average of 13.33% unchanged over 34 years. While, both Forest and Shrublands were not converted into Wetland; and the contribution of Water, Wetland and Settlement for forest recovery was zero percent.

Some of the remnant forests except the Church forest which has been under the custody of the religious and local community the remaining forest and shrublands notably Alemsaga Forest and others were destroyed to the extent of disappearing. For instance, there is a place named as "Durlebes" (equivalent to dense forest), which had been considered as high forest (Personal communication, 2016), yet now it stayed with no natural vegetation as it is serving for cultivation and infrastructure.

The Forest coverage were increased while Shrubland continue decreasing between 2000 and 2017 on the account of different factors such as (i) The afforestation program held throughout the country in the 1980's to conserve the remnant natural forests minimize the impact, (ii) Development and partial implementation of the proclamation on participatory forest management: It was cited as "Forest Development, Conservation and Utilization Proclamation No. 542/2000" implemented by different practitioners such as Organization for Rehabilitation and Development in Amhara (ORDA), on Church forest management, Tana Sub-basin Organization (TaSBO), on gully rehabilitation and enclosure activities on integrated Natural resource management; and Blue Nile Watershed Authority in collaboration with the local government and local community through encouraging enclosure practices and expanding Agro-forestry. Notably, article 7, sub-article 2 (a-e) as explained bellow has been contributing a lot: 7-2 (a): follow sound forest development methods and replace in different ways trees when harvested; 7-2 (b): take necessary measures to protect their forests from pest and disease; 7-2 (c): notify the appropriate body the existence of forest pest and disease; 7-2 (d): ensure that the forest is protected from fire and other hazards and; 7-2 (e): In general comply with directives issued on the safety of the environment, conservation of catchments, biodiversity and unique natural trees

and wildlife. This promotes the community to grow plants in their home range which in turn increase forest coverage.

Similarly, on the same proclamation, article 13 sub-article 1 on production and movement of forest products states as "No person shall harvest forest products from a state forest without having the necessary permit from the Ministry or the appropriate regional body", has also its contribution. In the future, a proclamation on Access and Benefit Sharing (ABS) cited as "Access to Genetic Resources and Community Knowledge and Community rights, proclamation No. 482/2006", might have its own contribution to avoid misappropriation through providing the community a legal frameworks on how the resources are to be accessed and how the benefits are obtained from their use. This has its own contribution to maintaining the resource against the benefit from the resource which has been commercially and culturally exploited without the consent, benefit and compensation of the community. iii) The awareness of the community was relatively raised as they have tested the consequence deforestation (interview and group discussion, 2017).

The minimum decreasing rate was observed in Grassland (49 ha/year) and Wetland with a decreasing rate of 75 ha/year in which both observed between 2000 and 2017. The decreasing rate of Grassland (1984 and 2000), representing the maximum with a decreasing rate of 1,120 ha/year, dramatically decreased in 2000 and 2017 and represent the least with a decreasing rate of 49 ha/year. This might be due to the implementation of the law by Proclamation No. 542/2000 (Forest Development, Conservation and Utilization Proclamation) and Proclamation No. 456/2005 (Rural Land Administration and Land use Proclamation), which protect the changing of Grassland into other LU/LC types. Even though, still there is a shortage of grassland to feed cattle to the extent that, farmers tie their cattle around their house and providing them straw and

water. These days, the farmers forced to limit their cattle number through destocking due to the observed grazing land scarcity (Appendix 12). The same problem was indicated by Olson and Maitima (2006), as there is a swift LU/LC in East Africa due to the expansion of mixed crop-livestock systems over former grazing land and intensive agriculture. In general, all the information on LU/LC change was validated by the target groups set for an interview

5.1.3.3. Conversion of LU/LC types between three time periods

All LU/LC types maintain its original state with various extent and percent of area cover. Between 1984 and 2000, the tendency to remain unchanged is high in water with 87.97% followed by Settlement and Cropland with 86.09% and 78.42% respectively. In this period the smallest value to remain unchanged is observed in Shrubland which shows that the land use is exposed to deforestation for different purposes. However, it gains from Cropland (23.37%), Grassland (22.54) and Forest (11.37%).

Between 1984 and 2017, the incidence of LU/LC remains unchanged was high in Settlement with 96.05% followed by Water (82.86%) and Cropland (73.41%). Compared to all time periods and LU/LC types transformation was high in Shrublands to Croplands (56.13%), Grassland (23.95%) and Forest (15.15). About 4.14% remained unchanged the remaining (0.59%) was distributed to Water (0.11%) and Settlement (0.48%). While its contribution to Wetland was zero (0%) as it does for Forest, Grassland, Shrubland and Settlement. Forest was the second highly transformed LU/LC type into Croplands (53.74%) and Shrubland (27.02%), but about 11.34% remained unchanged, the remaining (1.23%) was distributed to Water (0.77%) and Settlement (0.46%).

In 2000 and 2017, Settlement was the highest to remain unchanged (97.41%), when compared to all classes followed by Cropland (74.84%) and Water (76.16%). During this relatively the highest LU/LC conversion was also made in Shrubland to Cropland (43.52%), Grassland (26.06%) and Forest (24.34%).

In general, LU/LC types with the highest affinity to maintain their original state (unchanged), such as Water (87.97%), Settlement (86.09%), Cropland (78.42%), in 1984 and 2000; Settlement (96.05%), Water (82.86%), Cropland (73.41%), in 1984 and 2017; and Settlement (97.41%), Cropland (74.84%) and Water (76.16%), in 2000 and 2007 have been increasing (gain), with increasing time period. This indicates that the probability of such LU/LC to be converted into another land use relatively less. This might be due to different factors. For example, most of the time there is an interest in continuous expansion of Cropland and Settlement instead of changing themselves into another land use types.

While, those LU/LC types with high percent of area conversion such as Shrubland with 30.62% (1984 and 2000), 4.14 (1984 and 2017) and 5.22% (2000 and 2017), remain unchanged were changed into different land use types and show a continuous decrease with increasing time period. This also indicates that the expansion of Cropland through changing such LU/LC types as most of their portion converted to Cropland with 48.99% (1984 and 2000), 56.13% (1984 and 2017) and 43.52% (2000 and 2017).

Relatively settlement gain more percent area from Cropland with a trend of 33.55% (1984 and 2000), to 44.10% (2000 and 2017). Similarly, Wetlands gain from a Cropland with a contribution of 38.11% (1984 and 2000), 50.30% (2000 and 2017). Because, as a water level increase with a rate of 39.56 ha per year, the probability of establishing a Wetland over Croplands would be

high. Water LU/LC gain 26.42% from Wetlands (1984 and 2000) and 15.53% (2000 and 2017), to supplement its unchanged percentage in decreasing pattern with increasing period. Forest expanded from Shrublands with 7.75% (1984 and 2000) and 15.53% (2000 and 2017). This indicates that the probability of increasing Forest and decreasing of Shrubland between 2000 and 2017 is due this conversion.

5.2. CONCLUSION

Three hundred forty two identified plant species are documented in the study area, of which 97.53% are angiosperms, 52.05% herbs, 5.84% endemic to Ethiopia, 3.51% invasive plants. The dominance of angiosperms is due to their floral adaptation and more efficient pollination systems and seed dispersal agents. Herbs were also dominant in the soil seed bank and different LU/LC types. This dominance might be due to the high number of viable seeds, wide ecological range of the species and their high prolific seed amount produced in one reproductive season. However, some of the herbs such as *Eichornia crassipes*, *Cotula cryptocephala*, *Cyperus articulatus* and others were limited to the Wetland. Similarly, *Festuca macrophylla* and *Trifolium acaule* were limited to the Afroalpine and sub Afroalpine parts of the study area. Among the five community types, Community I has more species compared to others which is attributed by relatively wide range of elevations. About 52.34% of the species were represented by eight families of which Asteraceae was the most dominant with 34 plant species followed by Poaceae with 23 species.

The pattern of the distribution of the DBH and height class sizes of woody species are inversely proportional to the number of individuals due to selective cutting. This is substantiated by the fact that about 87.15% of the individuals represented by 113 (90.40%) plant species appeared in the first DBH class (2.5-12.5 cm) and about 81.79% of the individuals are represented by 114 (91.2%) species within the first height class (2.5-5.5 m). Due to limited number of plants with thick stem (big trees) the value of basal area decreases while, the density value relatively increases as the number of individuals are high at the low class sizes. This is an indicator that the study area is in the process of regeneration.

Boosted Regression Tree Model, indicates that the average number species in each plot increases with increasing elevation and reaches its maximum (21.05 average species/plot), between 1781

and 3200 and then shows a decreasing pattern as elevation increases beyond 3200 m asl. This distribution pattern holds true for *Senna didymobotrya* as Maxent Model validates it.

Among 17 environmental variables considered, only nine were significant ($P \leq 0.05$) with different correlation affinity. As it is observed from ordination diagram most of the species were concentrated to the origin of the axis. This shows that the habitat preference of the species to grow with optimum values of all considered environmental variables. The soil physical and chemical test indicates that the study area is acidic soil type and characterized by low soil fertility.

A total of 12, 896 individuals were represented by 140 species, 103 genera and 44 families, of which about 98.86% of the plant species emerged as seedlings. About 42.86% of the species were contributed by Poaceae with 32 (22.86%) plant species, followed by Asteraceae and Fabaceae with 15 (10.71%) and 13 (9.29%) species respectively. These families were also dominant in the corresponding soil seed bank sampling layers and LU/LC types with the exceptions made in sampling layer C, where Asteraceae and Fabaceae were rated as 2nd and in Wetlands, Cyperaceae and Asteraceae were rated as 2nd and 3rd respectively. This shows the presence of habitat preference for the species in the corresponding families.

The number of species and distribution of seeds found in the soil samples varied among LU/LC types as the highest observed in shrublands while the lowest recorded in Wetlands with 94 and 32 plant species respectively. Herbs were the most dominant both in vertical and horizontal distributions. The presence of high number of species in the soil seed bank and different LU/LC types indicates that herbaceous flora has a better chance of natural recovery than woody species.

The general pattern of plant species (Composition) and density distribution decreases from the first layer (0-3 cm) to the third layer (6-9 cm), with increasing depth due predation and rotting factors. There is a relatively high degree of floristic similarity among sampling layers as observed in vertical distribution and a low degree of similarity among land use types. This shows that similar to the above ground vegetation, soil seed bank is dynamic in its composition and abundance due to dispersal and related factors.

The number of species/richness in the soil seed bank is much lower than the above ground vegetation as it shares only 21% of the soil seed bank species and 15% of the woody species. It shows that low representation of the soil seed bank.

The identified seven LU/LC types over the three time periods have an impact on the spatial distribution of vegetation. The aggregate change of the LU/LC, its rate and extent of change was different in different periods. Some of the LU/LC types such as Cropland, Settlement and Water continuously increased while others such as Wetland, Grassland and Shrublands show a decreasing pattern. However, Forest showed an irregular pattern over the three periods. This LU/LC change was mainly driven by anthropogenic factors such as drought observed on the recent study area by 1980s, the negative impact of resettlement program during Derg regime, Ethiopian Civil War, extensive use of plants for different purpose to mention a few.

Among the LU/LC types, Cropland 46.91% (1984), 66.03% (2000) and 66.78% (2017) followed by Grassland with 28.71% (1984), 18.53% (2000) and 18.10% (2017). The expansion and the highest contribution of Cropland was at the expense of other LU/LC types. For example, Wetland declined at an alarming rate due to the change to Cropland mainly for the cultivation of muddy-rice with 60.40% of an average area over 34 year. When the average loss and gain

compared between the corresponding time periods, the highest loss was observed between 1984 and 2017 with 41.12% compared with 38.2% observed in 1984 and 2000. Relatively the presence of small average loss (14.23%), in 2000 and 2017 indicates that the intervention on the rehabilitation program and the enforcement of the laws such as Forest Development, Conservation and Utilization (Proclamation No. 542/2000) and Forest Development, Conservation and Utilization Proclamation (Proclamation No. 456/2005) protect the expansion of Agricultural land from Grassland, Shrubland, Forest and Wetland.

5.3. RECOMMENDATIONS

It is hoped that this study will provide information for decision makers, development practitioners and academicians on the vegetation status, long-term LU/LC changes, their drivers, impacts and community mitigating strategies in the catchments of Rib and Gumara. Because understanding such changes is critical for formulating effective environmental regulations and controlling mechanisms in collaboration with the local community living within the catchments taking into consideration their local ecological knowledge, practices and consent. The local communities need to be involved in that most of the driving causes for LU/LC changes which have impact on the spatial distribution of aboveground vegetation and soil seed bank flora are arise from them.

- ✚ Establishing nursery sites to grow selected woody species notably for **locally rare** (e.g *Albizia malacophylla*, *Celtis africana* and *Gnidia glauca*), **unique to soil seed bank** (e.g *Phyllanthus ovalifolius*), **unique to the above ground vegetation** (e.g *Maytenus arbutifolia* and *Flueggea virosa*), **poor restoration potential** (e.g *Chionanthus mildbraedii* and *Cordia africana*), **poor regeneration potential** (e.g *Pittosporum viridiflorum*), **not regenerating** (e.g *Albizia malacophylla* and *Acacia venosa*), **with high IVI value** (*Chionanthus mildbraedii* and *Juniperus procera*) and organizing plantation campaign.
- ✚ it is here recommended to have the need for developing habitat suitability modeling of prioritized locally rare, endemic and invasive plant species to predict and understand their long-term impact and developing mitigation measures;
- ✚ Undertaking soil and water conservation activities to control nutrient loss and to recover the normal range of pH (4-8), suitable for the growth of most plants in the study area;

- ✚ Raising awareness activity on how to control the invasive plant species on LU/LC at the early stage;
- ✚ Special attention be given to plant species notably unique to the soil seed bank can be grown in potential areas through demarcating and establishing enclosures and/or enclosure;
- ✚ Consultation with NGOs such as ORDA and TaSBO that are currently working on the rehabilitation activities in the area;
- ✚ Donate the emerged seedlings to the institutions that would take care of the species (For example, Gullele Botanic Garden);
- ✚ Developing a land use land cover plan for the landscape to manage the watersheds;
- ✚ The enforcement of the laws notably laws on biodiversity such as Proclamation No. 542/2000, on Forest Development, Conservation and Utilization to respect biodiversity conservation and others;
- ✚ Minimizing the threats of LU/LC changes such as high population growth followed by a scarcity of agricultural land.

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Appendices

Appendix 1: List of plants species with their family for the above ground vegetation

Key: Cl= Climber, H = Herb, Sh = Shrub, T = Tree; AB = above ground vegetation

No	Scientific name	Local name	Habit	Family	Code
1	<i>Abutilon bidentatum</i> (Hochst.) A. Rich.	Wulkifa	H	Malvaceae	AB-00007
2	<i>Abutilon longicuspe</i> Hochst. ex A. Rich.	Nacha	H	Malvaceae	AB-00011
3	<i>Acacia abyssinica</i> Hochst. ex Benth.	Girar	T	Fabaceae	AB-00732
4	<i>Acacia albida</i> Del.	Timbilka	T	Fabaceae	AB-00447
5	<i>Acacia lahai</i> Steud. and Hochst. ex Benth.	Nech girar	Sh	Fabaceae	AB-00799
6	<i>Acacia seyal</i> Del.	Key girar	T	Fabaceae	AB-00856
7	<i>Acacia sieberiana</i> DC.	Bedeno	T	Fabaceae	AB-00067
8	<i>Acacia tortilis</i> (Forssk.) Hayne	Girar	T	Fabaceae	AB-00297
9	<i>Acacia venosa</i> Hochst. ex Benth.	Kontir	T	Fabaceae	AB-01538
10	<i>Acanthus polystachius</i> Delile	Kosheshila	Sh	Acanthaceae	AB-0005A
11	<i>Acanthus sennii</i> Chiov.	Kosheshila	Sh	Acanthaceae	AB-00163
12	<i>Achyranthes aspera</i> L.	Telenji	H	Amaranthaceae	AB-00150
13	<i>Achyrospermum schimperi</i> (Hochst. ex Briq.) Perkins	-	H	Lamiaceae	AB-00569
14	<i>Acmella caulirhiza</i> Del.	-	H	Asteraceae	AB-00400
15	<i>Acokanthera schimperi</i> (A. DC.) Schweinf.	Merenz	Sh	Apocynaceae	AB-00153
16	<i>Adiantum poiretii</i> Wikstr.	Sire-bizu	H	Adiantaceae	AB-00595
17	<i>Ageratum conyzoides</i> L. subsp. <i>conyzoides</i>	Kuasero	H	Asteraceae	AB-00193
18	<i>Agrocharis melanantha</i> Hochst.	-	H	Apiaceae	AB-01026
19	<i>Albizia gummifera</i> (J.F. Gmel.) C.A. Sm.	Kachena	T	Fabaceae	AB-1521A
20	<i>Albizia malacophylla</i> (A. Rich.) Walp.	Sendel	T	Fabaceae	AB-00037
21	<i>Albizia schimperiana</i> Oliv.	Kachena	T	Fabaceae	AB-00070
22	<i>Alchemilla abyssinica</i> Fresen.	Yemidir-koso	H	Rosaceae	AB-00064
23	<i>Alchemilla pedata</i> A. Rich.	Yemidir-	H	Rosaceae	AB-00391

		koso			
24	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Kimo	T	Sapindaceae	AB-0004A
25	<i>Aloe macrocarpa</i> Tod.	Eret	H	Aloaceae	AB-00090
26	<i>Amaranthus spinosus</i> L.	-	H	Amaranthaceae	AB-00044
27	<i>Ammannia baccifera</i> L.	-	H	Lythraceae	AB-00036
28	<i>Andropogon abyssinicus</i> Fresen.	Gaja	H	Poaceae	AB-00084
29	<i>Andropogon chrysostachyus</i> Steud.	Gaja	H	Poaceae	AB-00548
30	<i>Anthemis tigrensensis</i> J. Gay ex A. Rich.	-	H	Asteraceae	AB-00491
31	<i>Apodytes dimidiata</i> E. Mey. ex Arn.	Gina	T	Icacinaceae	AB-00405
32	<i>Argemone mexicana</i> L.	Nechilo	H	Papaveraceae	AB-00162
33	<i>Arisaema schimperianum</i> Schott	Amoch	H	Araceae	AB-00499
34	<i>Arundinaria alpina</i> K.Schum.	Kerkeha	H	Poaceae	AB-00549
35	<i>Asparagus africanus</i> Lam.	Yeset-kest	Sh	Asparagaceae	AB-00524
36	<i>Aspilia mossambicensis</i> (Oliv.) Wild	-	H	Asteraceae	AB-00248
37	<i>Astragalus atropilosulus</i> (Hochst.) Bunge	-	H	Fabaceae	AB-0449C
38	<i>Azolla nilotica</i> Decne. ex Mett.	-	H	Azollaceae	AB-00168
39	<i>Bersama abyssinica</i> Fresen.	Azamir	Sh	Melanthaceae	AB-00187
40	<i>Bidens pilosa</i> L.	Yeseyitan- merife	H	Asteraceae	AB-00205
41	<i>Bidens prestinaria</i> (Sch. Bip.) Cufod.	Adyo	H	Asteraceae	AB-0449A
42	<i>Bothriocline schimperi</i> Olivo and Hiern ex Benth.	Kese	Sh	Asteraceae	AB-01135
43	<i>Bridelia micrantha</i> (Hochst.) Baill.	Yenebir-tifir	Sh/T	Euphorbiaceae	AB-00913
44	<i>Brucea antidysenterica</i> J.F. Mill.	Abalo	Sh	Simaroubaceae	AB-00935
45	<i>Buddleja davidii</i> Franch.	Anfar	Sh	Loganiaceae	AB-00180
46	<i>Buddleja polystachya</i> Fresen.	Atquar	Sh	Loganiaceae	AB-00251
47	<i>Caesalpinia decapetala</i> (Roth) Alston	Kontir	Sh	Fabaceae	AB-00354
48	<i>Calotropis procera</i> (Ait.) Ait. f.	-	Sh	Asclepiadaceae	AB-00360
49	<i>Calpurnia aurea</i> (Ait.) Benth.	Zigta	Sh/T	Fabaceae	AB-00018
50	<i>Canthium oligocarpum</i> Hiern subsp. <i>oligocarpum</i>	Dingay- seber	Sh	Rubiaceae	AB-00382
51	<i>Capparis tomentosa</i> Lam.	Gumero	Sh	Capparidaceae	AB-00008

52	<i>Cardamine africana</i> L.	-	H	Brassicaceae	AB-01199
53	<i>Cardamine trichocarpa</i> A. Rich.	Yewof-gomenzer	H	Brassicaceae	AB-01003
54	<i>Carduus nyassanus</i> (S. Moore) R.E. Fr.	Guale	H	Asteraceae	AB-00492
55	<i>Carex spicato-paniculata</i> Böck, ex C.B. Clarke	-	H	Cyperaceae	AB-1162A
56	<i>Carissa spinarum</i> L.	Agam	Sh	Apocynaceae	AB-00030
57	<i>Caylusea abyssinica</i> (Fresen.) Fisch. and Mey.	-	H	Resedaceae	AB-01194
58	<i>Celtis africana</i> Burm. f.	Kawoot	T	Ulmaceae	AB-00787
59	<i>Centella asiatica</i> (L.) Urban	-	H	Apiaceae	AB-00396
60	<i>Chenopodium ambrosioides</i> L.	-	H	Chenopodiaceae	AB-00536
61	<i>Chiliocephalum tegetum</i> Mesfin	-	H	Asteraceae	AB-00487
62	<i>Chionanthus mildbraedii</i> (Gilg and Schellenb.) Stearn	Wogeda	T	Oleaceae	AB-00394
63	<i>Chloris gayana</i> Kunth	Yewusha-dagussa	H	Poaceae	AB-00450
64	<i>Chloris pycnothrix</i> Trin.	Wariat	H	Poaceae	AB-1133A
65	<i>Cirsium vulgare</i> (Savi.) Ten.	-	H	Asteraceae	AB-00451
66	<i>Cissus petiolata</i> Hook. f.	Kuk	Cl	Vitaceae	AB-00023
67	<i>Clausena anisata</i> (Willd.) Benth.	Limich	Sh/T	Rutaceae	AB-00093
68	<i>Clematis hirsuta</i> Perr and Guill.	Azo-Hareg	Cl	Ranunculaceae	AB-0545A
69	<i>Clematis simensis</i> Fresen.	Azo-Hareg	Cl	Ranunculaceae	AB-00458
70	<i>Clerodendrum myricoides</i> (Hochst.) Vatke	Misirch	Sh	Lamiaceae	AB-00237
71	<i>Clutia abyssinica</i> Jaub. and Spach.	Feyele-fej	Sh	Euphorbiaceae	AB-00411
72	<i>Combretum collinum</i> Fresen. subsp. <i>collinum</i>	Avalo	T	Combretaceae	AB-0133A
73	<i>Combretum molle</i> R. Br. ex G. Don	Avalo	T	Combretaceae	AB-00133
74	<i>Commelina diffusa</i> Burm.f.	wuha-ankur	H	Commelinaceae	AB-00078
75	<i>Commelina latifolia</i> Hochst. ex A. Rich.	Wuha-ankur	H	Commelinaceae	AB-0078A

				e	
76	<i>Conyza schimperi</i> Sch. Bip. ex A. Rich.	-	H	Asteraceae	AB-00353
77	<i>Cordia africana</i> Lam.	Wanza	T	Boraginaceae	AB-00263
78	<i>Corrigiola capensis</i> Willd. subsp. <i>africana</i>	Yebeg-lat	H	Molluginaceae	AB-00461
79	<i>Cotula cryptocephala</i> Sch. Bip. ex A. Rich.	Lenchi-sar	H	Asteraceae	AB-00472
80	<i>Crassocephalum macropappum</i> (Sch. Bip. ex A. Rich.) S. Moore	-	H	Asteraceae	AB-00165
81	<i>Crassula schimperi</i> Fisch. and Mey.	-	H	Crassulaceae	AB-00542
82	<i>Crepis rueppellii</i> Sch. Bip.	Wotete	H	Asteraceae	AB-01023
83	<i>Crotalaria quartiniana</i> A. Rich.	Abachenane	H	Fabaceae	AB-00467
84	<i>Croton macrostachyus</i> Del.	Misana	T	Euphorbiaceae	AB-00475
85	<i>Cyathula cylindrica</i> Moq.	-	H	Amaranthaceae	AB-01235
86	<i>Cynodon dactylon</i> (L.) Pers.	Lemlem-sar	H	Poaceae	AB-00025
87	<i>Cynoglossum coeruleum</i> Hochst. ex A.DC. in DC. subsp. <i>coeruleum</i>	Chegogit	H	Boraginaceae	AB-00480
88	<i>Cyperus articulatus</i> L.	-	H	Cyperaceae	AB-00493
89	<i>Cyperus assimilis</i> Steud.	Gicha	H	Cyperaceae	AB-00088
90	<i>Cyperus dichroöstachyus</i> A. Rich.	Ketema	H	Cyperaceae	AB-00495
91	<i>Cyperus distans</i> L.f.	Gicha	H	Cyperaceae	AB-00498
92	<i>Cyperus fischerianus</i> A. Rich.	Ketema	H	Cyperaceae	AB-00005
93	<i>Cyperus imbricatus</i> Retz.	Ketema	H	Cyperaceae	AB-00544
94	<i>Cyperus latifolius</i> Poir.	Enchachiwa	H	Cyperaceae	AB-01046
95	<i>Cyperus longus</i> L.	Ketema	H	Cyperaceae	AB-00547
96	<i>Cyperus macrostachyos</i> Lam.	Gicha	H	Cyperaceae	AB-00565
97	<i>Cyperus rigidifolius</i> Steud.	Key-gicha	H	Cyperaceae	AB-00001
98	<i>Cyperus rotundus</i> L.	Gicha	H	Cyperaceae	AB-00568
99	<i>Cyperus triceps</i> Endl.	Ketema	H	Cyperaceae	AB-00598
100	<i>Datura stramonium</i> L.	Astenagir	H	Solanaceae	AB-00191
101	<i>Daucus carota</i> L.	Engochiye	H	Apiaceae	AB-01455
102	<i>Delphinium dasycaulon</i> Fresen.	Gedel-admik	H	Ranunculaceae	AB-00247

103	<i>Desmodium repandum</i> (Vahl) DC.	-	H	Fabaceae	AB-01134
104	<i>Dianthoseris schimperi</i> Sch. Bip. ex A. Rich.	-	H	Asteraceae	AB-00462
105	<i>Dicrocephala integrifolia</i> (L. f.) O. kuntze	-	H	Asteraceae	AB-00610
106	<i>Digitaria abyssinica</i> (Hochst. ex A. Rich.) Stapf	Serdo	H	Poaceae	AB-00615
107	<i>Dinebra retroflexa</i> (Vahl) Panzer	Chewtamie	H	Poaceae	AB-01484
108	<i>Dioscorea quartiniana</i> A. Rich.	Hareg	Cl	Dioscoreaceae	AB-01542
109	<i>Diospyros abyssinica</i> (Hiern) F. white	Selchegn	T	Ebenaceae	AB-01099
110	<i>Dipsacus pinnatifidus</i> Steud. ex A. Rich.	-	H	Dipsacaceae	AB-00320
111	<i>Discopodium penninervium</i> Hochst.	Almit	T	Solanaceae	AB-00618
112	<i>Dodonea angustifolia</i> L.f.	Kitkita	Sh	Sapindaceae	AB-00628
113	<i>Dombeya torrida</i> (J.F. Gmel.) P. Bamps	Wulkifa	T	Sterculiaceae	AB-00624
114	<i>Dovyalis abyssinica</i> (A. Rich.) Warb.	Koshim	Sh	Flacourtiaceae	AB-00174
115	<i>Dracaena steudneri</i> Engl.	Itsepatos	T	Dracaenaceae	AB-00620
116	<i>Dregea schimperi</i> (Decne.) Bullock	Hareg	Sh	Asclepiadaceae	AB-00710
117	<i>Dryopteris schimperiana</i> (Hochst. ex A.Br.) C.Chr.	-	H	Dryopteridaceae	AB-00761
118	<i>Dyschoriste multicaulis</i> (A. Rich.) O. Kuntze	-	H	Acanthaceae	AB-01452
119	<i>Echinochloa pyramidalis</i> (Lam.) Hitchc. and Chase	Guangurda	H	Poaceae	AB-1144A
120	<i>Echinops longisetus</i> A. Rich.	Guale	Sh	Asteraceae	AB-00630
121	<i>Echinops ellenbeckii</i> O. Hoffm.	Guale	Sh	Asteraceae	AB-00636
122	<i>Eichornia crassipes</i> (Mart.) Solms in A. DC.	Enboch	H	Pontederiaceae	AB-1425A
123	<i>Ekebergia capensis</i> Sparrm.	Lol	T	Meliaceae	AB-00591
124	<i>Eleocharis marginulata</i> Hochst. ex Steud	Chimatu	H	Poaceae	AB-00470
125	<i>Eleusine indica</i> (L.) Gaertn.	Yasama dagussa,	H	Poaceae	AB-00034
126	<i>Embelia schimperi</i> Vatke	Enkoko	Sh	Myrsinaceae	AB-00938
127	<i>Entada abyssinica</i> Steud. ex A. Rich.	Kentafa	T	Fabaceae	AB-01548

128	<i>Eragrostis botryodes</i> W.D. Clayton	Yewusha-teff	H	Poaceae	AB-00164
129	<i>Eragrostis cilianensis</i> (AIL.) Vign. ex Janchen	Yewusha-teff	H	Poaceae	AB-00035
130	<i>Eragrostis tenuifolia</i> (A. Rich.) Steud.	Yewusha-teff	H	Poaceae	AB-00636
131	<i>Erica arborea</i> L.	Asta	Sh	Ericaceae	AB-00477
132	<i>Erythrina abyssinica</i> Lam. ex DC.	korch	T	Fabaceae	AB-00234
133	<i>Ethulia gracilis</i> Del.	-	H	Asteraceae	AB-01421
134	<i>Eucalyptus camaldulensis</i> Dehnh.	Bahir-zaf	T	Myrtaceae	AB-00638
135	<i>Euclea racemosa</i> Murr. subsp. <i>schimperi</i> (A. DC.) White	Dedeho	Sh	Ebenaceae	AB-00645
136	<i>Euphorbia abyssinica</i> Gmel.	Kulkual	T	Euphorbiaceae	AB-00384
137	<i>Euphorbia tirucalli</i> L.	Kinchib	Sh	Euphorbiaceae	AB-00104
138	<i>Euphorbia petitiana</i> A. Rich.	Avidamo	H	Euphorbiaceae	AB-00650
139	<i>Euphorbia schimperiana</i> Scheele	Avidamo	H	Euphorbiaceae	AB-00655
140	<i>Eustachys paspaloides</i> (Vahl) Lanza and Mattei	Yewusha-dagussa	H	Poaceae	AB-00188
141	<i>Festuca macrophylla</i> Hochst. ex A. Rich.	Guasa	H	Poaceae	AB-00459
142	<i>Ficus sur</i> Forssk.	Shola	T	Moraceae	AB-00584
143	<i>Ficus sycomorus</i> L.	Bamba	T	Moraceae	AB-00673
144	<i>Ficus thonningii</i> Blume	Chebeha	T	Moraceae	AB-00689
145	<i>Ficus vasta</i> Forssk.	Warka	T	Moraceae	AB-00675
146	<i>Flacourtia indica</i> (Burm. f.) Merr.	Yenebir-tifir	Sh	Flacourtiaceae	AB-00385
147	<i>Flueggea virosa</i> (Willd.) Voigt. subsp. <i>virosa</i>	Wonahi	Sh	Euphorbiaceae	AB-00124
148	<i>Galiniera saxifraga</i> (Hochst.) Bridson	Yewof-buna	Sh	Rubiaceae	AB-01169
149	<i>Galinsoga quadriradiata</i> Ruiz and Pavon	Diha-nekay	H	Asteraceae	AB-00194
150	<i>Gardenia ternifolia</i> Schumach. and Thonn.	Gambilo	Sh/T	Rubiaceae	AB-00682
151	<i>Geranium arabicum</i> Forssk.	-	H	Geraniaceae	AB-00429
152	<i>Girardinia bullosa</i> (Steudel) Wedd.	Alevlavit	H	Urticaceae	AB-00061
153	<i>Glycine wightii</i> (Wight and Arn.) Verdc.	Hareg	Cl	Fabaceae	AB-00249

154	<i>Gnaphalium tweedieae</i> Hilliard	-	H	Asteraceae	AB-00686
155	<i>Gnidia glauca</i> (Fresen.) Gilg	Awura	Sh	Thymelaeaceae	AB-01365
156	<i>Grewia ferruginea</i> Hochst. ex A. Rich.	Lenkuata	Sh/T	Tiliaceae	AB-00690
157	<i>Guizotia scabra</i> (Vis.) Chiov.	Mechi	H	Asteraceae	AB-00694
158	<i>Haplocarpha rueppellii</i> (Sch. Bip.) Beauv.	-	H	Asteraceae	AB-00697
159	<i>Haplocarpha schimperi</i> (Sch. Bip.) Beauv.	Getin	H	Asteraceae	AB-00398
160	<i>Harpachne schimperi</i> Hochst. ex A. Rich.	-	H	Poaceae	AB-00003
161	<i>Helichrysum citrispinum</i> Del.	Yekok- shock	Sh	Asteraceae	AB-00460
162	<i>Helichrysum schimperi</i> (Sch. Bip. ex A. Rich.) Moeser	-	H	Asteraceae	AB-00800
163	<i>Helinus mystacinus</i> (Ait.) E. Mey. ex Steud.	Hareg	Cl	Rhamnaceae	AB-00629
164	<i>Heliotropium supinum</i> L.	Amedmado	H	Boraginaceae	AB-00815
165	<i>Hibiscus macranthus</i> Hochst. ex A. Rich.	-	Sh	Malvaceae	AB-00071
166	<i>Hygrophila schulli</i> (Hamilt.) M.R. and S.M Almeida	Amekala	H	Acanthaceae	AB-00820
167	<i>Hyparrhenia anthistirioides</i> (Hochst. ex A. Rich.) Stapf	Kuaya	H	Poaceae	AB-0030A
168	<i>Hyparrhenia filipendula</i> (Hochst.) Stapf	Kuaya	H	Poaceae	AB-00133
169	<i>Hyparrhenia hirta</i> (L.) Stapf	Kuaya	H	Poaceae	AB-00830
170	<i>Hyparrhenia rufa</i> (Nees) Stapf	Kuaya	H	Poaceae	AB-00840
171	<i>Hypericum revolutum</i> Vahl	Amija	Sh	Hypericaceae	AB-00488
172	<i>Hypericum peplidifolium</i> A. Rich.	-	H	Hypericaceae	AB-00683
173	<i>Hypericum quartinianum</i> A. Rich.	Amija	Sh	Hypericaceae	AB-00419
174	<i>Hypoestes triflora</i> (Forssk.) Roem and Schult.	-	H	Acanthaceae	AB-01156
175	<i>Hypoestest forskaolii</i> (vahl) R. Br.	-	H	Acanthaceae	AB-00004
176	<i>Inula paniculata</i> (Klatt) Burt-Davy	Daba- akimada	H	Asteraceae	AB-01297

177	<i>Ipomoea aquatica</i> Forssk.	-	H	Convolvulacea e	AB-00844
178	<i>Ipomoea cairica</i> (L.) Sweet	-	H	Convolvulacea e	AB-01132
179	<i>Ipomoea tenuirostris</i> Choisy subsp. tenuirostris	-	H	Convolvulacea e	AB-01126
180	<i>Jasminum grandiflorum</i> L. subsp. <i>floribundum</i> (R.Br. ex Fresen.) P.S. Green	Tenbelel	Cl	Oleaceae	AB-00207
181	<i>Jasminum abyssinicum</i> Hochst. ex DC.	Tenbelel	Cl	Oleaceae	AB-00240
182	<i>Juniperus procera</i> Hochst. ex Endl.	Tsid	T	Cupressaceae	AB-00388
183	<i>Justicia ladanoides</i> Lam.	-	H	Acanthaceae	AB-01150
184	<i>Justicia schimperiana</i> (Hochst. ex Nees) T. Anders.	Simiza	Sh	Acanthaceae	AB-00091
185	<i>Kalanchoe petitiiana</i> A. Rich.	Endahuhla	H	Crassulaceae	AB-00850
186	<i>Laggera crispata</i> (Vahl) Hepper and wood	Nechilo	H	Asteraceae	AB-00072
187	<i>Laggera tomentosa</i> (Sch. Bip. ex A. Rich.) Oliv. and Hiern	Nechilo	H	Asteraceae	AB-00392
188	<i>Lantana camara</i> L.	Yewof-kolo	Sh	Lamiaceae	AB-00854
189	<i>Lantana viburnoides</i> (Forssk.) Vahl	Yewof-kolo	Sh	Lamiaceae	AB-0744A
190	<i>Leonotis ocymifolia</i> (Burm. f.) Iwarsson	Yeferese- zeng	Sh	Lamiaceae	AB-00744
191	<i>Lepidotrichilia volkensis</i> (Gürke) Leroy	Yekola- abalo	T	Meliaceae	AB-01168
192	<i>Leucas martinicensis</i> (Jacq.) R. Br.	Ras-kimir	H	Lamiaceae	AB-00057
193	<i>Leucas stachydiformis</i> (Hochst. ex Benth.) Briq.	Ras-kimir	Sh	Lamiaceae	AB-00528
194	<i>Lippia adoënsis</i> Hochst. ex Walp.	Dama-kese	Sh	Verbenaceae	AB-00306
195	<i>Lobelia rhynchopetalum</i> Hemsl.	Jibera	H	Lobeliaceae	AB-00860
196	<i>Ludwigia stolonifera</i> (Guill. and Perr.) Raven	Key-kitel	H	Onagraceae	AB-01418

197	<i>Maesa lanceolata</i> Forssk.	Kurava	Sh	Myrsinaceae	AB-00241
198	<i>Maytenus arbutifolia</i> (A. Rich.) Wilczek	Tikur-atat	Sh	Celastraceae	AB-00045
199	<i>Maytenus gracilipes</i> (Welw. ex Oliv.) Exell	Atat	Sh	Celastraceae	AB-00578
200	<i>Maytenus obscura</i> (A. Rich.) Cuf.	Kummel	Sh	Celastraceae	AB-00386
201	<i>Maytenus serrata</i> (A. Rich.) Wilczek	Atat	Sh	Celastraceae	AB-01080
202	<i>Maytenus undata</i> (Thunb.) Blakelock	Eshebaria	Sh/T	Celastraceae	AB-01449
203	<i>Medicago polymorpha</i> L.	-	H	Fabaceae	AB-01021
204	<i>Mikaniopsis clematoides</i> Sch. Bip. ex A. Rich.) Milne-Redh.	Nech-hareg	Cl	Asteraceae	AB-00865
205	<i>Millettia ferruginea</i> (Hochst.) Bak. Subsp. <i>Ferruginea</i>	Birbira	T	Fabaceae	AB-00252
206	<i>Mimosa pigra</i> L.	Kentafa	Sh	Fabaceae	AB-00868
207	<i>Mimusops kummel</i> A. DC.	Ishe	T	Sapotaceae	AB-00095
208	<i>Momordica foetida</i> Schumach.	Enkurareg	Cl	Cucurbitaceae	AB-00345
209	<i>Myrsine africana</i> L.	Kechem	Sh	Myrsinaceae	AB-00455
210	<i>Nicandra physaloides</i> (L.) Gaertn.	-	H	Solanaceae	AB-00870
211	<i>Nuxia congesta</i> R.Br. ex Fresen.	Anfar	Sh/T	Loganiaceae	AB-00573
212	<i>Nymphaea lotus</i> (L.)	-	H	Nymphaeaceae	AB-00874
213	<i>Nymphoides brevipedicellata</i> (Vatke) A. Raynal	Meti-arem	H	Nymphaeaceae	AB-00878
214	<i>Ocimum gratissimum</i> L.	Kese	Sh	Lamiaceae	AB-00884
215	<i>Ocimum lamiifolium</i> Hochst. ex Beth.	Dama-kese	Sh	Lamiaceae	AB-01124
216	<i>Ocimum urticifolium</i> Roth	Kese	Sh	Lamiaceae	AB-00160
217	<i>Odontelytrum abyssinicum</i> Hack.	Asendabo	H	Poaceae	AB-00890
218	<i>Olea europaea</i> L. subsp. <i>cuspidata</i> (Wall. ex G. Don) Cif.	Woirra	T	Oleaceae	AB-00893
219	<i>Oplismenus hirtellus</i> (L.) P. Beauv.	Yekok-sar	H	Poaceae	AB-01231
220	<i>Oryza longistaminata</i> A. Chev. and Roehr.	Zura	H	Poaceae	AB-01094
221	<i>Osyris quadripartita</i> Decn.	Keret	Sh	Santalaceae	AB-00901
222	<i>Otostegia integrifolia</i> Benth.	Tunjut	Sh	Lamiaceae	AB-00327

223	<i>Oxalis corniculata</i> L.	-	H	Oxalidaceae	AB-0972A
224	<i>Panicum atrosanguineum</i> A. Rich.	<u>Yekok-sar</u>	H	Poaceae	AB-00910
225	<i>Panicum calvum</i> Stapf	Yefiyel-kolet	H	Poaceae	AB-00323
226	<i>Parthenium hysterophorus</i> L.	-	H	Asteraceae	AB-00915
227	<i>Pavetta abyssinica</i> Fresen.	Yewof-buna	Sh	Rubiaceae	AB-00171
228	<i>Pavetta oliveriana</i> Hiern	Yewof-buna	Sh	Rubiaceae	AB-00696
229	<i>Pavonia burchellii</i> (DC.) Dyer	Kacha	Sh	Malvaceae	AB-00137
230	<i>Pavonia schimperiana</i> Hochst. ex A. Rich.	Kacha	H	Malvaceae	AB-01115
231	<i>Pennisetum macrourum</i> Trin.	Tucha	H	Poaceae	AB-00920
232	<i>Pennisetum ramosum</i> (Hochst.) Schweinf.	Gingira	H	Poaceae	AB-01485
233	<i>Pennisetum sphacelatum</i> (Nees) Th. Dur. and Schinz	Tucha	H	Poaceae	AB-00077
234	<i>Pennisetum thunbergii</i> Kunth	Tucha	H	Poaceae	AB-00922
235	<i>Pergularia daemia</i> (Forssk.) Chiov.	Hareg	Cl	Asclepiadaceae	AB-00050
236	<i>Persicaria nepalensis</i> (Meisn.) Miyabe	Wuha-ankur	H	Polygonaceae	AB-0162A
237	<i>Persicaria senegalensis</i> (Meisn.) Sojak	Wuha-ankur	H	Polygonaceae	AB-00162
238	<i>Phaulopsis imbricata</i> (Forssk.) Sweet	-	H	Acanthaceae	AB-00066
239	<i>Phoenix reclinata</i> Jacq.	Senel	T	Arecaceae	AB-00930
240	<i>Phragmanthera regularis</i> (Sprague) M. Gilbert	Teketsila	Sh	Loranthaceae	AB-00933
241	<i>Phyllanthus ovalifolius</i> Forssk.	Zigita	Sh	Euphorbiaceae	AB-00941
242	<i>Phytolacca dodecandra</i> L'H'erit.	Mehan-endod	Sh	Phytolaccaceae	AB-00945
243	<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	kelawanza	Sh	Fabaceae	AB-01501
244	<i>Pimpinella hirtella</i> (Hochst.) A. Rich.	Yedimet-tiris	H	Apiaceae	AB-01180
245	<i>Pittosporum viridiflorum</i> Sims	Ahot	T	Pittosporaceae	AB-00561
246	<i>Plantago lanceolata</i> L.	Wonberet	H	Plantaginaceae	AB-00538
247	<i>Plectranthus punctatus</i> (L.f.) L' H'er.	Yewusha-	H	Lamiaceae	AB-00083

		zikakibe			
248	<i>Pluchea dioscoridis</i> (L.) DC.	Shito	Sh	Asteraceae	AB-00950
249	<i>Plumbago zeylanica</i> L.	Yergo-filaki	H	Plumbaceae	AB-00074
250	<i>Poa annua</i> L.	Esar	H	Poaceae	AB-00401
251	<i>Podocarpus falcatus</i> (Thunb.) R. B. ex. Mirb.	Zigba	T	Podocarpaceae	AB-00972
252	<i>Premna schimperi</i> Engl.	Chocho	Sh	Verbenaceae	AB-00337
253	<i>Protea gaguedi</i> J.F. Gmel.	-	Sh	Proteaceae	AB-01366
254	<i>Prunus africana</i> (Hook. f.) Kalkm.	Homma	T	Rosaceae	AB-0405A
255	<i>Pteridium aquilinum</i> (L.) Kuhn	-	H	Hypolepidaceae	AB-00326
256	<i>Pterocephalus frutescens</i> Hochst. ex A. Rich.	Kelem	H	Dipsacaceae	AB-01298
257	<i>Pterolobium stellatum</i> (Forssk.) Brenan	kentafa	Sh	Fabaceae	AB-00022
258	<i>Ranunculus oligocarpus</i> Hochst. ex A. Rich.	Tinkushit	H	Ranunculaceae	AB-00955
259	<i>Rhabdotosperma scrophulariifolia</i> (Hochst. ex A. Rich.) Hartl	-	H	Scrophulariaceae	AB-00543
260	<i>Rhamnus staddo</i> A. Rich.	Tedo	Sh	Rhamnaceae	AB-0550A
261	<i>Rhoicissus tridentata</i> (L.f.) Wild and Drummond	Hareg	Cl	Vitaceae	AB-00158
262	<i>Rhus glutinosa</i> A. Rich. subsp. <i>glutinosa</i>	Kamo	Sh	Anacardiaceae	AB-00699
263	<i>Rhus glutinosa</i> A. Rich. subsp. <i>neoglutinosa</i> (M. Gilbert) M. Gilbert	Enbis	Sh	Anacardiaceae	AB-00962
264	<i>Rhus vulgaris</i> Meikle	Kamo	Sh	Anacardiaceae	AB-00121
265	<i>Rhynchosia elegans</i> A. Rich.	Yekefo-hareg	Cl	Fabaceae	AB-01537
266	<i>Rosa abyssinica</i> Lindley	Kega	Sh	Rosaceae	AB-00243
267	<i>Rubia cordifolia</i> L.	-	Cl	Rubiaceae	AB-00688
268	<i>Rubus apetalus</i> Poir.	Enzorerit	Sh	Rosaceae	AB-00905
269	<i>Rumex abyssinicus</i> Jacq.	Embacho	H	Polygonaceae	AB-00968
270	<i>Rumex nepalensis</i> Spreng.	Yebere-milas	H	Polygonaceae	AB-00975

271	<i>Rumex nervosus</i> Vahl	Embacho	Sh	Polygonaceae	AB-01127
272	<i>Ruttya speciosa</i> (Hochst.) Engl.	Checho	Sh	Acanthaceae	AB-00560
273	<i>Rytigynia neglecta</i> (Hiern) Robyns	Dingay-seber	Sh	Rubiaceae	AB-00978
274	<i>Sacciolepis africana</i> C. E. Hubb. and Snowden	Molale sar	H	Poaceae	AB-01142
275	<i>Salix subserrata</i> Willd.	Mefakia	Sh	Salicaceae	AB-00992
276	<i>Salvia tiliifolia</i> Vahl	Yewush-zikakibe	H	Lamiaceae	AB-00880
277	<i>Sanicula elata</i> Buch.-Ham. ex D. Don.	-	H	Apiaceae	AB-1003A
278	<i>Sapium ellipticum</i> (Krauss) Pax	kawoot	T	Euphorbiaceae	AB-00038
279	<i>Satureja abyssinica</i> (Benth.) Briq.	Yemeda-zikakibe	H	Lamiaceae	AB-01287
280	<i>Satureja pseudosimensis</i> Brenan	-	H	Lamiaceae	AB-00546
281	<i>Satureja punctata</i> (Benth.) Briq.	Lomi-shita	H	Lamiaceae	AB-0255A
282	<i>Satureja simensis</i> (Benth.) Briq.	-	H	Lamiaceae	AB-00486
283	<i>Scabiosa columbaria</i> L.	-	H	Dipsacaceae	AB-00481
284	<i>Scadoxus multiflorus</i> (Martyn) Raf.	-	H	Amaryllidaceae	AB-00984
285	<i>Schefflera abyssinica</i> (Hochst. ex A. Rich.) Harms	Getem	T	Araliaceae	AB-00937
286	<i>Schinus molle</i> L.	-	T	Anacardiaceae	AB-01001
287	<i>Schoenoplectus articulatus</i> (L.) Palla	Chanfia	H	Cyperaceae	AB-1147A
288	<i>Schoenoplectus corymbosus</i> (Roem. and Schult.) Rayn.	Ketema	H	Cyperaceae	AB-01044
289	<i>Schrebera alata</i> (Hochst.) Welw.	Senef-woyra	T	Oleaceae	AB-00563
290	<i>Scolopia theifolia</i> Gilg	Tedo	T	Flacourtiaceae	AB-00550
291	<i>Selaginella goudotiana</i> Spring var <i>abyssinica</i> (Spring) Bizzarri	-	H	Selaginellaceae	AB-00965
292	<i>Senecio myriocephalus</i> Sch. Bip. ex A. Rich.	-	H	Asteraceae	AB-01015
293	<i>Senecio unionis</i> Sch. Bip. ex A. Rich.	-	H	Asteraceae	AB-00473
294	<i>Senna didymobotrya</i> (Fresen.) Irwin and Barneby	Serkabeba	Sh	Fabaceae	AB-00115

295	<i>Senna obtusifolia</i> (L.) Irwin and Barneby	-	Sh	Fabaceae	AB-00040
296	<i>Senna occidentalis</i> (L.) Link	-	H	Fabaceae	AB-01024
297	<i>Senna petersiana</i> (Bolle) Lock	Azegemar	Sh	Fabaceae	AB-01030
298	<i>Senna singueana</i> (Del.) Lock	Guffa	Sh/T	Fabaceae	AB-01035
299	<i>Sesbania sesban</i> (L.) Merr.	Kuakuya	Sh	Fabaceae	AB-00085
300	<i>Setaria pumila</i> (Poir.) Roem. and Schult.	Asendabo	H	Poaceae	AB-00679
301	<i>Sida rhombifolia</i> L.	Chifrig	H	Malvaceae	AB-00136
302	<i>Sida schimperiana</i> Hochst. ex A. Rich.	Chifrig	Sh	Malvaceae	AB-00350
303	<i>Solanecio gigas</i> (Vatke) C. Jeffrey	Shokolo	T	Asteraceae	AB-01170
304	<i>Solanum anguivi</i> Lam.	Enboy	H	Solanaceae	AB-00208
305	<i>Solanum giganteum</i> Jacq.	Enboy	Sh/T	Solanaceae	AB-0573A
306	<i>Solanum incanum</i> L.	Enboy	Sh	Solanaceae	AB-00338
307	<i>Solanum marginatum</i> L.f.	Zerch-enboy	Sh	Solanaceae	AB-00504
308	<i>Solanum nigrum</i> L.	Enboy	Sh	Solanaceae	AB-01040
309	<i>Solanum villosum</i> Mill.	Awutign	H	Solanaceae	AB-00186
310	<i>Sonchus bipontini</i> Asch.	Binagn	H	Asteraceae	AB-01147
311	<i>Sphaeranthus suaveolens</i> (Forssk.) DC.	-	H	Asteraceae	AB-01049
312	<i>Sporobolus africanus</i> (Poir.) Robyns and Tournay	Mure	H	Poaceae	AB-01053
313	<i>Sporobolus pyramidalis</i> P. Beauv.	Mure	H	Poaceae	AB-00170
314	<i>Steganotaenia araliacea</i> Hochst. ex A. Rich.	Wagesho	T	Apiaceae	AB-00832
315	<i>Stephania abyssinica</i> (Dillon and A.Rich.) Walp.	Nech-hareg	Cl	Menispermaceae	AB-00529
316	<i>Stereospermum kunthianum</i> Cham.	Zana	T	Bignoniaceae	AB-00210
317	<i>Stylosanthes fruticosa</i> (Retz.) Alston	Kibe-gotit	H	Fabaceae	AB-00143
318	<i>Syzygium guineense</i> (Willd.) DC.	Dokima	T	Myrtaceae	AB-00144
319	<i>Tagetes minuta</i> L.	Shito	H	Asteraceae	AB-01058
320	<i>Tagetes patula</i> L.	Shito	H	Asteraceae	AB-01061
321	<i>Teclea nobilis</i> Del.	Sehil	Sh/T	Rutaceae	AB-00377
322	<i>Terminalia schimperiana</i> Hochst.	Tej	T	Combretaceae	AB-01068
323	<i>Thalictrum rhynchocarpum</i> Dill. and A. Rich.	-	H	Ranunculaceae	AB-0458A

324	<i>Thymus schimperi</i> Ronniger subsp. <i>schimperi</i>	Tosign	H	Lamiaceae	AB-00490
325	<i>Trichodesma physaloides</i> (Fenzl) A.DC. in DC.	-	H	Boraginaceae	AB-01413
326	<i>Trifolium acaule</i> Steud. ex A. Rich.	Maget	H	Fabaceae	AB-00484
327	<i>Trifolium rueppellianum</i> Fresen.	Maget	H	Fabaceae	AB-00135
328	<i>Trifolium semipilosum</i> Fresen.	Maget	H	Fabaceae	AB-01020
329	<i>Triumfetta rhomboidea</i> Jacq.	-	H	Tiliaceae	AB-00073
330	<i>Urera hypselodendron</i> (A. Rich.) Wedd.	Lanqueso	Cl	Urticaceae	AB-00586
331	<i>Urtica simensis</i> Steudel	Sama	H	Urticaceae	AB-00508
332	<i>Verbena officinalis</i> L.	-	H	Verbenaceae	AB-01423
333	<i>Vernonia amygdalina</i> Del.	Grawa	Sh	Asteraceae	AB-00448
334	<i>Vernonia adoensis</i> Sch. Bip. ex Walp.	Grawa	Sh	Asteraceae	AB-00065
335	<i>Vernonia hochstetteri</i> Sch. Bip. ex Walp.	Grawa	Sh	Asteraceae	AB-01070
336	<i>Vernonia leopoldi</i> (Sch. Bip. ex Walp.) Vatke	Grawa	Sh	Asteraceae	AB-0251A
337	<i>Vernonia myriantha</i> Hook. f.	Qotiqoto	Sh	Asteraceae	AB-01979
338	<i>Vernonia wollastonii</i> S. Moore	-	Sh	Asteraceae	AB-01159
339	<i>Vigna membranacea</i> A. Rich. Subsp. <i>membranacea</i>	-	Cl	Fabaceae	AB-00642
340	<i>Xanthium spinosum</i> L.	Akakima	H	Asteraceae	AB-01414
341	<i>Xanthium strumarium</i> L.	Kakucha	H	Asteraceae	AB-00871
342	<i>Ximenia americana</i> L.	Inkoy	Sh/T	Olacaceae	AB-01075

Appendix 2: Important value index (IVI value) of the woody species

Key: F (frequency), FR (Relative Frequency), BA (Basal Area), Do (Dominance), RDO

(Relative Dominance), D (Density), RD (Relative Density) and IVI (Importance Value Index).

No	Species Name	F	RF	Count	BA	Do	RDO	D	RD	IVI
1	<i>Acacia abyssinica</i>	4	0.51	50	0.16	0.04	0.16	12.76	0.94	1.62
2	<i>Acacia albida</i>	15	1.93	93	2.26	0.58	2.33	23.72	1.75	6.00
3	<i>Acacia lahai</i>	7	0.90	28	0.50	0.13	0.52	7.14	0.53	1.95
4	<i>Acacia seyal</i>	3	0.39	20	0.59	0.15	0.60	5.10	0.38	1.37
5	<i>Acacia sieberiana</i>	2	0.26	6	0.23	0.06	0.23	1.53	0.11	0.60
6	<i>Acacia tortilis</i>	1	0.13	5	0.12	0.03	0.13	1.28	0.09	0.35
7	<i>Acacia venosa</i>	6	0.77	21	0.37	0.09	0.38	5.36	0.39	1.55
8	<i>Acokanthera schimperi</i>	6	0.77	30	0.05	0.01	0.06	7.65	0.56	1.39
9	<i>Albizia gummifera</i>	2	0.26	4	0.11	0.03	0.11	1.02	0.08	0.44
10	<i>Albizia malacophylla</i>	1	0.13	1	0.02	0.00	0.02	0.26	0.02	0.17
11	<i>Albizia schimperiana</i>	15	1.93	52	1.85	0.47	1.91	13.27	0.98	4.81
12	<i>Allophylus abyssinicus</i>	7	0.90	21	0.39	0.10	0.40	5.36	0.39	1.70
13	<i>Apodytes dimidiata</i>	4	0.51	13	1.05	0.27	1.08	3.32	0.24	1.84
14	<i>Arundinaria alpina</i>	1	0.13	30	0.01	0.00	0.01	7.65	0.56	0.70
15	<i>Bersama abyssinica</i>	10	1.29	295	0.23	0.06	0.24	75.26	5.54	7.07
16	<i>Bridelia micrantha</i>	6	0.77	22	0.09	0.02	0.10	5.61	0.41	1.28
17	<i>Brucea antidysenterica</i>	5	0.64	11	0.01	0.00	0.01	2.81	0.21	0.86
18	<i>Buddleja polystachya</i>	6	0.77	35	0.15	0.04	0.15	8.93	0.66	1.58
19	<i>Caesalpinia decapetala</i>	2	0.26	5	0.01	0.00	0.01	1.28	0.09	0.36
20	<i>Calotropis procera</i>	1	0.13	3	0.01	0.00	0.01	0.77	0.06	0.19
21	<i>Calpurnia aurea</i>	40	5.14	337	0.65	0.17	0.67	85.97	6.33	12.15
22	<i>Canthium oligocarpum</i>	2	0.26	33	0.04	0.01	0.04	8.42	0.62	0.92
23	<i>Capparis tomentosa</i>	16	2.06	70	0.10	0.03	0.10	17.86	1.32	3.48

No	Species Name	F	RF	Count	BA	Do	RDO	D	RD	IVI
24	<i>Carissa spinarum</i>	36	4.63	285	0.44	0.11	0.45	72.70	5.36	10.44
25	<i>Celtis africana</i>	1	0.13	2	1.48	0.38	1.53	0.51	0.04	1.70
26	<i>Chionanthus mildbraedii</i>	9	1.16	74	16.81	4.29	17.35	18.88	1.39	<u>19.90</u>
27	<i>Cissus petiolata</i>	1	0.13	4	0.00	0.00	0.00	1.02	0.08	0.20
28	<i>Clausena anisata</i>	24	3.08	103	0.18	0.05	0.18	26.28	1.94	5.20
29	<i>Clerodendrum myricoides</i>	7	0.90	21	0.04	0.01	0.04	5.36	0.39	1.33
30	<i>Clutia abyssinica</i>	2	0.26	6	0.02	0.00	0.02	1.53	0.11	0.39
31	<i>Combretum collinum</i> subsp. <i>collinum</i>	1	0.13	4	0.30	0.08	0.31	1.02	0.08	0.51
32	<i>Combretum molle</i>	6	0.77	28	0.62	0.16	0.64	7.14	0.53	1.94
33	<i>Cordia africana</i>	8	1.03	24	1.03	0.26	1.06	6.12	0.45	2.54
34	<i>Croton macrostachyus</i>	34	4.37	129	2.58	0.66	2.67	32.91	2.42	9.46
35	<i>Diospyros abyssinica</i>	1	0.13	4	0.37	0.09	0.38	1.02	0.08	0.58
36	<i>Discopodium penninervium</i>	3	0.39	15	0.03	0.01	0.03	3.83	0.28	0.70
37	<i>Dodonea angustifolia</i>	14	1.80	217	0.48	0.12	0.50	55.36	4.08	6.37
38	<i>Dombeya torrida</i>	4	0.51	8	0.05	0.01	0.05	2.04	0.15	0.71
39	<i>Dovyalis abyssinica</i>	6	0.77	29	0.10	0.03	0.11	7.40	0.55	1.42
40	<i>Echinops longisetus</i>	1	0.13	6	0.05	0.01	0.05	1.53	0.11	0.29
41	<i>Ekebergia capensis</i>	10	1.29	29	3.11	0.79	3.21	7.40	0.55	5.04
42	<i>Embelia schimperi</i>	2	0.26	7	0.01	0.00	0.01	1.79	0.13	0.40
43	<i>Entada abyssinica</i>	1	0.13	2	0.06	0.02	0.06	0.51	0.04	0.23
44	<i>Erica arborea</i>	2	0.26	73	0.08	0.02	0.08	18.62	1.37	1.71
45	<i>Erythrina abyssinica</i>	2	0.26	4	0.02	0.01	0.02	1.02	0.08	0.35
46	<i>Eucalyptus camaldulensis</i>	2	0.26	35	0.74	0.19	0.76	8.93	0.66	1.68
47	<i>Euclea racemosa</i>	3	0.39	14	0.03	0.01	0.03	3.57	0.26	0.68
48	<i>Euclea racemosa</i> <i>Murr.</i> subsp.	1	0.13	1	0.01	0.00	0.01	0.26	0.02	0.16

No	Species Name	F	RF	Count	BA	Do	RDO	D	RD	IVI
	<i>schimperii</i>									
49	<i>Euphorbia abyssinica</i>	6	0.77	37	0.86	0.22	0.88	9.44	0.70	2.35
50	<i>Ficus sur</i>	2	0.26	6	0.21	0.05	0.22	1.53	0.11	0.59
51	<i>Ficus sycomorus</i>	6	0.77	10	2.49	0.63	2.57	2.55	0.19	3.53
52	<i>Ficus thonningii</i>	4	0.51	6	3.31	0.85	3.42	1.53	0.11	4.05
53	<i>Ficus vasta</i>	2	0.26	4	1.00	0.26	1.04	1.02	0.08	1.37
54	<i>Flacourtia indica</i>	1	0.13	6	0.06	0.02	0.06	1.53	0.11	0.30
55	<i>Flueggea virosa</i> subsp. <i>Virosa</i>	10	1.29	111	0.11	0.03	0.11	28.32	2.09	3.48
56	<i>Galiniera saxifraga</i>	6	0.77	31	0.20	0.05	0.21	7.91	0.58	1.56
57	<i>Gardenia ternifolia</i>	9	1.16	37	0.15	0.04	0.16	9.44	0.70	2.01
58	<i>Gnidia glauca</i>	1	0.13	5	0.01	0.00	0.01	1.28	0.09	0.23
59	<i>Grewia ferruginea</i>	28	3.60	245	0.84	0.21	0.87	62.50	4.60	9.07
60	<i>Hypericum revolutum</i>	3	0.39	13	0.01	0.00	0.01	3.32	0.24	0.64
61	<i>Hypericum</i> <i>quartinianum</i>	2	0.26	6	0.01	0.00	0.01	1.53	0.11	0.38
62	<i>Jasminum</i> <i>grandiflorum</i>	7	0.90	49	0.06	0.02	0.07	12.50	0.92	1.89
63	<i>Jasminum</i> <i>abyssinicum</i>	6	0.77	20	0.03	0.01	0.03	5.10	0.38	1.18
64	<i>Juniperus procera</i>	5	0.64	36	15.84	4.04	16.35	9.18	0.68	17.67
65	<i>Justicia schimperiana</i>	3	0.39	72	0.00	0.00	0.00	18.37	1.35	1.74
66	<i>Lantana viburnoides</i>	1	0.13	2	0.00	0.00	0.00	0.51	0.04	0.17
67	<i>Lepidotrichilia</i> <i>volkensis</i>	5	0.64	53	0.24	0.06	0.25	13.52	1.00	1.89
68	<i>Lobelia</i> <i>rhynchopetalum</i>	2	0.26	33	0.17	0.04	0.18	8.42	0.62	1.06
69	<i>Maesa lanceolata</i>	8	1.03	34	0.11	0.03	0.11	8.67	0.64	1.78
70	<i>Maytenus arbutifolia</i>	37	4.76	507	0.31	0.08	0.32	129.34	9.53	14.61
71	<i>Maytenus gracilipes</i>	1	0.13	4	0.01	0.00	0.01	1.02	0.08	0.21
72	<i>Maytenus obscura</i>	1	0.13	1	0.05	0.01	0.05	0.26	0.02	0.20
73	<i>Maytenus serrata</i>	1	0.13	169	0.01	0.00	0.01	43.11	3.18	3.32

No	Species Name	F	RF	Count	BA	Do	RDO	D	RD	IVI
74	<i>Maytenus undata</i>	3	0.39	14	0.43	0.11	0.45	3.57	0.26	1.10
75	<i>Millettia ferruginea</i>	5	0.64	19	0.53	0.13	0.54	4.85	0.36	1.54
76	<i>Mimosa pigra</i>	1	0.13	8	0.00	0.00	0.00	2.04	0.15	0.28
77	<i>Mimusops kummel</i>	1	0.13	1	0.04	0.01	0.04	0.26	0.02	0.19
78	<i>Myrsine africana</i>	5	0.64	26	0.02	0.00	0.02	6.63	0.49	1.15
79	<i>Nuxia congesta</i>	1	0.13	2	0.64	0.16	0.66	0.51	0.04	0.83
80	<i>Ocimum urticifolium</i>	1	0.13	7	0.01	0.00	0.01	1.79	0.13	0.27
81	<i>Olea europaea</i>	7	0.90	26	3.75	0.96	3.88	6.63	0.49	5.26
82	<i>Osyris quadripartita</i>	11	1.41	83	0.16	0.04	0.17	21.17	1.56	3.14
83	<i>Pavetta oliveriana</i>	2	0.26	4	0.01	0.00	0.01	1.02	0.08	0.34
84	<i>Phoenix reclinata</i>	10	1.29	63	0.51	0.13	0.53	16.07	1.18	3.00
85	<i>Phyllanthus ovalifolius</i>	2	0.26	7	0.01	0.00	0.01	1.79	0.13	0.40
86	<i>Phytolacca dodecandra</i>	4	0.51	13	0.07	0.02	0.07	3.32	0.24	0.83
87	<i>Piliostigma thonningii</i>	2	0.26	3	0.03	0.01	0.03	0.77	0.06	0.34
88	<i>Pittosporum viridiflorum</i>	9	1.16	50	0.69	0.18	0.71	12.76	0.94	2.81
89	<i>Pluchea dioscoridis</i>	2	0.26	12	0.02	0.00	0.02	3.06	0.23	0.50
90	<i>Podocarpus falcatus</i>	2	0.26	12	0.38	0.10	0.39	3.06	0.23	0.88
91	<i>Premna schimperi</i>	22	2.83	167	0.44	0.11	0.45	42.60	3.14	6.42
92	<i>Protea gagedi</i>	1	0.13	2	0.01	0.00	0.01	0.51	0.04	0.18
93	<i>Prunus africana</i>	6	0.77	15	1.25	0.32	1.29	3.83	0.28	2.35
94	<i>Pterolobium stellatum</i>	27	3.47	104	0.13	0.03	0.14	26.53	1.95	5.56
95	<i>Rhamnus staddo</i>	1	0.13	3	0.00	0.00	0.00	0.77	0.06	0.19
96	<i>Rhoicissus tridentata</i>	6	0.77	13	0.04	0.01	0.05	3.32	0.24	1.06
97	<i>Rhus glutinosa</i> subsp. <i>gulutinosa</i>	2	0.26	6	0.02	0.01	0.02	1.53	0.11	0.39
98	<i>Rhus glutinosa</i> subsp. <i>neoglutinosa</i>	1	0.13	3	0.00	0.00	0.00	0.77	0.06	0.19
99	<i>Rhus vulgaris</i>	19	2.44	102	0.40	0.10	0.41	26.02	1.92	4.77
100	<i>Rosa abyssinica</i>	6	0.77	17	0.03	0.01	0.03	4.34	0.32	1.12

No	Species Name	F	RF	Count	BA	Do	RDO	D	RD	IVI
101	<i>Rubus apetalus</i>	3	0.39	9	0.01	0.00	0.01	2.30	0.17	0.57
102	<i>Ruttya speciosa</i>	2	0.26	12	0.03	0.01	0.03	3.06	0.23	0.51
103	<i>Rytigynia neglecta</i>	1	0.13	2	0.01	0.00	0.01	0.51	0.04	0.17
104	<i>Salix subserrata</i>	1	0.13	3	0.01	0.00	0.01	0.77	0.06	0.19
105	<i>Sapium ellipticum</i>	9	1.16	24	4.42	1.13	4.56	6.12	0.45	6.17
106	<i>Schefflera abyssinica</i>	3	0.39	8	5.45	1.39	5.62	2.04	0.15	6.16
107	<i>Schinus molle</i>	1	0.13	1	0.01	0.00	0.01	0.26	0.02	0.15
108	<i>Schrebera alata</i>	7	0.90	27	0.88	0.22	0.91	6.89	0.51	2.31
109	<i>Scolopia theifolia</i>	1	0.13	1	0.01	0.00	0.01	0.26	0.02	0.16
110	<i>Senna didymobotrya</i>	4	0.51	10	0.00	0.00	0.00	2.55	0.19	0.71
111	<i>Senna obtusifolia</i>	1	0.13	9	0.02	0.01	0.02	2.30	0.17	0.32
112	<i>Senna petersiana</i>	2	0.26	9	0.04	0.01	0.04	2.30	0.17	0.47
113	<i>Senna singueana</i>	9	1.16	40	0.08	0.02	0.08	10.20	0.75	1.99
114	<i>Solanecio gigas</i>	3	0.39	14	0.03	0.01	0.03	3.57	0.26	0.68
115	<i>Solanum giganteum</i>	2	0.26	3	0.01	0.00	0.01	0.77	0.06	0.32
116	<i>Steganotaenia araliacea</i>	2	0.26	5	0.03	0.01	0.03	1.28	0.09	0.39
117	<i>Stereospermum kunthianum</i>	9	1.16	13	0.17	0.04	0.17	3.32	0.24	1.57
118	<i>Syzygium guineense</i>	11	1.41	79	10.83	2.76	11.18	20.15	1.48	14.08
119	<i>Teclea nobilis</i>	10	1.29	137	0.82	0.21	0.84	34.95	2.57	4.70
120	<i>Terminalia schimperiana</i>	3	0.39	8	0.05	0.01	0.05	2.04	0.15	0.59
121	<i>Urera hypselodendron</i>	2	0.26	6	0.06	0.02	0.06	1.53	0.11	0.43
122	<i>Vernonia amygdalina</i>	5	0.64	32	0.09	0.02	0.09	8.16	0.60	1.33
123	<i>Vernonia adoensis</i>	1	0.13	5	0.01	0.00	0.01	1.28	0.09	0.23
124	<i>Vernonia myriantha</i>	21	2.70	240	0.24	0.06	0.25	61.22	4.51	7.46
125	<i>Ximenia americana</i>	6	0.77	36	0.20	0.05	0.21	9.18	0.68	1.66
Total		778	100	5321	96.88	24.72	100	1357.40	100	300

Appendix 3: Synoptic table of the five community types with >0.2 value

Species Name	Cluster number				
	1	2	3	4	5
<i>Cynodon dactylon</i>	1.38	1.33	0.79	0	0
<i>Eleusine indica</i>	0.54	0.11	0.45	0	0
<i>Cordia africana</i>	0.51	0	0.48	0	0
<i>Acacia seyal</i>	0.46	0	0	0	0
<i>Argemone mexicana</i>	0.44	0	0	0	0
<i>Eichornia crassipes</i>	0.41	0	0	0	0
<i>Erica arborea</i>	0.41	0	0	0	0
<i>Festuca macrophylla</i>	0.36	0	0	0	0
<i>Laggera crispata</i>	0.36	0.22	0.21	0	0.11
<i>Buddleja polystachya</i>	0.33	0	0.21	0	0
<i>Eucalyptus camaldulensis</i>	0.33	0	0	0	0
<i>Ficus thonningii</i>	0.33	0	0	0.33	0
<i>Oryza longistaminata</i>	0.33	0	0	0	0
<i>Cyperus latifolius</i>	0.31	0	0	0	0
<i>Digitaria abyssinica</i>	0.31	0	0.17	0.25	0
<i>Diospyros abyssinica</i>	0.28	0	0	0	0
<i>Echinochloa pyramidalis</i>	0.28	0	0	0	0
<i>Heliotropium supinum</i>	0.28	0	0	0	0
<i>Trifolium acaule</i>	0.28	0	0	0	0
<i>Amaranthus spinosus</i>	0.26	0	0	0	0
<i>Cyperus rigidifolius</i>	0.26	0.11	0	0	0
<i>Helichrysum citrispinum</i>	0.26	0	0	0	0
<i>Xanthium spinosum</i>	0.26	0	0	0	0
<i>Hypericum revolutum</i>	0.23	0	0	0	0
<i>Lobelia rhynchopetalum</i>	0.23	0	0	0	0
<i>Odontelytrum abyssinicum</i>	0.23	0	0	0	0
<i>Pennisetum ramosum</i>	0.23	0.22	0	0	0
<i>Alchemilla abyssinica</i>	0.21	0	0	0	0
<i>Haplocarpha rueppellii</i>	0.21	0	0.07	0	0
<i>Ipomoea aquatica</i>	0.21	0	0	0	0
<i>Senna petersiana</i>	0.21	0	0	0	0

Species Name	Cluster number				
	1	2	3	4	5
<i>Syzygium guineense</i>	0	7.22	0	0.5	0
<i>Phoenix reclinata</i>	0	2.44	0.24	0.17	0
<i>Persicaria senegalensis</i>	0.05	1.44	0	0	0
<i>Hygrophila schulli</i>	0.54	1.33	0.17	0	0
<i>Senna didymobotrya</i>	0.26	1.22	0.31	0	0
<i>Ageratum conyzoides</i>	0.38	0.89	0.66	0.08	0
<i>Sida schimperiana</i>	0.31	0.89	0.17	0.17	0
<i>Xanthium strumarium</i>	0.28	0.78	0	0	0
<i>Aloe macrocarpa</i>	0	0.56	0.07	0	0
<i>Pennisetum thunbergii</i>	0.38	0.44	0.03	0.17	0
<i>Celtis africana</i>	0	0.33	0	0	0
<i>Abutilon bidentatum</i>	0	0.33	0	0	0
<i>Pavonia schimperiana</i>	0.03	0.33	0.07	0	0
<i>Rumex nepalensis</i>	0.21	0.33	0	0	0.11
<i>Sporobolus africanus</i>	0.13	0.33	0.03	0.08	0
<i>Vernonia hochstetteri</i>	0	0.33	0	0	0
<i>Eragrostis botryodes</i>	0	0.22	0	0	0
<i>Eragrostis tenuifolia</i>	0.03	0.22	0	0	0
<i>Galinsoga quadriradiata</i>	0.03	0.22	0.21	0	0
<i>Pennisetum sphacelatum</i>	0	0.22	0	0	0
<i>Persicaria nepalensis</i>	0.1	0.22	0	0.17	0
<i>Steganotaenia araliacea</i>	0	0.22	0.14	0	0
<i>Trifolium rueppellianum</i>	0.13	0.22	0.07	0.08	0
<i>Croton macrostachyus</i>	0.15	1.78	2.62	1	0.89
<i>Grewia ferruginea</i>	0.13	0.56	1.9	1.67	0
<i>Guizotia scabra</i>	0.49	0.33	1.69	1.33	0.89
<i>Acacia albida.</i>	0.21	0	1.55	1.17	0
<i>Albizia schimperiana</i>	0.36	0	1.21	0.75	1
<i>Capparis tomentosa</i>	0.03	0.56	1.03	0.42	0
<i>Achyranthes aspera</i>	0.31	0.22	1	0.5	0.44
<i>Schrebera alata</i>	0	0	0.93	0.25	0
<i>Ficus sycomorus</i>	0.1	0	0.83	0	0

Species Name	Cluster number				
	1	2	3	4	5
<i>Olea europaea</i>	0.18	0	0.72	0.42	0
<i>Flueggea virosa</i>	0.13	0.22	0.69	0.17	0
<i>Rhoicissus tridentata</i>	0	0.22	0.69	0.17	0
<i>Acacia venosa</i>	0	0	0.66	0.25	0
<i>Girardinia bulbosa</i>	0	0	0.66	0	0.44
<i>Sapium ellipticum</i>	0.31	0.44	0.66	0.5	0
<i>Acokanthera schimperi</i>	0	0.11	0.62	0	0
<i>Senna singueana</i>	0.05	0.22	0.62	0.08	0
<i>Acacia lahai</i>	0.36	0	0.59	0	0
<i>Allophylus abyssinicus</i>	0.08	0	0.55	0.5	0
<i>Apodytes dimidiata</i>	0	0	0.55	0.25	0
<i>Ficus vasta</i>	0	0	0.52	0	0
<i>Bersama abyssinica</i>	0.28	0.22	0.48	0.17	1.11
<i>Justicia ladanoides</i>	0.15	0	0.45	0	0.33
<i>Leucas martinicensis</i>	0.03	0	0.45	0.25	0
<i>Cissus petiolata</i>	0.08	0	0.38	0	0
<i>Ficus sur</i>	0	0	0.38	0	0
<i>Millettia ferruginea</i>	0.31	0	0.34	0	0
<i>Acacia abyssinica</i>	0.1	0	0.28	0.25	0
<i>Bidens pilosa</i>	0.05	0	0.28	0.08	0
<i>Euclea racemosa</i>	0	0	0.28	0	0
<i>Kalanchoe petitiiana</i>	0.05	0	0.28	0.17	0.11
<i>Tagetes minuta</i>	0	0	0.28	0	0
<i>Combretum collinum</i> subsp. <i>collinum</i>	0	0	0.24	0	0
<i>Eustachys paspaloides</i>	0	0	0.24	0.08	0
<i>Rhamnus staddo</i>	0	0	0.24	0	0
<i>Triumfetta rhomboidea</i>	0	0	0.24	0.17	0
<i>Crotalaria quartiniana</i>	0	0	0.21	0	0
<i>Justicia schimperiana</i>	0.15	0	0.21	0	0
<i>Ruttya speciosa</i>	0	0	0.21	0	0
<i>Dodonea angustifolia</i>	0	0	0.24	5.33	0
<i>Premna schimperi</i>	0.08	0.33	0.97	2.92	0.22

Species Name	Cluster number				
	1	2	3	4	5
<i>Carissa spinarum</i>	0.08	0.67	1.69	2.58	2.22
<i>Rhus vulgaris</i>	0	0.22	1.1	2.33	0
<i>Osyris quadripartita</i>	0	0.22	0.28	2.08	0
<i>Hyparrhenia rufa</i>	0.21	0	0.38	1.42	0
<i>Acanthus polystachius</i>	0.03	0.33	0.21	1.33	0
<i>Combretum molle</i>	0.15	0	0	1.33	0
<i>Vernonia myriantha</i>	0.51	0	0.79	1.33	1
<i>Jasminum grandiflorum</i>	0.03	0	0	1.25	0.33
<i>Phaulopsis imbricata</i>	0	0	0.62	1.17	0.22
<i>Lippia adoensis</i>	0.1	0	0.07	1.08	0.56
<i>Pittosporum viridiflorum</i>	0	0	0.72	1.08	0.44
<i>Otostegia integrifolia</i>	0	0	0	1	0
<i>Bidens prestinaria</i>	0.08	0.11	0.17	0.92	0.22
<i>Jasminum abyssinicum</i>	0	0	0.24	0.75	0
<i>Ocimum urticifolium</i>	0	0.56	0.69	0.75	0
<i>Stereospermum kunthianum</i>	0.08	0.44	0.38	0.75	0
<i>Acacia tortilis</i>	0	0	0	0.58	0
<i>Gardenia ternifolia</i>	0.1	0.33	0.41	0.5	0
<i>Hyparrhenia filipendula</i>	0.08	0	0.24	0.5	0
<i>Juniperus procera</i>	0.44	0	0.34	0.5	0
<i>Pavonia burchellii</i>	0.08	0	0.14	0.5	0
<i>Clerodendrum myricoides</i>	0	0	0.41	0.42	0
<i>Tagetes patula</i>	0	0	0.21	0.42	0
<i>Pavetta oliveriana</i>	0	0	0	0.42	0.11
<i>Tagetes patula</i>	0	0	0.21	0.42	0
<i>Vernonia amygdalina</i>	0	0	0.1	0.42	0.33
<i>Ximenia americana</i>	0.08	0.22	0.21	0.42	0
<i>Andropogon abyssinicus</i>	0.23	0.11	0.03	0.33	0.33
<i>Clematis simensis</i>	0	0	0	0.33	0.33
<i>Erythrina abyssinica</i>	0	0	0.1	0.33	0
<i>Ficus thonningii</i>	0.33	0	0	0.33	0
<i>Buddleja davidii</i>	0	0	0	0.25	0

Species Name	Cluster number				
	1	2	3	4	5
<i>Gnidia glauca</i>	0	0	0	0.25	0
<i>Hyparrhenia hirta</i>	0	0	0	0.25	0
<i>Maytenus undata</i>	0.13	0	0.14	0.25	0
<i>Rhus glutinosa</i> subsp. <i>gulutinosa</i>	0	0	0.07	0.25	0
<i>Satureja abyssinica</i>	0	0	0	0.25	0
<i>Sida rhombifolia</i>	0.03	0	0.03	0.25	0
<i>Vernonia leopoldi</i>	0	0	0.03	0.25	0
<i>Chionanthus mildbraedii</i>	0	0	0	0	7.44
<i>Maytenus arbutifolia</i>	0	2.33	2.72	1.25	4.44
<i>Ekebergia capensis</i>	0	0	0.24	0	3.67
<i>Calpurnia aurea</i>	0.08	1.33	2.48	1.67	3.56
<i>Lepidotrichilia volkensii</i>	0	0	0	0	2.44
<i>Oplismenus hirtellus</i>	0.05	0	0.21	0.67	2.11
<i>Prunus africana</i>	0	0	0.24	0	2.11
<i>Clausena anisata</i>	0.15	0.33	0.97	0.92	2
<i>Bridelia micrantha</i>	0	0	0	0	1.89
<i>Hypoestest forskoolii</i>	0.08	0	0.59	0	1.67
<i>Teclea nobilis</i>	0	0	1.1	0	1.67
<i>Clutia abyssinica</i>	0.18	0	0.31	0.92	1.56
<i>Galinierea saxifraga</i>	0	0	0.14	0	1.56
<i>Schefflera abyssinica</i>	0	0	0.17	0	1.33
<i>Dombeya torrida</i>	0	0	0	0	1.22
<i>Podocarpus falcatus</i>	0	0	0	0	1.22
<i>Solanecio gigas</i>	0	0	0	0	1.22
<i>Bersama abyssinica</i>	0.28	0.22	0.48	0.17	1.11
<i>Hypoestes triflora</i>	0.05	0	0.59	0	0.89
<i>Achyrospermum schimperii</i>	0	0	0.17	0	0.89
<i>Euphorbia abyssinica</i>	0.15	0	0.34	0	0.78
<i>Dovyalis abyssinica</i>	0.05	0.33	0.07	0.25	0.78
<i>Pimpinella hirtella</i>	0.03	0	0.07	0.17	0.78
<i>Rubus apetalus</i>	0	0	0	0	0.78
<i>Geranium arabicum</i>	0.05	0	0.1	0	0.67

Species Name	Cluster number				
	1	2	3	4	5
<i>Cyperus fischerianus</i>	0	0.22	0.24	0.33	0.67
<i>Adiantum poiretii</i>	0	0	0.21	0.17	0.56
<i>Embelia schimperi</i>	0	0	0	0	0.56
<i>Brucea antidysenterica</i>	0.08	0	0.24	0.08	0.44
<i>Sanicula elata</i>	0	0	0	0	0.44
<i>Andropogon abyssinicus</i>	0.23	0.11	0.03	0.33	0.33
<i>Agrocharis melanantha</i>	0.15	0	0	0	0.33
<i>Bothriocline schimperi</i>	0	0	0	0	0.33
<i>Carex spicato paniculata</i>	0	0	0.03	0	0.33
<i>Clematis simensis</i>	0	0	0	0.33	0.33
<i>Ocimum lamiifolium</i>	0	0.22	0	0	0.33
<i>Phytolacca dodecandra</i>	0	0.22	0.07	0.08	0.33
<i>Selaginella abyssinica</i>	0	0	0	0	0.33
<i>Urera hypselodendron</i>	0	0	0.14	0	0.33
<i>Plectranthus punctatus</i>	0.08	0	0	0	0.22
<i>Solanum anguivi</i>	0.05	0	0.07	0	0.22
<i>Desmodium repandum</i>	0	0	0	0	0.22
<i>Mikaniopsis clematoides</i>	0	0	0	0	0.22
<i>Sonchus bipontini</i>	0	0	0.03	0.08	0.22
<i>Vernonia wollastonii</i>	0	0	0	0	0.22

Appendix 4: Incidence of species in the corresponding DBH and species number

Key: (1) = 2.51-12.5, (2) = 12.51-22.5, (3) = 22.51-32.5, (4) = 32.51-42.5, (5) = 42.51-52.5, (6) = 52.51-62.5, (7) = 62.51-72.5, (8) = 72.51-82.5, (9) = 82.51-92.5, (10) = 92.51-102.5 and (11) = >102.5.

No	Species Name	DBH Class											
		1	2	3	4	5	6	7	8	9	10	11	Total
1	<i>Acacia abyssinica</i>	1	1	0	0	0	0	0	0	0	0	0	2
2	<i>Acacia albida</i>	1	1	1	1	0	0	0	0	0	0	0	4
3	<i>Acacia lahai</i>	1	1	1	1	0	0	0	0	0	0	0	4
4	<i>Acacia seyal</i>	1	1	1	1	0	0	0	0	0	0	0	4
5	<i>Acacia sieberiana</i>	1	1	1	0	0	0	0	0	0	0	0	3
6	<i>Acacia tortilis</i>	1	0	1	0	0	0	0	0	0	0	0	2
7	<i>Acacia venosa</i>	1	1	1	1	0	0	0	0	0	0	0	4
8	<i>Acokanthera schimperi</i>	1	0	0	0	0	0	0	0	0	0	0	1
9	<i>Albizia gummifera</i>	0	1	0	0	0	0	0	0	0	0	0	1
10	<i>Albizia malacophylla</i>	0	1	0	0	0	0	0	0	0	0	0	1
11	<i>Albizia schimperiana</i>	1	1	1	1	1	0	1	0	0	0	0	6
12	<i>Allophylus abyssinicus</i>	1	1	1	1	0	0	0	0	0	0	0	4
13	<i>Apodytes dimidiata</i>	1	1	1	0	1	0	1	0	0	0	0	5
14	<i>Arundinaria alpina</i>	1	0	0	0	0	0	0	0	0	0	0	1
15	<i>Bersama abyssinica</i>	1	1	1	0	0	0	0	0	0	0	0	3
16	<i>Bridelia micrantha</i>	1	0	0	0	0	0	0	0	0	0	0	1
17	<i>Brucea antidysenterica</i>	1	0	0	0	0	0	0	0	0	0	0	1
18	<i>Buddleja polystachya</i>	1	1	0	0	0	0	0	0	0	0	0	2
19	<i>Caesalpinia decapetala</i>	1	0	0	0	0	0	0	0	0	0	0	1
20	<i>Calotropis procera</i>	1	0	0	0	0	0	0	0	0	0	0	1
21	<i>Calpurnia aurea</i>	1	1	0	0	0	0	0	0	0	0	0	2
22	<i>Canthium oligocarpum</i>	1	0	0	0	0	0	0	0	0	0	0	1
23	<i>Capparis tomentosa</i>	1	0	0	0	0	0	0	0	0	0	0	1
24	<i>Carissa spinarum</i>	1	1	0	0	0	0	0	0	0	0	0	2
25	<i>Celtis africana</i>	0	0	0	0	0	0	0	0	0	1	0	1
26	<i>Chionanthus mildbraedii</i>	1	1	1	1	1	1	1	1	1	1	0	10
27	<i>Cissus petiolata</i>	1	0	0	0	0	0	0	0	0	0	0	1

No	Species Name	DBH Class											
		1	2	3	4	5	6	7	8	9	10	11	Total
28	<i>Clausena anisata</i>	1	0	0	0	0	0	0	0	0	0	0	1
29	<i>Clerodendrum myricoides</i>	1	0	0	0	0	0	0	0	0	0	0	1
30	<i>Clutia abyssinica</i>	1	0	0	0	0	0	0	0	0	0	0	1
31	<i>Combretum collinum</i> subsp. <i>collinum</i>	1	1	0	1	1	0	0	0	0	0	0	4
32	<i>Combretum molle</i>	1	1	1	1	0	1	0	0	0	0	0	5
33	<i>Cordia africana</i>	1	1	1	1	0	1	0	0	0	0	0	5
34	<i>Croton macrostachyus</i>	1	1	1	1	1	0	1	0	0	0	0	6
35	<i>Diospyros abyssinica</i>	0	1	1	0	0	1	0	0	0	0	0	3
36	<i>Discopodium penninervium</i>	1	0	0	0	0	0	0	0	0	0	0	1
37	<i>Dodonea angustifolia</i>	1	1	0	0	0	0	0	0	0	0	0	2
38	<i>Dombeya torrida</i>	1	1	0	0	0	0	0	0	0	0	0	2
39	<i>Dovyalis abyssinica</i>	1	1	0	0	0	0	0	0	0	0	0	2
40	<i>Echinops longisetus</i>	1	1	0	0	0	0	0	0	0	0	0	2
41	<i>Ekebergia capensis</i>	1	1	0	1	0	1	1	0	1	1	0	7
42	<i>Embelia schimperi</i>	1	0	0	0	0	0	0	0	0	0	0	1
43	<i>Entada abyssinica</i>	0	1	0	0	0	0	0	0	0	0	0	1
44	<i>Erica arborea</i>	1	0	0	0	0	0	0	0	0	0	0	1
45	<i>Erythrina abyssinica</i>	1	0	0	0	0	0	0	0	0	0	0	1
46	<i>Eucalyptus camaldulensis</i>	1	1	1	0	0	0	0	0	0	0	0	3
47	<i>Euclea racemosa</i>	1	0	0	0	0	0	0	0	0	0	0	1
48	<i>Euclea racemosa</i> Murr. subsp. <i>schimperi</i>	1	0	0	0	0	0	0	0	0	0	0	1
49	<i>Euphorbia abyssinica</i>	1	1	1	1	1	0	0	0	0	0	0	5
50	<i>Ficus sur</i>	1	1	1	0	0	0	0	0	0	0	0	3
51	<i>Ficus sycomorus</i>	0	1	1	1	1	0	1	0	0	1	0	6
52	<i>Ficus thonningii</i>	0	1	0	1	0	0	0	1	0	0	1	4
53	<i>Ficus vasta</i>	0	0	0	1	0	0	0	0	0	1	0	2
54	<i>Flacourtia indica</i>	1	1	0	0	0	0	0	0	0	0	0	2
55	<i>Flueggea virosa</i> subsp. <i>Virosa</i>	1	0	0	0	0	0	0	0	0	0	0	1

No	Species Name	DBH Class											
		1	2	3	4	5	6	7	8	9	10	11	Total
56	<i>Galiniera saxifraga</i>	1	0	0	1	0	0	0	0	0	0	0	2
57	<i>Gardenia ternifolia</i>	1	1	0	0	0	0	0	0	0	0	0	2
58	<i>Gnidia glauca</i>	1	0	0	0	0	0	0	0	0	0	0	1
59	<i>Grewia ferruginea</i>	1	1	1	0	0	0	0	0	0	0	0	3
60	<i>Hypericum revolutum</i>	1	0	0	0	0	0	0	0	0	0	0	1
61	<i>Hypericum quartinianum</i>	1	0	0	0	0	0	0	0	0	0	0	1
62	<i>Jasminum grandiflorum</i>	1	0	0	0	0	0	0	0	0	0	0	1
63	<i>Jasminum abyssinicum</i>	1	0	0	0	0	0	0	0	0	0	0	1
64	<i>Juniperus procera</i>	1	1	1	0	1	0	1	1	0	1	1	8
65	<i>Justicia schimperiana</i>	1	0	0	0	0	0	0	0	0	0	0	1
66	<i>Lantana viburnoides</i>	1	0	0	0	0	0	0	0	0	0	0	1
67	<i>Lepidotrichilia volkensisii</i>	1	0	0	0	0	0	0	0	0	0	0	1
68	<i>Lobelia rhynchopetalum</i>	1	0	0	0	0	0	0	0	0	0	0	1
69	<i>Maesa lanceolata</i>	1	0	0	0	0	0	0	0	0	0	0	1
70	<i>Maytenus arbutifolia</i>	1	1	0	0	0	0	0	0	0	0	0	2
71	<i>Maytenus gracilipes</i>	1	0	0	0	0	0	0	0	0	0	0	1
72	<i>Maytenus obscura</i>	0	0	1	0	0	0	0	0	0	0	0	1
73	<i>Maytenus serrata</i>	1	0	0	0	0	0	0	0	0	0	0	1
74	<i>Maytenus undata</i>	1	1	1	0	0	0	1	0	0	0	0	4
75	<i>Millettia ferruginea</i>	1	1	1	0	0	0	0	0	0	0	0	3
76	<i>Mimosa pigra</i>	1	0	0	0	0	0	0	0	0	0	0	1
77	<i>Mimusops kummel</i>	0	0	1	0	0	0	0	0	0	0	0	1
78	<i>Myrsine africana</i>	1	0	0	0	0	0	0	0	0	0	0	1
79	<i>Nuxia congesta</i>	0	0	0	0	0	1	1	0	0	0	0	2
80	<i>Ocimum urticifolium</i>	1	0	0	0	0	0	0	0	0	0	0	1
81	<i>Olea europaea</i>	1	1	1	1	1	1	1	0	0	1	0	8
82	<i>Osyris quadripartita</i>	1	0	0	0	0	0	0	0	0	0	0	1
83	<i>Pavetta oliveriana</i>	1	0	0	0	0	0	0	0	0	0	0	1
84	<i>Phoenix reclinata</i>	1	1	0	0	0	0	0	0	0	0	0	2
85	<i>Phyllanthus ovalifolius</i>	1	0	0	0	0	0	0	0	0	0	0	1
86	<i>Phytolacca dodecandra</i>	1	1	0	0	0	0	0	0	0	0	0	2

No	Species Name	DBH Class											Total
		1	2	3	4	5	6	7	8	9	10	11	
87	<i>Piliostigma thonningii</i>	1	1	0	0	0	0	0	0	0	0	0	2
88	<i>Pittosporum viridiflorum</i>	1	1	1	1	0	0	0	0	0	0	0	4
89	<i>Pluchea dioscoridis</i>	1	0	0	0	0	0	0	0	0	0	0	1
90	<i>Podocarpus falcatus</i>	1	1	1	0	0	0	0	0	0	0	0	3
91	<i>Premna schimperi</i>	1	0	0	0	0	0	0	0	0	0	0	1
92	<i>Protea gagedi</i>	1	0	0	0	0	0	0	0	0	0	0	1
93	<i>Prunus africana</i>	1	1	1	1	0	0	1	1	0	0	0	6
94	<i>Pterolobium stellatum</i>	1	0	0	0	0	0	0	0	0	0	0	1
95	<i>Rhamnus staddo</i>	1	0	0	0	0	0	0	0	0	0	0	1
96	<i>Rhoicissus tridentata</i>	1	0	0	0	0	0	0	0	0	0	0	1
97	<i>Rhus glutinosa</i> subsp. <i>gulinosa</i>	1	0	0	0	0	0	0	0	0	0	0	1
98	<i>Rhus glutinosa</i> subsp. <i>neoglutinosa</i>	1	0	0	0	0	0	0	0	0	0	0	1
99	<i>Rhus vulgaris</i>	1	1	0	0	0	0	0	0	0	0	0	2
100	<i>Rosa abyssinica</i>	1	0	0	0	0	0	0	0	0	0	0	1
101	<i>Rubus apetalus</i>	1	0	0	0	0	0	0	0	0	0	0	1
102	<i>Ruttya speciosa</i>	1	0	0	0	0	0	0	0	0	0	0	1
103	<i>Rytigynia neglecta</i>	1	0	0	0	0	0	0	0	0	0	0	1
104	<i>Salix subserrata</i>	1	0	0	0	0	0	0	0	0	0	0	1
105	<i>Sapium ellipticum</i>	1	1	1	1	1	1	1	0	1	1	0	9
106	<i>Schefflera abyssinica</i>	0	0	0	0	0	1	1	1	1	1	1	6
107	<i>Schinus molle</i>	1	0	0	0	0	0	0	0	0	0	0	1
108	<i>Schrebera alata</i>	1	1	1	1	1	0	0	0	0	0	0	5
109	<i>Scolopia theifolia</i>	1	0	0	0	0	0	0	0	0	0	0	1
110	<i>Senna didymobotrya</i>	1	0	0	0	0	0	0	0	0	0	0	1
111	<i>Senna obtusifolia</i>	1	0	0	0	0	0	0	0	0	0	0	1
112	<i>Senna petersiana</i>	1	1	0	0	0	0	0	0	0	0	0	2
113	<i>Senna singueana</i>	1	0	0	0	0	0	0	0	0	0	0	1
114	<i>Solanecio gigas</i>	1	0	0	0	0	0	0	0	0	0	0	1
115	<i>Solanum giganteum</i>	1	0	0	0	0	0	0	0	0	0	0	1

No	Species Name	DBH Class											
		1	2	3	4	5	6	7	8	9	10	11	Total
116	<i>Steganotaenia araliacea</i>	1	1	0	0	0	0	0	0	0	0	0	2
117	<i>Stereospermum kunthianum</i>	1	1	1	0	0	0	0	0	0	0	0	3
118	<i>Syzygium guineense</i>	1	1	1	1	1	1	1	1	0	1	0	9
119	<i>Teclea nobilis</i>	1	1	1	1	0	0	0	0	0	0	0	4
120	<i>Terminalia schimperiana</i>	1	0	0	0	0	0	0	0	0	0	0	1
121	<i>Urera hypselodendron</i>	1	0	0	0	0	0	0	0	0	0	0	1
122	<i>Vernonia amygdalina</i>	1	0	1	0	0	0	0	0	0	0	0	2
123	<i>Vernonia adoensis</i>	1	0	0	0	0	0	0	0	0	0	0	1
124	<i>Vernonia myriantha</i>	1	0	0	0	0	0	0	0	0	0	0	1
125	<i>Ximenia americana</i>	1	1	0	0	0	0	0	0	0	0	0	2
Total species		113	55	35	24	12	10	14	6	4	10	3	286

Appendix 5: Incidence of species in the corresponding height class and species number

Key: 1 (2.5-5.5), 2 (5.51-8.5), 3 (8.51-11.5), 4 (11.51-14.5), 5 (14.51-17.5), 6 (17.51-20.5), 7 (20.51-23.5), 8 (23.51-26.5), 9 (26.51-29.5) and 10 (>29.5) in meter.

No	Species Name	Height Class										Total
		1	2	3	4	5	6	7	8	9	10	
1	<i>Acacia abyssinica</i>	1	1	0	0	0	0	0	0	0	0	2
2	<i>Acacia albida</i>	1	1	1	1	0	0	0	0	0	0	4
3	<i>Acacia lahai</i>	1	1	1	0	0	0	0	0	0	0	3
4	<i>Acacia seyal</i>	1	1	1	0	0	0	0	0	0	0	3
5	<i>Acacia sieberiana</i>	1	1	1	0	0	0	0	0	0	0	3
6	<i>Acacia tortilis</i>	1	1	1	0	0	0	0	0	0	0	3
7	<i>Acacia venosa</i>	1	1	1	0	0	0	0	0	0	0	3
8	<i>Acokanthera schimperi</i>	1	0	0	0	0	0	0	0	0	0	1
9	<i>Albizia gummifera</i>	0	1	1	0	0	0	0	0	0	0	2
10	<i>Albizia malacophylla</i>	1	0	0	0	0	0	0	0	0	0	1
11	<i>Albizia schimperiana</i>	1	1	1	1	1	1	0	1	1	0	8
12	<i>Allophylus abyssinicus</i>	1	1	1	1	1	0	0	0	0	0	5
13	<i>Apodytes dimidiata</i>	1	1	0	1	0	1	0	0	0	0	4
14	<i>Arundinaria alpina</i>	1	1	0	0	0	0	0	0	0	0	2
15	<i>Bersama abyssinica</i>	1	1	1	0	0	0	0	0	0	0	3
16	<i>Bridelia micrantha</i>	1	1	0	0	0	0	0	0	0	0	2
17	<i>Brucea antidysenterica</i>	1	0	0	0	0	0	0	0	0	0	1
18	<i>Buddleja polystachya</i>	1	1	0	0	0	0	0	0	0	0	2
19	<i>Caesalpinia decapetala</i>	1	0	0	0	0	0	0	0	0	0	1
20	<i>Calotropis procera</i>	1	0	0	0	0	0	0	0	0	0	1
21	<i>Calpurnia aurea</i>	1	1	0	1	0	0	0	0	0	0	3
22	<i>Canthium oligocarpum</i>	1	1	0	0	0	0	0	0	0	0	2
23	<i>Capparis tomentosa</i>	1	1	1	1	0	0	0	0	0	1	5
24	<i>Carissa spinarum</i>	1	1	1	1	0	0	0	0	0	0	4
25	<i>Celtis africana</i>	0	0	0	0	0	1	1	0	0	0	2
26	<i>Chionanthus mildbraedii</i>	1	1	1	1	1	1	1	1	1	1	10
27	<i>Cissus petiolata</i>	0	0	1	0	0	0	0	0	0	0	1
28	<i>Clausena anisata</i>	1	1	0	0	0	0	0	0	0	0	2

No	Species Name	Height Class										Total
		1	2	3	4	5	6	7	8	9	10	
29	<i>Clerodendrum myricoides</i>	1	1	0	0	0	0	0	0	0	0	2
30	<i>Clutia abyssinica</i>	1	0	0	0	0	0	0	0	0	0	1
31	<i>Combretum collinum</i> subsp. <i>collinum</i>	1	1	0	0	0	0	0	0	0	0	2
32	<i>Combretum molle</i>	1	1	1	1	0	0	0	0	0	0	4
33	<i>Cordia africana</i>	1	1	1	0	1	0	0	0	0	0	4
34	<i>Croton macrostachyus</i>	1	1	1	1	1	1	0	0	0	0	6
35	<i>Diospyros abyssinica</i>	0	1	1	1	0	0	0	0	0	0	3
36	<i>Discopodium penninervium</i>	1	0	0	0	0	0	0	0	0	0	1
37	<i>Dodonea angustifolia</i>	1	0	0	0	0	0	0	0	0	0	1
38	<i>Dombeya torrida</i>	1	1	0	0	0	0	0	0	0	0	2
39	<i>Dovyalis abyssinica</i>	1	1	0	0	0	0	0	0	0	0	2
40	<i>Echinops longisetus</i>	1	0	0	0	0	0	0	0	0	0	1
41	<i>Ekebergia capensis</i>	1	1	1	0	0	1	0	1	1	1	7
42	<i>Embelia schimperi</i>	1	0	0	0	0	0	0	0	0	0	1
43	<i>Entada abyssinica</i>	1	1	0	0	0	0	0	0	0	0	2
44	<i>Erica arborea</i>	1	0	0	0	0	0	0	0	0	0	1
45	<i>Erythrina abyssinica</i>	1	1	0	0	0	0	0	0	0	0	2
46	<i>Eucalyptus camaldulensis</i>	1	1	1	1	1	1	0	0	0	0	6
47	<i>Euclea racemosa</i>	1	0	0	0	0	0	0	0	0	0	1
48	<i>Euclea racemosa</i> Murr. subsp. <i>schimperi</i>	1	0	0	0	0	0	0	0	0	0	1
49	<i>Euphorbia abyssinica</i>	1	1	1	1	0	0	0	0	0	0	4
50	<i>Ficus sur</i>	1	1	1	0	1	0	0	0	0	0	4
51	<i>Ficus sycomorus</i>	0	1	1	1	1	0	0	0	0	1	5
52	<i>Ficus thonningii</i>	0	1	1	1	0	0	0	0	0	1	4
53	<i>Ficus vasta</i>	1	0	1	0	0	1	0	1	0	0	4
54	<i>Flacourtia indica</i>	0	1	0	0	0	0	0	0	0	0	1
55	<i>Flueggea virosa</i> subsp. <i>Virosa</i>	1	0	0	0	0	0	0	0	0	0	1
56	<i>Galiniera saxifraga</i>	1	1	0	0	0	1	0	0	0	0	3
57	<i>Gardenia ternifolia</i>	1	0	0	0	0	0	0	0	0	0	1

No	Species Name	Height Class										Total
		1	2	3	4	5	6	7	8	9	10	
58	<i>Gnidia glauca</i>	1	0	0	0	0	0	0	0	0	0	1
59	<i>Grewia ferruginea</i>	1	1	1	1	0	0	0	0	0	0	4
60	<i>Hypericum revolutum</i>	1	0	0	0	0	0	0	0	0	0	1
61	<i>Hypericum quartinianum</i>	1	0	0	0	0	0	0	0	0	0	1
62	<i>Jasminum grandiflorum</i>	1	1	0	0	0	0	0	0	0	0	2
63	<i>Jasminum abyssinicum</i>	1	0	0	0	0	0	0	0	0	0	1
64	<i>Juniperus procera</i>	1	1	1	1	1	1	1	0	0	0	7
65	<i>Justicia schimperiana</i>	1	1	0	0	0	0	0	0	0	0	2
66	<i>Lantana viburnoides</i>	1	0	0	0	0	0	0	0	0	0	1
67	<i>Lepidotrichilia volkensii</i>	1	1	0	0	0	0	0	0	0	0	2
68	<i>Lobelia rhynchopetalum</i>	1	0	0	0	0	0	0	0	0	0	1
69	<i>Maesa lanceolata</i>	1	0	0	0	0	0	0	0	0	0	1
70	<i>Maytenus arbutifolia</i>	1	1	0	0	0	0	0	0	0	0	2
71	<i>Maytenus gracilipes</i>	1	0	0	0	0	0	0	0	0	0	1
72	<i>Maytenus obscura</i>	1	0	0	0	0	0	0	0	0	0	1
73	<i>Maytenus serrata</i>	1	0	0	0	0	0	0	0	0	0	1
74	<i>Maytenus undata</i>	1	1	1	0	1	1	0	0	0	0	5
75	<i>Millettia ferruginea</i>	1	1	1	1	1	0	0	0	0	0	5
76	<i>Mimosa pigra</i>	1	1	0	0	0	0	0	0	0	0	2
77	<i>Mimusops kummel</i>	0	0	0	1	0	0	0	0	0	0	1
78	<i>Myrsine africana</i>	1	0	0	0	0	0	0	0	0	0	1
79	<i>Nuxia congesta</i>	0	0	0	1	1	0	0	0	0	0	2
80	<i>Ocimum urticifolium</i>	1	0	0	0	0	0	0	0	0	0	1
81	<i>Olea europaea</i>	1	1	1	1	1	1	1	1	1	1	10
82	<i>Osyris quadripartita</i>	1	1	0	0	0	0	0	0	0	0	2
83	<i>Pavetta oliveriana</i>	1	0	0	0	0	0	0	0	0	0	1
84	<i>Phoenix reclinata</i>	1	1	0	0	0	0	0	0	0	0	2
85	<i>Phyllanthus ovalifolius</i>	1	0	0	0	0	0	0	0	0	0	1
86	<i>Phytolacca dodecandra</i>	1	1	1	0	0	0	0	0	0	0	3
87	<i>Piliostigma thonningii</i>	1	0	0	0	0	0	0	0	0	0	1
88	<i>Pittosporum viridiflorum</i>	1	1	1	1	0	1	0	0	0	0	5

No	Species Name	Height Class										Total
		1	2	3	4	5	6	7	8	9	10	
89	<i>Pluchea dioscoridis</i>	1	0	0	0	0	0	0	0	0	0	1
90	<i>Podocarpus falcatus</i>	1	1	1	1	1	1	1	0	0	0	7
91	<i>Premna schimperi</i>	1	1	0	0	0	0	0	0	0	0	2
92	<i>Protea gagedi</i>	1	0	0	0	0	0	0	0	0	0	1
93	<i>Prunus africana</i>	1	1	1	0	0	1	1	1	1	0	7
94	<i>Pterolobium stellatum</i>	1	1	1	0	0	1	0	0	0	1	5
95	<i>Rhamnus staddo</i>	1	0	0	0	0	0	0	0	0	0	1
96	<i>Rhoicissus tridentata</i>	1	1	1	1	1	0	0	0	0	0	5
97	<i>Rhus glutinosa</i> subsp. <i>glutinosa</i>	1	0	0	0	0	0	0	0	0	0	1
98	<i>Rhus glutinosa</i> subsp. <i>neoglutinosa</i>	1	0	0	0	0	0	0	0	0	0	1
99	<i>Rhus vulgaris</i>	1	1	0	0	0	0	0	0	0	1	3
100	<i>Rosa abyssinica</i>	1	0	0	0	0	0	0	0	0	0	1
101	<i>Rubus apetalus</i>	1	0	0	0	0	0	0	0	0	0	1
102	<i>Ruttya speciosa</i>	1	1	0	0	0	0	0	0	0	0	2
103	<i>Rytigynia neglecta</i>	1	0	0	0	0	0	0	0	0	0	1
104	<i>Salix subserrata</i>	1	0	0	0	0	0	0	0	0	0	1
105	<i>Sapium ellipticum</i>	1	1	1	1	0	1	1	1	1	1	9
106	<i>Schefflera abyssinica</i>	0	0	0	0	0	1	1	1	1	1	5
107	<i>Schinus molle</i>	1	0	0	0	0	0	0	0	0	0	1
108	<i>Schrebera alata</i>	1	1	1	1	0	1	0	0	0	0	5
109	<i>Scolopia theifolia</i>	1	0	0	0	0	0	0	0	0	0	1
110	<i>Senna didymobotrya</i>	1	0	0	0	0	0	0	0	0	0	1
111	<i>Senna obtusifolia</i>	1	0	0	0	0	0	0	0	0	0	1
112	<i>Senna petersiana</i>	1	1	0	0	0	0	0	0	0	0	2
113	<i>Senna singueana</i>	1	0	0	0	0	0	0	0	0	0	1
114	<i>Solanecio gigas</i>	1	0	0	0	0	0	0	0	0	0	1
115	<i>Solanum giganteum</i>	1	0	0	0	0	0	0	0	0	0	1
116	<i>Steganotaenia araliacea</i>	1	1	0	0	0	0	0	0	0	0	2
117	<i>Stereospermum kunthianum</i>	1	1	0	0	0	0	0	0	0	0	2
118	<i>Syzygium guineense</i>	1	1	1	1	1	1	1	0	0	0	7

No	Species Name	Height Class										Total
		1	2	3	4	5	6	7	8	9	10	
119	<i>Teclea nobilis</i>	1	1	1	1	0	0	0	0	0	0	4
120	<i>Terminalia schimperiana</i>	1	0	0	0	0	0	0	0	0	0	1
121	<i>Urera hypselodendron</i>	0	1	0	1	1	1	0	0	0	1	5
122	<i>Vernonia amygdalina</i>	1	1	0	0	0	0	0	0	0	0	2
123	<i>Vernonia adoensis</i>	1	0	0	0	0	0	0	0	0	0	1
124	<i>Vernonia myriantha</i>	1	0	0	0	0	0	0	0	0	0	1
125	<i>Ximenia americana</i>	1	0	0	0	0	0	0	0	0	0	1
Total species		114	69	40	29	17	21	9	8	7	11	325

Appendix 6: List of Seedlings and/or Saplings with their correspond family

No	Species	Seedling	Sapling	Family	Habit
1	<i>Urera hypselodendron</i>	0	10	Urticaceae	Cl
2	<i>Diospyros abyssinica</i>	0	2	Ebenaceae	T
3	<i>Hypericum quartinianum</i>	0	1	Hypericaceae	Sh
4	<i>Schefflera abyssinica</i>	0	3	Araliaceae	T
5	<i>Steganotaenia araliacea</i>	0	3	Apiaceae	T
6	<i>Calotropis procera</i>	3	0	Asclepiadaceae	Sh
7	<i>Entada abyssinica</i>	2	0	Fabaceae	T
8	<i>Salix subserrata</i>	5	0	Salicaceae	Sh
9	<i>Clausena anisata</i>	462	279	Rutaceae	Sh/T
10	<i>Dodonea angustifolia</i>	409	349	Sapindaceae	Sh
11	<i>Myrsine africana</i>	73	42	Myrsinaceae	Sh
12	<i>Chionanthus mildbraedii</i>	339	33	Oleaceae	Sh/T
13	<i>Maytenus arbutifolia</i>	1200	557	Celastraceae	Sh
14	<i>Pterolobium stellatum</i>	130	68	Fabaceae	Sh
15	<i>Dombeya torrida</i>	1	0	Sterculiaceae	Sh/T
16	<i>Ficus sur</i>	2	0	Moraceae	T
17	<i>Flueggea virosa subsp. Virosa</i>	5	0	Euphorbiaceae	Sh
18	<i>Senna petersiana</i>	4	0	Fabaceae	Sh
19	<i>Pavetta oliveriana</i>	3	6	Rubiaceae	Sh
20	<i>Erica arborea</i>	127	498	Ericaceae	Sh
21	<i>Hypericum revolutum</i>	34	43	Hypericaceae	Sh
22	<i>Maytenus gracilipes</i>	18	80	Celastraceae	Sh
23	<i>Rhamnus staddo</i>	97	103	Rhamnaceae	Sh
24	<i>Discopodium penninervium</i>	5	5	Solanaceae	T
25	<i>Rosa abyssinica</i>	4	4	Rosaceae	Sh
26	<i>Acacia albida</i>	7	6	Fabaceae	T
27	<i>Clutia abyssinica</i>	40	30	Euphorbiaceae	Sh
28	<i>Dovyalis abyssinica</i>	9	6	Flacourtiaceae	Sh
29	<i>Gardenia ternifolia</i>	12	5	Rubiaceae	Sh/T
30	<i>Lobelia rhynchopetalum</i>	23	15	Lobeliaceae	H

No	Species	Seedling	Sapling	Family	Habit
31	<i>Maytenus undata</i>	10	2	Celastraceae	Sh
32	<i>Otostegia integrifolia</i>	36	12	Lamiaceae	Sh
33	<i>Phoenix reclinata</i>	29	26	Arecaceae	T
34	<i>Rhus vulgaris</i>	24	19	Anacardiaceae	Sh
35	<i>Solanecio gigas</i>	17	9	Asteraceae	Sh/T
36	<i>Syzygium guineense</i>	42	4	Myrtaceae	Sh/T
37	<i>Teclea nobilis</i>	60	35	Rutaceae	Sh
38	<i>Vernonia myriantha</i>	70	17	Asteraceae	Sh
39	<i>Bersama abyssinica</i>	36	46	Melanthaceae	Sh
40	<i>Clerodendrum myricoides</i>	5	35	Lamiaceae	Sh
41	<i>Ficus thonningii</i>	3	25	Moraceae	Sh/T
42	<i>Juniperus procera</i>	2	56	Cupressaceae	T
43	<i>Acacia abyssinica</i>	2	5	Fabaceae	T
44	<i>Acacia seyal</i>	1	3	Fabaceae	T
45	<i>Albizia schimperiana</i>	7	9	Fabaceae	T
46	<i>Allophylus abyssinicus</i>	5	18	Sapindaceae	T
47	<i>Brucea antidysenterica</i>	1	5	Simaroubaceae	Sh/T
48	<i>Buddleja polystachya</i>	7	17	Loganiaceae	Sh/T
49	<i>Calpurnia aurea</i>	207	218	Fabaceae	Sh/T
50	<i>Capparis tomentosa</i>	10	18	Capparidaceae	Sh
51	<i>Carissa spinarum</i>	32	65	Apocynaceae	Sh
52	<i>Croton macrostachyus</i>	20	37	Euphorbiaceae	Sh/T
53	<i>Ekebergia capensis</i>	4	15	Meliaceae	T
54	<i>Galiniera saxifraga</i>	7	14	Rubiaceae	Sh
55	<i>Grewia ferruginea</i>	65	95	Tiliaceae	Sh/T
56	<i>Jasminum grandiflorum</i>	7	17	Oleaceae	Cl
57	<i>Jasminum abyssinicum</i>	3	5	Oleaceae	Cl
58	<i>Lippia adoensis</i>	2	3	Verbenaceae	Sh
59	<i>Maesa lanceolata</i>	5	8	Myrsinaceae	Sh/T
60	<i>Maytenus serrata</i>	30	58	Celastraceae	Sh
61	<i>Millettia ferruginea</i>	7	10	Fabaceae	T

No	Species	Seedling	Sapling	Family	Habit
62	<i>Olea europaea</i>	6	13	Oleaceae	Sh/T
63	<i>Osyris quadripartita</i>	16	17	Santalaceae	Sh/T
64	<i>Pittosporum viridiflorum</i>	32	34	Pittosporaceae	T
65	<i>Premna schimperi</i>	7	36	Verbenaceae	Sh/T
66	<i>Prunus africana</i>	8	13	Rosaceae	T
67	<i>Rutya speciosa</i>	2	11	Acanthaceae	Sh
68	<i>Sapium ellipticum</i>	1	2	Euphorbiaceae	Sh/T
	Total	3842	3180		

Appendix 7: Soil chemistry test compared with standard soil fertility classes

Source: B. Frank 1990 (Adapted from Agricultural compendium; FAO and Booker (MTS))

Environmental variables	Soil Test Result				
	Very low	Low	Medium	High	Very high
Organic carbon	<2	2-4	4-10	10-20	>20
Recent study result (%)	0.9	-	7.4	-	-
Organic matter	<1	1-2	2-4.2	4.2-6	>6
Recent study result (%)	0	0	21.28	19.15	59.57
Total nitrogen (%)	<0.05	0.05-0.125	0.125-0.225	0.225-0.300	>0.300
Recent study result (%)	0	0	31.25	10.42	58.33
Available phosphorous (ppm)	<5	5-8	8-12	12-20	>20
Recent study result (%)	7.89	10.53	13.16	18.42	50
CEC cmol(+)kg ⁻¹	<6	6-12	13-25	26-40	>40
Recent study result (%)	0	0	8.33	52.08	39.58
Exchangeable Ca ²⁺ cmol(+)kg ⁻¹	<2	2-5	5-10	10-20	>20
Recent study result (%)		2.34	-	-	67.44
Exchangeable Mg ²⁺ cmol(+)kg ⁻¹	<0.5	0.5-1.5	1.5-3	3-8	>8
Recent study result (%)	0.09	-	2.11	-	-
Exchangeable K ¹⁺ cmol(+)kg ⁻¹	<0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2

Recent study result (%)	-	0.10	-	-	7.42
Exchangeable Na ¹⁺ cmol(+)kg ⁻¹	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2
Recent study result (%)	0.08	-	-	1.67	-
pH	<4	4-6.6	6.6-7.3	7.3-8.5	>8.5
Recent study result (%)	0	94.23	5.77	0	0
Salinity (EC dS/m)	<2	2-4	4-8	8-15	>15
Recent study result (%)	0.03-0.72	-	-	-	-

Appendix 8: List of plants species with the corresponding family in the soil seed bank

No	Species Name	Habit	Family	Code
1	<i>Acacia</i> Sp.	T	Fabaceae	SB-062
2	<i>Achyranthes aspera</i> L.	H	Amaranthaceae	SB-058
3	<i>Adiantum poiretii</i> Wikstr.	H	Adiantaceae	SB-119
4	<i>Ageratum conyzoides</i> L. subsp. <i>conyzoides</i>	H	Asteraceae	SB-036
5	<i>Agrostis quinqueseta</i> (Hochst. ex Steud.) Hochst.	H	Poaceae	SB-022
6	<i>Alchemilla pedata</i> A. Rich.	H	Rosaceae	SB-069
7	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	T	Sapindaceae	SB-064
8	<i>Amaranthus dubius</i> Thell.	H	Amaranthaceae	SB-047
9	<i>Amaranthus hybridus</i> L. <i>hybridus</i>	H	Amaranthaceae	SB-115
10	<i>Anagallis arvensis</i> L.	H	Primulaceae	SB-054
11	<i>Andropogon abyssinicus</i> Fresen.	H	Poaceae	SB-107
12	<i>Andropogon amethystinus</i> Steud.	H	Poaceae	SB-57A
13	<i>Andropogon chrysostachyus</i> Steud.	H	Poaceae	SB-114
14	<i>Arabis alpina</i> L.	H	Brassicaceae	SB-146
15	<i>Argemone mexicana</i> L.	H	Papaveraceae	SB-063
16	<i>Arthraxon micans</i> (Nees) Hochst.	H	Poaceae	SB-133
17	<i>Bidens macroptera</i> (Sch. Bip. ex Chiov.) Mesfin	H	Asteraceae	SB-42A
18	<i>Bidens pilosa</i> L.	H	Asteraceae	SB-065
19	<i>Bromus leptoclados</i> Nees	H	Poaceae	SB-098
20	<i>Buddleja polystachya</i> Fresen.	Sh	Loganiaceae	SB-082
21	<i>Calpurnia aurea</i> (Ait.) Benth.	Sh/T	Fabaceae	SB-139
22	<i>Cardamine africana</i> L.	H	Brassicaceae	SB-31A
23	<i>Cardamine hirsuta</i> L.	H	Brassicaceae	SB-060
24	<i>Cardamine trichocarpa</i> A. Rich.	H	Brassicaceae	SB-051
25	<i>Centella asiatica</i> (L.) Urban	H	Apiaceae	SB-017
26	<i>Cheilanthes farinosa</i> (Forssk.) Kaulf.	H	Sinopteridaceae	SB-007
27	<i>Chionanthus mildbraedii</i> (Gilg & Schellenb.) Stearn	T	Oleaceae	SB-106
28	<i>Chloris pycnothrix</i> Trin.	H	Poaceae	SB-057
29	<i>Clematis simensis</i> Fresen.	Cl	Ranunculaceae	SB-021

No	Species Name	Habit	Family	Code
30	<i>Clutia abyssinica</i> Jaub. & Spach.	sh	Euphorbiaceae	SB-08A
31	<i>Commelina diffusa</i> Burm.f	H	Commelinaceae	SB-048
32	<i>Commelina latifolia</i> Hochst. ex A. Rich.	H	Commelinaceae	SB-113
33	<i>Commelina reptans</i> Brenan	H	Commelinaceae	SB-053
34	<i>Cordia africana</i> Lam.	T	Boraginaceae	SB-071
35	<i>Coronopus didymus</i> (L.) Smith	H	Brassicaceae	SB-040
36	<i>Corrigiola capensis</i> Willd.	H	Molluginaceae	SB-008
37	<i>Cotula abyssinica</i> Sch. Bip. ex A. Rich.	H	Asteraceae	SB-30A
38	<i>Crassocephalum rubens</i> (Juss. ex Jacq.) S. Moore	H	Asteraceae	SB-050
39	<i>Crassula schimperi</i> Fisch. & Mey.	H	Crassulaceae	SB-143
40	<i>Crepis rueppellii</i> Sch. Bip.	H	Asteraceae	SB-025
41	<i>Crotalaria microphylla</i> Vahl	H	Fabaceae	SB-059
42	<i>Crotalaria quartiniana</i> A. Rich.	H	Fabaceae	SB-091
43	<i>Cyanotis barbata</i> D. Don	H	Commelinaceae	SB-030
44	<i>Cynodon dactylon</i> (L.) Pers.	H	Poaceae	SB-003
45	<i>Cynoglossum coeruleum</i> Hochst. Ex A.DC. in DC.	H	Boraginaceae	SB-010
46	<i>Cyperus assimilis</i> Steud.	H	Cyperaceae	SB-142
47	<i>Cyperus fischerianus</i> A. Rich.	H	Cyperaceae	SB-116
48	<i>Cyperus pauper</i> Hochst. ex A. Rich.	H	Cyperaceae	SB-123
49	<i>Cyperus sesquiflorus</i> (Torr.) Mattf & Kiik.	H	Cyperaceae	SB-127
50	<i>Cyperus</i> sp.	H	Cyperaceae	SB-131
51	<i>Datura stramonium</i> L.	H	Solanaceae	SB-01A
52	<i>Dichondra repens</i> J. R. & G. Forst.	H	Convolvulaceae	SB-070
53	<i>Dicrocephala integrifolia</i> (L. f.) O. Kuntze	H	Asteraceae	SB-073
54	<i>Digitaria abyssinica</i> (Hochst. ex A. Rich.) Stapf	H	Poaceae	SB-055
55	<i>Digitaria ternata</i> (A. Rich.) Stapf	H	Poaceae	SB-100
56	<i>Dodonea angustifolia</i> L.f.	Sh	Sapindaceae	SB-103
57	<i>Echinochloa colona</i> (L.) Link	H	Poaceae	SB-035
58	<i>Echinochloa pyramidalis</i> (Lam.) Hitchc. &	H	Poaceae	SB-55A

No	Species Name	Habit	Family	Code
	Chase			
59	<i>Ehrharta erecta</i> Lam.	H	Poaceae	SB-099
60	<i>Eleusine coracana</i> (L.) Gaertn.	H	Poaceae	SB-045
61	<i>Eleusine floccifolia</i> (Forssk.) Spreng.	H	Poaceae	SB-046
62	<i>Eleusine indica</i> (L.) Gaertn.	H	Poaceae	SB-138
63	<i>Eragrostis botryodes</i> W.D. Clayton	H	Poaceae	SB-105
64	<i>Eragrostis cilianensis</i> (AIL.) Vign. ex Janchen	H	Poaceae	SB-038
65	<i>Eragrostis macilentia</i> (A. Rich.) Steud.	H	Poaceae	SB-117
66	<i>Eragrostis tenuifolia</i> (A. Rich.) Steud.	H	Poaceae	SB-102
67	<i>Erica arborea</i> L.	Sh	Ericaceae	SB-020
68	<i>Exotheca abyssinica</i> (Hochst. ex A. Rich.) Anderss.	H	Poaceae	SB-072
69	<i>Festuca macrophylla</i> Hochst. ex A. Rich.	H	Poaceae	SB-118
70	<i>Ficus sur</i> Forssk.	T	Moraceae	SB-120
71	<i>Galinsoga quadriradiata</i> Ruiz & Pavon	H	Asteraceae	SB-002
72	<i>Galium aparinoides</i> Forssk.	H	Rubiaceae	SB-024
73	<i>Girardinia bullosa</i> (Steudel) Wedd.	H	Urticaceae	SB-049
74	<i>Guizotia scabra</i> (Vis.) Chiov.	H	Asteraceae	SB-095
75	<i>Helichrysum forsskahlii</i> (J.F Gmel.) Hilliard & Burt	H	Asteraceae	SB-041
76	<i>Helichrysum schimperi</i> (Sch. Bip. ex A. Rich.) Moeser	H	Asteraceae	SB-013
77	<i>Hordeum vulgare</i> L.	H	Poaceae	SB-51A
78	<i>Hyparrhenia anthistirioides</i> (Hochst. ex A. Rich.) Stapf	H	Poaceae	SB-097
79	<i>Hypericum revolutum</i> Vahl	Sh	Hypericaceae	SB-33A
80	<i>Hypericum peplidifolium</i> A. Rich.	H	Hypericaceae	SB-121
81	<i>Hypoestes triflora</i> (Forssk.) Roem & Schult.	H	Acanthaceae	SB-090
82	<i>Impatiens hochstetteri</i> Warb.	H	Balsaminaceae	SB-014
83	<i>Impatiens tinctoria</i> A. Rich. subsp. <i>Tinctoria</i>	H	Balsaminaceae	SB-037
84	<i>Juncus bufonius</i> L.	H	Juncaceae	SB-23A

No	Species Name	Habit	Family	Code
85	<i>Kalanchoe petitiiana</i> A. Rich.	H	Crassulaceae	SB-034
86	<i>Laggera crispata</i> (Vahl) Hepper & Wood	H	Asteraceae	SB-005
87	<i>Lens culinaris</i> Medik.	H	Fabaceae	SB-074
88	<i>Leucas aequistylosa</i> Sebald	H	Lamiaceae	SB-052
89	<i>Leucas martinicensis</i> (Jacq.) R. Br.	H	Lamiaceae	SB-140
90	<i>Maesa lanceolata</i> Forssk.	Sh	Myrsinaceae	SB-029
91	<i>Mollugo</i> Sp.	H	Molluginaceae	SB-55B
92	<i>Nelsonia canescens</i> (Lam.) Spreng.	H	Acanthaceae	SB-132
93	<i>Ocimum urticifolium</i> Roth	Sh	Lamiaceae	SB-023
94	<i>Odontelytrum abyssinicum</i> Hack.	H	Poaceae	SB-125
95	<i>Oldenlandia capensis</i> L. f.	H	Rubiaceae	SB-129
96	<i>Olea europaea</i> L. subsp. <i>cuspidata</i> (Wall. ex G. Don) Cif.	T	Oleaceae	SB-02A
97	<i>Oxalis corniculata</i> L.	H	Oxalidaceae	SB-089
98	<i>Panicum atrosanguineum</i> A. Rich.	H	Poaceae	SB-124
99	<i>Panicum hochstetteri</i> Steud.	H	Poaceae	SB-37A
100	<i>Paspalum scrobiculatum</i> L.	H	Poaceae	SB-54A
101	<i>Parthenium hysterophorus</i>	H	Asteraceae	SB-084
102	<i>Pennisetum sphacelatum</i> (Nees) Th. Dur. & Schinz	H	Poaceae	SB-122
103	<i>Persicaria glabra</i> (Willd.) Gomez de la Maza	H	Polygonaceae	SB-128
104	<i>Persicaria nepalensis</i> (Meisn.) Miyabe	H	Polygonaceae	SB-093
105	<i>Persicaria setosula</i> (A. Rich.) K.L. Wilson	H	Polygonaceae	SB-134
106	<i>Phyllanthus ovalifolius</i> Forssk.	Sh	Euphorbiaceae	SB-086
107	<i>Phytolacca dodecandra</i> L'Herit.	Sh	Phytolaccaceae	SB-094
108	<i>Pilea tetraphylla</i> (Steudel) Blume	H	Urticaceae	SB-108
109	<i>Plantago lanceolata</i> L.	H	Plantaginaceae	SB-126
110	<i>Plantago major</i> L.	H	Plantaginaceae	SB-019
111	<i>Plectranthus sylvestris</i> Gürke	H	Lamiaceae	SB-096
112	<i>Poa annua</i> L.	H	Poaceae	SB-080
113	<i>Polygonum aviculare</i> L.	H	Polygonaceae	SB-075

No	Species Name	Habit	Family	Code
114	<i>Portulaca oleracea</i> L. subsp. <i>oleracea</i>	H	Portulacaceae	SB-056
115	<i>Pterolobium stellatum</i> (Forssk.) Brenan	Sh	Fabaceae	SB-110
116	<i>Rubus apetalus</i> Poir.	sh	Rosaceae	SB-042
117	<i>Scleranthus annuus</i> L.	H	Caryophyllaceae	SB-043
118	<i>Selaginella goudotiana</i> Spring	H	Selaginellaceae	SB-027
119	<i>Senna didymobotrya</i> (Fresen.) Irwin & Barneby	Sh	Fabaceae	SB-001
120	<i>Setaria pumila</i> (Poir.) Roem. & Schult.	H	Poaceae	SB-044
121	<i>Sida rhombifolia</i> L.	Sh	Malvaceae	SB-012
122	<i>Sida ternata</i> L. f.	H	Malvaceae	SB-016
123	<i>Snowdenia polystachya</i> (Fresen.) Pilg.	H	Poaceae	SB-092
124	<i>Solanum anguivi</i> Lam.	Sh	Solanaceae	SB-33B
125	<i>Solanum giganteum</i> Jacq	Sh/T	Solanaceae	SB-112
126	<i>Solanum nigrum</i> L.	Sh	Solanaceae	SB-134
127	<i>Solanum villosum</i> Mill.	H	Solanaceae	SB-135
128	<i>Tagetes patula</i> L.	H	Asteraceae	SB-009
129	<i>Trifolium acaule</i> Steud. ex A. Rich.	H	Fabaceae	SB-026
130	<i>Trifolium rueppellianum</i> Fresen.	H	Fabaceae	SB-136
131	<i>Trifolium schimperii</i> A. Rich.	H	Fabaceae	SB-076
132	<i>Trifolium semipilosum</i> Fresen.	H	Fabaceae	SB-03A
133	<i>Trifolium simense</i> Fresen.	H	Fabaceae	SB-29A
134	<i>Triumfetta rhomboidea</i> Jacq.	H	Tiliaceae	SB-033
135	<i>Uebelinia abyssinica</i> Hochst.	H	Caryophyllaceae	SB-33C
136	<i>Verbascum sinaiticum</i> Benth.	H	Scrophulariaceae	SB-009
137	<i>Vernonia wollastonii</i> S. Moore	Sh	Asteraceae	SB-104
138	<i>Veronica abyssinica</i> Fres.	H	Scrophulariaceae	SB-137
139	<i>Vigna heterophylla</i> A. Rich.	Cl	Fabaceae	SB-031
140	<i>Viola abyssinica</i> Oliv.	H	Violaceae	SB-145

Appendix 9: List of families and its species number in the soil seed bank

No	Family Name	Species No	%
1	Acanthaceae	2	1.43
2	Adiantaceae	1	0.71
3	Amaranthaceae	3	2.14
4	Apiaceae	1	0.71
5	Asteraceae	15	10.71
6	Balsaminaceae	2	1.43
7	Boraginaceae	2	1.43
8	Brassicaceae	5	3.57
9	Caryophyllaceae	2	1.43
10	Commelinaceae	4	2.86
11	Convolvulaceae	1	0.71
12	Crassulaceae	2	1.43
13	Cyperaceae	5	3.57
14	Ericaceae	1	0.71
15	Euphorbiaceae	2	1.43
16	Fabaceae	13	9.29
17	Hypericaceae	2	1.43
18	Juncaceae	1	0.71
19	Lamiaceae	4	2.86
20	Loganiaceae	1	0.71
21	Malvaceae	2	1.43
22	Molluginaceae	2	1.43
23	Moraceae	1	0.71
24	Myrsinaceae	1	0.71
25	Oleaceae	2	1.43
26	Oxalidaceae	1	0.71
27	Papaveraceae	1	0.71
28	Phytolaccaceae	1	0.71
29	Plantaginaceae	2	1.43
30	Poaceae	32	22.86

No	Family Name	Species No	%
31	Polygonaceae	4	2.86
32	Portulacaceae	1	0.71
33	Primulaceae	1	0.71
34	Ranunculaceae	1	0.71
35	Rosaceae	2	1.43
36	Rubiaceae	2	1.43
37	Sapindaceae	2	1.43
38	Scrophulariaceae	2	1.43
39	Selaginellaceae	1	0.71
40	Sinopteridaceae	1	0.71
41	Solanaceae	5	3.57
42	Tiliaceae	1	0.71
43	Urticaceae	2	1.43
44	Violaceae	1	0.71
Total		140	100.00

Appendix 10: List of plant species unique to the corresponding layer of SSB

Key: Litter (0), A (0-3 cm), B (3-6 cm) and C (6-9 cm)

No	Species Name	Family	Habit	Unique in layer
1	<i>Andropogon chrysostachyus</i> Steud.)	Poaceae	H	Litter
2	<i>Commelina reptans</i> Brenan	Commelinaceae	H	Litter
3	<i>Galium aparinoides</i> Forssk.	Rubiaceae	H	Litter
4	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	T	A
5	<i>Bromus leptoclados</i> Nees	Poaceae	H	A
6	<i>Crassocephalum rubens</i> (Juss. ex Jacq.) S. Moore	Asteraceae	H	A
7	<i>Digitaria ternata</i> (A. Rich.) Stapf	Poaceae	H	A
8	<i>Dodonea angustifolia</i> L.f.	Sapindaceae	Sh	A
9	<i>Eragrostis cilianensis</i> (ALL.) Vign. ex Janchen	Poaceae	H	A
10	<i>Olea europaea</i> L. subsp. <i>cuspidata</i> (Wall. ex G. Don) Cif.	Oleaceae	T	A
11	<i>Phytolacca dodecandra</i> L 'Herit.	Phytolaccaceae	Sh	A
12	<i>Sida ternata</i> L. f.	Malvaceae	H	A
13	<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae	Sh/T	B
14	<i>Cheilanthes farinosa</i> (Forssk.) Kaulf.	Sinopteridaceae	H	B
15	<i>Cordia africana</i> Lam.	Boraginaceae	T	B
16	<i>Cyperus sesquiflorus</i> (Torr.) Mattf & Kiik.	Cyperaceae	H	B
17	<i>Erica arborea</i> L.	Ericaceae	Sh	B
18	<i>Impatiens tinctoria</i> A. Rich. subsp. <i>Tinctoria</i>	Balsaminaceae	H	B

No	Species Name	Family	Habit	Unique in layer
19	<i>Mollugo</i> Sp.	Molluginaceae	H	B
20	<i>Nelsonia canescens</i> (Lam.) Spreng.	Acanthaceae	H	B
21	<i>Ocimum urticifolium</i> Roth	Lamiaceae	Sh	B
22	<i>Portulaca oleracea</i> L. subsp. oleracea	Portulacaceae	H	B
23	<i>Scleranthus annuus</i> L.	Caryophyllaceae	H	B
24	<i>Arabis alpina</i> L.	Brassicaceae	H	C
25	<i>Crassula schimperi</i> Fisch. & Mey.	Crassulaceae	H	C
26	<i>Crepis rueppellii</i> Sch. Bip.	Asteraceae	H	C
27	<i>Eragrostis macilenta</i> (A. Rich.) Steud.	Poaceae	H	C
28	<i>Ficus sur</i> Forssk.	Moraceae	T	C
29	<i>Lens culinaris</i> Medik.	Fabaceae	H	C
30	<i>Leucas aequistylosa</i> Sebal	Lamiaceae	H	C
31	<i>Plectranthus sylvestris</i> Gürke	Lamiaceae	H	C
32	<i>Poa annua</i> L.	Poaceae	H	C
33	<i>Pterolobium stellatum</i> (Forssk.) Brenan	Fabaceae	Sh	C
34	<i>Verbascum sinaiticum</i> Benth.	Scrophulariaceae	H	C
35	<i>Viola abyssinica</i> Oliv.	Violaceae	H	C
36	<i>Vigna heterophylla</i> A. Rich.	Fabaceae	Cl	C

Appendix 11: Dominant families, species number and habit in the corresponding LU/LC of soil seed bank

LU/LC type	Family NO.	Family (%)	Family	Species/ family	Rating	species No/land use	Population No.	Habit				
								Cl	H	Sh	Sh/T	T
Cropland	17	14.66	Poaceae	11	1	40	8,908	1	36	0	3	0
			Asteraceae	6	2							
			Fabaceae	6	2							
			Brassicaceae	2	3							
			Cyperaceae	2	3							
			Polygonaceae	2	3							
Forest	34	29.31	Poaceae	17	1	74	10,576	1	62	6	1	4
			Asteraceae	7	2							
			Fabaceae	5	3							
Grassland	18	15.52	Poaceae	16	1	49	10,476	0	44	4	0	1
			Asteraceae	7	2							
			Fabaceae		2							
			Brassicaceae	2	3							
			Cyperaceae		3							
			Polygonaceae		3							
Solanaceae	2	3										
Shrubland	37	31.90	Poaceae	27	1	94	11,788	0	82	10	1	1
			Asteraceae	11	2							
			Fabaceae	9	3							
Wetland	10	8.621	Poaceae	10	1	32	8,576	0	31	1	0	0
			Cyperaceae	5	2							
			Asteraceae	4	3							
			Fabaceae									
Total	116	100		149	30	289	50324	2	255	21	5	6

Appendix 12: Semi-structured interview schedule for the inhabitants

1. Name of the respondent _____, Sex _____, Age _____
2. Marital status of the respondent: Married/widowed/divorced/single (Underline)
3. Educational status: Read and write? (Yes/No) Underline, Indicate level/grade completed
4. Locality: Detailed description of locality (Including Woreda and Kebeles)
5. Which plant is frequently used for farm and household implement?
6. Any restriction in cutting plants
7. How modernization interfere the sustainable use of plants?
8. What type of plant is frequently used for farm and household implement, fodder, food, medicine, firewood and others?
9. Where were the boundaries of the forest before certain period?
10. Which species have you been planting? Why and where:
11. How do you conserve plants?
12. For how long have you been here?
13. Is your yield increase/decrease from year after year? Why:
14. What are the major causes of the cover change?
15. When Rib Dam start to collect water?
16. How *Senna didymobotrya* affect the your cropping system

Please answer the following questions on a scale of 1 to 5 (1: strongly disagree 2: disagree 3: neutrals 4: agree, and 5: strongly agree).

N.B: for yes or no is better instead of grading 1-5

17. Has your land changed dramatically from the past to the present? 1 2 3 4 5
18. I use plants for my household well-being. 1 2 3 4 5
19. The plants on my land today differ from those in the past. 1 2 3 4 5
20. The vegetation is not what it was in the days of my elders. 1 2 3 4 5
21. Our family knows the local traditional uses of the plants on our land. 1 2 3 4 5
22. The forests have been cut down for agriculture. 1 2 3 4 5
23. Soil erosion has increased from what it was in the past to what it is today. 1 2 3 4 5
24. Which plant species (weed) is relatively difficult to manage? 1 2 3 4 5