ECOLOGICAL, FLORISTIC AND ETHNOBOTANICAL STUDIES IN AND AROUND *WEJIG-MAHGO-WAREN* MASSIF FOREST PATCHES IN SOUTHERN TIGRAY, ETHIOPIA

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Ecological, Floristic and Ethnobotanical studies in and around Wejig-Mahgo-Waren Massif Forest Patches in Southern Tigray, Ethiopia

By

Mebrahtu Hishe Gidey

A Thesis Presented to the Graduate Programmes of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Plant Biology & Biodiversity Management

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Abstract

Ecological, Floristic and Ethnobotanical Studies in and around *Wejig-Mahgo-Waren* Massif Forest Patches in Southern Tigray, Ethiopia

Mebrahtu Hishe Gidey, PhD Dissertation

Addis Ababa University, 2019

There is a declining trend of biodiversity in general and plant diversity in particular. This trend is leading to the loss of the associated indigenous and local botanical knowledge in Ethiopia, which is more severe in the northern highlands than elsewhere in the country. The purpose of this research was to study vegetation composition, soil seed bank and to document associated ethnobotanical and management practices applied by the forest fringe communities in and around Wejig-Mahgo-Waren Massif Forest area. Vegetation data were collected from a sample of 150 quadrats (each 20 m x 20 m) placed in ten transect lines, which were systematically laid. All vascular plant species were recorded. Diameter at breast height was measured and seedlings and saplings were counted and recorded. Height and percentage cover abundance were estimated. Soil samples were collected from 75 quadrats down to 0-5 cm and 5 -10 cm depth. Stratified random sampling of 309 informants was performed for collection of data on indigenous knowledge, of social classes associated with the forest and the resources in it. Thirty key informants were purposively selected with the help of local administrators, elders and other community members for collection of ranking exercises. For collection of ethnobotanical data, semi-structured interview, guided field walks and focus group discussions were applied. Basal area, density, frequency, importance value index, Shannon-wiener diversity index, cluster analysis and ordination were computed on ecological data. Density, composition, depth distribution and Sorensen coefficient of similarity were computed for soil seed bank analysis. Ethnobotanical analytical tools, including preference ranking, informant consensus factor, fidelity level, direct matrix ranking and cultural significance index were employed to describe the reciprocal relationship between the forest vegetation and forest fringe communities. Vegetation study revealed a total of 264 plant species belonging to 162 genera and 82 families. Woody (45.45%) species were higher than herbs (42.04%). Asteraceae (27 species, 32.93%), Poaceae (24 species, 29.27%) and Fabaceae (23 species, 20.05%) were the dominant families in terms of number of species. Five plant communities were identified in the forest vegetation, namely Cadia purpurea – Carissa spinarum, Olea europaea subsp. cuspidata – Juniperus procera, Dodonaea angustifolia – Acacia abyssinica, Erica arborea – Myrsine africana and Acacia etbaica – Acacia tortilis. The highest (3.87) and the least (3.21) Shannon-Wiener diversity indices were found in communities two and five, respectively. Altitude, slope, livestock grazing and human impacts were the factors influencing species distribution. From soil samples, the total number of species recorded was 54, representing 42 genera and 23 families. The number of viable seeds in the soil samples corresponded to a seed bank density down to 10 cm was 1115 m^{-2}. Herbs (85.16%) and woody species (14.84%) were the plants counted from the germination assay. Soil Seed bank and standing vegetation shared 36 species and their similarity was 23 %. The informants viewed the forest as an important entity for attraction of rain and for wildlife habitation followed by beekeeping and foraging as well as for sourcing straw and fuelwood. Of 79 plant species differentiated as useful to the community, 52 (66%) were used in traditional medicine (human and livestock), 28 (35%) as livestock fodder/ forage and 27 (34%) were recognized as honeybee forage. The highest informant consensus factor values were calculated for dermatological ailments (0.98,) followed by external injuries, bleeding and snakebites (0.92). The highest fidelity level (96.15%) was recorded for Verbascum sinaiticum followed by Withania somnifera (89.47%). Deforestation, agricultural expansion, fuelwood collection, grazing and settlement in decreasing order were considered responsible for forest resources depletion. Both the associated indigenous knowledge and the forest resources were under pressure. Thus, to restore the forest in the shortest possible time, restoration strategy that combines planting of seedlings of indigenous species and natural restoration techniques need to be applied.

Keywords/phrases: Multiuse, Plant communities, Restoration, Tigray, *Wejig-Mahgo-Waren* Forest

DEDICATION

This dissertation is dedicated to the local people of the study area who maintained the forest and their indigenous botanical knowledge, even at the worst drought times.

"A nation that destroys its soils destroys itself. Forests are the lungs of our land, purifying the air and giving fresh strength to our people."

(Franklin D. Roosevelt, 29 Jan 1935)

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List of acronyms and abbreviations

AAU	Addis Ababa University
AR	Arsi Floristic region
BA	Bale Floristic region
BA	Basal Area
CCA	Canonical Correspondence Analysis
CF	Correction Factor
CSI	Cultural Significance Index
CSA	Central Statistical Agency

DAF	Dry Afromontane Forest
DBH	Diameter at Breast Height
DCA	Detrended Correspondence Analysis
DCR-DNH	Department of Conservation and Recreation/Division of Natural Heritage
DF	Degree of Freedom
DMR	Direct Matrix Ranking
EFAP	Ethiopian Forestry Action Program
ETH	Ethiopia
EW	Eritrea West Floristic region
EWNHS	Ethiopian Wildlife and Natural History Society
EVI	Ethno-ecological importance value index
FAO	Food and Agriculture organization
FEE	Flora of Ethiopia and Eritrea
FL	Fidelity Level
GD	Gondar Floristic region
GG	Gamo-Gofa Floristic region
GIS	Geographic Information System
GJ	Gojjam Floristic region
GPS	Geographic Position System
HA	Harerge Floristic region
ha	hectare
ICF	Informant Consensus Factor
IL	I11ubabor Floristic region

IVI	Important Value Index
IUCN	International Union for the Conservation of Nature
IUFRO	International Union of Forest Research Organizations
MEF	Ministry of Environment and Forest
KF	Kefa Floristic region
MEFCC	Ministry of Environment, Forest and Climate Change
m.a.s.l	Meter Above Sea Level
NGO	Non-governmental organization
NMSA	National Metrological Service Agency
RCI	Relative Cultural Importance
REDD^{++}	Reduced Emission from Degradation and Deforestation
RDO	Relative Dominance
SD	Standard Deviation
SD	Sidamo Floristic region
SPSS	Statistical Package for Social sciences
SR	Similarity Ratio
SS	Sorensen Coefficient of Similarity
SU	Shewa Floristic region
TFAP	Tigray Forestry Action Program
TU	Tigray Floristic region
WCMC	World Conservation Monitoring Centre
WG	Welega Floristic region
WU	Welo Floristic region

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Ethiopia is located in the horn of Africa stretching from 3^{o} N to 15^{o} N latitude and from 33^{o} E to 48^{o} E longitude with an area coverage of 1,104,300 km^{2}. It is a country of great geographic diversity with wide altitudinal and physiographic variations. The altitude ranges from 125 meters below sea level in the Danakil Depression in Afar National Regional State to the highest peak of 4,553 meters above sea level (m.a.s.l.) on Mount Ras Dashen in Amhara National Regional State. The Great Rift Valley divides the Western and Southeastern highlands and the highlands on each side give way to vast semi-arid lowland areas in the East and West, especially in the southern part of the country (Friis *et al.*, 2010).

Biodiversity is understood as a key factor for the sustainability of life and its loss is one of the greatest environmental crises. The growing human population and the demand for natural resources have put great pressure on the biodiversity wealth of the world through deforestation, habitat fragmentation and overexploitation of species (Terborgh and van Schaik, 1997; Noss, 1999). Habitat loss and change, over-harvesting and climate change have been the direct causes of global biodiversity loss (Wood *et al*., 2000), while population growth, changes in economic activities, socio-political factors, cultural factors and technological change are indirect drivers (Ministry of Agriculture, 2003). Beside these global factors, lack of technical knowledge and awareness and political instability has exacerbated the problem in many developing countries (Ayyad, 2003).

Ethiopia is one of the top 25 biodiversity-rich or megadiverse countries in the world where two of the world's 34 biodiversity hotspots (Brooks *et al*., 2002), namely the Eastern Afromontane and the Horn of Africa hotspots (WCMC, 1994) trespass through its highland and lowland areas. It is also among the countries in the Horn of Africa regarded as the major center of diversity and endemism for several plants and animals. It is assumed that its diverse topography that gave rise to a wide range of altitude variations and other environmental gradients endowed the country with diversity of life. This has resulted in wide variations in rainfall, humidity and temperature because of which the country comprises ten ecosystems that range from Afro-alpine at the highest elevations to desert and semi-desert ecosystems at the lowest elevations. Present assessment of the flora of Ethiopia (Ensermu Kelbessa and Sebsebe Demissew, 2014) shows that the country is home to about 5,757 species of vascular plants. Nearly 10.58% (544 species) of which are known to be endemic to Ethiopia.

The definition of forest given in important studies of East-African vegetation (Greenway, 1973; White, 1983; Friis, 1992) has been adopted: "Forest is a continuous stand of woody individuals, at least 5 m in height, with crowns touching or intermingling." However, Ethiopia adopted a new forest definition as follows: "Land covering at least 0.5 hectare covered by (trees and bamboo), attaining a height of at least 2 meters and a canopy cover of at least 20%, or trees with the potential to reach these thresholds *in situ* in due course" (MEFCC, 2016). This forest definition differs from the definition used for international reporting to the Global Forest Resources Assessment (FAO, 2011) and from the forest definition used in the National Forest Inventory that applied the FAO forest definition with the thresholds of 10% canopy cover, a 0.5 ha area and a 5 m height. The reason for Ethiopia to change its national forest definition is to better capture dry and lowland-moist vegetation resources. The reason for lowering the tree height from five to two meters is to capture *Combretum - Terminalia* dense woodlands found in Gambella and Benishangul Gumuz Regional States (MEFCC, 2016).

Currently, natural forests in Ethiopia mainly occur in the southwestern part of the country, while the forests that originally existed in central and northern Ethiopia have almost disappeared (EFAP, 1994; Feoli *et al*., 2002; Melaku Bekele, 2003). Accelerated deforestation and habitat fragmentation that arises largely due to the conversion of forests to agricultural land-use types and the overutilization of forest resources to satisfy food and energy requirements of the increasing population are major environmental concerns in Ethiopia (Friis *and* Sebsebe Demissew, 2001; Gessesse Dessie and Kleman, 2007).

According to Zerihun Woldu *et al*. (2002) improving the management of the natural resources while providing ecological services and immediate economic needs are the major research and development challenges for the degraded areas of dry lands of East Africa in general and northern Ethiopia in particular. Due to fast population growth, overgrazing and deforestation for agricultural activities, fuelwood and construction material and the natural forest cover had decreased to a level of 2.5 percent in 1999 (Reusing and Kasberger, 2000). The combination of high endemism and fast habitat degradation in Ethiopia leads to a great risk of species extinction (Nyssen, 2001).

Tigray is one of the most environmentally degraded regions in Ethiopia, which has been left with relatively low remnant natural vegetation. According to pollen and charcoal studies in northern Ethiopia, forest disturbance has a 3000-year history (Darbyshire *et al*., 2003) and soil erosion following vegetation clearance in Tigray occurred in the middle Holocene (Bard *et al*., 2000).

Around 500 BC, *Podocarpus-Juniperus* forest that was common in the area was converted into a secondary vegetation of *Dodonaea* scrub and grasslands that dominated northern Ethiopia for 1800 years while *Juniperus, Olea* and *Celtis* spread around AD 1400 to 1700 (Darbyshire *et al*., 2003).

Ecological degradation, as evidenced by a declining forest area and several erosion phenomena, is most dramatic in the northern highlands of Tigray with the prevalence of recurrent drought spells and war events in the recent decennia (Janzen, 1988; Muys *et al*., 2004). At present, the original vegetation is confined to around religious and worship sites where cutting trees and removal of plants are forbidden and in limited other isolated and protected areas (Feoli, 1996). In this region, remains of the original climax forest now only occur as sparse forest patches of just a few hectares, either surrounding churches, or in inaccessible places, like cliffs and mountain ridges (Kindeya Gebrehiwot, 1997). These small remnants of forest are called forest relics and are classified as dry Afromontane forest ecosystems. Mitiku Haile and Kindeya Gebrehiwot (2000) stated that the misuse of natural resources has resulted in very serious land degradation in most places. It can be said that environmental degradation, drought and socioeconomic instability are common in contemporary Tigray.

In 2003, the natural forest cover in Tigray was only 0.2 % of the total land mass of the region (Ministry of Agriculture, 2003), indicating the severity of forest degradation in the region. Currently, the western escarpment of the Great Rift Valley is the only site with an intact Afromontane forest cover in northern Ethiopia, such as Hugumburda, Dess'a and *Wejig-Mahgo-Waren* massif forests. *Wejig-Mahgo-Waren* massif forest faces a great danger from agricultural expansion, settlement, overgrazing, incidence of tree falling, fuelwood and building material collection by the local community.

Local communities, government and NGOs are tackling the problem of soil and vegetation degradation through building stone bunds on slopes, thus creating terraces and construction of check dams in erosion valleys (Bossuyt and Hermy, 2001). In addition to biological techniques that make use of plantation of seedlings and natural restoration are receiving more and more attention nowadays.

These techniques combine both soil stabilization and reforestation. One widely used option here is the creation of closed areas, also called exclosures, i.e., demarcated areas under strict conservation management, often controlled by a local community (Nyssen *et al*., 2004). In these areas, cultivation, collection of fuelwood and grazing are forbidden, whereas harvesting of grass is strictly controlled in order to allow natural forest restoration from soil seed bank (Reubens *et al.*, 2007). Dormant seeds (viable seeds that would germinate when favorable conditions set in) in the soil, collectively known as the seed bank, play a crucial role in the restoration of vegetation (Hirsch *et al.*, 2012). Seed dormancy or longevity is an important parameter for the existence of a seed bank. Seed banks are formed by seeds, either born and produced on site or carried to the site by dispersal agents and accumulated in the soil and form seed banks (Hirsch *et al.*, 2012).

According to published reports, e.g., Mirutse Giday and Gobena Ameni (2003), Gidey Yirga (2010a), Gidey Yirga (2010b), Girmay Zenebe *et al*. (2012), Abraha Teklay *et al*. (2013), Gebremedhin Gebreegzabher *et al*. (2013), Kalayu Mesfin *et al.* (2013), Moravec *et al.* (2014), Abraha Teklay (2015), Meaza Gidey *et al.* (2015), Fitsumbirhan Tewelde *et al*. (2017), studies on medicinal and other uses of plants in Tigray is increasing. Furthermore, there are unpublished MSc. and PhD thesis on ethnobotanical studies conducted by Gebremedhin Hadera (2000), Abrha Tesfay (2008), Nurya Abdurhman (2010), Genet Atsbeha (2012) and Tadesse Beyene (2015). However, only few of the above-mentioned researches, have tried to assess the interaction of the local communities with respective nearby remnant forests (Gebremedhin Hadera, 2000; Abrha Tesfay, 2008) and their contribution to the livelihood of local communities.

It is known that traditional knowledge on conservation of forests and their uses have been transmitted orally from generation to generation. *Wejig-Mahgo-Waren* forest is one of the remnant dry Afromontane forests in northern Ethiopia which plays a crucial role in the livelihoods of local communities. However, because of the informal nature of oral transmission, there is a need to investigate and document the traditional use of plant species and management of the forest resources by the local people for sustainable resource utilization for the present as well as the future generations. Thus, accommodating new conservation approaches, such as participatory forest management could contribute significantly to mitigate the problem of forest destruction (Zerihun Woldu *et al.*, 2002).

In response to the loss of forests, the Ministry of Environment and Forest of Ethiopia (MEF) designated some Pilot REDD+ Project Sites Visit Report (Ministry of Environment and Forestry, 2015). Likewise, the Ministry of Agriculture (Ministry of Agriculture, 2015) and the Ethiopian Wildlife and Natural History Society (EWNHS, undated) independently made assessments on potential forest areas in Tigray. And all of these institutions identified *Wejig-Mahgo-Waren* massif forest as a potential area for restoration. Tigray region has six state forests, namely *Wejig-Mahgo-Waren* (Southern zone), *Hugumburda-Gratkahassu* (Southern zone), *Hirmi* (North

Western zone), *Waldiba* (North Western zone), *Asimba* (Eastern zone) and *Dess'a* (Eastern zone) (Ministry of Agriculture, 2015). Among these, the vegetation ecology of *Hugumburda-Gratkahsu* (Leul Kidane, 2015; Ermias Aynekulu (2011), and *Dess'a* (Ermias Aynekulu, 2011) have been studied. However, no work has been conducted to date on the vegetation ecology, population structure, regeneration status, soil seed bank, cognitive domain, use and management of *Wejig-Mahgo-Waren* massif forest. It is, therefore, imperative and urgent to assess the standing vegetation, soil seed bank of the forest and indigenous botanical knowledge of the forest fringe communities.

1.2 Statement of the research problem

The vascular plant species of *Wejig-Mahgo-Waren* massif forest have not been investigated previously; the plant communities that exist in the forest have not been described; the regeneration status of the forest has not been known; the species present in the soil seed bank and the restoration potential of the forest have not been quantitatively assessed. Information on how the surrounding communities look upon, use and manage the forest resources has not been documented. The research ideas presented below were developed to address the gaps identified by applying a combination of relevant methods from the fields of plant taxonomy (floristics), plant ecology, and ethnobotany.

1.3 Research questions, hypotheses and objectives

1.3.1 Research questions

1. What is the vascular plant species composition in *Wejig-Mahgo-Waren* massif forest?
2. What type of plant communities exist in *Wejig-Mahgo-Waren* massif forest?
3. What is the regeneration status of trees/shrubs in *Wejig-Mahgo-Waren* massif forest?

4. What is the soil seed bank of *Wejig-Mahgo-Waren* massif forest?
5. What are the correlations between the standing vegetation and species richness in the soil seed bank?
6. What is the interaction between *Wejig-Mahgo-Waren* massif forest and the communities living around the forest?

1.3.2 Research hypotheses

H_0: The fringe communities around *Wejig-Mahgo-Waren* massif forest exert high pressure on the forest through extraction of its resources for several use values and deforestation leading to less floristic diversity and community types with very low restoration potential from soil seed bank.

H_a: The fringe communities around *Wejig-Mahgo-Waren* massif forest exert no pressure on the forest making the forest high in floristic diversity and community types with very good restoration potential from soil seed bank.

1.3.3 Objectives

1.3.3.1 Major objective

- ✓ To study the vegetation composition, population structure, soil seed bank and ethnobotanical knowledge of fringe communities in and around *Wejig-Mahgo-Waren* massif forest in Southern Tigray, Ethiopia.

1.3.3.2 Specific objectives

- ✓ To record the vascular plant species composition in *Wejig-Mahgo-Waren* massif forest.
- ✓ To describe and classify plant community types found in the study forest.
- ✓ To assess the population structure and regeneration status of the study forest.
- ✓ To assess the soil seed bank of the forest compared to the standing vegetation.
- ✓ To assess the interaction of forest fringe communities with forest vegetation in and around *Wejig-Mahgo-Waren* massif forest.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Vegetation types of Ethiopia

A large proportion of the Eastern Afromontane and Horn of Africa biodiversity hotspots lie in Ethiopia and the country is one of the biodiversity centers of the world (Conservation International, 2007). Ethiopia has a complex relief and a variety of climates and thus diverse habitats with rich flora and fauna. After completion of the writing of the modern flora of Ethiopia, an article published by Ensermu Kelbessa and Sebsebe Demissew (2014), showed that the total number of vascular plant species is 5,757 with 10.58% endemism. The Ethiopian vegetation is highly influenced by climate, which is associated with elevation (Dugdale, 1964). Southwestern Ethiopia receives more precipitation than other parts of the country due to the humid air coming from the Congo basin (Dugdale, 1964). This westerly wind, however, cannot penetrate further than 30°E and rarely influences the Horn region because the Ethiopian highlands act as barriers. The flora of southern Ethiopia is more similar to that of Kenya and Uganda than the flora of northern Ethiopia (Dugdale, 1964). The vegetation on the Afromontane belt (900-3200 m) of Ethiopia has been under tremendous pressure from human activities and over grazing, which has led to the replacement of the evergreen forests by grasslands (Tewolde Berhan Gebre Egziabher, 1988).

The most frequently cited studies on the vegetation of Ethiopia include that of Pichi-Sermolli (1957), Breitenbach (1963), White (1983) and Friis (1992). The extent and delineation of the vegetation maps of Pichi-Sermolli (1957) and Breitenbach (1963) are very similar, but differ in the descriptions and terminology of the mapping units (Friis and Sebsebe Demissew, 2001).

According to Pichi-Sermolli (1957), the vegetation of northern Ethiopia is classified as montane evergreen thicket and savanna. The common species in this vegetation type include *Juniperus procera*, *Olea europaea* subsp. *cuspidata, Acokanthera schimperi*, *Carissa spinarum* and species of *Euclea*, *Rhamnus*, *Rhus* and *Maytenus* (Friis and Sebsebe Demissew, 2001).

Breitenbach (1963) mapped the vegetation of Ethiopia and Eritrea into seven basic categories using a physiognomic approach. The seven categories are Lowland savannah, Lowland savannahs, Lowland woodlands, Highland forests, Mountain woodlands, Mountain savannahs and Mountain savannah. The sub-categories are based on local rainfall (arid, semi-arid, semi-humid and humid) and stages of succession, which range from pioneer to climax types. According to Breitenbach's (1963) vegetation map, the three dominating vegetation types in Ethiopia in a decreasing order are Lowland steppes, Lowland woodlands and Mountain savannahs.

White (1983) classified the vegetation of Africa into 81 vegetation groups using physiognomy and floristic composition. Accordingly, the dominant vegetation types in Ethiopia are Forest transitions and mosaics, Woodland, Woodland mosaics and transitions, Bushland and thicket, Semi-desert vegetation, Grassland, Edaphic grassland mosaics, Altimontane vegetation, Azonal vegetationand Desert. The vegetation on the lower escarpment is classified as bushland and thicket and the vegetation on the Tigrean plateau and the upper escarpment as forest transition and mosaics.

Friis (1992) classified the forests of the Horn of Africa into nine vegetation types. He followed the classification and terminologies of White (1983) and added the lowland semi-deciduous forest (dry peripheral semi-deciduous Guineo-Congolian forest) and the attitudinally transitional forest (transitional rain forest), which were identified after White's vegetation map had been published. According to the classification of the forests and forest trees of northeast tropical Africa (Friis, 1992), *Wejig-Mahgo-Waren* massif forest is broadly categorized as a dry single-dominant Afromontane forest. It is characterized by a dry climate annual precipitation less than 1000 mm, and with *Juniperus procera* and *Olea europaea* subsp. *cuspidata* as the dominant species. This dry single-dominant Afromontane forest of the escarpment and transition between single-dominant Afromontane forest and East African evergreen and semi-evergreen bush land that occurs between 1500 and 2400 characterizes the escarpments in northern Ethiopia.

The vegetation map of Ethiopia was later simplified into eight major vegetation types by Sebsebe Demissew *et al*. (1996) as Afroalpine and sub-Afroalpine zone, dry evergreen mountain forest and grassland, moist evergreen mountain forest, evergreen scrub, *Combretum-Terminalia* and savanna, *Acacia-Commiphora* woodland, lowland (semi-) evergreen forest, desert and semi-desert scrublandand coastal vegetation. According to Sebsebe Demissew *et al.* (1996), dry evergreen mountain forest, grasslandand evergreen scrub characterize the forest remnants in northern Ethiopia. The most recent revision of the vegetation map of Ethiopia was by Friis *et al.* (2010). In this work twelve vegetation types are recognized Desert and semi-desert scrubland, *Acacia-Commiphora* woodland and bushland, Wooded grassland of the western Gambela region, *Combretum-Terminalia* woodland and wooded grassland, Dry evergreen Afromontane forest and grassland complex, Moist evergreen Afromontane forest, Transitional rainforest, Ericaceous belt, Afro alpine belt, Riverine vegetation, Fresh-water lakes, lake shores, marsh and floodplain vegetation, Salt-water lakes, salt-lake shores, marsh and pan vegetation. The classification was mainly based on altitude and/or climatic variables.

2.2 Determinants of biodiversity

Latitude and elevation are important drivers of species distribution patterns (Gaston, 2000; Lomolino, 2001). However, the effect of these two factors varies with local, regional and global scales, as well as with historical factors (ter Steege and Zagt, 2002). A palaeobotanic study by Bobe (2006), for instance, indicates that the differentiation of moist forests and drier *Acacia* woodlands in Africa occurred during the early Cenozoic period. Pollen studies in Kenya (Lamb *et al*., 2003) and northern Ethiopia (Darbyshire *et al*., 2003) indicate that the flora of East Africa had experienced several changes due to climate change and anthropogenic disturbances.

At a global scale, diversity decreases with increasing distance from the equator (Gaston, 2000; Mutke and Barthlott, 2005; Kreft and Jetz, 2007). However, the general species-richness pattern along latitudinal gradients is sometimes reduced due to other factors, like longitude, elevation, topography and aridity (Gaston, 2000). There are several reasons for the higher species diversity in the tropics compared to other regions, one of which is the larger area of the tropics than of any other zone (Rosenzweig, 1995).

The other reason for a large number of species in the tropics is the low-temperature variability in space and time that increases the probability of similar habitats (Rosenzweig, 1995). Constant and higher temperatures in the tropics also contribute to higher species diversity by increasing the rate of metabolism, which speeds up the passing of generations and increases the rate of mutation that again leads to new species (Tokeshi, 1999).

Elevation plays a major role in plant species diversity and floristic formations, especially in mountainous areas (Gaston 2000; Kreft and Jetz, 2007). Compared to species-latitude and species-area relationships, the species-elevation relationship is less studied (Lomolino, 2001). Elevation determines species distribution in montane systems by influencing area, climate, geographical isolation of montane communities and feedback among zonal communities (Kreft and Jetz, 2007). Generally, habitat diversity is a widely accepted determinant of species diversity (Mutke and Barthlott, 2005). The theory of spatial heterogeneity (Pianka, 1966) stated that more heterogeneous and complex physical environments support more diverse plant and animal communities.

Apart from environmental drivers of species diversity, anthropogenic disturbance affects species diversity through habitat loss and fragmentation (Brooks *et al*., 2002). Habitat loss is the leading cause of species extinction (Pimm and Raven, 2000). Biodiversity loss is more serious than other environmental threats because it is irreversible (Mittermeier *et al*., 1998). Habitat fragmentation affects biodiversity by reducing the area of a habitat, which reduces the persistence of a species and through the negative edge effect that increases mortality while decreasing reproduction (Farhrig, 2003).

Identifying diversity hotspots can support conservation planning (Myers *et al*., 2000). Conservation International (2007), for instance, used the world biodiversity hotspots to prioritize biodiversity conservation areas. The hotspot concept is based on species richness, endemism and threat (Myers *et al*., 2000). Studies at global scale have documented less overlap among the three criteria (Orme *et al*., 2005). Nearly half of the world's vascular plant species are endemic to 25 hotspots (Myers *et al*., 2000), of which 17 are in tropical forests each having at least 1500 endemic plant species (Brooks *et al*., 2002). However, many plant species have a too small population sizes to be viable and this may increase the rate of extinction in the long term

(Whitemore, 1997). The human population growth rate in the hotspots is higher than the average rate worldwide, suggesting that human-induced habitat loss is still a major threat (Cincotta *et al*., 2000). Mckee *et al*. (2004) found a strong relationship between population growth and number of threatened species.

Recently, nine new areas were included as part of the world biodiversity hotspots (Conservation International, 2007). Among these are the Horn of Africa and eastern Afromontane hotspots that include large parts of the lowlands and highlands of Ethiopia, respectively. However, Africa has fewer endemic species and is less rich in tropical species, which is probably due to the slow rate of geographical speciation (Rosenzweig, 1995). Large-scale vegetation changes in Africa occurred due to changes in the atmospheric moisture content driven by tropical sea surface temperature changes in the mid-Pleistocene (Schefus *et al*., 2003).

2.3 Plant communities

A plant community is defined as the collection of plant species growing together in a particular location that show a definite association or affinity with each other (Kent and Coker, 1992). Plant community study is a useful approach in conservation planning (Ferrier *et al*., 2009). The concept of plant community, for instance, provides useful information on the underlying environmental drivers of species distribution, as plants that live together have similar environmental requirements for their existence. The principles of plant communities are based either on the continuum or on the individualistic theories. Clements (1916) in his plant succession theory considered plant communities as one big organ (superorganismic concept) composed of various species, which repeats itself with regularity over a given region. In his holistic approach, forests, scrubs and grassland are considered as major groups of vegetation, which can develop to climax communities with sufficient time and long-term stability. Gleason (1926), on the other hand, considered plant species distribution as a continuum. Gleason takes environmental factors and tolerance ranges of species as determinants of the existence and abundance of a species in a given region. This viewpoint is known as the individualistic concept of the plant community.

Although differences still exist among ecologists on the concepts of plant communities, the Gleason's individualistic theory has been widely used (Callaway, 1997). Plant ecologists who favor vegetation classification follow the approach of Clements and group species into communities. Those ecologists who do not believe in classification follow the continuum theory and arrange species along environmental gradients as continua, using ordination methods (Kent and Coker, 1992).

2.4 Multivariate analysis

Multivariate analysis of community data is very challenging due to various reasons (Green, 1979), namely noise, redundancy, relationship and outliers and large data matrix. To facilitate communication among ecologists, there is a need for the selection of only a modest number of preferred methods for the common usage (Pielou, 1977). In order to meet these challenges, ecologists have developed, applied and tested a number of multivariate methods, among others, the two are cluster analysis and ordination.

2.4.1 Cluster analysis

For ecological data, cluster analysis classifies sites, species or variables. Cluster analysis is an explicit way of identifying groups in raw data and helps us to find structure in the data. There are several types of cluster analysis, based on different ideas about the cluster concept. A major distinction can be made between divisive and agglomerative methods. A second way of distinguishing methods is to classify them by hierarchical and non-hierarchical methods. Hierarchical methods start from the idea that the groups can be arranged in a hierarchical system.

2.4.1.1 Hierarchical agglomerative methods

Agglomerative methods start with individual objects, which are combined into groups by collection of objects or groups into larger groups. Agglomerative methods require a similarity or dissimilarity matrix (site by site). In many sciences, agglomerative techniques are employed much more frequently than divisive techniques. The historical reason for this is the inefficient way early polythetic divisive techniques used computer resources, while the agglomerative ones were more efficient (van Tongeren, 1995).

The first step in agglomerative clustering is to choose a distance or dissimilarity measure, such as euclidean, manhattan or similarity ratio. Hierarchical clustering method produces a dendrograms, which allow the user to read off the “height” at which items, or clusters or both are combined which together would form a new and larger cluster (Zerihun Woldu, 2017). Clustering algorithms, which link different groups with each other, are principally of three types: single linkage, complete linkage and average linkage. Average linkage is most often used in ecology (average linkage includes also popular ward method (weighted average linkage) and beta flexible).

Ward's method, also known as error sum of squares clustering, is in some respects similar to average-linkage clustering and centroid clustering. Between-cluster distance can either be computed as a squared distance between all pairs of sites in a cluster weighted by cluster size (resembling average-linkage clustering) or as an increment in squared distances towards the cluster centroid when two clusters are fused (resembling centroid clustering). Penalty by squared distance and cluster size makes the clusters tighter than those in centroid clustering and average linkage and more like those obtained in complete linkage (van Tongeren, 1995).

2.4.2 Ordination analysis

Ordination is the collective term for multivariate techniques that arrange sites along axes on the basis of data on species composition. The use of Principal Component Analysis (PCA), Redundancy Analysis (RA), Canonical correspondence Analysis (CCA) or Canonical Analysis (CA), therefore, depends on whether the relationship between species data and environmental data is linear or unimodal. Species respond linearly along environmental gradient, which could be true for rather homogeneous ecological data, where ecological gradients are not too long, while species respond unimodally along gradient is having its optima at certain gradient position. This model is more close to reality of ecological data and is more suitable for heterogeneous datasets structured by strong or long ecological gradients, with high species turnover and many zeroes in the species matrix (Zerihun Woldu, 2017).

Lepš and Šmilauer (2001) proposed a simple rule to decide whether to use unimodal or linear method based on the length of the first DCA axis. If the length is > 4, data are heterogeneous and unimodal methods should be used. If the length is < 3, data are homogeneous and linear methods should be used.

Legendre and Legendre (1998) and Zerihun Woldu (2017) recommend the following conditions while choosing the approaches to fit our specific purposes based on the nature of the input data:

PCA and RDA should be used to analyze species data if the relations along the gradients are linear. CA and CCA can be used to analyze unimodal relationships between species and environmental variables.

2.5 Measures of species diversity

Whittaker (1972) stated that species diversity can be interpreted in terms of species richness and evenness and identifies alpha, beta and gamma types of species diversity. Alpha diversity (species richness) is the number of species per standard size or community. Beta diversity is the difference in species diversity between areas or communities. It is sometimes called habitat diversity because it represents differences in species composition between different areas or environments (Whittaker, 1972; Kent and Coker, 1992). Since communities and habitats are often difficult to delineate, beta-diversity is measured among study quadrats (Mark, 2001). The total or gamma diversity of a landscape or geographic area is a product of the alpha diversity of its communities and the degree of beta differentiation among them (Whittaker, 1972). The difference between alpha and gamma diversity is a matter of scale, which is often subjectively defined (Peet, 1974).

A large number of diversity indices have been used to measure species diversity. Magurran (2004) provided an in-depth review of concepts and measurements of diversity. Species richness, meaning a count of the number of plant species in a quadrat, area or community, is often equated with diversity. However, as Magurran states, most methods used in measuring diversity actually consist of two components.

The first is species richness and the second is the relative abundance (evenness or unevenness) of species within a sample or community. Whittaker (1972) considers species richness as a strong measure of species diversity. However, using species richness *per se* as a measure of diversity is criticized, because species richness is just one component of species diversity (Sanjit and Bhatt, 2005). The Shannon index and Simpson's index of diversity, which combine species richness with relative abundance, are widely used in species diversity studies (Kent and Coker, 1992). The Shannon index expresses the relative evenness or equitability of species, while Simpson's index (Simpson, 1949) gives weight to dominant species (Whittaker, 1972). The diversity indices are biased either on species richness or species evenness, which makes it difficult to obtain one robust index of diversity measurement (Magurran, 2004). The Shannon index is insensitive to rare species (Sanjit and Bhatt, 2005).

2.6 Plant population structure and regeneration status

Studies on population structure and density of major canopy tree species help to understand the status of regeneration of species and management history and ecology of the forest. Plant population structure shows whether or not the population has a stable distribution that allows continuous regeneration to take place. Size class distribution as diameter at breast height (DBH) and height are used to evaluate structure and regeneration of species. The structure of the species may have inverted J-shape pattern, which is an indicator of stable population structure and is a reflection of healthy regeneration potential of the species exhibited in a natural forest where disturbance is minimum (Harper, 1977; Getachew Tesfaye *et al.*, 2010). Any population pattern that differed from inverted J-shaped, have been attributed to disturbed forest (Poorter *et al.*, 1996), e.g. bell shape, J-shape and U-shape.

The variation in relative abundance of size classes and population structure of species is the result of past and present disturbance as well as management history of the forest. Based on intensity of disturbance species show variation in population structure pattern reflected through difference in the abundance of different size classes (Tamrat Bekele, 1993). Size class distribution or population structure gives good indication of the impact of disturbance and forest successional trends.

The population structure, characterized by the presence of sufficient population of seedlings, saplings and adults, indicates successful regeneration of forest species. Seedling densities in forest understory's are dynamic and rates may vary among species and in gap and shade environments. Information on tree seedling ecology can provide options for forest development through improvement in recruitment, establishment and growth of the desired species. Regeneration studies have significant implication on the conservation and restoration of degraded natural forests (Getachew Tesfaye *et al.*, 2010). Thus, regeneration status of woody species can be predicted by the age structure of their populations. The study of regeneration of forest trees has important implications for the management of natural forests and in one of the thrust areas of forestry. Research in this field contributes to planning, conservation and decision making in forest resources management programs (Pokhriyal *et al*., 2010).

2.7 Soil seed bank and its importance in vegetation study

The soil seed bank refers to all viable seeds and fruits present in the soil. Soil seed banks can be either transient, with seeds that germinate within a year of initial dispersal, or persistent, with seeds that remain in the soil for more than one year (Simpson *et al*., 1989). They exhibit variations in space as well as time and display both horizontal and vertical dispersion, reflecting initial dispersal onto the soil and subsequent movement (Simpson *et al.*, 1989).

Soil seed banks reflect partly the history of the vegetation and can play an important role in its restoration after disturbances. They have been exploited in two contexts: to manage the composition and structure of existing vegetation and to restore or establish native vegetation (van der Valk and Pederson, 1989).

The bank of long-lived seeds in the soil stores over many decades and contributes as a source of propagules that ensure continual occupation of a site after disturbances while serving as a gene pool by buffering genetic changes in the population (Hill and Morris, 1992). Soil seed banks play a crucial role in the dynamics of plant populations. In forest management, natural seed banks play a vital role in restoration after disturbances, for example, tree felling. The fact that many economically important trees are canopy species whose seeds have little dormancy makes it important to leave some individuals of the species to act as local seed sources. Knowledge of which species are not represented in the persistent soil seed bank can be just as important as knowing which species are represented. This is especially true in the management of vegetation for conservation. The dynamics of a soil seed bank include recruitment into the dormant seed bank population through seed rain, losses from the dormant seed bank through seed predation or death and change into the active seed bank to germinate and form a seedling bank, through a stimulus.

2.7.1 Seed longevity in the soil

Depending on internal and external environmental factors as well as species to species interactions, the period of seed viability in the soil varies. The longevity of seeds in soil commonly depends on the conditions through which they pass; for example, some seeds can stay long in the soil if kept in dry atmosphere. Viability is also affected by ageing; with increase in age viability of seeds decreases until it stops completely. The common reasons for loss of viability are denaturation and inactivation of proteins and enzymes, over drying and exhaustion of reserve foods of dormant seeds due to respiration (Rajan, 2000).

The longevity of seeds in the soil seed bank associated with the principle of dormancy caused by either seed coat, condition of embryo, light sensitivity, or chemical inhibitors. The dormancy generally helps the embryo to pass adverse environmental conditions (Rajan, 2000).

Evidences of longevity in seeds come from archeological sites, dated herbarium sheets, or experiments on shelf-stored seeds or seeds buried in the field. However, only viability tests of seeds, which have been subjected to the moisture, temperature and gaseous compositions of soil under field condition provide results of ecological importance (Demel Teketay and Granström, 1997).

2.7.2 Significance of soil seed banks

The seed banks found in different environments represent a record of past as well as present vegetation growing on the area and nearby. If an existing vegetation stand is destroyed by various causes, the seed bank will immediately serve as a source from which new vegetation arises (Harper, 1977). In addition, their significance in restoration of lost vegetation, seed banks are also essential in rehabilitation of a degraded land.

2.7.3 Spatial variation

The vertical distribution of the soil seed bank and number of species was consistent at all sites with the highest densities in the upper three centimeters of soil and then gradually decreasing densities with increasing depth (Demel Teketay and Granström, 1997). There was considerable variation among species in depth distribution. Some species, e.g. *Juniperus procera, Clematis hirsuta, Girardinia diversifolia* and *Pilea tetraphylla* were almost entirely confined to the litter layer. Some other species, e.g. *Laggera crispata, Lobelia giberroa, Crassula alsinoides, Veronica abyssinica* and *Poa leptoclada*, had almost uniform depth distribution (Demel Teketay and Granström, 1997).

Another set of species, e.g. *Indigofera rothii, Solanum nigrum* and *Eragrostis schweinfurthii* had their seeds distributed in the deeper layers. In general, seeds of herbs, grasses and sedges were more deeply distributed in the soil than those of trees, shrubs and climbers. Herbs, grasses and sedges have small seeds compared with many woody species and species with small seeds have a better chance of becoming buried in deeper layers of the soil (Thompson, 1987). Considerable intra-site differences of horizontal distribution of seeds in the soil were also apparent among species. Some species, such as *Crassula alsinoides* and *Dichrocephala integrifolia,* showed a relatively even distribution while most of the woody species and some herbaceous species had patchy or clumped distribution.

2.7.4 Seedling emergence and seed extraction techniques

Several methods have been used to estimate the density and composition of soil seed banksand there has been much debate on the utility of the different approaches (Bernhardt *et al.*, 2008). The ‘seedling emergence method’, which involves spreading a thin layer of soil over a sterilized medium in a glasshouse and identifying and counting emerging seedlings, is commonly used (Ter Heerdt *et al.*, 1999). This method gives a good indication of the more germinable seed bank, but does not provide a complete assessment of the seed bank flora unless the soil sample is maintained for extended periods at simulated habitat conditions (Thompson and Grime, 1979).

Indeed, the seedling emergence method can dramatically underestimate the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Bernhardt *et al.*, 2008; Wright and Clarke, 2009).

A second method, regarded as providing a better estimate of total seed bank densities, is seed extraction from the soil (Brown, 1992). This can be achieved through ‘rinsing’, flotation in a salt solution or other high specific gravity liquid, or a combination of both (Bernhardt *et al*., 2008). Seeds are then hand sorted under a microscope and identified. Seed extraction is not commonly used as it is time consuming, ineffective at finding small seeded species and may overestimate the viable seed bank by including non-viable seeds (Baskin and Baskin, 1998).

Besides, depending on when samples are collected, seeds may lose viability before the next germination season, i.e., if one determine the seed content several months before the next germination season, one do not know if these seeds would have survived until the germination season.

Studies comparing these two methods have found contrasting results (Johnson and Anderson, 1986; Brown, 1992). Seed extraction methods detected greater seed densities and species richness of a forest soil seed bank compared with seedling emergence techniques (Brown, 1992). Johnson and Anderson (1986) reported similar estimates for seed density, but greater species richness of the soil seed bank with the emergence method. Bernhardt *et al.* (2008) found that the seedling emergence method failed to detect nearly 90% of all most germinable seeds found via the 'rinsing method'. Despite large differences between the two approaches, seedling emergence is the most commonly used method (Capon and Brock, 2006; Robertson and James, 2006; *Poorter et al.*, 2007).

2.8 Ethnobotany and its relevance

2.8.1 The concept of ethnobotany

Ethnobotany is a multidisciplinary science encompassing botany, anthropology, economics and linguistics, few among others, which studies the way in which a society relates to its environment and particularly to the plant world. These relationships can be social, economic, symbolic, religious, commercial and artistic (Aumeeruddy-Thomas and Pei, 2003). Ethnobotany as an interdisciplinary science is in a position to contribute much to plant conservation. Ethnobotany was originally based largely on qualitative methods, such as inventories of plants and their uses, with a major focus on the economic importance of plants. In addition, it focuses on documenting, analyzing and using of indigenous knowledge, beliefs and practices related to plant resources (Martin 1995; Balick and Cox, 1996; Zemede Asfaw, 1997). Consequently, applied ethnobotany strives to bridge the gap between traditional knowledge and scientific knowledge and to understand the relationships between local practices and knowledge systems and policies, rules and economic trends at the national and international level (Aumeeruddy-Thomas and Pei, 2003). The contribution of applied ethnobotany is not limited to pure science, but has an important role to play in understanding the dynamic relationships between biological diversity and social and cultural systems and their development.

2.8.2 Relevance of scientific documentation in indigenous botanical knowledge

Ethnobotany is an indispensable tool to identify and document plant species that have been underutilized by human beings for centuries for various reasons (Martin, 1995; Balick and Cox, 1996; Tilahun Teklehaymanot and Mirutse Giday, 2007).

Traditional people all over the world, through their indigenous knowledge know which plant species are threatened and need priority management (Given, 1994; Aumeeruddy-Thomas and Pei, 2003). Based on this knowledge, ethnobotanists need to study the traditional diverse use of plants and the indigenous knowledge on management in a scientific way. This ethnobotanical information will further enable to set priority management for those areas and species useful for human consumption (i.e., culturally and economically useful plants) and areas of high species diversity (Given, 1994) as well as areas and plant species threatened due to habitat change and overuse.

Moreover, ethnobotany becomes useful tool in the introduction of alternative resource management systems that involve local people–the key generators, custodians and promoters of local biodiversity (Rastogi *et al*., 1998), which helps in the effective joint-management of resources between government and local people.

Therefore, rigorous ethnobotanical study is indispensable to get the information from the indigenous societies using different approaches and methods in a scientific way before its death with the knowledgeable elderly people (Martin, 1995; Cotton, 1996; Furze *et al*., 1997; Zemede Asfaw, 1997; Mushongi, 2001). Ethnobotany faces challenges from loss of biodiversity and the low regard to indigenous knowledge (Martin, 1995; Balick and Cox, 1996), which needs immediate attention by all concerned bodies for the benefit and continued existence of all living things.

2.8.3 Recent methodological advances in ethnobotanical studies

2.8.3.1 Perspectives of ethnobotanical data collection

Ethnobotanical study refers to the broad range of data scientifically collected by researchers on the interactions between people and plants. Data are recorded in many different forms, collection of plants, recorded by interviews, laboratory analyses, photographs, market surveys and so on (Martin, 1995). When an informant describes the use of a plant, he/she is clearly or indirectly denoting to the concepts and categories drawing from his/her cultural experience that may or may not correspond to the concepts and categories of the ethnobotanist (Alexiades 1996).

Ethnobotanists follow definite sets of procedures to retrieve reliable ethnobotanical data set. The most important and first step in collecting ethnobotanical dataset is to delimit the cultural domain or subject of interest. For example, the cultural domain chosen may be plants used as stomachaches or as edible fruits. The next important step is to define how to categorize and measure local knowledge and management of the environment. Either types of cognitive systems or behavioral study approaches may be followed when collecting data on the local use categories or domains of the cultural significance of plants and their relationships with the environment and community. An emic point of view corresponds to the perceptions, nomenclature, classifications, knowledge, beliefs, rules, and ethics of the local plant world as defined by a native of the local cultural community. Emic knowledge allows a native person to behave in culturally appropriate and meaningful ways in different cultural contexts. An etic denotes the conceptual categories and organization of the ethnobotanical environment according to the researcher, who often is alien to the local culture and whose conceptual system ideally derives from the language and rules of science (Zent, 1996).

2.8.3.2 Perspectives of ethnobotanical data analysis

Since Harshberger coined the term ‘ethnobotany’, the field of study has long been criticized for being too qualitative (Albuquerque, 2009) until efforts were made to apply quantitative techniques to the direct analysis of field-collected plant use data. There has been increasing trend in using quantitative techniques in the analysis of ethnobotanical data (Prance *et al*., 1987; Martin, 1995). Ethnobotanical methods are increasing from qualitative to quantitative analysis. The methods of ethnobotany started with the qualitative approach and gradually added more quantitative methods. Phillip and Gentry (1993) defined quantitative ethnobotany as the direct application of quantitative techniques to the analysis of contemporary plant use data. Progress made in the field of quantitative ethnobotany allowed to employ reproducible methods, statistical measures of variation and hypothesis testing in ethnobotanical research (Höft *et al.,* 1999). Most recently, data collected from ethnobotany can be quantitatively analyzed through three major categories, namely informant consensus, subjective allocation and use totaled.

In the method of informant consensus factor, the relative importance of each use is calculated directly from the degree of consensus in informants' responses. The importance of different plants or uses is assessed by the proportion of informants who independently report knowledge of a given use or who claim to have used a plant in a specific way (Phillips *et al.*, 1994). In the subjective allocation method, the relative importance of each use is subjectively assigned by the researcher. The importance of different plants or uses is estimated by the researcher on the basis of his or her assessment of the cultural significance of each plant or use (Stoffle *et al.*, 1990). In the uses totaled method, no attempt is made to quantify the relative importance of each use. The number of uses are simply totaled, by category of plant use, plant taxon, or vegetation type. Not surprisingly, this has been the most popular approach, since it is the fastest and most straightforward way to quantify ethnobotanical data according to some researchers (Bennett, 1992).

Höft *et al.* (1999) presented elaborated techniques on the application of multivariate statistical analyses in ethnobotany. Castaneda and Stepp (2007) developed the ethno-ecological importance value index (EVI) by combining the cultural and ecological data to evaluate the cultural importance of vegetation types. Depending on the aim of the research, it is possible to make comparisons between different cultural groups, plant species and vegetation categories from ethnobotanical perspectives. This includes identification of differences in the relative cultural importance of species or determination of the magnitude of ethnobotanical knowledge held by different demographic groups or communities. Relative Cultural Importance (RCI) indices are quantitative measures designed to transform the complex, multidimensional concept of "importance" into standardized and comparable numerical scales or values. Per-taxon plant use citation data from ethnographic plant interviews is applied to RCI formulas to derive values.

A range of cultural significance indices (CSI) has been developed to measure the cultural importance of a species or a family of plants provided to a community (Hoffman and Gallaher, 2007). The Cultural Significance Index (CSI), an anthropological approach presented by Turner (1988) and modified by Stoffle *et al.* (1990) and Silva *et al.* (2006), calculates importance through researcher- determined weighted ranking of multiple factors. Turner (1988) assigned scores on a five-point scale to the variables of quality and intensity of useand assigned a score of 2, 1, or 0.5 for the exclusivity or preference of use. To reduce the subjectivity of this approach, Silva *et al*. (2006) revised the CSI with a two-point scale for the variables. They also incorporated a consensus method called a correction factor to reduce the sensitivity of this method to sampling intensity. The ethnographic, qualitative approach of the CSI method requires considerable experience and rapport with a cultural group for meaningful results.

2.8.4 Status of forest resources and threats on indigenous botanical knowledge

An increasing demand for arable land and forest products due to the rapidly growing population and poverty of the rural people have also been mentioned as major threats to the survival of many of the Ethiopian plant species (Ensermu Kelbessa *et al*., 1992). If present trends in population growth continue, deterioration of natural resources will be more rapid in the future and will result in a great loss of biodiversity (Ensermu Kelbessa *et al.,* 1992; Zerihun Woldu, 1999).

Traditional plant use is of extremely high importance in many societies and is prevalent in African communities who lived in harmony with the natural resources for centuries without bringing any detrimental effect on the survival of the biodiversity (Thrupp, 1997; Bussmann, 2006). According to Plotkin (1995), indigenous people living in forests best know, use and protect biodiversity. However, the survival and existence of indigenous people and their long-term accumulated knowledge faces challenges, because of modernization, genetic erosion on plant and animal resources, low recognition to their knowledge and varied culture, loss of biodiversity (Martin, 1995; Balick and Cox, 1996; Thrupp, 1997; Almaz Negash, 2001; Bussmann, 2006).

Indigenous knowledge face challenges from genetic erosion because of the destruction of trees and bush land, including land clearance for agricultural lands, the collection of fuelwood and the burning of forests and bush to provide pastureland (Almaz Negash, 2001). In addition to these, indigenous people are also suffering from the displacement and restriction of using their local ecosystems and resources because of the establishment of strict protected areas (Furze *et al*., 1997), which is believed to be one factor for the encroachment and destruction of most of the world-protected areas.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study area description

3.1.1 Location of the *Wejig-Mahgo-Waren* massif forest

Wejig-Mahgo-Waren massif forest is an elongated chain of natural forest that is located in Southern Tigray at about 630 km North of Addis Ababa, the capital of Ethiopia, and 120 km south of Mekelle town, the capital of Tigray National Regional State. It is located between 12º 47′-12º 58′ North latitude and 39 º 30′-39 º 48′ East longitudes with altitudinal variation from 1627 to 2970 m.a.s.l., covering a total area of 8,772 ha (MEF, 2015).

According to MEF (2015), *Wejig-Mahgo-Waren* massif forest is partly degraded with remnant of some intact forest patches. The patches of remnant natural forests belong to the Dry Afromontane forest types with dominant trees, including *Juniperus procera*, *Olea europaea* subsp. *cuspidata* and *Acacia abyssinica*. The vegetation type in most of the area is of the secondary forest type.

The lower part of *Wejig-Mahgo-Waren* massif forest seen adjacent to the highway from *Mekoni* to *Mekelle* is mainly *Acacia* woodland. The forest area falls within five sub-districts of three districts found in and near the forest: *Alaje* (Ayba), *Hintalo-Wajirat* (Tsehafti) and *Raya-Azebo* (Tsigea, Ebo) (Figure 1).

3.1.2 Topography

Wejig-Mahgo-Waren massif forest is within the domain of the northern highlands of Ethiopia in the western escarpment of the rift valley. The topography includes hill areas, flat lands, mountains and valleys.

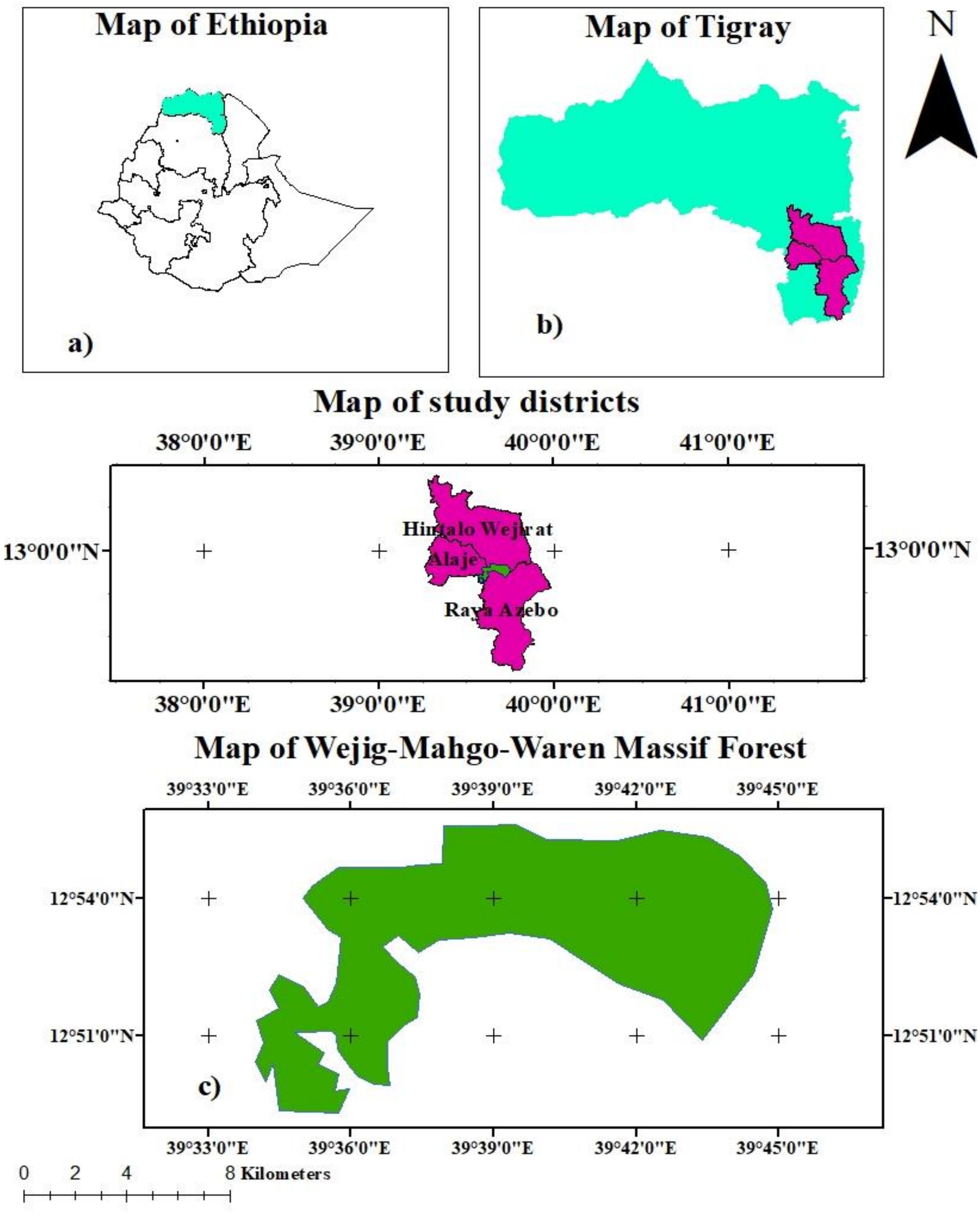
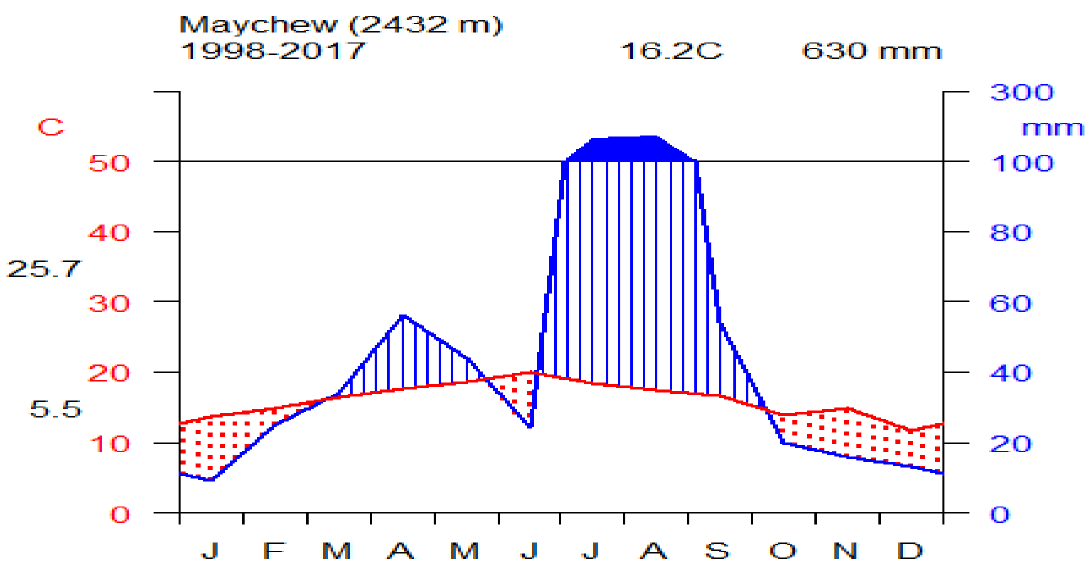


Figure 1. a) Map of Ethiopia, b) Tigray Regional State, c) The study areas (*Hintalo-Wejirat*, *Alaje* and *Raya-Azebo* districts), d) The forest area shaded green (developed using ArcGIS 10.4.1).

3.1.3 Rainfall and temperature (climate)

The rainfall and temperature data for this study were collected from Maychew, the nearest meteorological station. The data were collected from 1998-2017 by the National Meteorological Service Agency (NMSA, 2017). Climate diagram was computed by using R for window version 3.4.1 statistical package (R Development Core Team, 2017). The average maximum temperatures in the study area were recorded in June (25.68 ^{o}C) and May (24.90 ^{o}C). On the other hand, average minimum temperatures were observed in December (5.47 ^{o}C) and January (6.88 ^{o}C). According to the twenty years rainfall summarized data, the study area has a high rainfall distribution between July and August and a little bit between March, April and May. The mean annual rainfall of the study area is 630 mm (NMSA, 1998-2017). Generally, the study area has bimodal rainfall pattern, with low rainfall from March to May and the main rainy season from July to September (Figure 2).



Data Source: NMSA (1998-2017) data bank

Figure 2. Climatic diagram of Maychew town

3.1.4 Geology and soil

Wejig-Mahgo-Waren massif forest is formed on tertiary basalt, alkali-alluvial basalt and tuff. A number of transgressions of the sea in the Mesozoic era deposited sandstones (Adigrat Sandstone) and limestones (Antalo Limestone) in the Tigray Upland floristic region (TU) of northern Ethiopia (Friis *et al.*, 2010). They appear in the deep river valleys of the central part of the Western highlands, and arc visible in the much eroded TU floristic region, where Enticho Sandstone, Adigrat Sandstone, Angula Shale and Antalo limestone are particularly prominent. Large parts of the undulating terrains in northern Ethiopia are characterized by shallow soils and frequent rock outcrops, while relatively thick soils are found along valley bottoms. Vertisols, Cambisols, Fluvisols, Regosols, and Leptosols are dominant soil types in the study area (Amanuel Zenebe *et al*., 2015).

3.1.5 Vegetation

Based on the broad classificaion of the forests of Ethiopia (Friis *et al*., 2010), *Wejig-Mahgo-Waren* massif forest is categorized as a dry evergreen Afromontane and grassland complex forest. It is characterized by dry climate with an annual mean precipitation less than 1000 mm and with *Juniperus procera* and *Olea europaea* subsp. *cuspidata* as dominant canopy trees. According to Friis (1992), this forest occurs on the highlands in the TU floristic regions at altitudes between (1600-) 2200 and 3200 (-3300) meters with annual rainfall between 500 and 1500 millimeters. Smaller trees and shrubs recorded from the northern forests include *Acokanthera schimperi* (dominant species), *Carissa spinarum, Clutia abyssinica, Discopodium penninervium, Euclea racemosa* subsp. *schimperi*, *Grewia ferruginea*, *Maesa lanceolata*, *Psydrax schimperianum*, *Teclea nobilis* and *Rhus natalensis*. There are comparatively few lianas, epiphytes, shrubs and forest floor herbs, apart from some species of grasses. It conserves a number of wildlife species, including Leopard, Greater Kudu, Warthog, Ratel, Grey Duiker, Serval Cat, Wild Pig and Spotted Hyena (EWNHS, undated).

3.1.6 Demographics analysis

Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA, 2007), *Alaje, Hintalo-Wejirat* and *Raya-Azebo* districts have a total population of 107,972, 153,505 and135,870, respectively. The population growth as compared with the 1994 national census, there is significant increment of population. Based on the 1994 national census conducted by the CSA, *Alaje*, *Hintalo-Wejirat* and *Raya-Azebo* districts had a total population of 83,692, 110,926 and 87,638, respectively. Languages spoken in *Alaje* districts are 98.78% (Tigrigna) and 0.96% (Agaw Kamyr), in *Raya-Azebo* 85.52% of the people speak Tigrigna, 11.04% Amharic, 1.83% Afaan Oromo and 1.53% Afarigna, while in *Hintalo-Wejirat* almost all speak Tigrigna as their first language (99.8%). Concerning education, *Alaje*, *Hintalo-Wejirat* and *Raya-Azebo* districts have literacy rates of 10.46%, 9.12% and 8.44%, respectively.

3.1.7 Economic activities

The community in the study area practice rain-fed subsistence mixed farming. All rural lands are collectively owned by the state. Distribution of land was done based on the fertility status of the soil (fertile, less fertile and moderately fertile), and the functional category of the plot (field plot and backyard plot). Concerning the land holding size in the area, it is estimated that a household owns 0.85 ha on average. Crops are produced in rain fed agriculture mainly for subsistence purpose. The major crops growing in the area are teff, maize, barley, wheat, beans, peas, lentils, sorghum and pepper. Livestock husbandry is an integral part of the mixed farming system in the study area.

3.2 Methods

3.2.1 Ecological data collection

3.2.1.1 Vegetation sampling

A reconnaissance survey was made from 25 September to 10 October 2015 to get a general impression of the physiognomy of the forest and select sampling sites. Field trips were undertaken covering both dry and wet seasons from March 2016 to September 2017.

Vegetation data were collected from sample quadrats placed along transect lines, which were systematically laid at Southeast edge of forest part. Quadrats were laid along transect lines following systematic sampling approach as described by Mueller-Dombois and Ellenberg (1974). For trees and shrubs, 150 quadrats of 20 m x 20 m (400 m^2) were laid at every 200 meters drop of elevation following transect lines (10 in total); the distance between two consecutive transects was 700 meters. For herbaceous species, sub quadrats of 1 m x 1 m at four corners and in the center of each quadrat were laid down. Transects were used because they are considerably important in description of vegetative change along an environmental gradient, or in relation to some marked feature of topography.

All plant species encountered in each quadrat were recorded and samples were collected. Vernacular (local) names were recorded when available. The habits of species were identified based on the conventions in the *Flora of Ethiopia* and *Eritrea*. For each quadrat, altitude, longitude and latitude were measured using GPS and slope measured using clinometer. Grazing scale was classified visually as ‘no or slightly grazed (0)’, ‘intermediately grazed (1)’, ‘intensively grazed (2)’ and ‘over grazed (3)’ as used by Getinet Masresha (2014). State of human interference at each quadrat was estimated following Leul Kidane (2015). A 0-3 subjective scale was taken into consideration to record stumps, logs and signs of fuelwood collection. Therefore, the magnitude of impact was quantified as follows: 0=nil; 1= low; 2= moderate; and 3=heavy.

For population structure analysis, woody species having height greater than 2 m and circumference greater than 6 cm at breast height, i.e., 1.3 m were measured and counted. Circumference was later converted into a diameter. Diameter was calculated from circumference (C) using the formula $C = \pi d$, where d is diameter at breast height. Plant species were selected based on the following two or three criteria: higher frequency, higher relative abundance and higher basal area. For other woody and herbaceous plants, percentage cover-abundance was estimated and later converted into modified 1-9 Braun-Blanquet scale (van der Maarel, 1979; DCR-DNH, 2011). The scales are $1 \leq 0.1\%$, 2 = 0.1 to 1%, 3 = 1 to 2%, 4 = 2 to 5%, 5 = 5 to 10%, 6 = 10 to 25%, 7 = 25 to 50%, 8 = 50 to 75% and 9 >75%.

Plant specimens were brought to the National Herbarium (ETH) of Addis Ababa University for identification. Specimens were identified by referring to volumes of *Flora of Ethiopia* and *Eritrea* (1-8) and comparing with authenticated specimens at the National Herbarium and finally were deposited there with their labels.

3.2.2 Determination of vegetation regeneration status

For the purpose of the study “seedlings”, “saplings” and “mature trees/shrubs” were defined as plants with heights less than 1 m, 1-3 m and greater than 3 m, respectively. Following Tadesse Woldemariam (2003), five sub quadrats (3 m x 3 m) were laid at four corners and center of main sample quadrats to count sapling and seedling of all tree and shrub/tree species.

Densities of seedlings and saplings were considered as indicators of the regeneration potential of a forest and this was recorded as good, fair, and poor. A species is considered in a good regeneration state if the number of seedlings is greater than the number of saplings, which in turn is greater than that of trees (seedlings > saplings > trees). Fair regeneration is a condition of a species where the number of seedlings is greater than the number of saplings, and the number of saplings is also less than the number of trees (seedlings > saplings < tree). Poor regeneration is a status of regeneration where density of saplings is greater than that of seedlings (saplings may be <, > or = tree). A species is considered not regenerating if it survives only in adult stage. A species is considered as newly if it is presents only in the seedling stage (Khan *et al*., 1987; Pokhriyal *et al*., 2010). To apply regeneration analysis for conservation priority setting, tree and selected shrub species recorded in the study area were grouped into three categories, based on density of seedlings following Simon Shibru and Girma Balcha (2004) and Getinet Masresha (2014). Those species with no or one seedling were grouped under category I, whereas those species with seedlings between 2 and 14 were categorized under category II and species with seedling number greater than or equal to 15 were grouped under category III.

3.2.3 Soil sampling

Soil samples were collected to assess species richness, vertical distribution, composition, density in the soil seed bank and restoration potential of the study area. For soil samples, 20 m × 20 m quadrats (75 in total) were established at every 400 meters drop of altitude following transects; the distance between two consecutive transects was 700 meters. The samples were taken from five points covering 15 cm x 15 cm (one at the center and the other four at the corners). The reduction of quadrats number was because of manageability. A total of 150 soil samples were collected from the 2 separate soil layers, each layer had 5 cm depth (0-5 cm, 5-10 cm) following Price *et al*. (2010), Li *et al.* (2011) and Wang *et al.* (2015) using a digger. The probability of predation, rain-washing seeds from the surface resulted in poorly guided to conclude restoration potential of woody species from litter layer. Consequently, the litter layer was deliberately removed. Soil samplings were completed within one month (January 2017) to avoid differences in temporal bias in seed availability and composition following the method used by Toledo and Ramos (2011). The samples from each soil layer were used to determine variations of seed distribution at each depth of the soil layers (Mulugeta Lemenih and Demel Teketay, 2006). Soil samples from each layer were packed in to plastic bags and then it was transported to greenhouse of Addis Ababa University, Ethiopia.

Each soil sample was first passed through a 2 mm sieve to remove plant materials and gravels buried in the soil. Seeds with diameter > 2 mm were retrieved and then re-deposited in the final sieved soil samples (Dainou *et al*., 2011). Several methods have been used to estimate the density and composition of soil seed banks and there has been much debate on the utility of the different approaches (Brown 1992; Bernhardt *et al*., 2008). The 'seedling emergence method', which involves spreading a thin layer of soil over a sterilized medium in a greenhouse and identifying and counting emerging seedlings, is commonly used (Ter Heerdt *et al.*, 1996; Ter Heerdt *et al.*, 1999). This method gives a good indication of the readily germinable seed bank, but does not provide a complete assessment of the seed bank flora unless the soil sample is maintained for extended periods at simulated habitat conditions (Thompson and Grime, 1979). Consequently, it was kept for about eleven months (February 2017 – December 2017). Indeed, the seedling emergence method can underestimate the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Brown, 1992; Bernhardt *et al.*, 2008; Wright and Clarke, 2009).

Soil samples remained after removal of debris and these were spread immediately in 20×20×6 cm rectangular plastic trays in Addis Ababa University greenhouse for germination of the seeds (Appendix 21). Each plastic tray was perforated at the bottom and plugged by cotton to facilitate proper drainage of water without losing soil. The seedling trays were kept continuously moist by daily watering following the method used by Toledo and Ramos (2011). The emerging seedlings were identified, counted and recorded. Unidentified seedlings were transplanted into additional germination trays for further growth until the species could be identified. After the newly germinated seedlings were identified and removed, the soil in each tray was thoroughly stirred to stimulate germination of remaining viable seeds from the deeper in the soil to come to the surface (Smith *et al.*, 2002). Ten seed trays filled with sterilized sand were kept under the same conditions as a control for seed contamination; no seedlings were found in these control trays. Each of the plant specimens were pressed, deposited in the National Herbarium (ETH) of Addis Ababa University. Photographs of seedlings were taken after they produced reproductive organs and became viable for identification.

3.2.4 Ethnobotanical data collection

3.2.4.1 Site selection

Selection of districts was carried out by considering sub-districts and villages that were found in the forest and nearby villages. The following were sub-districts found in and around the forest: Ayba, Tsehafti, Ebo and Tsigea.

3.2.4.2 Sample size determination

The sample size for collecting quantitative data for this research to ensure the required representative sample size of households from the five sub-districts was determined using Cochran's (1977) formula as indicated by Bartlett et *al.* (2001) as follow:

$$n = \frac{N}{1 + N(e)^2}$$

n = sample size the research uses; N= total number of households in all five sub-districts

e= maximum variability or margin of error 5% (.05); 1= the probability of the event occurring.

According to sub-districts administrations, the total number of households in five villages of *Arera*, *Ago*, *Mahgo*, *Waren* and *Wejig* were 2236. Applying the above formula, the total sample size for general and key informants was determined to be 339 households. Accordingly, the number of households to be interviewed in each village was calculated using the proportion of the number of households in each village to the total number of households of the two sub-districts. Therefore, the sample size of *Arera* village (*Alaje* district) with a total household of 450 was 68 (450 x 339/2236 = 68). Same calculations were employed for the other study sub-districts (Table 1).

Table 1. Number of households included in the study sub-districts and villages that were found around the forest

District	Sub-district	Village	Total No. households	Key informants	General informants	Total informant
Alaje	Ayba	Arera	450	5	63	68
		Subtotal	450	5	63	68
Hintalo-Wejirat	Tsehafti	Ago	463	5	66	71
		Waren	386	4	54	58
		Subtotal	849	9	120	129
Raya-Azebo	Ebo	Mahgo	418	8	56	64
	Tsigea	Wejig	519	8	70	78
		Subtotal	937	16	126	142
Grand total			**2236**	**30**	**309**	**339**

3.2.3.3 Selection of informants

The total number of informants involved in the ethnobotanical survey from the study sites were 339 (200 male and 139 female). Informants' ages ranged from 22-86 years (254 were < 50, and 85 were > 50 years old). Three hundred nine informants were selected based on gender stratified random sampling for collecting data about cognitive domain, use, management and threats of the forest during random visits made to houses in the study sub-districts. A total of 30 key informants were purposively selected with the help of local administrators, elders and other community members for ranking exercise and collection of specific ailments known by key informants. The key informants include elders, local experts in some domains and plant use categories and knowledgeable men and women. Oral consent was obtained from each informant after informing the purpose of the study.

3.2.3.4 Semi-structured interview, guided field walks and focus group discussion

Ethnobotanical data were collected through semi-structured interview (Appendix 17), guided field walks and group discussion with informants on forest use, cognitive domain, management and level of threats following Martin (1995) and Cotton (1996). Guided field walks give the chance to observe and discuss signs of harvesting or patterns of plant distribution. It also gives local people the opportunity to observe and get to know the researchers who are new to the study area (Cunningham, 1996).

Five focus group discussions were conducted, one group from each village with purposely selected informants, and each group containing four to five informants. The groups contained village administer, development agents for natural resource (DA), male households, female households and guards of the forest. This method was used to gain an insight in to the forest management systems and their suggestions for appropriate solutions to the current problems facing the forest. Interviews and discussions were conducted in the local language of the people in the districts, which is Tigrigna.

3.3 Data analysis

3.3.1 Species accumulation curve

Since number of species is highly dependent on sample size, comparing communities having different sample size is problematic (Peet, 1974; Magurran, 2004). Hence, to overcome this problem, all samples from different communities were standardized to a common sample size of the same number of individuals as recommended by Krebs (1999). Species accumulation curve is a statistical method for estimation of the number of species expected in a random sample of individuals taken from a collection (Krebs, 1999). Species accumulation curves have also been used to estimate the expected number of new species to be detected given a level of additional sampling effort, which can lead to efficient planning and sampling protocols (Krebs, 1999).

Species accumulation curves were plotted for the vascular plants recorded in *Wejig-Mahgo-Waren* massif forest. A graph was plotted for the cumulative number of species recorded as a function of sampling effort, i.e., the number of samples pooled. Species accumulation curve helps to illustrate the rate at which new species were included as the sampling effort proceed.

3.3.2 Plant community analysis

3.3.2.1 Cluster analysis

Classification by means of hierarchical cluster analysis is the most common multivariate technique to analyze community data. Cluster analysis helps to group a set of observations (here quadrats or vegetation samples) together based on their attributes or floristic similarities (Kent and Coker, 1992; McCune and Grace, 2002). Clustering is a multidimensional analysis that consists in partitioning the collection of sampling quadrats (Legendre and Legendre, 1998).

Accordingly, hierarchical cluster analysis was performed using R for window version 3.4.1 statistical package (R Development Core Team, 2017) to classify the vegetation into plant community types based on cover-abundance data of the species in each quadrat. The Similarity Ratio (SR) was measured using Ward's method. The data matrix contained 150 quadrats and 252 species collected from the sample quadrats. The SR was used because it eliminates the differences in total abundance among sample units and the Ward's method was used, because it minimizes the total within group mean of squares or residual sum of squares and is favorite as it produces nicely compact clusters (van Tongeren, 1995; McCune and Grace, 2002).

The three-column data, abundance or cover, were imported to R Package 3.4.3 (R Core Team, 2018) and matrified to carry out analysis for various parameters.

3.3.2.2 Ordination

To analyze the relationship between the plant communities and environment gradients, ordination method was employed. Leps and Smilauer (2001) proposed a simple rule to decide whether to use unimodal or linear method based on the length of the first Dedtrended CCorrespondce Analysis axis. If the length is > 4, data are heterogeneous and unimodal methods should be used. If the length is < 3, data are homogeneous and linear methods should be used. According to Zerihun Woldu (2017), the unimodal model is closer to reality of ecological data and is more suitable for heterogeneous data sets (structured by strong or long ecological gradients, with high species turnover and many zeroes in the species matrix).

Community environment relationship was analyzed with ordination program ''Cannonical Correspondence Analysis (CCA)'' using R or window version 3.4.1 statistical package (R Development Core Team, 2017). CCA can be used to analyze unimodal relationships between species and environmental variables. CCA performs quite well with skewed species distributions, with quantitative noise in species abundance data, with samples taken from unusual sampling designs, with highly intercorrelated environmental variables and with situations where not all of the factors determining species composition are known (Palmer, 1993). According to ter Braak and Šmilauer (1998), CCA is preferred for most ecological data sets (since unimodality is common). Moreover, the ordination diagram generated by CCA visualizes not only a pattern of community variation, but also the main features of the distributions of species along the environmental variables (ter Braak, 1987).

Before the CCA analysis, forward and backward stepwise selection of environmental variables was carried out to identify variables that could significantly explain the variability of species or plant community distributions. This assumes that the large majority of the explanatory variables may add little to the explanation since it is highly likely that many of them are collinear (significantly correlated to each other) (Graham, 2003; Dormann *et al*., 2012; Zerihun Woldu, 2017). According to Dormann *et al.* (2012), there is some degree of collinearity between predictor variables in all real-world data.

3.3.3 Diversity indices

Shannon-Wiener's diversity index was computed to determine diversity and evenness of plant communities. It is given as:

$$H' = -\sum_{i=1}^{s} pilnpi$$

Where, H’ = Shannon-Wiener Diversity Index; Σ = Summation symbol; pi = the proportion of individuals or the abundance of i^{th} species expressed as a proportional of total cover in the sample and ln = log base (natural logarithms).

Equitability or evenness index was calculated from the ratio of diversity observed to maximum diversity using the equation.

$$E = H' / \ln(S) = H' / Hmax$$

Where, E = Evenness; H' = Shannon-Wiener Diversity Index; Hmax = lnS; S = total number of species in the study area. The value of evenness index falls between zero and one. The higher the value of evenness index, the more even the species is in their distribution within the given area.

Floristic similarity analysis between *Wejig-Mahgo-Waren* massif forest and eight other montane forests of Ethiopia was computed using;

Sorensen’s similarity coefficient (Ss),

$$Ss = \frac{2a}{(2a + b + c)}$$

Where, a = number of species common to both forests compared; b = number of species in one forest; and c = number of species in the other forest (Kent and Coker, 1992).

3.3.4 Population structure

Diameter at breast height, basal area, tree density, height, frequency and important value index were used for description of vegetation structure.

3.3.4.1 Diameter at Breast Height (DBH)

Measurements of diameter were made at about 1.3 m from the ground using a measuring tape for those woody plants having circumferences greater than 6 cm. Plants with multiple stems below 1.3 m height were treated as a single individual and the DBH of all the stems were taken and then the average of the diameter was used for basal area calculation. If a tree was buttressed and abnormal at 1.3 m, the diameter was measured just above the buttress. Later the diameter were calculated from circumference (C) using the formula C = πd, where d is diameter at breast height. This technique is easy, quick, inexpensive and relatively accurate. There is direct relationship between DBH and basal area (Kent and Coker, 1992).

3.3.4.2 Basal area (BA) and relative dominance

Basal area is the area outline of a plant near ground surface. It is expressed in square m/hectare (Mueller-Dombois and Ellenberg, 1974). Basal area was used to calculate the dominance of species using the following formula:

$\mathrm{BA} = \pi(\mathrm{d}/2)^2$, where d is diameter at breast height.

$$\text{Relative dominance (RDo)} = \frac{\text{Toatl basal area of a species}}{\text{Total basal area of all tree species}} \times 100$$

3.3.4.3 Density (D)

Density is a count of the numbers of individuals of a species within a quadrat (Kent and Coker, 1992). It is closely related to abundance, but more useful in estimating the importance of a species. Counting is usually done in quadrats placed several times in vegetation communities under study. Afterwards, the sum of individuals per species is calculated in terms of species density per convenient area unit, such as hectare (Mueller-Dombois and Ellenberg, 1974).

$$D = \frac{\text{The numebr of above ground stems of a species}}{\text{Sampled area in hectare}} \times 100$$

$$\text{Relative density} = \frac{\text{Number of ground stems of a species}}{\text{Total number of above stems in the sample area}} \times 100$$

3.3.4.4 Frequency (F)

Frequency is defined as the probability or chance of finding a species in a given sample area or quadrat. It is dependent on quadrat size, plant size and patterning in the vegetation (Kent and Coker, 1992).

It is calculated using the following formula:

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

The frequencies of the tree species in all quadrats were computed. The higher the frequency, the more important the plant is in the community. Although a high frequency value means that the plant is widely distributed through the study area, the same is not necessarily true for a high abundance value. This abundance is not always an indicator of the importance of a plant in a community. Better ideas of the importance of a species with the frequency were obtained by comparing the frequency of occurrences of all of the tree species present. The result is called the relative frequency and is given by the formula:

$$\text{Relative frequency(RF)} = \frac{\text{Frequency of species}}{\text{Total frequency of all species}} \times 100$$

3.3.4.5 Importance Value Index (IVI)

Important value index (IVI) is useful to compare the ecological significance of species. It combines data from three parameters (relative frequency, relative density and relative dominance). It often reflects the extent of the dominance, occurrence and density of a given species in relation to other associated species in an area (Kent and Coker, 1992).

$$\text{IVI} = \text{RD} + \text{RF} + \text{RDO}$$

Where, RD is Relative Density, RF is Relative Frequency and RDO is Relative Dominance.

3.3.5 Analysis of soil seed bank

The species richness of soil seed bank in each soil profile were analyzed. Sorensen coefficient of similarity (Ss, Sorensen, 1948) was used to analyze the similarity between soil seed bank compositions with the standing vegetation and it is given as:

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

Where, a= species common to soil seed bank and standing vegetation; b = total species recorded in standing vegetation; c = total species recorded in soil seed bank.

The composition, frequency and density of seeds in the soil was determined from the germination data recorded in the green house.

3.3.6 Ethnobotanical data analysis

The data were summarized using Microsoft Office Excel 2010 computer programme and SPSS 20. Descriptive and Inferential (T-test) statistical methods were employed to analyze and summarize and test significance level of the ethnobotanical data. The relevant analytical tools of ethnobotany were used to determine the ranks, importance as level of benefits accumulated from various ethnocategories of plants.

3.3.6.1 Preference Ranking (PR)

Preference ranking is a system of ranking of lists or group of plants or other resources in order of first choice (Martin, 1995). This tool was used to determine the level of people's preference based on ranking most threatened plant species; most preferred medicinal plants used against febrile illness, most preferred wild edible plants and honeybee forage species. The selection of ailment for PR of medicinal plants was carried based on the highest number of medicinal plants recorded for healing. Therefore, informants were asked to list, score and rank plants based on their threats and uses stated above. A total of eight to fifteen informants were purposively selected for the collection of PR data.

3.3.6.2 Informant Consensus Factor (ICF) and Fidelity Level (FL)

The calculation of informant consensus factor (ICF) is used for testing homogeneity on the informant's knowledge in choosing certain medicinal plants against a given ailment group. The factor provides a range of 0 to 1, where a high value acts as a good indicator for a high rate of informant consensus. ICF was obtained by "number of use citation (reports) in each category

(n_{ur}) minus the number of species used (n_t), divided by the numbers of use citations (reports) in each category minus one" (Heinrich *et al*., 1998).

$$ICF = \frac{n_{ur} - n_t}{n_{ur\,-1}}$$

High ICF values are obtained when only one or a few plant species are reported to be used by a high proportion of informants to treat a particular ailment category, whereas low ICF values indicate that informants disagree over which plant to use. The main use of ICF is to select ailment categories where there is consensus on the use of plants among the informants and to identify species with particular importance in a culture. To use ICF, it is necessary to classify human illnesses into broad ailment categories (several ailments based on the organ systems in one category). The original categories used by Heinrich *et al.* (1998) and Ermias Leulekal (2014) include conditions common to eight ailment categories in the study area: (1) gastrointestinal, (2) dermatological, (3) external injuries, bleeding and snakebites, (4), evil eye, (5) febrile illness, (6) oral, dental and pharyngeal, (7) sensory and nervous system and (8) others.

The relative healing potential of each reported medicinal plant used against human ailments was evaluated using an index of fidelity level (FL) (Alexiades, 1996), given as:

$$FL = \frac{Ip}{Iu} \times 100$$

Where, Ip is the number of informants who independently cited the importance of a species for treating a particular ailment and Iu is the total number of informants who reported the plant for any given ailment. Independent T- test was employed to the test significance among different social groups on average number of medicinal plants.

3.3.6.3 Direct Matrix Ranking (DMR)

Direct matrix ranking is a system of ranking items in which instead of arranging a series of objects on one characteristic, informants were requested to order them by considering several attributes one at a time, i.e., it draws explicitly upon multiple dimensions (Martin, 1995). As it is described by Martin (1995), direct matrix ranking method was employed to score the use diversity and selected informants were asked to assign use values (5 = best, 4 = very good, 3 = good, 2 = less used, 1 = least used and 0 = not used) to each species. However, it was modified for efficient data recording as high, medium and low (no use) which corresponds to 1.0, 0.5 and 0.0, respectively and for convenience an average of the scores given by the informants were taken. Plants species selected for DMR were *Olea europaea* subsp. c*uspidata, Rhus glutinosa, Opuntia ficus-indica, Podocarpus falcatus, Becium grandiflorum, Carissa spinarum, Teclea nobilis, Pittosporum viridiflorum, Dodonaea angustifolia, Juniperus procera*. Most cited plant species were selected for DMR exercise. Eight informants were purposively selected for the collection of DMR data.

3.3.6.4 Cultural Significance Index (CSI)

The Cultural Significance Index (CSI), an anthropological approach presented by Turner (1988) and modified by Stoffle *et al.* (1990) and Silva *et al.* (2006), calculates importance through researcher- determined weighted ranking of multiple factors. Turner (1988) assigned scores on a five-point scale to the variables of quality and intensity of use and assigned a score of two, one, or 0.5 for the exclusivity or preference of use. To reduce the subjectivity of this approach, Silva *et al*. (2006) revised the CSI with a two-point scale for the variables. They also incorporated a consensus method called a correction factor to reduce the sensitivity of this method to sampling intensity. The ethnographic, qualitative approach of the CSI method requires considerable experience and rapport with a cultural group for meaningful results.

Cultural Significance Index (Silva *et al*., 2006) computed as follows:

$$\mathrm{CSI} = \sum_{i=1}^{n} (i * e * c) * CF$$

Where, i = species management [non-managed (1) or managed (2)] e = Use Preference [not preferred (1) or preferred (2)] c = Use Frequency [rarely used (1) or used frequently (2)] CF = Correction factor [the number of informant citations for a given species divided by the number of informant citations for the most cited species].

CHAPTER FOUR

4. RESULTS

4.1 Vegetation study

4.1.1 Floristic diversity

A total of 264 species that belong to 162 genera and 82 families were identified (Appendix 1). Of these, 252 species were recorded in sampling quadrats and 12 species outside sampling quadrats. Angiosperms were represented by 254 species, gymnosperms by two species and Pteridophytes by eight species. The highest number of species were recorded for the families Asteraceae (27 species, 32.93%), Poaceae (24 species, 29.27%) and Fabaceae (23 species, 20.05%) followed by Lamiaceae (14 species, 17.07%), Solanaceae (12 species, 14.63%), Asclepiadaceae (9 species, 10.98%), Euphorbiaceae (7 species, 8.53%) and Amaranthaceae, Acanthaceae, Malvaceae and Scrophulariaceae (5 species, 6.09% each). Thirteen (about 4.92%) of species were endemic to Ethiopia (Appendix 2). Herbs were found to occur more abundantly (111 species, 42.04%) than shrubs (63 species, 23.86%), trees (57 species, 21.59%), lianas or woody climbers (19 species, 7.19%) and herbaceous climbers (14 species, 5.30%).

4.1.2 Plant community types

Five plant community types were identified from the hierarchical cluster analysis (Figure 3). Species with the highest synoptic values in the group were used to name the corresponding plant communities (Table 2).

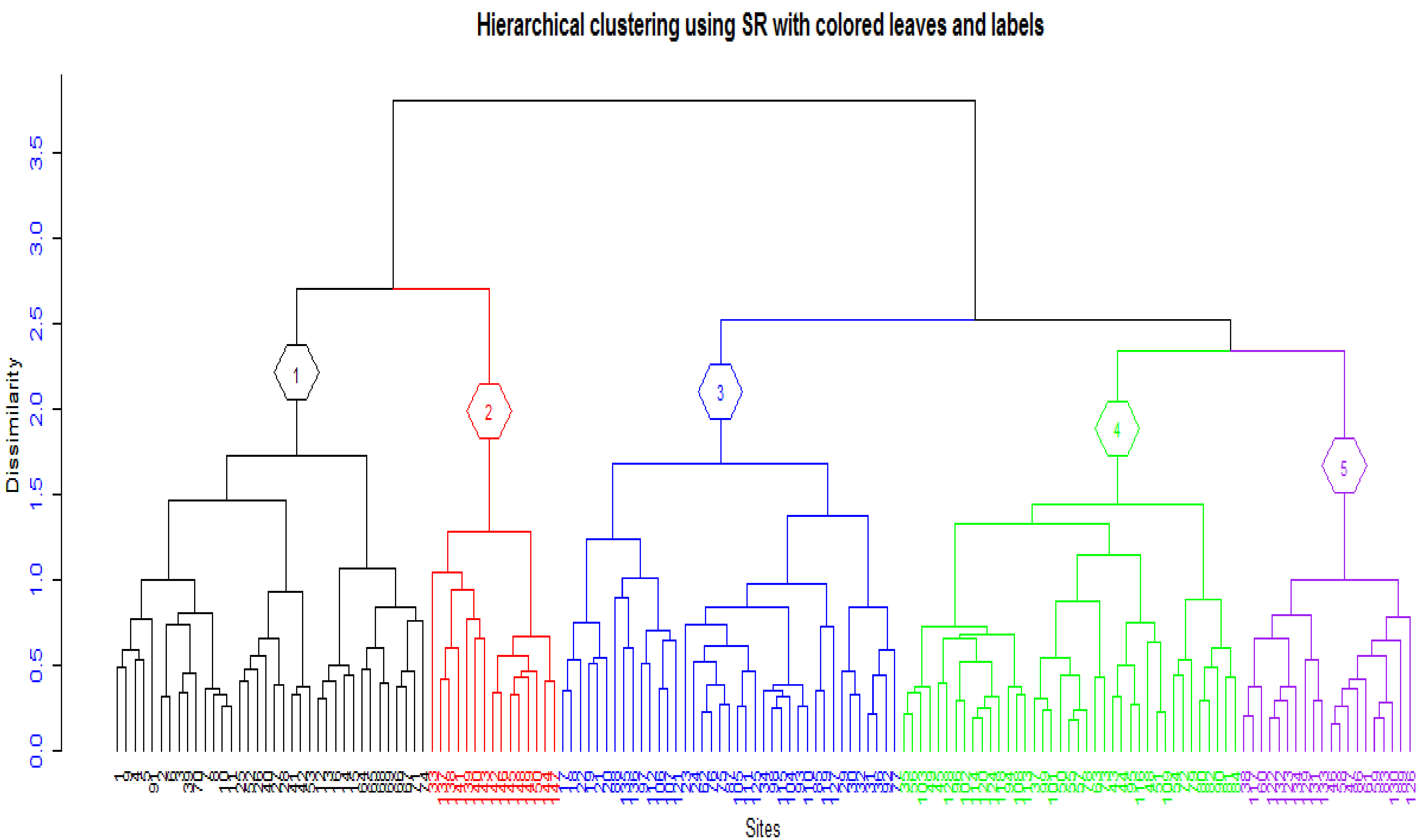


Figure 3. Dendrogram of the vegetation data from Agglomerative hierarchical cluster analysis using similarity ratio

Table 2. Synoptic cover abundance values of species in each community type. Values in **bold** refer to species used to name community types.

Plant Community	1	2	3	4	5
Total quadrats number	36	17	39	39	19
Cadia purpurea	**4.61**	1.11	2.32	0.21	2.80
Carissa spinarum	**2.76**	0.29	1.05	0.26	1.20
Calpurnia aurea	2.21	0.34	0.30	0.16	0
Celtis africana	1.84	0.32	0.14	0.21	0.20
Ficus sur	2.21	0.26	0.14	0.16	0
Podocarpus falcatus	2.71	0.61	0.07	0.32	0
Psydrax schimperiana	1.45	0.24	0.43	0.05	0
Pterolobium stellatum	2.26	0.08	0.20	0	0
Rhus natalensis	1.34	0.32	0.8	0.74	1.1
Olea europaea subsp. *cuspidata*	2.87	**4.84**	3.14	2.58	1.9
Juniperus procera	1.71	**4.32**	1.93	4.21	0
Maytenus undata	0.05	1.13	0.11	0.53	0
Pittosporum viridiflorum	0.08	1.08	0.73	0.68	0
Dodonaea angustifolia	1.11	1.63	**4.98**	4.32	0
Acacia abyssinica	0.89	0.74	**3.75**	2.37	0
Becium grandiflorum	0.26	0.53	1.09	0.47	0
Maytenus arbutifolia	1.42	0.61	1.52	1.21	0
Osyris quadripartita	0.34	0.74	1.45	1.16	0

Rhus glutinosa	1.76	1.71	1.86	1.37	0
Erica arborea	0	0.32	0.57	**6.53**	0
Myrsine africana	0.03	1.84	2.39	**2.95**	0
Nuxia congesta	0.34	0.55	0.3	1.11	0.20
Acacia tortilis	0.29	0	0	0	**5.40**
Acacia etbaica	0.05	0	0	0	**5.20**
Acacia senegal	0.21	0	0	0	2.80
Dichrostachys cinerea	0.05	0	0	0	2.60
Acacia sieberiana	0	0	0	0	1.50
Balanites aegyptiaca	0	0	0	0	1.40
Grewia ferruginea	0.03	0	0	0	1.10
Grewia bicolor	0.16	0.11	0	0.11	1.10

1. *Cadia purpurea – Carissa spinarum* community

The *Cadia purpurea – Carissa spinarum* community is found on the edge of of the forest. Sever livestock grazing and human impacts were observed.The altitudinal range of this community was from 2045 to 2481 m.a.s.l. The upper canopy was occupied by *Celtis africana, Podocarpus falcatus, Psydrax schimperiana, Bersama abyssinica* and *Ekebergia capensis.* The understory was dominated by *Cadia purpurea, Calpurnia aurea, Carissa spinarum, Acokanthera schimperi and Justicia schimperiana.* The shrubs-herbs layer includes *Achyranthes aspera, Bidens pilosa, Cynodon dactylon, Hypoestes forskaolii, Leucas abyssinica, Rumex nervosus, Solanum schimperianum, Tagetes minuta and Withania somnifera. Senecio hadiensis* is a climber.

The data obtained for plant species that produce non-timber forest products were from the ethnobotanical data anlysis. This community also contained 45 species that produced non-timber forest products. The following are among the common species: *Achyranthes aspera, Clematis simensis, Acokanthera schimperi, Abutilon longicuspe, Aloe camperi, Bidens pilosa, Cadia purpurea, Calpurnia aurea, Carissa spinarum, Celtis africana, Ficus sur, Justicia schimperiana, Dovyalis verrucosa, Ekebergia capensis, Phytolacca dodecandra* and *Opuntia ficus-indica*.

2. *Olea europaea* subsp. *cuspidata – Juniperus procera* community

The altitudinal range of this community was from 2453 to 2719 m.a.s.l. The upper canopy was dominated by *Olea europaea* subsp. *cuspidata, Juniperus procera, Allophylus abyssinicus* and *Cassipourea malosana,*. The understory layer was occupied by *Clerodendrum myricoides, Dovyalis abyssinica, Pavetta abyssinica and Pittosporum viridiflorum.* The shrub-herb layer was occupied by *Asparagus racemosus, Berbers holstii, Clutea abyssinica, Colutea abyssinica, Gerbera piloselloides, Smilax aspera, Periploca linearfoliaand Helichrysum quartinianum*.

This community type was also rich in having 63 species that produced non-timber forest products. Some of the abundant species are the following: *Olea europaea* subsp. *cuspidata, Asparagus racemosus, Cassipourea malosana, Dombeya torrida, Dovyalis abyssinica, Eucalyptus globulus, Heliotropium strigosum, Juniperus procera, Kalanchoe petitiana* and *Maytenus undata*.

3. *Dodonaea angustifolia – Acacia abyssinica* community

The altitudinal range of this community was from 2224 to 2640 m.a.s.l. The upper canopy was dominated by *Dodonaea angustifolia, Acacia abyssinica, Maytenus arbutifolia* and *Rhus* *glutinosa*. The shrub-herb layer was occupied by *Becium grandiflorum and Gomphocarpus fruticosus*.

A total of 47 species that produced non-timber forest products were distributed in this community type. *Becium grandiflorum, Clerodendrum myricoides, Cyphostemma adenocaule, Dodonaea angustifolia, Euphorbia petitiana, Myrica salicifolia, Rhus glutinosa* and *Rhus natalensis* were some of the most cited plant species.

4. *Erica arborea – Myrsine africana* community

The altitudinal range of this community was from 2497 to 2970 m.a.s.l. The upper canopy was dominated mainly by *Erica arborea*. The shrub-herb layer was occupied by *Myrsine africana, Anthospermum herbaceum, Epilobium hirsuta, Ferula communis, Hypericum revolutum and Smilax anceps*.

This community type also contained 36 species that produced non-timber forest products amongst the major species are the following: *Asparagus racemosus, Clutia lanceolata, Clerodendrum myricoides, Erica arborea, Laggera tomentosa, Maytenus arbutifolia* and *Nuxia congesta.*

5. *Acacia etbaica – Acacia tortilis* community

The altitudinal range of this community was from 1627 to 1830 m.a.s.l. The upper canopy was occupied by *Acacia etbaica, Acacia senegal, Acacia tortili* and *Ziziphus mucronata* (Appendix 18). The shrub-herb layer was dominated by *Ziziphus spina-christi, Dichrostachys cinerea, Grewia bicolor, Chloris gayana, Cissus quadrangularis, Cynanchum gerrardii, Sporobolus pyramidalis* and *Verbascum sinaiticum*.

This community type also comprised 17 species that produced non-timber forest products amongst the major species are the following: *Verbascum sinaiticum*, *Acacia etbaica*, *Acacia senegal*, *Ziziphus mucronata*, *Euclea racemosa* subsp. *schimperi*, *Datura stramonium*, *Grewia mollis* and *Acokanthera schimperi*.

4.1.3 Species diversity

The Shannon-Wiener diversity index and evenness values of plants in the study area were 3.87 and 0.89, respectively. Among the communities, community two (*Olea europaea* subsp. *cuspidata* – *Juniperus procera*) had the highest diversity value (3.87), while evenness was high in community three (*Dodonaea angustifolia* – *Acacia abyssinica*) (0.89) (Table 3).

Table 3. Overall species richness, diversity and evenness values of plant communities

Community types	Altitudinal range	Species richness (S)	Shannon-Wiener Diversity Index (H')	Shannon's-Evenness (J)
1	2045-2481	68	3.64	0.86
2	2453-2719	121	3.87	0.81
3	2224-2640	56	3.59	0.89
4	2497-2970	141	3.58	0.72
5	1627-1830	52	3.21	0.81

4.1.4 Ordination

Ordination with CCA of *Wejig-Mahgo-Waren* massif forest revealed the following relationship between community types and environmental factors. CCA1 reflects gradients of altitude and slope. Along CCA1 *Myrsine africana* - *Erica arborea* community type four found at relatively higher altitude or associated by altitude. CCA2 of the ordination diagram reflects livestock grazing and human impacts. Along CCA2, the differentiation is based on livestock grazing and human impact that was commonly found in *Acacia etbaica* – *Acacia tortilis* community type five (Figure 4 & 5).

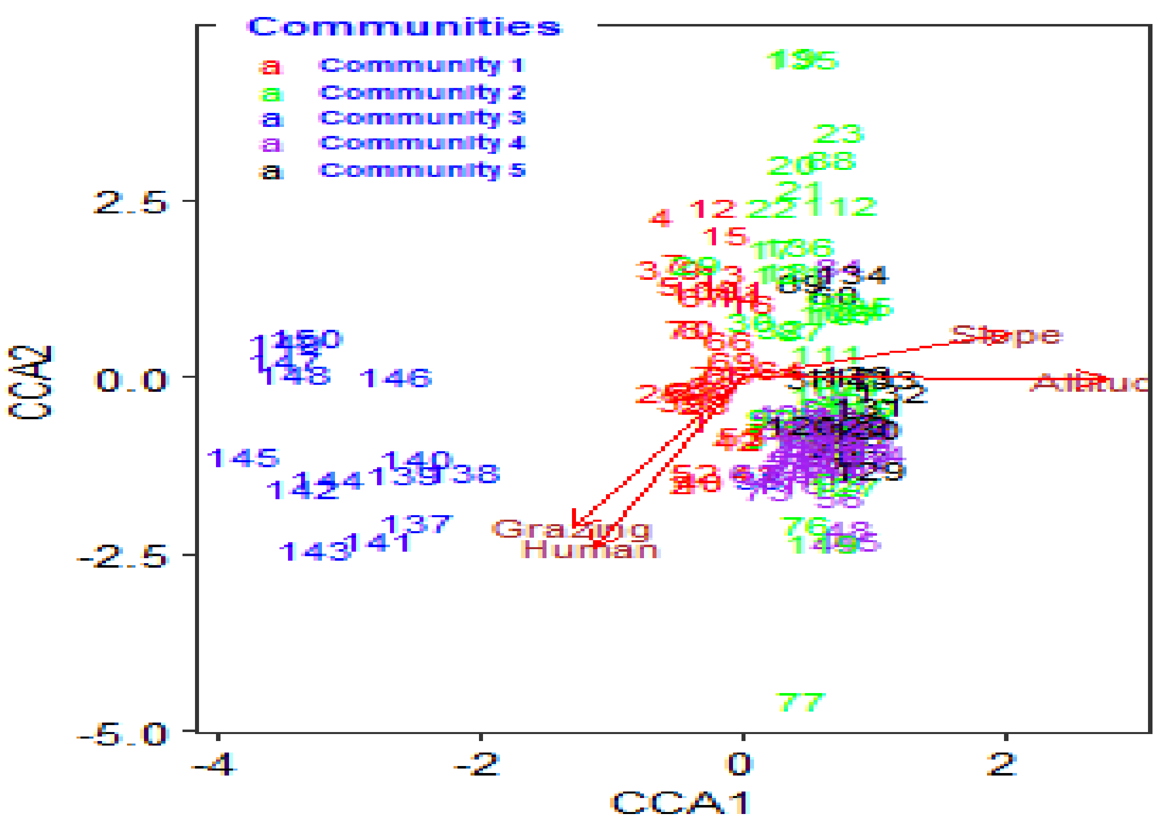


Figure 4. CCA displaying sites constrained by some selected environmental variables and community types identified by different colors

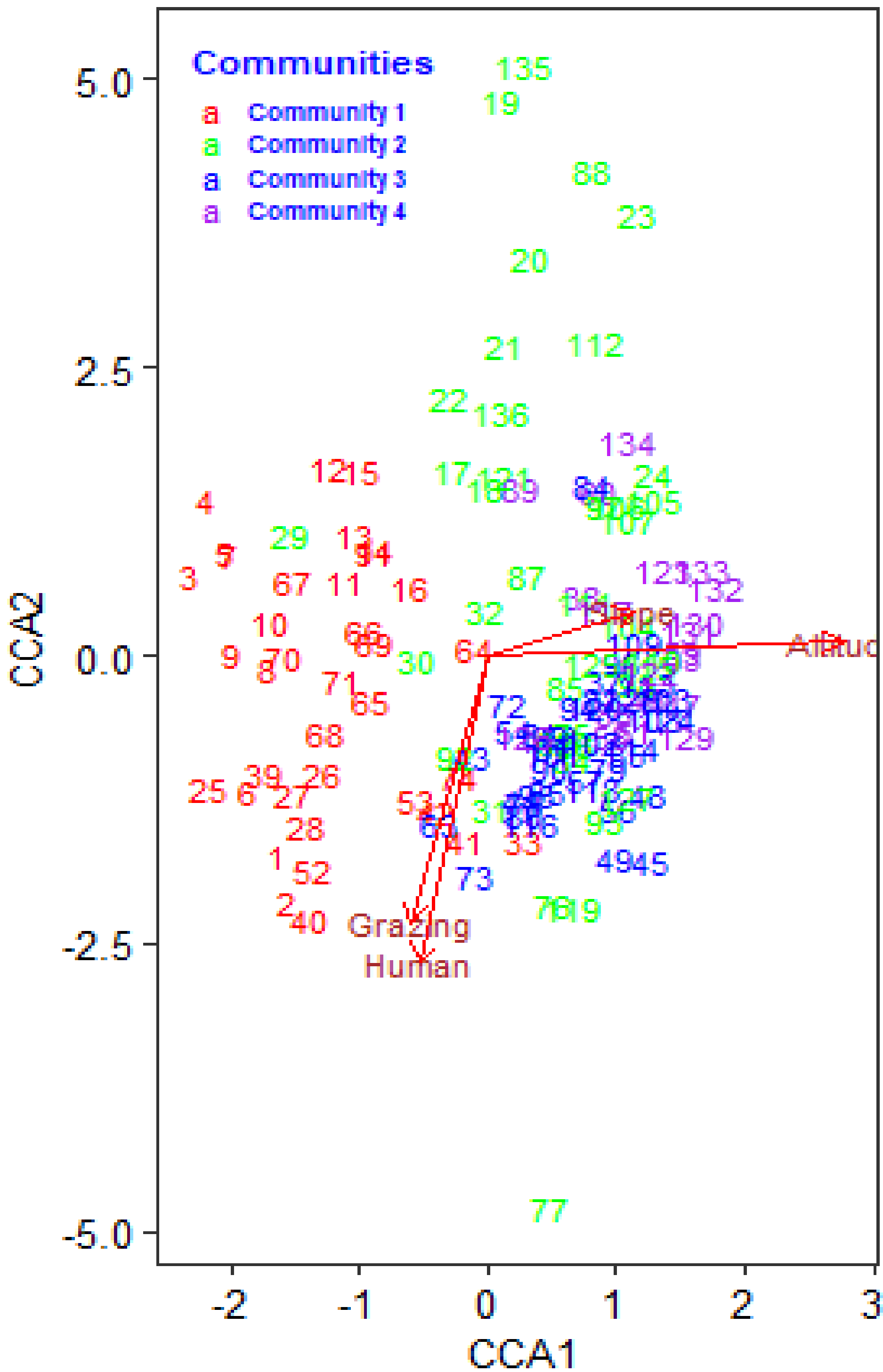


Figure 5. CCA displaying sites constrained by some selected environmental variables and community types identified by different colors

4.1.5 Structure of species population

The population structure of selected tree species followed four general diameter class distribution patterns (Figure 6). These are: A) **inverted-J-shaped**, which shows that the species frequency was highest in the lower diameter classes and decreased gradually towards the higher classes e.g. *Maytenus arbutifolia* B) **bell-shaped**, which shows a type of frequency distribution in which the number of individuals in the middle diameter classes was high and lower in the lower and higher diameter classes, e.g. *Cadia purpurea* C) **broken J-shaped**, which shows that there few individuals in the lower diameter class absent in the intermediate diameter class and in relatively higher number in the highest diameter class, e.g. *Bersama abyssinica* and D) **upward 'F'**, which shows that individuals concentrate in the lower (first) and intermediate (third and fourth) diameter classes. The rest of the classes had almost equally few numbers of individuals, e.g. *Myrsine africana.*

4.1.5.1 Density of some woody species

The higher selected woody plant species density per hectare (1351.50 ha^{-1}) was recorded. Densities of selected tree species per hectare are shown in (Table 4).

Table 4. Density of woody plants in the study area

Scientific name	**Density (ha^{-1})**
Podocarpus falcatus	25.50
Acacia abyssinica	121.67
Cadia purpurea	213.00
Olea europaea subsp. *cuspidata*	202.00
Juniperus procera	143.67
Dodonaea angustifolia	243.33
Myrsine africana	141.00
Maytenus arbutifolia	104.33
Rhus glutinosa	117.67
Bersama abyssinica	39.33

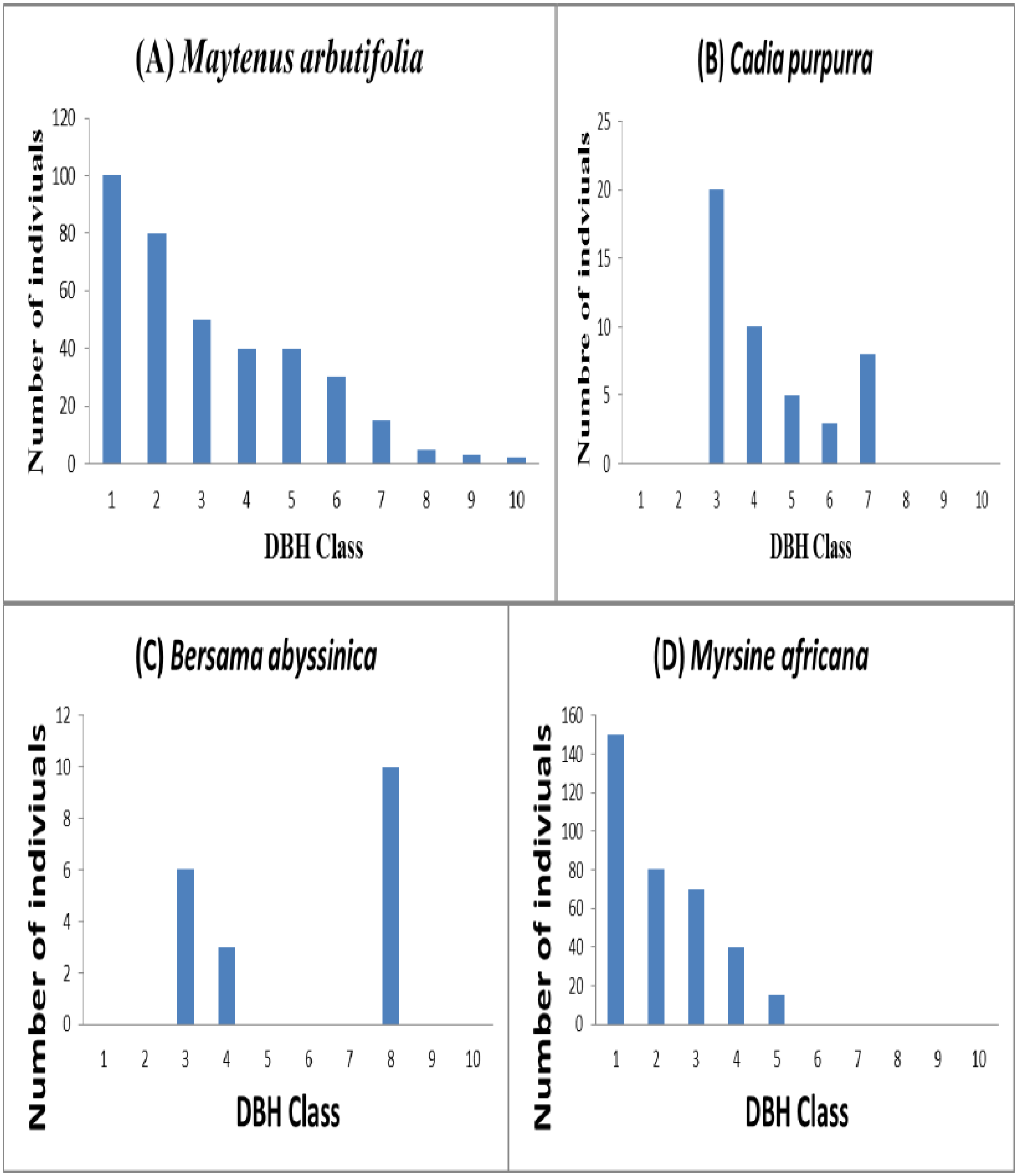


Figure 6. Four representative patterns of population structure based on DBH. DBH class: 1 = ≤2 cm, 2 = 2.01 – 7 cm, 3= 7.01 – 12 cm, 4 = 12.01 – 17 cm, 5 = 17.01 – 22 cm, 6 = 22.01 – 27 cm, 7 = 27.01 – 32 cm, 8 = 32.01 – 37 cm, 9 = 37.1 – 42 cm and 10 >42.01 cm.

4.1.5.2 Basal area

The total basal area was dominated by five woody species (57.45%), i.e., *Podocarpus falcatus, Dodonaea angustifolia, Olea europaea* subsp. *cuspidata, Juniperus procera* and *Myrsine africana* (Table 5).

Table 5**.** Basal area (BA) (m^2 ha^{-1}) of most dominant woody species

Scientific name	**BA (m^2ha^{-1})**	**Percent Contribution**
Podocarpus falcatus	0.95	13.41
Acacia abyssinica	0.30	4.23
Cadia purpurea	0.50	7.06
Olea europaea subsp. *cuspidata*	0.82	11.58
Juniperus procera	0.73	10.31
Dodonaea angustifolia	0.92	12.99
Myrsine africana	0.72	10.16
Maytenus arbutifolia	0.30	4.23
Rhus glutinosa	0.21	2.97
Bersama abyssinica	0.21	2.97

4.1.5.3 Frequency of species

Olea europaea subsp. *cuspidata* was found to be the most frequent species occurring in 82% of all quadrats sampled. Species, including *Rhus glutinosa* (73%), *Maytenus arbutifolia* (67%) and *Juniperus procera* (65%) were also common. A list of the most frequent trees in the quadrats sampled is given in Table 6.

Table 6. Most-frequent trees and shrubs in the study area

Scientific name	**Frequency (%)**
Olea europaea subsp. *cuspidata*	82
Rhus glutinosa	73
Maytenus arbutifolia	67
Juniperus procera	65
Dodonaea angustifolia	63
Cadia purpurea	58
Acacia abyssinica	54
Myrsine africana	45
Bersama abyssinica	32
Podocarpus falcatus	23

4.1.5.4 Importance Value Indices

Importance Value Indices (IVI) were computed for trees and shrubs in the forest. The highest IVI values were obtained for *Dodonaea angustifolia (*36.75) and *Olea europaea* subsp. *cuspidata* (35.70) (Table 7).

Table 7. Importance Value Indices (IVI) trees and shrubs species (RD = Relative density, RF = Relative frequency, RDo = Relative dominance)

Scientific name	**RD**	**RF**	**RDo**	**IVI**
Podocarpus falcatus	1.04	4.09	16.00	21.13
Acacia abyssinica	4.09	9.61	5.21	18.91
Cadia purpurea	8.65	10.32	8.69	27.66
Olea europaea subsp. *cuspidata*	7.20	14.59	13.91	35.70
Juniperus procera	5.83	11.57	12.38	29.78
Dodonaea angustifolia	9.89	11.21	15.65	36.75
Myrsine africana	5.73	8.01	12.17	25.91
Maytenus arbutifolia	4.24	11.92	5.21	21.37
Rhus glutinosa	4.78	12.99	3.48	21.25
Bersama abyssinica	1.6	5.69	3.48	10.77

4.2 Height distribution pattern of woody species

The cumulative height class distribution pattern was an inverted J-shape, showing a decline in density of woody plants with increasing height classes (Figure 7). The abundance of individuals (78.13%) were found in the first, second and third height class (≤ 6 m). The rest of the height classes (i.e., class 4 to class 11) contributed only 22.87% of the total individuals (Figure 7).

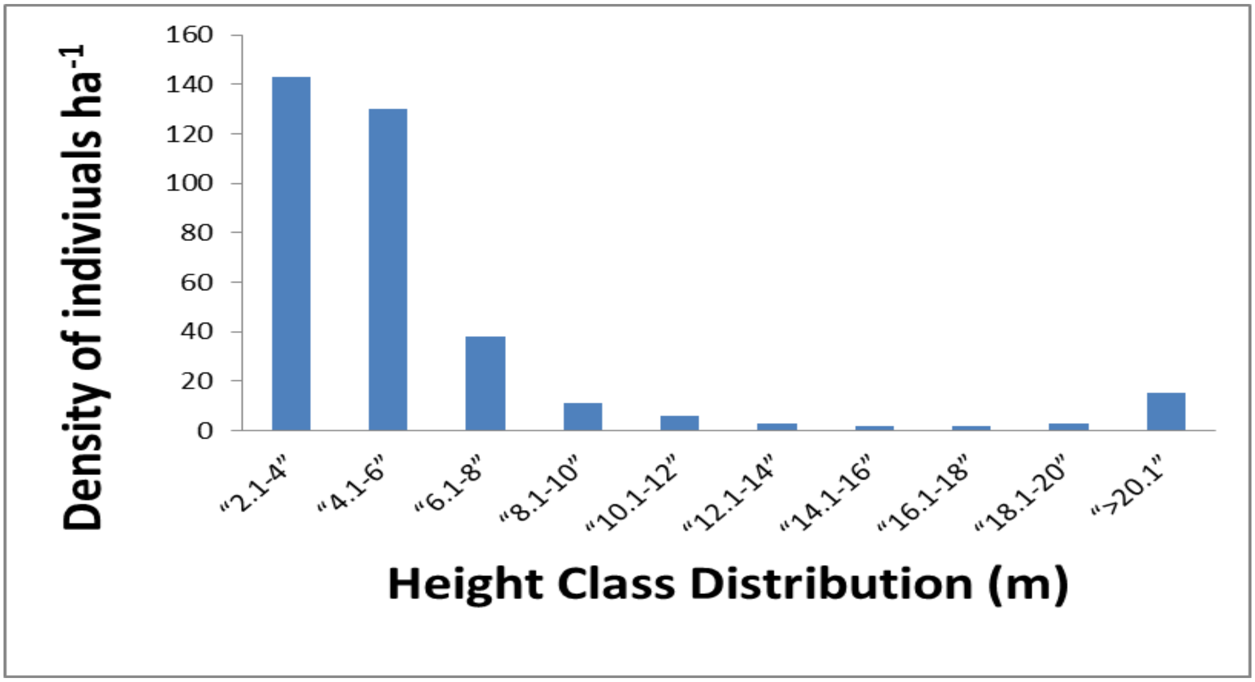


Figure 7. Height class distribution of woody species

4.3 Diameter at Breast Height distribution pattern of woody species

The density distribution of woody species by DBH class shows an inverted J – shaped pattern (Figure 8). For the whole data set, 30.92% of the individuals were found in class one (2.01 - 7 m) while class two (7.01 – 12 m) accounted for 25.77% (Figure 8). The greater percentage i.e., 38.50% were in classes 3 to 5. Individuals from the upper diameter class (greater than 27 m) contributed less than 9.73%. *Podocarpus falcatus*, *Olea europaea* subsp. *cuspidata*, *Juniperus procera*, *Ficus sur*, *Ekebergia capensis* and *Acacia abyssinica* were found to be the dominant large-sized trees in the forest, with DBH > 47.01 m.

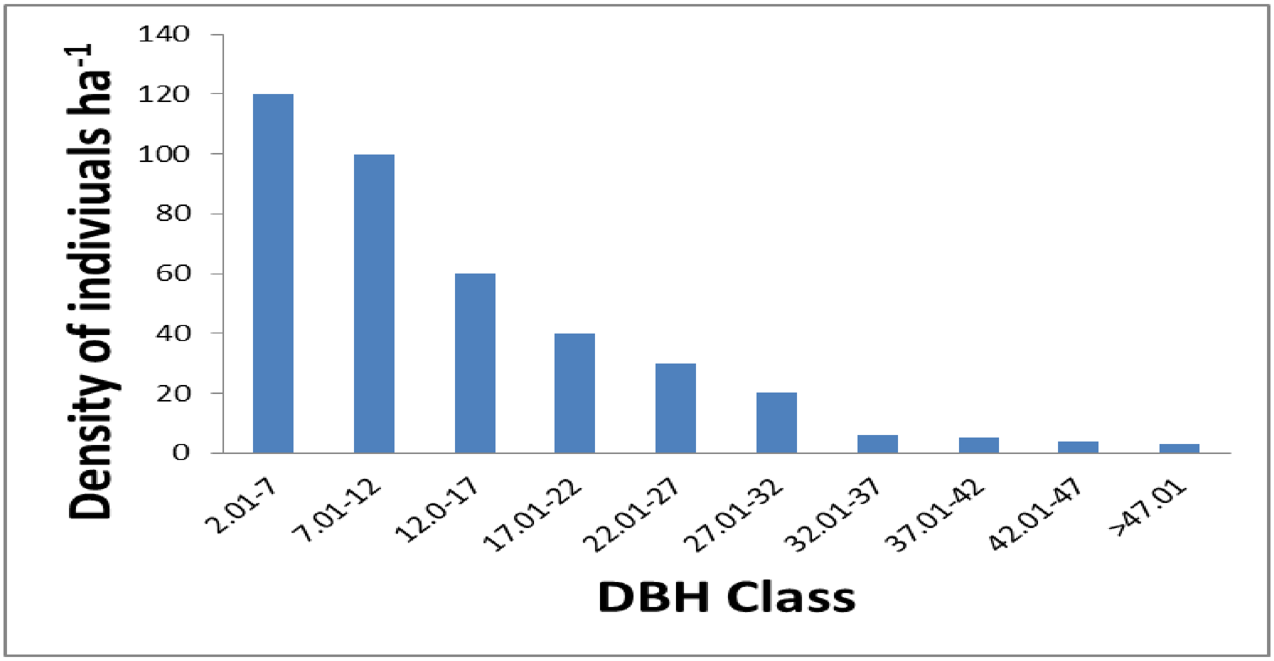


Figure 8. Cumulative frequency distribution by diameter class of woody species.

4.3 Regeneration status

A total of 301.00 (502 ha^{-1}) seedlings, 689.00 (1013.23 ha^{-1}) saplings and 571.00 (841.67 ha^{-1}) mature plants were recorded for all woody species (Figure 9).

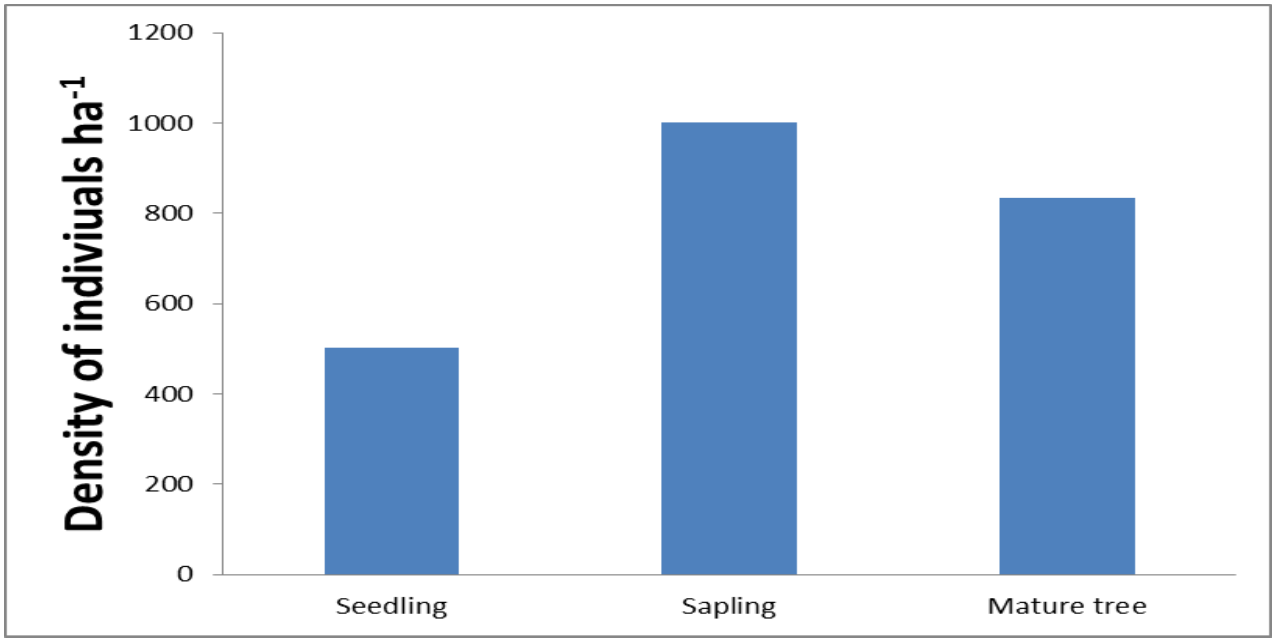


Figure 9. Diameter class distribution of woody species

To apply regeneration analysis for conservation priority setting, tree and selected shrub species recorded in the study area were grouped into three categories, based on the density of seedlings (Table 8). Therefore, those species with no or one seedling were grouped under category I, whereas those species with seedlings between 2 and 14 were categorized under category II and lastly species with seedling number greater than or equal to 15 were grouped under category III.

Table 8. Tree and shrub species categories for conservation priorities

Regeneration status		
Category I	**Category II**	**Category III**
Seedling density (0-1)	**Seedling density (2-14)**	**Seedling density (≥15)**
Ekebergia capensis	*Pittosporum viridiflorum*	*Olea europaea* subsp. *cuspidata*
Ficus sur	*Maytenus undata*	*Maytenus arbutifolia*
Allophylus abyssinicus	*Acokanthera schimperi*	*Cadia purpurea*
Hagenia abyssinica	*Bersama abyssinica*	*Calpurnia aurea*
Dombeya torrida	*Teclea nobilis*	*Erica arborea*
Rubus steudneri	*Osyris quadripartita*	*Myrsine africana*
Balanites aegyptica	*Rosa abyssinica*	*Acacia abyssinica*
Cassipourea malosana	*Celtis africana*	*Dodonaea angustifolia*
Grewia bicolor	*Nuxia congesta*	*Rhus glutinosa*
Rhus retinorrhea	*Podocarpus falcatus*	*Pterolobium stellatum*
	Rhus natalensis	
	Dovyalis verrucosa	
	Psydrax schimperiana	

4.4 Floristic similarity among the study forest and some dry afromontane forests

Wejig-Mahgo-Waren massif forest shared considerable number of species with *Dense, Hugumburda-Gratkahsu, Dess'a* and *Alemsaga* in decreasing order. Lower number of species was shared between the study area and *Tara Gedam-Abebaye*, *Dodola, Chencha* and *Peninsula-Zegie.* Output of a floristic similarity analysis between *Wejig-Mahgo-Waren* massif forest and some other Ethiopian montane forests, based on Sorensen's coefficient of similarity analysis was summarized in Table 9.

Table 9. Composition of floristic similarities among *Wejig-Mahgo-Waren* massif forest and some dry afromontane forests in Ethiopia (N= Number of species included in comparison; a= species composition to both forests compared; b= species available only in the study area; c= species available only in the other forest compared; SS = Sorensen's coefficient of similarity).

Forests	**Elevations range (m.a.s.l)**	**N**	**a**	**b**	**c**	SS
Alemsaga[a]	1970-4135	124	57	207	67	0.30
Chencha[b]	1180-2250	174	45	219	129	0.21
Dense[c]	2125-2921	158	78	186	80	0.37
Dess'a[d]	1000-2760	130	65	199	65	0.33
Dodola[e]	2500-3500	113	46	218	67	0.24
Hugumburda-Gratkahsu[f]	1560-2688	102	72	192	30	0.39
Peninsula-Zegie[g]	1770-1975	113	34	230	79	0.18
Tara Gedam-	2142-2484	143	47	217	96	0.23

Abebaye[h]						
Wejig-Mahgo-Waren	1627-2970	264	264	0	0	1

Data source used for comparison: [a]Getinet Masresha *et al*. (2015), [b]Desalegn Wana and Zerihun Woldu (2005), [c]Ermias Leulekal (2014), [d]Ermias Aynekulu (2011), [e]Kitessa Hundera *et al*. (2007), [f]Leul Kidane *et al*. (2010), [g]Alemnew Alelign *et al*. (2007), [h]Haileab Zegeye *et al*. (2011).

4.5 Soil seed bank study

4.5.1 Species composition

The total number of species recorded was 54, representing 42 genera and 23 families from soil samples collected (Appendix 3). Of the identified species recorded from the forest, 85.16% were herbs and 14.84% were woody plants. Five families, namely Poaceae (380 seedlings), Asteraceae (361 seedlings), Chenopodiaceae (68 seedlings), Brassicaceae (53 seedlings) and Amaranthaceae (46 seedlings) accounted for 81.43 percent of these seedlings. The dominant species in the seed bank were herbs and the proportion of woody species was very low.

4.5.2 Densities of seeds

The number of viable seeds in the soil samples, from germination corresponded to a seed bank density down to 10 cm in the soil was 1115 m^{-2}. The six species with the highest soil seed densities in descending order include *Tagetes minuta, Digitaria velutina, Galinsoga parviflora, Eragrostis cilianensis, Erucastrum abyssinicum and Chenopodium murale*. The most frequent species in the soil seed banks were *Chenopodium murale*, *Tagetes minuta, Galinsoga parviflora*, *Digitaria velutina* and *Eragrostis cilianensis* (Table 10).

Table 10. Density and frequency of species from soil samples collected from the study area

Scientific name	Density (%)	Frequency (%)
Amaranthus hybridus	1.70	9.00
Chenopodium murale	4.80	43.00
Chenopodium opulifolium	1.10	18.00
Digitaria velutina	16.14	39.00
Eragrostis cilianensis	7.35	27.00
Erucastrum abyssinicum	4.75	26.00
Galinsoga parviflora	11.12	41.00
Oxalis procumbens	2.20	20.00
Solanum nigrum	00.99	14.00
Tagetes minuta	22.87	41.00

4.5.3 Vertical distribution of seeds

The depth distribution of the seed bank was more or less consistent with the highest densities in the upper five centimeters of soil and decreasing densities in the lower centimeters. The soil seed bank density exhibited a declining trend with increasing soil depth accounting for 668 seeds m^{-2} (0-5 cm) and 447 seeds m^{-2} (5-10 cm) (Figure 10).

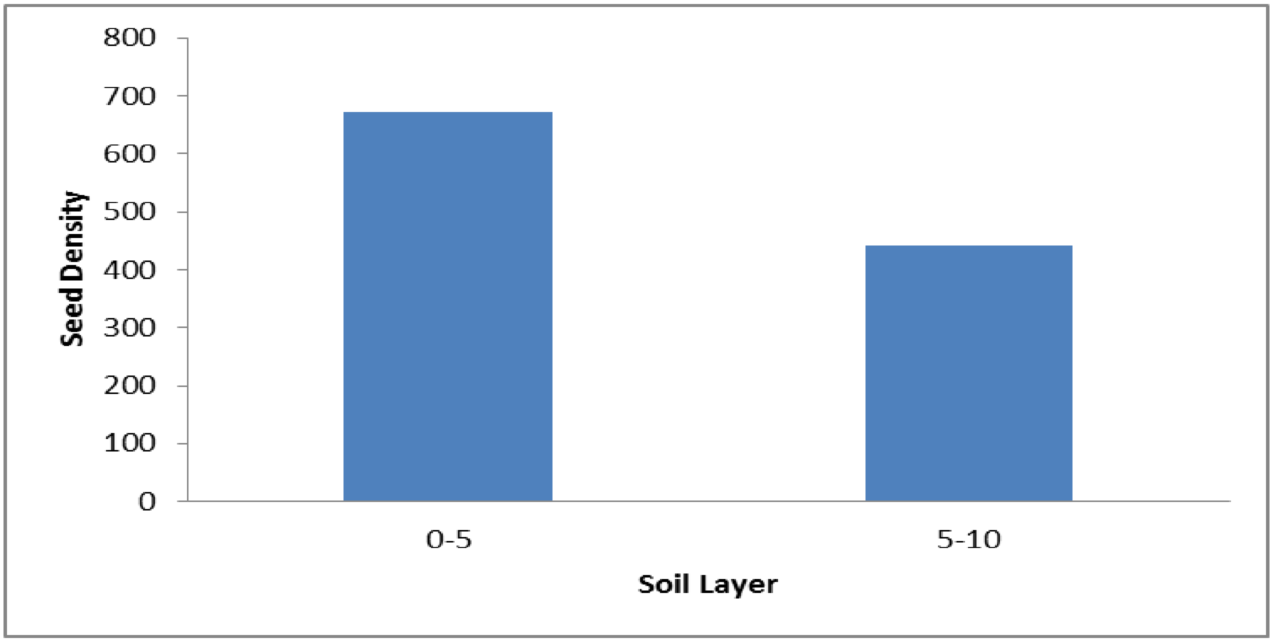


Figure 10. Depth distribution of species density recorded from soil samples

There was variation in relation to depth distribution that decreased to the lower centimeters for the sampled species (Table 11 and Table 12).

Table 11. Ten selected species with their depth distribution of seeds

Layer	**Density of seeds m^{-2}**								
	AH	CM	DV	EC	EA	GP	OP	SN	TM
0-5 cm	18	34	106	67	42	64	19	7	136
5-10 cm	1	24	76	15	10	60	8	5	123
Total	19	58	182	82	52	124	27	12	259

(Abbreviations: AM = *Amaranthus hybridus;* CM = *Chenopodium murale;* DV = *Digitaria velutina;* EC = *Eragrostis cilianensis;* EA = *Erucastrum abyssinicum;* GP = *Galinsoga parviflora;* OP = *Oxalis procumbens;* SN = *Solanum nigrum;* TM = *Tagetes minuta*)

Table 12. Densities of seeds of identified woody species

Layer	**Density of seeds m^{-2}**							
	BG	CP	DA	FP	OL	RN	SA	VS
0-5	2	1	2	9	4	1	2	2
5-10	0	0	0	1	2	1	0	0
Total	2	1	2	10	6	2	2	2

(Abbreviations: BG = *Becium grandiflorum*; CP = *Cadia purpurea*; DA = *Dodonaea angustifolia*; FP = *Ficus palmata*; OL = *Ocimum lamifolium*; RN = *Rumex nervosus*; SA = *Solanum adoense*; VS = *Vernonia* sp.)

4.5.4 Similarity between soil seed bank and standing vegetation

Species recorded only in the standing vegetation were 228, Species recorded only in soil seed bank were 18 and species recorded both in soil seed bank and standing vegetation were 36. The Sorensen Similarity coefficient was 23%. Eight woody species (14.84%) were encountered in the soil seed bank. 6.67% soil seed bank woody species were also found in the standing woody species. The similarity of woody species composition found in the seed bank and standing vegetation was low. Woody species found in soil seed bank were 100% represented in the standing vegetation.

4.6 Plants and People interaction

4.6.1 Concept about the forest and forest resources

Informants reported that forest is important to attract rain and to serve as home to wildlife. They also reported its importance for beekeeping and foraging and as source of straw for thatching and wood used as fuelwood. It is possible to use resources properly from the forest with the permission of the district administration at any time as long as it did not deplete later.

Emic categorizations of plants in the study area were practiced. Plants were described in physiognomic and generic terms. Based on growth form, individual plants were locally described as "*O'm*" (tree), "*Kotkoat*" (bush), "Hareg" (liana), "*Sa'eri*" (grass) and "*Tsahyai*" (weed).

4.6.2 Management of forest plant resources

The local communities have had indigenous knowledge of managing forest resources by their own rules. They nominated "*kessasi"* (accuser) and "*wardia*" (guards) and collected money used for buying ox or goat; slaughtered the ox or goat. Guidelines prepared to the guards how they would protect the forest. Punishment conducted when human enhanced dieback and illegal cutting of plant species have manifested. Moreover, there was a taboo related to *Olea europaea* subsp. *cuspidata* that illegal cutting encountered, it was considered as person was killed. The forest was used to oxen grazing from October to December. Currently, the regional government hired guards having monthly salary.

4.6.3 Major plant use categories

The local people around the study area had accumulated traditional knowledge on the use categorization of forest plant resources into wild edible plants, medicinal plants, farm implements, building materials, fuel wood, livestock fodder/ forage and honeybee forage. The study recorded 79 plant species belonging to 70 genera and 47 families. The families best represented were Fabaceae (7 species), Asteraceae (5 species), Lamiaceae, Solanaceae (4 species each) and Malvaceae (3 species). Thirteen families were represented by two species each and 30 families were represented by one species each.

Traditionally, local people in the study area had their own way of categorizing important plant species in the forest based on the value the later provided. Accordingly, from the 79 plant species, 52 (66%) were used as traditional medicine (human and livestock), 28 (35%) as livestock fodder/ forage and 27 (34%) as honeybee forage (Table 13).

Table 13. The seven major use categories of plants in the study area identified by local communities.

Use category	**Plant category**			**% of total species**	**Rank**
	Family	**Genera**	**Species**		
Traditional medicine	35	49	52	66	1st
Livestock fodder/ forage	20	24	28	35	2nd
Honeybee forage	20	25	27	34	3rd
Fuel wood	19	20	23	29	4th
Farm implements	19	20	22	28	5th
Building materials	16	17	19	24	6th
Wild edible plants	12	14	17	22	7th
Total	47	70	79	100	

Table 13 shows that the forest was primarily used as source of traditional medicine for both livestock and human and forage for the livestock and honeybees. Species cited for each category are listed in Appendices 13, 14, 15, 16, 17 and 18.

4.6.3.1 Medicinal plants collected from the study area

Fifty-two plant species were reported to be used against human and/or livestock ailments in the study area, of which eight were used against both human and livestock ailments. Growth habits of the medicinal plants included shrubs (23 species, 44.23%), trees (12 species, 25.00%), herbs (11 species, 21.15%), woody climbers (2 species, 3.84%) and herbaceous climbers (3 species, 5.77%).

4.6.3.1.1 Ailments treated

The reported medicinal plants were used to treat 50 human and 5 livestock ailments. Of the total number of medicinal plants, 45 (68.18%) were used to treat human ailments (Appendix 4), 13 (19.69%) were employed to treat ailments of livestock (Appendix 5) and 8 (12.12%) were used against ailments of both human and livestock ailments (Appendix 6). With regard to human ailments, febrile illness was the one, against which, a high number of medicinal plants (6 species) were prescribed, followed by evil eye (5 species), jaundice (4 species) and wound (4 species). Cancer, cholera, malaria, devil and snakebite were treated by 3 species each. Both eye infection and dislocation were the prevailing livestock ailments in the study area against each three species were used, followed by those (2 species) used against infestation by leeches. Based on the reports of the interview, a single plant could be used for treatment of different ailments as stated in Table 14.

Table 14. Plants with five or more medicinal uses as identified by the local people

Scientific name	Ailments treated
Olea europaea subsp. *cuspidata*	Febrile illness, Cholera, Typhus, Shanbu*, Fnfan*, Eye Infection, Stomachache
Balanites aegyptica	Cholera, Gulhay*, Hangnail, Dandruff, Anthrax, Tonsillitis,
Clematis simensis	Chibiti*, Cancer, Kidney Ailment, Dislocation, Paralysis,
Datura stramonium	Hemorrhoid, Tuberculosis, Werchi*, Wound, Toothache
Withania somnifera	Malaria, Satan, Wound, Febrile illness, Dislocation

*It refers to local name of an ailment that did not come across common name.

4.6.3.1.2 Plant parts used and mode of preparation

Interview results given in Table 15 shows that the leaf is the most commonly used plant part accounting for 59.04% of the total reported medicinal plants, followed by roots (22.86%) and leaf/root (8.57%).

Table 15. Plant parts used for traditional medicine preparations

Plant part	Total response	Percentage
Leaf	62	59.04
Root	24	22.86
Leaf or Root	9	8.57
Bark	4	3.81

Young shoot	2	1.90
Latex	1	0.95
Fruit	1	0.95
Whole plant	1	0.95
Leaf or bark	1	0.95
Total	105	99.98

It was found (Table 16) out that most remedies were processed by crushing (83.33%), chewing (9.26%) and boiling (4.63%) and the majority (68%) of the remedies were prepared from fresh materials only. Some (24%) remedies were prepared from either dried or fresh materials while few (8%) were prepared from dried materials only. Considerable preparations were made from mixture of different plant species with the use of water and different additives, such as honey, butter, water and cheese. The additives were believed to reduce poisonings, improve flavor and mitigate other side effects.

Table 16. Preparation methods of traditional medicine

Form of preparation	**Total response**	**Percentage**
Crushing	90	83.33
Chewing	10	9.26
Boiling	5	4.63
Others	3	2.78
Total	108	100

4.6.3.1.3 Modes of administration, dosage and use of antidotes

Informants indicated that drinking was the most employed mode of administration with 41 (34.75%) reports, followed by tying 28 (23.73%), smoking 15(12.71) and washing 11 (9.32%). Others were administered by rubbing on the affected/infected part and through swallowing (11.01%) (Table 17). Results show that there was no agreement among informants in materials used for measurement or units used. Most informants used cup, spoon, drops and fingers to determine doses and different doses were reported even for the same or similar ailments. Most of the remedies were reported to have no adverse effects except for some species, such as *Phytolacca dodecandra*, *Justicia schimperiana*, *Clematis simensis* and *Solanum marginatum* that were indicated to be poisonous both to human and livestock. Milk, honey, yoghurt and butter were the commonly reported antidotes in case of adverse side effects.

Table 17. Method of administration of traditional medicine

Administration	**Total response**	**Percentage**
Drinking	41	34.75
Tying	28	23.73
Smoking	15	12.71
Washing	11	9.32
Rubbing	9	7.63
Swallowing	4	3.38
Smearing	5	4.24
Others	5	4.24
Total	118	100

4.6.3.1.4 The most-preferred plants for treating febrile illness

Preference ranking exercise on six medicinal plants that were reported to be used against febrile illness revealed *Eucalyptus globulus* as the best-preferred species. *Withania somnifera* and *Olea europaea* subsp. *cuspidata* were also among the most-preferred species ranked 2nd and 3rd, respectively and others followed (Table 18).

Table 18. Preference ranking to medicinal plants used to treating febrile illness

Medicinal plants	Informants labeled A to O																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total score	Rank
Eucalyptus globulus	6	6	6	6	5	6	5	6	6	6	6	5	6	6	6	87	1st
Withania somnifera	5	5	5	5	6	4	6	5	5	4	5	6	5	5	5	76	2nd
Olea europaea subsp. *cuspidata*	2	4	4	4	4	2	3	4	2	5	4	3	3	4	4	52	3rd
Zehneria scabra	3	3	3	1		5	4	3	4	3	3	4	4	3	3	46	4th
Becium grandiflorum	4	2	2	2	1	3	1	1	3	1	1	2	2	2	2	29	5th
Carissa spinarum	1	1	1	3	2	1	2	2	1	2	2	1	1	1	1	22	6th

NB: Scores given in the table indicate ranks of medicinal plants based on their efficacy. The highest number (6) given to the medicinal plant which informants thought most effective and the lowest number (1) for the least effective plant.

4.6.3.1.5 Efficacy of medicinal plants

About eight major ailment categories were identified from the 50 human ailments reported in the study area. The category with the highest Informat Consensus Factor (ICF) value was that of dermatological ailments (0.98), followed by external injuries, bleeding and snakebites (0.92) and gastrointestinal complaints (0.84) (Table 19). The highest plant use citation (17.72% each) was found for external injuries, bleeding and snakebites and sensory and nervous system, followed by dermatological ailments (15.19% each).

Table 19. ICF values of traditional medicinal plants used for treating human ailments

No.	Ailment category	No. of Species	% all species	Use citations	ICF
1	Dermatological ailments	12	15.19	52	0.98
2	External injuries, bleeding and snakebites	14	17.72	43	0.92
3	Gastrointestinal complaints	7	8.86	39	0.84
4	Evil eye	5	6.33	24	0.82
5	Febrile illness	6	7.59	27	0.80
6	Sensory and nervous system	14	17.72	60	0.77
7	Oral, dental and pharyngeal ailment	10	12.66	18	0.47
8	Others	7	8.86	12	0.45

4.6.3.1.6 Healing potential of medicinal plants used for treating human ailments

The highest fidelity level (96.15%) was obtained for *Verbascum sinaiticum,* followed by *Withania somnifera* (89.47%), *Eucalyptus globulus* (88.24%) and *Datura stramonium* (75.86%) (Table 20). *Verbascum sinaiticum* and *Withania somnifera* were reported to be used agaist dermatological ailments and sensory and nervous systems, respectively.

Table 20. Fidelity level values of medicinal plants commonly reported against a given human ailment category

No.	Medicinal plant	Therapeutic category	Ip*	Iu*	FL (%)*
1	*Verbascum sinaiticum*	Dermatological ailments	25	26	96.15
2	*Withania somnifera*	Sensory and nervous systems	17	19	89.47
3	*Eucalyptus globulus*	Febrile illness	15	17	88.24
4	*Datura stramonium*	External injuries, bleeding and snakebites	22	29	75.86
5	*Clematis simensis*	Ailments of sensory and nervous systems	18	24	75.00
6	*Olea europaea* subsp. *cuspidata*	Gastrointestinal complaints	20	27	74.07
7	*Rumex nepalensis*	Evil eye	10	19	52.63
8	*Balanites aegyptica*	Oral, dental and pharyngeal ailments	6	12	50.00

4.6.3.1.7 Comparison between different social groups

Significant differences ($p < 0.05$) were observed between the average numbers of medicinal plants claimed by men and women informants, by informants belonging to age groups below 50 and above 50 years, illiterate and literate informants and by key and general informant categories (Appendices 7,8,9 and 10). The higher averages were calculated for men than women, for older people than younger ones, for illiterate people than literate ones and for key informants than general informants (Table 21).

Table 21. Statistical test of significance on average number of medicinal plants among different informant groups.

Parameters	Informant groups	N	Average± SD	t -value**	p –value
Gender	Male	200	4.21±9.20	5.88	0.000*
	Female	139	0.32±1.39		
Age	Young members (<50)	254	1.61±5.99	-1.38	0.030*
	Old members (>50)	85	2.66±6.22		
Literacy level	Literate	140	1.63±4.27	-2.79	0.000*
	Illiterate	199	3.55±8.29		
Informant	Key informant	30	14.57±13.74	17.86	0.000*
Category	General informant	309	0.34±1.12		

*Significant difference (p<0.05); ** t (0.05) (two tailed), df = 337, N= number of informants

4.6.3.1.8 Source and transfer of indigenous knowledge on medicinal plants

In the study area, it was widely observed that parents (50.66%) and grandparents (30.22%) served as the main source of traditional medical knowledge (Table 22). They commonly transferred their knowledge orally to their eldest son and other trusted family members secretly.

Table 22. Sources of knowledge on the practice of traditional medicine

Source of knowledge for traditional healer	**Percentage**
Parents	50.00
Grandparents	35.22
Wife/Husband	8.55
Neighbors	3.00
Friends	1.22
Sister/Brother	0
Uncle/Aunt	0
Other	2.00
Total	100

4.6.3.2 Wild edible plants

Seventeen plant species were identified as edible. Of the recorded edible plants, shrubs constituted 15 species (88.23%) and trees two species (11.76%). In terms of plant parts used, fruits included 17 species (94.12%) and only one species (5.88%) was reported to be consumed for its young shoots (Appendix 11).

The preference ranking exercise on wild edible plants ranked: *Opuntia ficus-indica*, *Ficus sur* and *Carissa spinarum*: 1st, 2nd and 3rd, respectively (Table 23).

Table 23. Results of preference ranking of eight wild edible plants

Wild edible plants	**Informants labeled A to K**												
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total score**	**Rank**
Opuntia ficus-indica	8	8	6	4	8	8	7	7	8	8	8	80	1st
Ficus sur	6	6	3	8	7	3	8	8	7	7	3	66	2nd
Carissa spinarum	7	5	8	6	5	7	5	6	5	4	5	63	3rd
Dovyalis verrucosa	3	3	2	7	6	6	2	4	6	5	4	48	4th
Rosa abyssinica	5	7	4	3	2	2	4	5	3	6	6	47	5th
Dovyalis abyssinica	4	4	5	2	3	4	3	3	2	2	7	39	6th
Sageretia thea	2	2	7	5	4	1	1	2	4	2	2	32	7th
Rubus steudneri	1	1	1	1	1	5	6	1	1	1	1	20	8th

NB: Scores in the table indicate ranks given to wild edible plants based on their edibility. Highest number (8) given for the edible plant which informants thought most preferred and the lowest number (1) for least preferred.

4.6.3.3 Fuelwood

Twenty-three plant species were preferred sources of fuelwood. The different plants harvested by the local community as a source of fuelwood included shrub (16 species, 69.57%) and tree (7 species, 30.43%) species. Fifteen species (65.22%) were used for their main trunk (stems) and eight species (34.78%) for their branches and were mostly harvested from the forest (Appendix 12).

4.6.3.4 Farm implements and building materials

Twenty-two plants were reported to be used for making traditional farm implements. Shrubs (15 species, 68.18%) and trees (7 species, 31.81%) were used. Concerning the plant part used, stem was commonly used (Appendix 13). Plough and its parts, yoke, handlers of (spade, pickaxe, scythe, harrow and hoe) were few among the specific uses of the plants species recorded.

Nineteen plant species were used for traditional construction of houses. Of these, shrubs (13 species, 68.42%) and trees (6 species, 31.58%) were frequently used. Stems were the commonly used plants parts (Appendix 14).

4.6.3.5 Livestock fodder/ forage

Twenty-six plant species were used as livestock fodder/ forage. Shrubs (19 species, 73.07%) were the most represented plant habits, followed by trees (4 species, 15.38%) and herb (3 species, 11.53%). With reference to the plant parts used only leaves were used as a source of fodder/ forage in the study area (Appendix 15).

4.6.3.6 Honeybee forage

Twenty-seven plant species were identified as sources of honeybee forage. The study shows that Fabaceae with four species followed by Lamiaceae, Acanthaceae, Malvaceae and Anacardiaceae with three species each were the major sources of nectar/pollen. Based on growth habit, shrubs contributed the highest number (22 species, 81.48%) followed by that of trees (4 species, 14.81%) and herb (1 species, 3.70%) (Appendix 16). Nectar/pollen was used the sole sources of honeybee forage. Preference ranking indicated *Erica arborea*, *Hypoestes forskaolii, Leucas abyssinica* and *Becium grandiflorum* as 1st, 2nd, 3rd and 4th, respectively (Table 24).

Table 24. Results of preference ranking of eight honeybee plants (**NB**: Scores in the table indicate ranks given to honeybee plants based on pollinators visiting. Highest number (8) given for the honeybee plant which informants thought most visited and the lowest number (1) for least visited)

Honeybee plants	**Informants labeled A to J**											
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**Total score**	**Rank**
Erica arborea	8	8	1	7	4	6	7	6	7	8	62	1st
Hypoestes forskaolii	5	7	2	6	8	8	8	2	6	7	59	2nd
Becium grandiflorum	7	5	4	5	2	4	5	7	8	6	53	3rd
Leucas abyssinica	6	4	3	4	7	7	4	8	5	5	53	3rd
Olea europaea subsp. *cuspidata*	2	6	8	8	6	5	6	4	4	4	53	3rd
Opuntia ficus-indica	4	3	6	3	1	2	2	3	3	3	30	6th
Aloe camperi	3	2	5	2	5	3	3	1	1	1	26	7th
Justicia schimperiana	1	1	7	1	3	1	1	5	2	2	24	8th

4.6.4 Multipurpose plants

Informants in all study sites reported that many forest plants have multiple uses. For example, *Olea europaea* subsp. *cuspidata* and *Rhus glutinosa* were reported to have about six uses each followed by *Teclea nobilis* with five uses. The rest of the plants had three to four uses each (Table 25).

Table 25. Direct matrix ranking of top seven multipurpose plants. Note: **Fo =** food; **Me** medicine; F**i = farm** implement; **Bm =** building materials; **Fw =** fuelwood; **Fd =** fodder; **Hb** = honeybee forage; **R= rank**)

Species	**Use category**								
	Fo	**Me**	**Fi**	**Bm**	**Fw**	**Fd**	**Hb**	**Total**	**R**
Olea europaea subsp. c*uspidata*	0.0	0.5	1.0	1.0	1.0	0.5	0.5	4.5	1st
Rhus glutinosa	0.5	0.0	1.0	1.0	0.5	0.5	0.5	4	2nd
Podocarpus falcatus	0.0	1.0	1.0	0.5	1.0	0.0	0.0	3.5	3rd
Teclea nobilis	0.0	0.0	0.5	0.5	1.0	1.0	1.0	3.5	3rd
Opuntia ficus-indica	1.0	0.0	0.0	0.0	0.0	1.0	1.0	3	5th
Becium grandiflorum	0.0	0.5	0.0	0.0	1.0	0.5	1.0	3	6th
Juniperus procera	0.0	0.5	1.0	1.0	1.0	0.0	0.0	3.0	7th
Carissa spinarum	1.0	1.0	0.0	0.0	0.0	0.0	0.5	2.5	8th
Pittosporum viridiflorum	0.0	0.0	0.5	0.5	0.5	0.5	0.5	2.5	8th
Dodonaea angustifolia	0.5	0.0	0.0	0.5	1.0	0.5	0.0	2.5	8th

4.6.5 Major threats to forest resources

Information showed that the forest had been subjected to frequent tree cutting by members of the local community, because of population growth and poverty. According to the informants, the major factors reported for forest destruction were deforestation (38%), agricultural expansion (25%), fuelwood collection (18%), livestock grazing (9%), drought (5%) and settlement (3%) in decreasing order.

There were a number of plant species that were commonly over exploited, because of human influence. Priority ranking was employed to identify those locally threatened plant species as perceived by the local people. The results indicated that *Olea europaea* subsp. *cuspidata*, *Erica arborea* and *Podocarpus falcatus* were the 1st, 2nd and 3rd most threatened plant species in the forest, respectively (Table 26).

Table 26. Priority ranking of locally threatened tree/shrub species as identified by the local people

Species	**Informants and scores**															**Total score**	**Rank**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**		
Olea europaea subsp. *cuspidata*	8	8	8	8	8	8	8	8	8	8	7	8	8	8	7	118	1st
Erica arborea	5	6	7	7	7	4	6	5	7	6	8	7	8	7	8	98	2nd
Podocarpus falcatus	4	5	5	5	6	6	7	7	5	7	4	5	7	6	6	85	3rd
Juniperus procera	7	4	6	6	4	7	6	6	6	5	5	4	5	5	4	80	4th
Ficus sur	2	3	1	3	5	2	5	4	4	4	6	2	8	3	1	53	5th
Teclea nobilis	6	7	2	4	2	3	1	1	3	3	1	6	2	1	3	45	6th
Psydrax schimperiana	3	1	3	1	1	5	3	3	2	1	3	1	1	4	5	37	7th
Dovyalis abyssinica	1	2	4	2	3	1	2	2	1	2	2	3	5	2	2	34	8th

NB: Scores in the table indicate ranks given to locally threatened plants. Highest number (8) given for the most threatened plant which informants thought and the lowest number (1) for least threatened.

4.6.6 Cultural Significance Index

Table 27 presents a cultural significance index of eight most cited plant species. The calculation revealed *Olea europaea* subsp. *cuspidata, Podocarpus falcatus, Acacia etbaica, Juniperus procera* and *Balanites aegyptiaca* as the first five most culturally significant plant species.

Table 27. Cultural Significance Index (CSI) of some most cited plants: **NIC** = Number of informant citations; **WV** = Weighted Variables (**i** = species mgmt [non-managed (1) or managed (2)] **e** = Use Preference [not preferred (1) or preferred (2)] **c** = Use Frequency [rarely used (1) or used frequently (2)), **Fo =** food; **Me =** medicine, **Fi =** farm implement, **Bm =** building materials; **Fw =** fuelwood, **Fd =** fodder; **Hb =** honeybee forage, [**CF** = Correction factor the numberof informant citations for a given species divided by the number of informant citations for the most cited species].

No.	Plant species	NIC	WV	Specific uses (SU)							Sum		
				Fo	Me	Fi	Bm	Fw	Fd	Hb	(i*e*c)	CF	CSI
1	*Acacia etbaica*	46	(i)	1	1	1	1	1	1	1			
			(e)	2	1	2	1	2	1	1			
			(c)	2	2	2	2	2	2	2			
			(i*e*c)	4	2	4	2	4	2	2	20	0.76	15.20
2	*Balanites aegyptiaca*	55	(i)	1	1	1	1	1	1	1			
			(e)	1	1	1	1	1	1	1			
			(c)	2	2	2	2	1	1	1			
			(i*e*c)	2	2	2	2	1	1	1	11	.91	10.01

No.	Plant species	NIC	WV	Specific uses (SU)							Sum		
				Fo	Me	Fi	Bm	Fw	Fd	Hb	(i*e*c)	CF	CSI
3	*Becium grandiflorum*	30	(i)	1	1	1	1	1	1	1			
			(e)	1	2	1	1	2	2	2			
			(c)	1	2	1	1	2	2	2			
			(i*e*c)	1	4	1	1	4	4	4	19	0.50	9.5
4	*Cadia purpurea*	25	(i)	1	1	1	1	1	1	1			
			(e)	1	1	2	2	2	1	1			
			(c)	1	1	2	2	2	2	2			
			(i*e*c)	1	1	4	4	4	4	2	20	0.41	8.2
5	*Erica arborea*	19	(i)	1	1	1	1	1	1	1			
			(e)	1	1	1	1	1	1	2			
			(c)	2	1	1	2	2	2	2			
			(i*e*c)	2	1	1	2	2	2	4	14	0.32	4.48
6	*Juniperus procera*	57	(i)	1	1	1	1	1	1	1			
			(e)	1	2	1	1	2	1	1			
			(c)	1	2	1	1	2	1	1			
			(i*e*c)	1	4	1	1	4	1	1	13	0.95	12.35
7	*Olea europaea* subsp. *cuspidata*	60	(i)	1	1	1	1	1	1	1			
			(e)	1	2	2	2	2	2	2			
			(c)	1	2	2	2	2	2	2			
			(i*e*c)	1	4	4	4	4	4	4	25	1	25.00
8	*Podocarpus falcatus*	50	(i)	1	1	1	1	1	1	1			
			(e)	1	2	2	2	2	1	1			
			(c)	1	2	2	2	2	1	1			
			(i*e*c)	1	4	4	4	4	1	1	19	0.83	15.77

CHAPTER FIVE

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Vegetation study

5.1.1.1 Floristic composition and diversity

According to this study, there are 264 species in the area with the possibility of discovering few species more as seen from species accumulation curve, which seems to indicate the possibility for discovering few additional species with increasing sampling effort. The richness of the study site agrees with the fact that the pattern of species richness in East African montane forests (Conservation International, 2007). Variations of species richness occurred among the forests could be attributed to the area sampled (Hill and Curan, 2003) and large range of altitude (Tamrat Bekele, 1993), climate variability (Schmitt *et al.*, 2013) and forest disturbance (Økland, 1990). The Ethiopian vegetation was highly influenced by climate, which was associated with elevation (Dugdale, 1964). Pollen studies in Kenya (Lamb *et al.*, 2003) and northern Ethiopia (Darbyshire *et al.*, 2003) indicated that the flora of East Africa has experienced several changes due to climate change and anthropogenic disturbances.

Consequently, species richness in the study area was greater than in *Alemsaga* with 124 species (Getinet Masresha *et al.* 2015), *Chencha* with 174 species (Desalegn Wana and Zerihun Woldu, 2005), *Dense* with 158 species (Ermias Lulekal, 2014)), *Dess'a* with 130 species (Ermias Aynekulu, 2011), *Dodola* with 113 species (Kitessa Hundera *et al.*, 2007), *Hugumburda-Gratkahsu* with 102 species (Leul Kidane *et al.* 2010), *Peninsula-Zegie* with 113 species

(Alemnew Alelign *et al.,* 2007) and *Taragedam Abebaye* with 143 species (Haileab Zegeye *et al*., 2011). However, the study area less species-rich than *Borena Sayint* with 397 species (Hussien Adal, 2014) and *Hugumburda-Gratkahsu* with 326 species (Leul Kidane, 2015).

The family with high species representation was Asteraceae (27 species, 32.93%). Mesfin Tadesse (2004) stated that Asteraceae was among the richest family in the flora area (Flora of Ethiopia and Eritrea (FEE). According to Hedberg (1964), wind dispersal is one of the main mechanisms affecting long-distance dispersal for Afromontane landscapes. Moreover, many species of Asteraceae have umbrella shape capitula that are adapted for wind dispersal (Hedberg, 1964) and increase their opportunity for the successful establishment of their populations. The study was in accordance with results of other studies, for instance, *Boditi* (39 species, 17%; Haile Yineger *et al.*, 2008), *Komto* (17 species, 9.44%; Fekadu Gurmersa *et al*., 2013), *Dense* (20 species, 27%; Ermias Lulekal, 2014), *Hugumburda-Gratkahsu* (38 species, 11%; Leul Kidane, 2015). However, in terms of species richness found in the FEE, Fabaceae (678 species), Poaceae (609 species), Asteraceae (472 species) and Euphorbiaceae (472 species) were the richest families (Ensermu Kelbessa and Sebsebe Demissew, 2014). Compared to other life forms or habits, high richness of herbaceous species was recorded. This may be attributed to disturbance events that created gaps in canopy cover increasing open spaces in favor of pioneer herbaceous and shrub species. As disturbance increase, pioneer shrubs and herbs may encroach into tree-dominated landscapes (Ermias Aynekulu, 2011), which may be the case in the present study area. Similar studies have reported related results from other dry Afromontane forest whereby herbs are found to be dominant life form or habits (Haile Yineger *et al*., 2008; Fekadu Gurmessa *et al*., 2013; Ermias Leulekal, 2014; Leul Kidane, 2015).

The number of endemic species harbored in the forest was 13 species. Of this, six species were included in the IUCN Red List Categories of Ethiopia and Eritrea (Vivero *et al.*, 2005). Asteraceae and Lamiaceae were the largest families having three endemic species each in the study area. Studies conducted elsewhere in the flora area reported Asteraceae as the largest family (Abiyou Tilahun *et al*., 2011; Ensermu Kelbessa and Sebsebe Demissew, 2014; Abiyot Berhanu, 2017). Nearly half of the world's vascular plant species are endemic to 25 hotspots (Myers *et al*., 2000), of which 17 are in tropical forests each having at least 1500 endemic plant species (Brooks *et al*., 2002). The hotspot concept is based on species richness, endemism and potential threat (with 70% of its natural habitats degraded; Myers *et al.*, 2000). However, many plant species have a too small population size to be viableand this may increase the rate of extinction in the long term (Whitemore, 1997). It has been known that the Afromontane forests contained higher endemism (White, 1978) than the other regions in Africa. Consequently, over 3,000 endemic plant species estimated to be found in this region (White, 1978). However, there has been a threat to the endemic plants found in the study area and thus need immediate action to protect them.

The Shannon - Wiener diversity index was high (H' = 3.87) in the study area. Kent and Coker (1992) explained that the Shannon – Wiener diversity index normally varies between 1.5 and 3.5, rarely exceeds 4.5. This value is found to be higher than that of other montane forests, such as *Chilimo* (H' = 2.72; Tadesse Woldemariam *et al.*, 2000), *Tara Gedam* (H' = 2.98; Haileab Zegeye *et al*., 2011). Similarly, the evenness (J = 0.89) was higher than that of *Chilimo* (J = 0.68; Tadesse Woldemariam *et al*., 2000), *Tara Gedam* (J = 0.65; Haileab Zegeye *et al*., 2011). Altitude and slope were important environmental variables to influence species richness and dispersal activities (Tamrat Bekele, 1994; Ermias Aynekulu, 2011). Generally, habitat diversity is a widely accepted determinant of species diversity (Mutke and Barthlott, 2005). The theory of spatial heterogeneity (Pianka, 1966) stated that more heterogeneous and complex physical environments support more plants that are diverse.

5.1.1.2 Plant communities

The vegetation types in the study site can be broadly classified as dry single-dominant Afromontane forest of the Ethiopian highlands, transition between single dominant Afromontane and east African evergreen and semi-evergreen bushland (Friis, 1992), and modified to dry evergreen Afromontane forest and grassland complex (DAF) (Undifferentiated Afromontane forest, Afromontane woodland, wooded grassland and grassland and dry single-dominant Afromontane of the Ethiopian highlands) (Friis *et al*., 2010).

The plant communities identified from Agglomerative hierarchical cluster analysis are described below:
Cadia purpurea – Carissa spinarum community belongs to the undifferentiated Afromontane forests. *Cadia purpurea* occurred in association with *Calpurnia aurea, Acokanthera schimperi* and *Carissa spinarum*. They were found on the edge of the forest that was exposed to frequent livestock grazing and human impacts. It can be classified as degraded shrub vegetation. All the indicator species were shrub species. Thus, the expansion of *Cadia purpurea* in the community can be considered as an indicator of disturbance. *Podocarpus falcatus, Allophylus abyssinicus, Celtis africana* and *Bersama abyssinica* were common in the undifferentiated Afromontane forests (Friis, 1992), though small number, because of the presence of human-induced disturbances.

Olea europaea subsp. *cuspidata* – *Juniperus procera* community is a dry single dominant Afromontane forest with *Juniperus procera* and *Olea europaea* subsp. *cuspidata* as dominant species (Friis, 1992). It was found on the higher altitude and sloppy area for having little disturbance in the community. The forest occurred NW and SE Ethiopian highlands (especially the Tigrean and the Harar plateau), at altitudes from 2200- 3200 at annual average temperature 12 – 18 °C and annual rainfall between 500 and 1500 mm (Friis, 1992). A sample of dry forest from central Tigray has been described by Wilson (1977) and perhaps be taken as an example of the northern plateau forests.

Dodonaea angustifolia – *Acacia abyssinica* community formed like a belt on the massif that preferred non-calcareous soil and at an altitude 2224 to 2640 m.a.s.l. It can be classified into dry single-dominant Afromontane forest and East African evergreen and semi-evergreen bushland. This category includes a range of physiognomic types, from typical forest to evergreen scrub with dispersed trees, but floristically the whole range is connected. The forest-like types exist in parts of Eritrea, on the eastern escarpment of the NW Highlands (part of Tigray) and on the northern escarpment of the SE highlands (Friis, 1992).

Erica arborea – *Myrsine africana* community was dominated by *Erica arborea* in the upper canopy and the lower story was dominated by *Myrsine africana*. It was found on the primary high and medium altitude montane evergreen bushland (Friis, 1992). This was in agreement with the general pattern presence of *Erica arborea* dominated communities at higher ranges of Afromontane forests (Demel Teketay and Tamrat Bekele, 1995a). *Erica arborea* was found as low as 2100 m.a.s.l, but they were few in number.

Acacia etbaica – Acacia tortilis community was found at the lower altitudes, having shallow soils and that received a lower amount of annual rainfall with higher temperatures. This community was highly influenced by people collecting firewood, charcoal making and livestock grazing. This was due to the place where it was found on the junction of the Afar and Tigray regions (*Raya-Azebo* and *Hintalo-Wejirat* districts), where the tragedy of the commons affected the community. However, there were attempts to protect from severe livestock grazing and overexploitation by the *Hintalo-Wejirat* district for they believed that the forest had a paramount role in bringing rainfall to the rest of their area (Agricultural and pastureland).

5.1.1.3 Ordination

Based on the CCA examination of the relationship between environmental gradients revealed that a strong relationship between altitude and slope, which means that steep slope was more common at higher altitudes (Tamrat Bekele, 1993; Leul Kidane, 2010; Ermias Aynekulu, 2011). Altitude and slopes have mainly influenced *Olea europaea* subsp. *cuspidata – Juniperus procera and Erica arborea - Myrsine africana* communities. Hedberg (1964) stated that altitude affects atmospheric pressure, moisture and temperature in an area whereby the latter directly influence the growth and development of plants and the corresponding patterns of vegetation distribution. Altitude and slope were important environmental gradients portioning forest communities in the Afromontane forests of Ethiopia (Zerihun Woldu and Backeus, 1991; Tamrat Bekele, 1994). *Cadia purpurea – Carissa spinarum* community experienced disturbances. It was found that shrubs were very common in this community. Canopy gaps may favor the spread of shrub and herb species, like *Cadia purpurea* (Ermias Aynekulu, 2011. The disturbances were human impacts and livestock grazing that have also had a connection in the pattern. If there was livestock grazing, there were illegal cutting. *Acacia etbaica – Acacia tortilis* community type was highly influenced by livestock grazing and human impacts and habitat fragmentation from the continuous mountainous forest. CCA2 was positively correlated to livestock grazing and human impacts, while negatively correlated to slope and altitude. Anthropogenic disturbance affects species diversity through habitat loss and habitat fragmentation (Brooks *et al*., 2002). Habitat fragmentation affects biodiversity by reducing the area of a habitat, which reduces the persistence of a species and through the negative edge effect that increases mortality while decreasing reproduction (Farhrig, 2003). The vegetation on the Afromontane belt (900-3200 m) of Ethiopia has been under tremendous pressure from human activities and overgrazing, which has led to the replacement of the evergreen forests by grasslands (Tewolde Berhan Gebre Egziabher, 1988).

5.1.1.4 Vegetation structure

Woody species density in the study area showed relatively high value (1351. 50 ha^{-1}; Table 4) as compared to other afromontane forests, such as *Dense* (1138 stems ha^{-1}; Ermias Leulekal, 2014) and *Hugumburda* (1235.9 stems ha^{-1}; Ermias Aynekulu, 2011). Variations in density distributions can be attributed to variations in habitat preferences of species and topographic gradients forming the forest and the degree of anthropogenic influences (Whittaker *et al*., 2003).

The stand basal area at the study forest (7.08 m^2 ha^{-1}) is far less than that of other tropical and subtropical dry forests (17-40 m^2 ha^{-1}; Murphy and Lugo, 1986), which is evidence for the over-exploitation of the forest, especially of tree species, such as *Olea europaea* subsp. *cuspidata*, *Podocarpus falcatus* and *Juniperus procera*. The plant species with the largest basal area in the forest could be the most important in terms of economic, cultural, ecological and social significance.

The most frequent species were *Olea europaea* subsp. *cuspidata*, *Juniperus procera*, *Rhus glutinosa* and *Maytenus arbutifolia*. Canopy trees, such as *Olea europaea* subsp. *cuspidat* and *Juniperus procera* are also dominant species in the dry Afromontane forests between (1600-) 2200 and 3200 (-3300) meters with annual rainfall between 500 and 1500 millimeters (Friis *et al*., 2010). High frequency of a species always depends on factors, which relate to habitat preferences, adaptation, degree of exploitation and availability of suitable conditions for regeneration (Rey *et al*., 2000).

5.1.1.5 Vertical structure of the forest

The International Union of Forest Research Organizations (IUFRO) classification scheme classifies vertical structure of forests into three layers/storys based on mean heights of canopy tree species (Lampercht, 1989). This classification is entirely related to woody species (trees and shrubs). The upper story species were *Podocarpus falcatus, Celtis africana, Olea europaea* subsp. *cuspidata, Juniperus procera, Allophylus abyssinicus, Ekebergia capensis, Acacia abyssinica,* and *Pittosporum viridiflorum.*The most common middle story species were *Psydrax schimperiana, Bersama abyssinica, Teclea nobilis, Cadia purpurea, Calpurnia aurea, Carissa spinarum, Acokanthera schimperi* and *Justicia schimperiana, Cassipourea malosana, Dovyalis abyssinica, Pavetta abyssinica, Erica arborea, Dodonaea angustifolia, Maytenus arbutifolia* and *Rhus glutinosa, Acacia etbaica, Acacia senegal, Ziziphus spina-christi* and *Dichrostachys cinerea*. Some of the most common lower story species were *Acacia tortilis, Myrsine africana, Clerodendrum myricoides, Asparagus racemosus, Berbers holstii, Clutea abyssinica, Colutea* *abyssinica, Smilax aspera, Becium grandiflorum* and *Gomphocarpus fruticosus.* Most of the shrubs were in this category. According to White (1983), this layer is mixed and the shrub layer is less distinguished from the lower tree layer.

5.1.1.6 Importance value index of woody species

Importance value index (IVI) analysis showed higher values for *Dodonaea angustifolia* and *Olea europaea* subsp. *cuspidata* than for any other species in the study area. Higher basal area for *Dodonaea angustifolia* and higher frequency for *Olea europaea* subsp. *cuspidata* of these species were the contributing factors for having high IVI values. The relative ecological significance and/or dominance of a tree species in a forest ecosystem could be identified from IVI analysis (Mueller-Dombois and Ellenberg, 1974; Curtis and McIntosh, 1951). Hence, in this study, the IVI results also confirmed that these two species (*Dodonaea angustifolia* and *Olea europaea* subsp. *cuspidata*) are the most important/dominant species in the study area.

5.1.1.7 Species population structure and regeneration status

Measurements of DBH for some woody plant species showed a different species population structure. The first population structure represented by *Maytenus arbutifolia* (Figure 6), revealed the presence of the highest density in the lower DBH classes with a gradual decrease in the density towards the higher classes. It represents an inverted J – shaped distribution except for a slight decrease in the first DBH class. Such population was an indication of stable population structure and good regeneration status (Fekadu Gurmessa *et al.*, 2012; Ermias Leulekal, 2014; Leul Kidane, 2015).

The second structure was represented by *Cadia purpurea* (Figure 6), it represented by Gauss-type distribution structure or bell-shaped distribution formed by species where the frequency distribution of individuals in the lower and higher DBH classes was lower than the middle classes. It was found on the edge and disturbed area that experienced selective cutting of big individuals and grazed the seedling severely.

The third structure was represented by *Bersama abyssinica* (Figure 6) revealed that few individuals in the lower diameter class and individuals were absent in the intermediate diameter class and relatively higher number of individuals in the highest diameter class. It represented Broken J-shaped. This structure was caused by the selective removal of a mature individual for construction purpose (Feyera Senbeta, 2006; Alemnew Alelign *et al*., 2007). The fourth structure was *Myrsine africana* (Figure 6), showed that individuals concentrate in the first (lower) and intermediate (third and fourth) diameter classes. The rest of the classes had almost equally few numbers of individuals that were few.

According to Popma *et al*. (1988), plant population structures help to understand population dynamics and regeneration status of species in the forest. Overall, population structure of tree species depending on size-class distribution yielded an inverted J-shaped curve in the forest (Figure 8). This agrees with a general of normal population structure where the number of individual's decreases as the height and DBH class increases, showing the forest was in a stage of a sign of regeneration. This type of population structure was an indicator of a healthy forest. Nevertheless, this does not meant each species found in the study area followed the same population structure. There were species that do not have seedlings so that it was the sum total of the whole forest indicated promising result for regeneration. Climatic factors and biotic interference influence the regeneration of different species in the vegetation (Khan *et al*., 1987). According to Alemayehu Wassie (2007), some species livestock-induced disturbance might be among the major factors constraining regeneration and recruitment of woody species and contributing, ultimately, to the decline of woody species population in the forests.

5.1.1.8 Floristic similarities with other dry Afromontane forests

The observed high Sorensen similarity values obtained from the floristic comparison of *Wejig-Mahgo-Waren* and *Hugumburda-Gratkahsu* (0.39; Leul Kidane, 2015) forests and *Wejig-Mahgo-Waren* and *Dense* (0.37; Ermias Leulekal, 2014) forests indicated that *Wejig-Mahgo-Waren* massif forest was floristically more close to *Hugumburda-Gratkahsu* and *Dense* forests than to the other six forests compared. The least similarity was revealed with *Peninsula-Zegie* (0.18; Alemnew Alelign *et al*., 2007) and *Chencha* (0.26; Desalegn Wana and Zerihun Woldu, 2005). The regional climate has a paramount role in differences for species distribution patterns in tropical montane forests, especially in those with highly diverse topography (Schmitt *et al*., 2013). The higher similarity observed was both forests found in the dry Afromontane forests that believed they share a close similar climate, altitude interval and geographical proximity with Hugumburda-Gratkahsu. The ecological distance between any two areas has also been noted to play an important part for differences in species composition (Mueller-Dombois and Ellenberg, 1974). For example, Chencha forest found in the southern nation, nationalities and people region that was very far from the study area, which is at the northern tip of the country. Thus, the dissimilarity observed between the study area and Chencha forest was owing to ecological distance.

5.1.2 Soil seed bank study

Knowledge of which species are not represented in the persistent soil seed bank can be just as important as knowing which species are represented. Soil seed banks reflect partly the history of the vegetation and can play an important role in its restoration after disturbances. They have been exploited in two contexts: to manage the composition and structure of existing vegetation and to restore or establish native vegetation (van der Valk and Pederson, 1989). In forest management, natural seed banks play a vital role in restoration after disturbances. The findings of the study area revealed that the prevailing habits in the soil seed bank of the forest were herbs and only a small proportion of seed abundance and species richness of woody species. The predominance of herbaceous may be attributed to small seed size, which makes them more easily incorporated into the soil to form seed bank and also less prone to predation (Thompson, 1987, Guo *et al*., 1998, Luzuriaga *et al*., 2005). Previous researches have indicated that seeds of non-woody species can be dormant for a long time under unfavorable environmental conditions, while the tree species with large seed masses easily tend to be rotten or germinate soon after seed fall (Decocq *et al.,* 2004; Daws *et al*., 2005).

The buildup of seeds in the soil was favored by the dormancy of many of the seeds, which is attributed to either the presence of embryo dormancy or impermeable seed coat or both. Dormancy is selected in most dry Afromontane species, which are characterized by long dry seasons and unreliable rainy periods. In non-dormant seeds, dormancy will be induced if the seeds are dispersed under a dense canopy or buried in the soil (Demel Teketay and Granstrom, 1995b; Demel Teketay and Granström, 1997).

Most of the woody component of the forest lacked reserves of long-lived seeds in the soil. Of the 120 woody species recorded in the standing vegetation of the forest, only eight species (6.67%) were represented in the soil seed banks. Low similarity levels between standing vegetation and the seed banks indicate that one should increase work on forest protection and management because of its potentially low restoration ability (Cui *et al.* 2016). Indeed, the seedling emergence method can dramatically underestimate the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Bernhardt *et al.,* 2008; Wright and Clarke, 2009). These findings agreed with those of different authors (Kebrom Tekle and Tesfaye Bekele, 2000; Feyera Senbeta and Demel Teketay, 2001; 2002; De Villiers *et al*., 2003; Ericksson *et al.,* 2003; Amiaud and Touzard, 2004; Tefera Mengistu *et al*., 2005; Alemayehu Wassie, 2007) who reported higher and lower proportions of herbaceous and woody species in the soil seed banks, respectively. The low values of similarity indices between the seed bank and the standing vegetation provided more proof of the weak contribution of soil seed banks to mature stands. Similar conclusions were made from other studies (Perera, 2005; Uasuf *et al*., 2009).

The spatial distribution of seeds of different species in vertical distribution varied greatly. Seed abundance and number of species generally decrease with the soil depth, especially the seeds of woody species accumulated in the upper 0-5 cm soil layers. For example, seeds of *Becium grandiflorum, Cadia purpurea* and *Dodonaea angustifolia* characterized relatively by their large sizes, when compared with the herbaceous ones, were found on the upper 0-5 cm soil layers. These variations may reflect differences of species in terms of seed longevity in the soil, mode of seed dispersal, seed predation and probable differences in altitude and local edaphic conditions where seeds land. This result is also in agreement with past similar works (Feyera Senbeta and

Demel Teketay, 2001; 2002; Ericksson *et al*., 2003; Matus *et al*., 2005; Tefera Mengistu *et al*., 2005; Alemayehu Wassie, 2007).

Soil seed bank species have been reported to have the following characters related to their success in establishing after disturbance: production of numerous small seeds means of long-distance dispersal, formation of persistent soil seed banks and the capacity to remain viable in a dormant state for a long period of time (Demel Teketay, 2002; Alemayehu Wassie, 2007).

Dry Afromontane forests can be characterized by possessing large populations of buried seeds of herbs whereas trees mainly have persistent seedling banks and the ability to sprout from damaged roots or shoots. The fact that most of the dominant tree species do not accumulate seeds in the soil suggests that their restoration from seeds would be prevented by removal of mature individuals in the standing vegetation. This, in turn, implies that restoration forests would be difficult and slow to accomplish if they are destroyed (Demel Teketay, 2002). The herbaceous vegetation has a better chance of recovery since it has a diverse soil seed bank with great seed longevity (Alemayehu Wassie, 2007). The results provide further evidences that consolidate the conclusions of previous studies on soil seed banks, i.e., the future existence of the woody flora characteristic of dry Afromontane areas in Ethiopia depends on the conservation and sustainable utilization of the few remnant natural forests (Alemayehu Wassie, 2007), revegetation of indigenous seedlings from nursery and exclosure for natural restoration.

The soil seed banks appeared not to contribute largely to the restoration of woody species. Clearly, the soil seed bank could not provide a good supply of diaspores of woody species. For such purpose, planting in logging gaps with threatened indigenous seedlings coming from the nursery should be more efficient (Doucet *et al*., 2009).

5.1.3 People and plant interactions

5.1.3.1 Concept about the forest and forest resources

The results indicated that traditional concept about forest resources was tied up with the use of plants. Forest is the most precious gift, nature has provided to us, as it is meeting all kinds of essential requirements of the humans in the form of medicine, food, fodder, fuel. According to Zemede Asfaw (2006), the people of Ethiopia are knowledgeable about the name and classification of their environment, plants in their surroundings and their value for the local people, which they have gained orally from generation to generation. Forest for the majority of the rural people meant everything, no-forest-no-life (Melese Damite, 2001). Indigenous knowledge about plants has been a matter of survival to the people who have generated these systems (Grenier, 1998) and indigenous or local people throughout the world have their own distinct culture, linguistic, geographical separation, values and beliefs (Furze *et al*., 1997). The concept of local people on plants is developed over time involvement, reflection and discussion that affect their beliefs and attitudes towards forest management practices (Cotton, 1996).

5.1.3.2 Management of forest plant resources

There was a belief related to *Olea europaea* subsp. *cuspidata* in the community when a single tree of the plant was cut, the community considered it as if a person was killed. In seeking to understand how indigenous peoples might live in harmony or balance with the natural world, the idea of taboo as a conservation strategy was popularized. Cultural taboos are informal activities that determine human behavior (Colding and Folke, 2001). They involve restrictions by certain sectors of society on the use of particular resources and habitats, sometimes only at particular times or in particular places (Colding and Folke, 2001). Cultural taboos are an important aspect of plant selection by societies throughout the world. It is a taboo to use certain plant species to protect them from overexploitation and extinction.

This study has brought into picture the traditional management system of the forest held by the local people that has been handed over down to the present. The forest massif was found on the common borders of the three districts and that resulted in competition for resources. The tragedy of the commons has been observed in the study area. People fought for grazing, fuelwood and agricultural lands. As a result, there were places on the border areas that were highly affected. The forest was used for intermittent oxen grazing, though it was illegal.

Currently, the Tigray Bureau of Agriculture (Natural Resource Division) had managed to take the responsibility of protecting the forest. Guards were hired for a round clock protection of the forest. There were two types of local forest management types in the area, namely communal and protected "Hizaeti" where the ownership right was given to both the government and the community. The communal forest was protected through community consensus and grazing was allowed seasonally. While government protected forest was not allowed for grazing anytime, but there were times (September to November) that the community was allowed to let oxen in the forest graze without the permission of the district administration. This agrees with the report of the Kerreyu people of Ethiopia, where land is seasonally grazed (Kebu Balemie *et al*., 2004). The local communities in Mukogodo forest of Kenya similarly use the forest for dry grazing (Komwihangilo and Mwilawa, 2006). All these studies showed similar plant use knowledge among different traditional people of different geographic areas regarding grazing area management. When there happened to be a special program, which could be a wedding or funeral, collection of dried trees from the forest was possible with permission from sub-district natural resource agent.

One very fascinating phenomenon was beehive keeping inside the forest on the branches of *Podocarpus falcatus* and *Ficus sur,* owned by some so-called early settlers. Both the plants and traditional knowledge were received from their ancestors through legacy. There were no conflict of interests on the trees used for beehive inside the forest, though the forest was believed to be a property of the government and the community. However, there were orders from the government to remove beehive from the forest for fear of forest fire. Similar results have been reported from elsewhere in Ethiopia: Dess'a forest (Abrha Tesfay, 2008) and Borena Sayint National Park (Hussien Adal, 2014).

5.1.3.3 Major plant use categories

5.1.3.3.1 Medicinal plants

The local communities have accumulated substantial knowledge on natural resource found in their environment, including plants. Consequently, 79 plants were recorded to be used as medicinal plants, wild edible plants, fuelwood, farm implements, building materials, livestock fodder/ forage and honeybee forage. Among these resources, none has received more recent scientific and popular attention than tropical medicinal plants (Voeks and Leony, 2004). Of these resources, 52 were medicinal plants and the number was found to be higher compared to those reported elsewhere in Ethiopia: *Zay* people (33 species; Mirutse Giday, 2001), *Tanqua-Abergele* and *Kolla-Tembien* (29 species; Gebremedhin Gebrezgbiher *et al*., 2013), in and Around *Alamata* (16 species; Gidey Yirga, 2010a), *Mekelle* town (25 species; Gidey Yirga, 2010b) and less as compared to those reported from studies conducted in *Kilte Awlaelo* (114 species; Abraha Teklay *et al*., 2013), *Ofla* (113 species; Nurya Abdurhman, 2010), *Asgede Tsimbila* (68 species; Girmay Zenebe *et al*., 2012), *Ofla* and *Raya-Azebo* (83 species; Mirutse Giday and Gobena Ameni, 2003), *Atsbi* and *Adi* Keyih (58 species; Moravec *et al*., 2014) and *Ankober* (151 species; Ermias Leulekal, 2014). Results showed the role played by traditional medicinal plants in meeting the primary health care of people. Ease of accessibility, economic, culture and efficacy related aspects might have played key roles for the people to rely on traditional medicine (Ermias Leulekal, 2014). The informants agreed that more medicinal plants were used in the past than today. Moreover, there was deforestation and drought that resulted in the loss of medicinal plants in the study area.

The fact that shrubs were dominant in the study area may indicate the dry Afromontane forest has been converted into shrubland, because of massive deforestation. Other studies conducted elsewhere in Ethiopia also indicated the dominance of shrubs (Ermias Leulekal *et al*., 2008; Abrha Tesfay, 2008; Anteneh Belayneh, 2006). However, studies conducted elsewhere in Ethiopia noted that herbs were dominating (Nurya Abdurhman, 2010; Abraha Teklay *et al*., 2013; Moravec *et al*., 2014; Gebremedhin Gebrezgabiher *et al*., 2013). Herbs are more easily accessible from the nearby areas than trees and shrubs that are often harvested from patches of forests distantly located from resident areas (Ermias Leulekal, 2014).

High numbers of medicinal plants were used in the treatment of febrile illnesses (6 species) and this may suggest the high prevalence of the ailment in the study area. The fact that *Eucalyptus globulus* was the most frequently used plant to treat febrile illness could indicate better efficacy of the plant.

Leaves were the most used plant part in the preparation of remedies in the district as compared to other parts. Many studies conducted elsewhere in Ethiopia also showed the dominance of leaves in the preparation of remedies (Abraha Teklay *et al*., 2013; Nurya Abdurhman, 2010; Girmay Zenebe *et al*., 2012; Mirutse Giday and Gobena Ameni, 2003). This practice helps to reduce the rate of threat on plant species or helps for sustainable harvesting of plants as compared with utilization of roots. However, studies conducted elsewhere in the country showed the most common use of roots in the preparation of remedies (Moravec *et al*., 2014; Ermias Leulekal, 2014). The popularity of roots might be due to an easy way of their use, as they were mainly chewed or put on fire and inhaled. Roots can be also dried and powdered or homogenized with water. The extensive root excavation can be devastating and can lead to a threat of the species survival or extinction (Moravec *et al*., 2014; Ermias Leulekal, 2014).

The result showed that most remedies were prepared from fresh materials only. Some remedies were prepared from either dried or fresh materials while few were prepared from dried materials only. The frequent use of freshly collected medicinal plant could be attributed to the widespread traditional belief of attaining high efficacy from fresh remedies due to the higher presence of active ingredients in the cases of fresh plant parts, which community members thought, could be lost on drying. Considerable preparations were made from a mixture of different plant species with water and different additive substances, namely honey, butter, water and yogurt. A study conducted elsewhere in Ethiopia (Abraha Teklay *et al*., 2013; Nurya Abdurhman, 2010; Teshale Sori *et al*., 2004) also reported similar results.

Most informants reported the use of measuring units, such as cup, spoon, drops and fingers, but still, there were differences in doses. The variation in quantity, unit of measurement and duration of treatment of prescribed plant preparations was also noted in a study conducted elsewhere in Ethiopia (Abraha Teklay *et al.*, 2013).

Overdose of remedies was reported to bring adverse effects, like vomiting, diarrhea, burning sensations and sometimes fainting of the patient. Problem of precision and standardization taken as one drawback for the recognition of the traditional health care system (Dawit Abebe, 2001; Ermias Leulekal, 2014; Abraha Teklay *et al*., 2013). However, there were antidotes to the side effects caused doses problems, like honey, butter, water and yogurt. This finding is consistent with reports elsewhere in the country (Mirutse Giday *et al*., 2010; Ermias Leulekal, 2014).

The knowledge of some young people may be related to their lack of interest in plant-based medicines, mainly because of their lack of credibility; some believe that modern medicine is more efficient than traditional medicine. Similar findings were reported in studies conducted on other cultural groups in Ethiopia (Mirutse Giday *et al*., 2009; Ermias Leulekal, 2014). Furthermore, most of the knowledgeable people keep the knowledge secret and within their family members and this may put the continuity of medicinal plants and associated indigenous knowledge in question might be taken as a guarantee for social respect, effectiveness of healing and means of income. Other researchers reported similar findings elsewhere in the country (Mirutse Giday *et al*., 2009; Tilahun Teklehaymanot, 2009; Ermias Leulekal, 2014).

5.1.3.3.2 Efficacy, healing potential and ranking of medicinal plants

The calculated ICF results indicated the highest agreements among informants on the use of human medicinal plant species for treating dermatological ailments and external injuries, bleeding and snakebites. The observed highest informant agreement coupled with high plant use citations for these ailment categories could also indicate the relatively high incidence of the ailments in the area. High ICF values were important in identifying plants of particular interest in the search for bioactive compounds (Heinrich *et al*., 1998; Ermias Leulekal, 2014).

The reported highest fidelity level values were for *Verbascum sinaiticum* and *Withania somnifera* against dermatological ailments; and sensory and nervous system ailments, respectively. Fidelity level values could be used as a clue to identify medicinal plants of high healing potential and those needed for further phytochemical and bioactivity studies (Trotter and Logan, 1986; Heinrich *et al*., 1998).

Informants ranked the plants and identified the most-preferred medicinal plant species to treat febrile illness. Accordingly, *Eucalyptus globulus*, *Withania somnifera* and *Olea europaea* subsp. *cuspidata* scored highest values and were indicated as the most-preferred ones to treat febrile illness.

5.1.3.3.3 Comparison between different gender and social groups

The results revealed that men had better medicinal plant knowledge than women and this could probably be due to the reason that boys were usually selected in the study area for the proper transfer of the knowledge. In addition, this may also be attributed to the common use of medicinal plants in the area, which were less accessible to women. Other studies conducted elsewhere demonstrated similar findings (Begossi *et al*., 2002; Collins *et al*., 2006; Tilahun Teklehaymanot, 2009). Teferi Gedif and Hahn (2002) stated that parents in Ethiopia prefer to pass their traditional medical knowledge more to sons than to daughters. However, a study conducted elsewhere in Ethiopia demonstrated that there is no significant difference in medicinal plant knowledge between men and women (Hareya Fassil, 2003; Ermias Leulekal, 2014). By contrast, Voeks and Leony (2004) stated that on women are considerably more knowledgeable about the local healing flora than men. Consequently, elderly female achieve considerable community prestige, because of their healing abilities. Generally, gender-based differences in medicinal plant knowledge can be derived from experience and degree of cultural contact with curative plants (Voeks, 2007).

The average number of medicinal plants reported by different age groups in this investigation yielded very highly significant results. As the age of the informant increased, so did the person's knowledge about medicinal plants. Clearly, older people have had more time to assimilate knowledge about medicinal plants and their healing properties than younger people (Silva *et al*., 2011; Voeks and Leony, 2004). Moreover, the treatment of health problems often falls more on the elder members of a community, who have more time at their disposal and have during their lives been exposed to many more health crises than their younger counterparts. The impact of modernization (including urbanization and the advent of formal education) and the very poor system of sharing indigenous knowledge (through word of mouth, with maximum secrecy and only along family lines) on medicinal plants with the younger generation were the sources of difference in medicinal plants. The scenario is the same for other cultural groups in Ethiopia (Mirutse Giday *et al*., 2009; Tilahun Teklehaymanot, 2009; Ermias Leulekal 2014) and elsewhere in the world (Begossi *et al.,* 2002; Uniyal *et al*., 2006; Voeks and Leony (2004); Silva *et al*., 2011). The absence of continuous cultural interaction with plants was also reported as one factor for loss of traditional knowledge through generations (Reyes-García *et al.,* 2007; Winter and McClatchey, 2008). The much-used symbol that the death of each elder is like burning a book on traditional medicine (Voeks and Leony, 2004).

The other significant difference between key & general and literate & illiterate informants could relate to the impact of age-old experience and the maximum degree of secrecy in using medicinal plants on the former and modernization on the latter. Similar results were reported by Teferi Gedif and Hahn (2002), Mirutse Giday *et al*. (2009), Tilahun Teklehaymanot (2009) and Ermias Leulekal (2014). Furthermore, community members who have greater contact with medicinal plants were more knowledgeable about therapeutic uses of these plants than those with only intermittent contact (Voeks, 2007).

5.1.3.3.4 Source and transfer of indigenous knowledge

It was widely manifested in the study area that the sources of indigenous medicinal knowledge were mainly parents and grandparents. Such knowledge has frequently been transferred to the eldest son and trusted family members. It was transferred orally from generation to generation and kept secret as it was shared only within the family circle. Other studies conducted elsewhere in Ethiopia also indicated similar results (Nurya Abdurhman, 2010; Ermias Leulekal, 2014). However, currently, there were problems in interest to learn to the indigenous knowledge carefully and use properly owing to the expansion of modern education and healthcare centers.

5.1.3.4 Multipurpose use of forest resources

The forest and forest trees were the main source of seasonal food for the local communities, particularly children and men looking after cattle and collecting fuelwood. Plants that produced edible berries, such as *Opuntia ficus-indica, Rhus glutinosa*, *Carissa spinarum* and *Myrsine africana* were consumed as seasonal food. Fruits were the primary preference for local communities as food, because they can simply be consumed uncooked. Similar results were reported elsewhere in the country (Abrha Tesfay, 2008; Ermias Leulekal, 2014; Getachew Addis *et al.,* 2005).

Zemede Asfaw and Mesfin Tadesse (2001) stated that eight percent of the higher plants of Ethiopia were edible, where 203 wild edible plants with fruits constituted the highest edible parts. However, species richness in the study area was low because of deforestation and lack of interest to continually add wild edible plants to their culture. Tengnas (1994) indicated that food from trees makes supplemental, seasonal and emergency contribution to household food supplies, particularly during drought, famine and war.

According to Getachew Addis *et al*. (2005), the purpose of wild edible plants used by local people was to add dietary variety because of their good taste, as snacks during hungry periods of the day, seasonally during periods of scarcity or extreme famine, to moisten the mouth in the absence of drinking water. The most preferred plant species in the study area were *Opuntia ficus-indica*, *Ficus sur* and *Carissa spinarum* because of their high quantity and quality of fruit part, good taste, availability and easy to consume. However, currently, *Opuntia ficus-indica* has been infested by the cochineal insect that greatly affects its productivity. The dependence on wild edible plants in the study area has been decreasing from, because of modernization (with the young generation not wanting to use them as food), the less availability of the plants, fewer occurrences of famine and war and deprivation go into the forest. The importance of wild plants as food is believed to have gradually diminished with the advent of cultivation and modernization (Zemede Asfaw and Mesfin Tadesse, 2001).

According to the informants, the local communities have relied on plants as sources of energy. Stems and branches of woody plants were mainly used as source of fuelwood. Abbiw (1990) reported that 90% of the harvested wood is used as fuel. It is generally known that the vast majority of rural households in Ethiopia depend on wood or farm residues as fuel for cooking and heating (Abrha Tesfay, 2008). The study noted that men, women and children (shepherds) performed the collection of fuelwood. Similar findings were reported elsewhere in the world (Maundu *et al*., 2001; Mushongi, 2001). However, a study reported in Dess'a forest reported that only men had performed the collection of fuelwood (Abrha Tesfay, 2008). The most preferred plant species in the study area were *Olea europaea* subsp. *cuspidata* and *Acacia etbaica* because of easy burning, energy content, power to produce charcoal and availability. Although the majority of wild woody plant species can be used as a source of fuel by indigenous people, many species are recognized for particular burning qualities (Cotton, 1996). These species (*Olea europaea* subsp. *cuspidata* and *Acacia etbaica*) were also preferred elsewhere in Africa (Maundu *et al.,* 2001). However, a study conducted in and around the semi-arid Awash National Park reported that *Acacia tortilis a*nd *Acacia nilotica* are the most preferred wood plants, and those used for household consumptions and income generation (Tinsae Bahru *et al*., 2012). An inefficient and wasteful method of traditional open fire cooking accounts mainly for the consumption of a relatively higher proportion of fuel wood. If open fires were replaced by fuel saving stoves, fuel wood consumption could be reduced by one third by the more efficient use of fuel wood and in part also by a change in heating and cooking habits, fuel wood consumption in the area could be effectively cut down (Cotton, 1996).

Agricultural practices required certain traditional techniques, including the use of tools and implements due to steep and hilly terrain comprising shallow and stony soils. The high quality of timber wood is always in great demand for construction, making of agricultural implements and as handles of harvesting tools. The main occupation of people residing in the study area is traditional agriculture, which acts as a major source of income. From time immemorial, local plants have been used in making agricultural implements; handles of harvesting tools and their parts. Forest ecosystems have close linkages with traditional farming systems. The local farmers used traditional farm implements, such as plow and yoke for crop production. Forest was the backbone of the livelihood of the farming community, because it provided materials for farm implements. Traditional' agriculture driven rural communities in the plains or more 'traditional' upland societies practicing traditional multi-species complex agro ecosystems are linked with the forest resources on which they depend for a variety of their needs (Ramakrishnan, 1999).

As traditional constructions of houses are common in the countryside in Ethiopia, local communities residing in the study area have used forest resources for construction of traditional house, such as “Hidmo” and “Sekella.” The roof of the traditional stone house “Hidmo” and traditional huts “Sekella” were built with poles and sticks and plastered all round with a mixture of cow dung, straw and soil. These traditional houses were wasteful as they consumed a large amount of wood (Abrha Tesfay, 2008). Plant parts, especially stems and sheets of bark or split wood, were used in roof constructionin traditional dwellings (Abbiw, 1990). The roofing plant materials can be chosen according to functional properties, like durability and for being water-proof (Abbiw, 1990). Forest resources have a paramount role in building a shelter for the local community. Similar findings in Ethiopia reported elsewhere (TFAP, 1996; Maundu *et al*., 2001; Getachew Desalegn *et al*., 2003).

Fodder for domestic animals is of vital importance in a livestock keeping society. The traditional livestock feeding system made use of local resources, like tree leaves and pods from the forest. In a place where there was a scarcity of rainfall and soil moisture, trees and shrubs have utmost role due to better tolerance of unfavorable conditions. Tree fodder is particularly important as animal feed in the late dry season (April – June). Similar results were reported in studies conducted in Tigray and Afar regions (Gebremedhin Hadera, 2000; Abraha Tesfay, 2008; Emiru Berhane *et al.* 2014).

Forest plants were an important source of nectar and pollen for honeybees and as beehives. The forest was used as a source of honey for some local people as they kept their beehives inside the forest. Honey in the study area was harvested almost two times a year, namely in October and June during good climatic conditions. *Podocarpus falcatus* and *Ficus sur* were the most preferred plants to use as beehive inside the forest (Appendix 20). There were common occurrences that the socalled former settlers had much beehive trees transferred through generation without conflict of interests. The fact that they kept the beehive in the forest was to provide all the necessary amenities for the honeybees in order to produce much quantity and quality honey from the diversified plants and get water found in the forest. This result agrees with researches conducted elsewhere in Ethiopia (Gebremedhin Hadera, 2000; Abraha Tesfay, 2008; Hussien Adal, 2014). The most preferred plant species in the study area were *Erica arborea*, *Hypoestes forskaolii*, *Leucas abyssinica* and *Becium grandiflorum* because of the copious nectar and pollen production as well as their pleasant flowers they produce that attract honeybees.

The widely used multipurpose plants in the forest were *Olea europaea* subsp. *cuspidata*, *Rhus glutinosa*, *Podocarpus falcatus*, *Teclea nobilis* and *Juniperus procera*. However, study conducted in Dess'a forest (Abrha Tesfay, 2008) reported *Olea europaea* subsp. *cuspidata* followed by *Acacia etbaica, Boscia salicifolia, Erica arborea, Cordia africana, Tarchonanthus camhporatus* and *Teclea nobilis* as multipurpose plants. As it is described in FAO (2011), forests by their nature are multipurpose resources.

The cultural significance index of species is used to record the role of plants in a culture (Silvia *et al.,* 2006). Hoffman and Gallaher (2007) noted that many relative cultural importance indices pool in the unique uses of plant species mentioned by informants into major use categories. Plants frequently cited for uses that differ only slightly, thereby receiving exaggerated outlier of relative cultural importance values (Albuquerque *et al*., 2014). Standardized categorization facilitates compilation, comparison, as well as the efficient presentation of the whole data sets identifying that plant species is relatively the most important and which species is relatively the most preferred. In the study area, *Olea europaea* subsp. *cuspidata, Podocarpus falcatus, Acacia etbaica*, *Juniperus procera* and *Balanites aegyptiaca* were the most important plants.

5.1.3.5 Major threats and diminishing forest resources

Despite the attempts made by the local community and the government (regional and federal) to conserve the forest, the forest area was severely depleted. The major forest destruction activities were deforestation, agricultural expansion, fuelwood collection, livestock grazing, drought and settlement in decreasing order. Fast population growth in the study area and the demand for extra land for agriculture, grazing and settlement were the major threats for forest depletion. Moreover, demand for construction material, fuelwood and farm implement has also increased. An increasing demand for arable land and forest products due to the rapidly growing population and poverty of the rural people were the major threats to the survival of many of the Ethiopian plant species (Ensermu Kelbessa *et al*., 1992). If present trends in population growth continue, deterioration of natural resources will be more rapid in the future and will result in a great loss of biodiversity (Ensermu Kelbessa *et al.*, 1992; Zerihun Woldu, 1999). Alternative resource management systems that involve local people–the key generators, custodians and promoters of local biodiversity becomes useful(Rastogi *et al*., 1998) and this helps in the effective joint-management of resources between government and local people.

Over-exploitation of plants for various reasons in the study area led to the depletion of some species. Currently, many households have moved and settled at the edge and even inside the forest in order to be closer to the resources they need for their livelihood. Traditional people all over the world, through their indigenous knowledge know which plant species are threatened and need priority conservation (Given, 1994; Aumeeruddy-Thomas and Pei, 2003). Accordingly, *Olea europaea* subsp. *cuspidata, Erica arborea, Podocarpus falcatus, Juniperus procera* and *Ficus sur* were the most locally threatened plants in the study area. The 1997 IUCN Red List of Threatened Plants (Walter and Gillett, 1998) included 163 (2.5%) species from Ethiopia and Eritrea, with 48 woody species. Due to heavy pressure on *Juniperus procera*, the Food and Agriculture Organization (FAO) has listed it as a threatened species that requires *in-situ* conservation priority (FAO, 1975). In addition, it is listed under the Red List of the IUCN threatened species that requires *in-situ* conservation priority (World Conservation Monitoring Centre, 1998). Dry evergreen Afromontane forest and grassland complex (DAF) is the second richest vegetation type after *Acacia* - *Commiphora* woodland and bushland (ACB), which characterized by *Olea europaea* subsp. *cuspidata* and *Juniperus procera* (Friis *et al*., 2010). DAF has been intensely utilized by man for a long while, with the result that the forests have diminished in area, and are replaced by bushland in most areas (Zerihun Woldu, 1999). Hence, the *Olea europaea* subsp. *cuspidata* – *Juniperus procera* community type contains high species richness, contains many rare species and harbors considerable number of non-timber forest products that needs conservation priority.

According to Plotkin (1995), indigenous people living in forests know best on the use and protection of biodiversity. However, the survival and existence of indigenous people and their long-term accumulated knowledge faces challenges, because of modernization, genetic erosion on plant and animal resources, low recognition of their knowledge and varied culture, loss of biodiversity (Martin, 1995; Balick and Cox, 1996; Thrupp, 1997; Almaz Negash, 2001; Bussmann, 2006). Indigenous people are also suffering from the displacement and restriction of using their local ecosystems and resources, because of the establishment of strictly protected areas (Furze *et al*., 1997) which are believed to be one factor for the encroachment and destruction of most of the protected areas.

5.2 Conclusion

This study found that the forest has a considerable number of plant species of high diversity with 264 recorded species and five community types namely: *Cadia purpurea – Carissa spinarum, Olea europaea subsp. cuspidata – Juniperus procera, Dodonaea angustifolia – Acacia abyssinica, Erica arborea – Myrsine africana* and *Acacia etbaica – Acacia tortilis.* Among the five community types, three communities (*Olea europaea subsp. cuspidata – Juniperus procera, Dodonaea angustifolia – Acacia abyssinica, Erica arborea – Myrsine africana*) have overlapping altitudinal range to a certain extent while the remaining two community types (*Acacia etbaica – Acacia tortilis* and *Cadia purpurea – Carissa spinarum)* were found at low elevations isolated from the others and with relatively less similarity among them. It was found that the distribution of plant communities was influenced by altitude, slope and disturbance (human and grazing by livestock).

Studies of population structure showed a high proportion of small-sized individuals in the lower diameter classes indicating high regeneration potential of the forest. However, there were large variations among different tree species. For instance, some tree species have skewed population structure with no or few individuals at a lower size class, indicating poor regeneration or selective grazing or cutting. Overall, the population structure of the species investigated fall into four population density structure, namely Inverted-J shaped, bell-shaped, Broken J shape and upward ‘F’. Assessment of regeneration status based on age classes indicated that a significant proportion of woody species were represented by few or no seedlings, indicating that the species were under threat.

Seed bank studies are known tools for assessing restorative potential of an ecosystem and will be essential for developing appropriate forest restoration strategies. The study on soil seed bank through germination experiment showed that the soil seed bank was mostly dominated by the herbaceous flora and in terms of seed bank distribution, the upper 5 cm soil has high number of species when compared with the lower 5 cm soil. The study showed high variability of soil seed bank density and emerging vegetation among soil samples collected from the sampled quadrates. Overall, the diversity of woody species was very low where only eight woody species germinated from an experiment that run for almost a year. From this result, it was found that the soil seed bank might not be relied upon for restoration of the forest. This means passive restoration approach, such as exclosure may not be sufficient for restoration of the forest. Thus, any restoration attempt needs to take into consideration active restoration approaches, such as growing of seedlings from seeds and planting them in the degraded area of the forest. In addition, there may be a potential of seed rain from standing vegetation or seed dispersal by birds or other vectors from the surrounding.

It is an established fact that fringe communities on the edge of the forest use forests near them for various purposes. Even though the study forest is a protected forest by guards employed by the regional government, there were illegal grazing and cutting. From survey conducted on the local community, it was found that the forest provided important ecosystem services for the community through provision of medicinal plants, wild edible plants, fuelwood, livestock fodder/forage, honeybee forage, farm implements and building material. However, there were threats posed by the local community on the forest due to poverty and lack of awareness, agricultural expansion, deforestation, fuelwood collection and settlement. In addition, it is concluded that the traditional ecological knowledge of the community is threatened due to lack of documentation.Knowledge has been orally transmitted from generation to generation and this is also shown in high disparity among the present generation. This sort of study that document forest resources and indigenous knowledge's is important for restoring the forest to its original state and raising awareness among the community.

Finally, *Wejig-Mahgo-Waren* massif forest has relatively a considerable plant species richness and diversity in spite of the threats it faces and with the paramount importance of the forest for the fringe communities. However, it requires immediate and active intervention since the restoration potential of the forest is questionable as this study indicates.

5.3 Recommendations

- Based on the findings of the research, the following recommendations are forwarded:
    1. From the thirteen endemic species found in the forest, six of them: *Becium grandiflorum, Leucas abyssinica, Lippia adoensis, Rhus glutinosa, Vernonia leopoldii* and *Vernonia rueppellii*, are registered in the IUCN Red List Categories. Hence, responsible authorities, such as the Ethiopian Biodiversity Institute (EBI) are advised to devise appropriate conservation measures (*in situ* or *ex situ*) to save these valuable plant species.
    2. It is important to follow the ecosystem strategy of biodiversity conservation that integrates land, water and living resources. In the study area, to conserve a large number of species and plant communities, it is worth establishing a biodiversity conservation corridor along the landscape of *Wejig-Mahgo-Waren* forest massif. However, with the current socio-economic context in the study area, it may be difficult to implement some of the recommendation stated above. Dry evergreen Afromontane forest and grassland

complex (DAF) is the second richest vegetation type, which is characterized by *Olea europaea* subsp. *cuspidata* and *Juniperus procera* and harbored considerable number of non-timber forest products. Due to heavy pressure on *Juniperus procera*, the Food and Agriculture Organization (FAO) and Red List of the IUCN has listed it as a threatened species. Thus, it is important to prioritize conservation sites. The *Olea europaea* subsp. *cuspidata – Juniperus procera* community contained many locally threatened and rare species that requires *in-situ* conservation priority.

3. For plant species with irregular population structure and reduced regeneration status, there is a need to establish nursery sites to prevent local extinction by planting seedlings. The species *Cadia purpurea, Bersama abyssinica*, *Allophylus abyssinicus, Hagenia abyssinica*, *Ekebergia capensis*, *Ficus sur*, *Dombeya torrida*, *Celtis africana* and *Podocarpus falcatus*.
4. Illegal grazing and cutting mainly at the edges of the forest were found to be the principal drivers for deforestation, and this requires intervention by federal and regional governments in consultation with the community to put in place a long-term plan and strategy to reduce livestock density within and around the forest area to achieve sustainable utilization of forest resources.
5. Since the restoration potential from soil seed bank is limited, to restore the forest in the shortest possible time, restoration strategy that combines active restoration, planting of indigenous seedlings locally threatened plant species, such as *Olea europaea* subsp. *cuspidata, Erica arborea, Podocarpus falcatus, Juniperus procera* and *Ficus sur* and passive restoration techniques, (e.g. exclosures) from the available soil seed bank should be applied. Effort should also be made by the author of this work.

6. The ethnobotanical survey for many species is the preferred strategy for drug discovery. This approach assumes that species contain healing abilities as employed and demonstrated by traditional healers; especially promising medicinal plants should be pursued further. The local community relies on traditional herbal medicine in the area. However, since dosage of use varies from person to person, this practice poses a health problem to the community. Therefore, it is important to take those plants that have the highest FL, ICF and PR values and that require further phytochemical and bioactivity tests. The following plants seems to be the most promising plants obtained from both FL and PR that need extensive investigation: *Verbascum sinaiticum, Withania somnifera*, *Eucalyptus globulus, Olea europaea* subsp. *cuspidata* and *Datura stramonium*.
7. The fact that forest resources used as fuelwood are the cheapest and accessible energy source in the study area, the wasteful method of traditional open fire cooking are common that consume huge woody species which resulted in deforestation. Hence, to combat the problem of deforestation, there is a need for fuel saving stoves, as well as distribution of electricity in each household by the regional and federal government.
8. Because of poverty, the community relies on the forest resources for most of the activities that caused depletion of forest resources. Community-based conservation of the forest must be done through raising awareness.

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Appendices

Appendix 1. Plant species found in *Wejig-Mahgo-Waren* massif forest (Habit: T = Tree; S = Shrub; H = Herb; WC = Woody climber; HC = Herbaceous climber; Coll.No. = Collection number; MH = Mebrahtu Hishe)

Scientific name	Family	Vernacular name	Habit	Coll. No.
Abutilon longicuspe Hochst. ex A. Rich.	Malvaceae	Sa'da buwak	S	MH 109
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Chea	T	MH 154
Acacia etbaica Schweinf.	Fabaceae	Seraw	T	MH 120
Acacia polyacantha Willd.	Fabaceae		T	MH 123
Acacia senegal (L.) Willd.	Fabaceae	Sewansa	T	MH 141
Acacia seyal Del.	Fabaceae	Sa'da chea	T	MH 143
Acacia sieberiana DC.	Fabaceae		T	MH 155
Acacia tortilis (Forssk.) Hayne	Fabaceae		T	MH 124
Achyranthes aspera L.	Amaranthaceae	Machelo	H	MH 057
Acokanthera schimperi (A. DC.) Schweinf.	Apocynaceae	Mrenz	T	MH 067
Actiniopteris radiata (Sw.) Link	Actiniopteridaceae		H	MH 235
Adiantum lunulatum Burm.f.	Adiantaceae		H	MH 236
Aerva javanica (Burm.f.) Schultes	Amaranthaceae		S	MH 131
Aerva lanata (L.) Juss. ex Schultes	Amaranthaceae		H	MH 184
Agrocharis melanantha Hochst.	Apiaceae		H	MH 277
*Allophylus abyssinicus (*Hochst.) Radik	Sapindaceae	Tuemay/maara	T	MH 106
Aloe camperi Schweinf.	Aloaceae	Ere	S	MH 302
Anagallis arvensis L.	Primulaceae		H	MH 182
Andropogon chrysostachyus Steud.	Poaceae		H	MH 226
Andropogon distachyos L.	Poaceae		H	MH 227
Andropogon schirensis Hochst. ex A. Rich.	Poaceae	Qeran saeri	H	MH 205
Anthospermum herbaceum L.f.	Rubiaceae		H	MH 115
Argemone mexicana L.	Papaveraceae	Medafe	S	MH 077
Artemisia abyssinica Sch. Bip. ex A. Rich.	Asteraceae	Chena baria	H	MH 128
Asparagus africanus Lam.	Asparagaceae	Kestenosto	WC	MH 044
Asparagus racemosus Willd.	Asparagaceae	Kestenosto	WC	MH 045
Asplenium aethiopicum (Burm.f.) Bech.	Aspleniaceae		H	MH 234

Scientific name	Family	Vernacular name	Habit	Coll. No.
Balanites aegyptiaca (L.) Del.	Balanitaceae	Bedeno	T	MH 019
Barleria eranthemoides R. Br.	Acanthaceae	Melhas sebeyti	S	MH 168
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	Tebeb	S	MH 013
Berberis holstii Engl.	Berberidaceae	Mucha euf	S	MH 055
Bersama abyssinica Fresen.	Melianthaceae	Mirkuz zibei	T	MH 050
Bidens carinata Cufod. ex Mesfin	Asteraceae	Adey ababa	H	MH 200
Bidens pilosa L.	Asteraceae	Tselim Teneg	H	MH 011
Blepharis integrifolia (L.f.) E.Mey. ex Schinz	Acanthaceae		H	MH 291
Boscia salicifolia Oliv.	Capparidaceae	Tetem agazen	T	MH 138
Brachiaria brizantha (A. Rich.) Stapf	Poaceae		H	MH 206
Brachiaria leersioides (Hochst.) Stapf	Poaceae		H	MH 214
Brassica rapa L.	Brassicaceae		H	MH 180
Buddleja polystachya Fresen.	Loganiaceae	Metere	T	MH 137
Cadia purpurea (Picc.) Ait.	Fabaceae	Shilean	T	MH 002
Calotropis procera (Ait.) Ait.f.	Asclepiadaceae	Gindaea	S	MH 030
Calpurnia aurea (Ait.) Benth.	Fabaceae	Chrenchah	T	MH 001
Capparis tomentosa Lam.	Capparidaceae	Harengama	WC	MH 075
Carissa spinarum L.	Apocynaceae	Egam	S	MH 062
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tselim om	T	MH 073
Caylusea abyssinica (Fresen.) Fisch. & Mey.	Resedaceae	Hmak chenawi	H	MH 181
Celtis africana Burm. f.	Ulmaceae	Beto Koma	T	MH 094
Cenchrus ciliaris L.	Poaceae		H	MH 228
Cheilanthes farinosa (Forssk.) Kaulf	Sinopteridaceae		H	MH 233
Chloris gayana Kunth	Poaceae		H	MH 223
Cirsium vulgare (Savi.) Ten.	Asteraceae		H	MH 192
Cissampelos mucronata A. Rich.	Menispermaceae	Hareg mintaro	HC	MH 269
Cissus quadrangularis L.	Vitaceae	Anji afar	HC	MH 032
Clematis simensis Fresen.	Ranunculaceae	Hareghazo	HC	MH 025
Clerodendrum myricoides (Hochst.) Vatke	Lamiaceae	Shewha	S	MH 021
Clutia lanceolata Forssk.	Euphorbiaceae	Hirtmtmo	S	MH 023

Scientific name	Family	Vernacular name	Habit	Coll. No.
Colutea abyssinica Kunth & Bouche	Fabaceae	Tyt hibey/tatata	S	MH 008
Combretum molle R. Br. ex G. Don	Combretaceae	Tataso	T	MH 286
Commelina africana L.	Commelinaceae	Gamale	H	MH 158
Commelina benghalensis L.	Commelinaceae	Gamale	H	MH 159
Commicarpus pedunculosus (A.Rich.) Cufod.	Nyctaginaceae	Ezni anchwa	H	MH 022
Conyza hypoleuca A..Rich	Asteraceae		H	MH 203
Conyza vernonioides (Sch. Rip. ex A. Rich.) Wild	Asteraceae		S	MH 197
Cordia monoica Roxb.	Boraginaceae		T	MH 100
Craterostigma longicarpum Hepper	Scrophulariaceae		H	MH 167
Crotalaria incana L.	Fabaceae	Shamto amrakut	H	MH 280
Cupressus lusitanica Mill.	Cupressaceae	Tshdi ferenji	T	MH 037
Cyanotis barbata D.Don	Commelinaceae		H	MH 157
Cyathula orthacantha (Aschers.) Schinz	Amaranthaceae		H	MH 122
Cynanchum abyssinicum Decne.	Asclepiadaceae	Elbi	HC	MH 175
Cynanchum gerrardii (Harv.) Liede	Asclepiadaceae	Armed	HC	MH 121
Cynodon dactylon (L.) Pers.	Poaceae	Tehag	H	MH 218
Cynoglossum lanceolatum Forssk.	Boraginaceae		H	MH 144
Cyperus dubius Rottb.	Cyperaceae	Kunti	H	MH 268
Cyperus impubes Steud.	Cyperaceae	Saeri htshts	H	MH 267
Cyphostemma adenocaule (Steud. ex A. Rich.) Desc. ex Wild and Drummond	Vitaceae	Aserkuka	HC	MH 017
Dactyloctenium aegyptium (L.) Willd.	Poaceae	Tehag	H	MH 217
Datura stramonium L.	Solanaceae	Mestenagr	H	MH 169
Debregeasia saeneb (Forssk.) Hepper and Wood	Urticaceae	Tseada qotsli	S	MH 069
Dichrostachys cinerea (L.) Wight and Arn.	Fabaceae	Karshamarsha	S	MH 088
Dicrocephala chrysanthemifolia (Bl.) DC.	Asteraceae		H	MH 296
Discopodium penninervium Hochst.	Solanaceae	Alhim	S	MH 027
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	MH 059
Dombeya torrida (J.F.Gmel.) P. Bamps	Sterculiaceae	Buyak	T	MH 068
Dovyalis abyssinica (A. Rich) Warb.	Flacourtiaceae	Mongolhats	T	MH 112

Scientific name	Family	Vernacular name	Habit	Coll. No.
Dovyalis verrucosa (Hochst.) Warb.	Flacourtiaceae	Teumtegna	T	MH 038
Dregea abyssinica (Hochst.) K. Schum.	Asclepiadaceae	Hareg	WC	MH 166
Dryopteris schimperiana (Hochst. ex A.Br.) C.Chr.	Dryopteridaceae		H	MH 231
Echinops hispidus Fresen.	Asteraceae	Dander	H	MH 191
Echinops pappii Chiov.	Asteraceae	Dander	S	MH 193
Ehretia cymosa Thonn.	Boraginaceae	Aulaga	T	MH 095
Ekebergia capensis Sparrm.	Meliaceae	Kot	T	MH 042
Eleusine floccifolia (Forssk.) Spreng.	Poaceae		H	MH 219
Epilobium hirsutum L.	Onagraceae		H	MH 204
Equisetum ramosissimum Desf.	Equisetaceae		H	MH 136
Eragrostis papposa (Roem. & Schult.) Steud.	Poaceae		H	MH 208
Eragrostis pilosa (L.) P. Beauv.	Poaceae		H	MH 213
Erica arborea L.	Ericaceae	Hasti	T	MH 056
Erythrococca abyssinica Pax	Euphorbiaceae		S	MH 325
Eucalyptus globulus Labill.	Myrtaceae	Tseada bahirzaf	T	MH 049
Euclea racemosa subsp.*schimperi* (A. DC.) White	Ebenaceae	Kuleo	T	MH 102
Euphorbia abyssinica Gmel.	Euphorbiaceae	Qulqal	T	MH 300
Euphorbia petitiana A. Rich.	Euphorbiaceae	Hinzuqzuq	H	MH 176
Ferula communis L.	Apiaceae	Doeg	H	MH 029
Ficus glumosa Del.	Moraceae	Cheqante	T	MH 018
Ficus sur Forssk.	Moraceae	Shamfa	T	MH 085
Ficus sycomorus L.	Moraceae	Sagla	T	MH 104
Galium simense Fresen.	Rubiaceae		HC	MH 127
Geranium arabicum Forssk.	Geraniaceae		H	MH 108
Geranium dissectum L.	Geraniaceae		H	MH 281
Gerbera piloselloides (L.) Cass.	Asteraceae		H	MH 299
Glycine wightii (Wight and Arn.) Verdc.	Fabaceae		HC	MH 322
Gomphocarpus purpurascens A. Rich.	Asclepiadaceae	Tseba dimu	S	MH 024
Grewia bicolor Juss.	Tiliaceae	Rewey	T	MH 149

Scientific name	Family	Vernacular name	Habit	Coll. No.
Grewia ferruginea Hochst. ex A. Rich.	Tiliaceae	Rewey	T	MH 148
Grewia mollis A. Juss.	Tiliaceae	Rewey	T	MH 150
Grewia villosa Willd.	Tiliaceae	Rewey	S	MH 147
Hagenia abyssinica (Bruce) J.F. Gmel.	Rosaceae	Habi	T	MH 153
Halleria lucida L.	Scrophulariaceae		T	MH 282
Haplocarpha schimperi (Sch. Bip.) Beauv.	Asteraceae		H	MH 129
Harpachne schimperi Hochst. ex A. Rich.	Poaceae		H	MH 225
Hebenstretia angolensis Rolfe	Scrophulariaceae		H	MH 276
Helichrysum quartinianum A. Rich.	Asteraceae		H	MH 195
Helichrysum schimperi (Sch. Bip. ex A. Rich.) Moeser	Asteraceae		S	MH 202
Helinus mystacinus (Ait.) E. Mey. ex Steud.	Rhamnaceae	Hareg	WC	MH 323
Heliotropium strigosum Willd.	Boraginaceae	Amam gmel	H	MH 066
Helixanthera thomsonii (Sprague) Danser	Loranthaceae	Diqala	S	MH 145
Heteromorpha arborescens (Spreng.) Cham. & Schlecht.	Apiaceae		S	MH 005
Hibiscus crassinervius Hochst. ex A. Rich.	Malvaceae		S	MH 174
Hibiscus macranthus Hochst. ex A. Rich.	Malvaceae	Necha	S	MH 151
Huernia macrocarpa (A. Rich.) Sprenger	Asclepiadaceae	Ango	H	MH 033
Hyparrhenia hirta (L.) Stapf	Poaceae	Saeri geza	H	MH 212
Hyparrhenia rufa (Nees) Stapf	Poaceae	Demhala	H	MH 210
Hypericum revolutum Vahl	Hypericaceae	Abedi	T	MH 132
Hypericum roeperianum Schimp. ex A. Rich.	Hypericaceae		T	MH 183
Hypoestes forskaolii (Vahl) R. Br.	Acanthaceae	Girbia	H	MH 007
Hypoestes triflora (Forssk.) Roem & Schult.	Acanthaceae	Girbia	H	MH 289
Impatiens tinctoria A. Rich	Balsaminaceae	Gursht	H	MH 161
Ischaemum afrum (J.F. Gmel.) Dandy	Poaceae		H	MH 209
Jasminum abyssinicum Hochst. ex DC.	Oleaceae	Tenbelel	WC	MH 292
Jasminum grandiflorum L.	Oleaceae	Habi tselim	WC	MH 035
Juniperus procera Hochst. ex Endl.	Cupressaceae	Tshdi adi	T	MH 060
Justicia ladanoides Lam.	Acanthaceae		H	MH 179

Scientific name	Family	Vernacular name	Habit	Coll. No.
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	Shmeda	S	MH 061
Kalanchoe petitiana A. Rich.	Crassulaceae	Awo awo zbei	H	MH 036
Kickxia elatine (L.) Dumort.	Scrophulariaceae		H	MH 324
Kleinia odora (Forssk) DC.	Asteraceae	Bierere	S	MH 194
Kniphofia foliosa Hochst.	Asphodelaceae	Ashenda	H	MH 028
Laggera crispata (Vahl) Hepper and Wood	Asteraceae	Tuem chena	H	MH 103
Laggera tomentosa *(*Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	Kaskanso	S	MH 099
Lantana trifolia L.	Verbenaceae		S	MH 142
Lantana viburnoides (Forssk.) Vahl	Verbenaceae		S	MH 014
Lathyrus sphaericus Retz.	Fabaceae		H	MH 295
Leonotis ocymifolia (Burm. f.) Iwarsson	Lamiaceae		S	MH 058
*Leptadenia hastata (*Pers.) Decne.	Asclepiadaceae	Qntt	WC	MH 116
Leucas abyssinica (Benth.) Briq.	Lamiaceae	Shiwa qerni	S	MH 047
Lippia adoensis Hochst. ex Walp.	Verbenaceae		S	MH 083
Malva verticillata L.	Malvaceae	Enkftha	H	MH 172
Maytenus arbutifolia (A. Rich.) Wilczek	Celastraceae	Ats Ats	T	MH 092
Maytenus senegalensis (Lam.) Exell	Celastraceae	Qebqeb	T	MH 072
Maytenus undata (Thunb.) Blakelock	Celastraceae	Qfei	T	MH 091
Melinis repens (Willd.) Zizka	Poaceae		H	MH 224
Myrica salicifolia A. Rich.	Myricaceae	Shinet	T	MH 034
Myrsine africana L.	Myrsinaceae	Qechemo	T	MH 046
Nidorella rsedifolia DC.	Asteraceae		H	MH 190
Notholaena marantae (L.) Desv.	Sinopteridaceae		H	MH 232
Nuxia congesta R.Br. ex Fresen.	Loganiaceae	Tekarea	T	MH 041
Ocimum lamiifolium Hochst. ex Benth.	Lamiaceae	Tsomer	S	MH 294
Ocimum stirbeyi Schweinf. and Volk.	Lamiaceae		S	MH 015
Oenanthe palustris (Chiov.) Norman	Apiaceae		H	MH 290
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	MH 079
Opuntia ficus-indica (L.) Miller	Cactaceae	Beles	S	MH 301

Scientific name	**Family**	**Vernacular name**	**Habit**	**Coll. No.**
Osyris quadripartita Decn.	Santalaceae	Qetrets	T	MH 053
Otostegia fruticosa (Forssk.) Schweinf. ex Penzig	Lamiaceae	Chamo/sasa	S	MH 113
Otostegia integrifolia Benth.	Lamiaceae	Chiendog	S	MH 016
Otostegia tomentosa A. Rich.	Lamiaceae	Sasa	S	MH 170
Oxygonum sinuatum (Meisn.) Dammer	Polygonaceae	Kukaito	H	MH 114
Panicum maximum Jacq.	Poaceae		H	MH 211
Panicum monticola Hook. f.	Poaceae		H	MH 216
Parthenium hysterophorus L.	Asteraceae	Diha nekel	H	MH 130
Pavetta abyssinica Fresen.	Rubiaceae	Buna hibey	T	MH 089
Pavonia urens Cav.	Malvaceae	Nacha	S	MH 010
Pennisetum thunbergii Kunth	Poaceae	Waz wazo	H	MH 273
Pennisetum villosum Fresen.	Poaceae	Saeri hibey	H	MH 207
Periploca linearifolia Quart.-Dill. & A. Rich.	Asclepiadaceae	Qeyh hareg	WC	MH 135
Phragmanthera regularis (Sprague) M. Gilbert	Loranthaceae	Diqala	S	MH 287
Phyllanthus mooneyi M Gilbert	Euphorbiaceae		H	MH 297
Phytolacca dodecandra L 'Herit.	Phytolaccaceae	Shibti	S	MH 133
Pittosporum viridiflorum Sims	Pittosporaceae	May liho	T	MH 064
Plantago lanceolata L.	Plantaginaceae		H	MH 080
Plectranthus lanuginosus (Hochst. ex Benth.) Agnew	Lamiaceae	Guemfer	H	MH 278
Podocarpus falcatus (Thunb.) R. B. ex. Mirb.	Podocarpaceae	Zigba	T	MH 065
Polygala abyssinica Fres.	Polygalaceae		H	MH 0139
Polygala muratii Jacq.-Felix	Polygalaceae		H	MH 0185
Polygala steudneri Chod.	Polygalaceae		S	MH 0173
Prosopis juliflora (Sw.) DC.	Fabaceae	Woyane	T	MH 087
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tsehag	T	MH 098
Pteris dentata Forssk.	Pteridaceae		H	MH 230
Pterolobium stellatum (Forssk.) Brenan	Fabaceae	Qonteftefe	WC	MH 076
Pupalia lappacea (L.) A. Juss.	Amaranthaceae	Teneg	HC	MH 146
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	T	MH 040

Scientific name	**Family**	**Vernacular name**	**Habit**	**Coll. No.**
Rhus natalensis Krauss	Anacardiaceae	Atami	T	MH 118
Rhus retinorrhoea Oliv.	Anacardiaceae	Nefasito/ amus	S	MH 093
Rhus ruspolii Engl.	Anacardiaceae	Atami	S	MH 279
Rhus vulgaris Meikle	Anacardiaceae	Atami	S	MH 119
Rhynchosia ferruginea A. Rich.	Fabaceae		HC	MH 285
Rhynchosia minima (L.) DC.	Fabaceae		WC	MH 283
Rhynchosia stipulosa A. Rich.	Fabaceae		WC	MH 284
Ricinus communis L.	Euphorbiaceae	Gulei	H	MH 084
Rosa abyssinica Lindley	Rosaceae	Qega	WC	MH 051
Rubus apetalus Poir.	Rosaceae	Mongolil	WC	MH 270
Rubus steudneri Schweinf.	Rosaceae	Mongilil	WC	MH 074
Rumex abyssinicus Jacq.	Polygonaceae	Meqmeqo	H	MH 031
Rumex nepalensis Spreng.	Polygonaceae	Dengele	H	MH 071
Rumex nervosus Vahl,	Polygonaceae	Hehot	S	MH 054
Sageretia thea (Osbeck) M.C. Johnston	Rhamnaceae	Qenchil egam	S	MH 063
Salvia merjamie Forssk.	Lamiaceae		H	MH 171
Sansevieria forskaoliana (Schult.f.) Hepper & Wood	Dracaenaceae	Qacha	H	MH 140
Sarcostemma viminale (L.) R. Br.	Asclepiadaceae	Elbi	H	MH 110
Satureja abyssinica (Benth.) Briq.	Lamiaceae		H	MH 298
Satureja punctata (Benth.) Briq.	Lamiaceae		H	MH 052
Scabiosa columbaria L.	Dipsacaceae		H	MH 177
Senecio hadiensis Forssk.	Asteraceae	Sehum atali	HC	MH 048
Senecio ragazzii Chiov.	Asteraceae		H	MH 189
Senna occidentalis (L) Link	Fabaceae	Hambohambo	H	MH 164
Sida schimperiana Hochst. ex A. Rich.	Malvaceae	Tsfrer	S	MH 003
Smilax anceps Willd.	Smilacaceae	Hareg nebri	WC	MH 026
Smilax aspera L.	Smilacaceae	Hareg nebri	WC	MH 078
Solanum adoense Hoehst. ex A. Rich.	Solanaceae	Engule abyi	S	MH 039
Solanum anguivi Lam.	Solanaceae	Engule qola	S	MH 086

Scientific name	Family	Vernacular name	Habit	Coll. No.
Solanum hastifolium Hochst. ex Dunal in DC.	Solanaceae	Alamo kelbi	S	MH 272
Solanum incanum L.	Solanaceae	Engule nieshtey	S	MH 105
Solanum marginatum L.f.	Solanaceae	Engule dogae	S	MH 090
Solanum memphiticum Gmel.	Solanaceae		H	MH 178
Solanum nigrum L.	Solanaceae	Alamo	H	MH 134
Solanum schimperianum Hochst. ex A. Rich.	Solanaceae	Berbere awald	S	MH 020
Solanum sinaicum Boiss.	Solanaceae		H	MH 160
Sonchus oleraceus L.	Asteraceae		H	MH 187
Sporobolus discosporus Nees	Poaceae		H	MH 220
*Sporobolus ioclados (*Trin.) Nees	Poaceae	Saeri tefetafo	H	MH 221
Sporobolus pyramidalis P. Beauv.	Poaceae		H	MH 222
Stephania abyssinica (Quart. Dillon & A. Rich.) Walp.	Menispermaceae	Hareg mintaro	HC	MH 043
Swertia lugardae Bullock	Gentianaceae		H	MH 186
Tagetes minuta L.	Asteraceae	Chenawi qotsli	H	MH 012
Teclea nobilis Del.	Rutaceae	Selah	T	MH 101
Tephrosia hochstetteri Chiov.	Fabaceae		H	MH 117
Tephrosia interrupta Hochst. and Steud. ex Engl.	Fabaceae		S	MH 288
Thalictrum rhynchocarpum Dill. & A. Rich.	Ranunculaceae	Sre bizu	H	MH 162
Thymus schimperi Ronniger	Lamiaceae	Teshine	H	MH 156
*Toddalia asiatica (*L.) Lam.	Rosaceae		WC	MH 271
Tragia cinerea (Pax) M.G. Gilbert & Radcl.-Sm.	Euphorbiaceae	Harengama	HC	MH 004
Trifolium campestre Schreb.	Fabaceae		H	MH 163
Urtica simensis Steudel	Urticaceae	Amea	H	MH 097
Verbascum sinaiticum Benth.	Scrophulariaceae	Trnake	H	MH 009
Vernonia auriculifera Hiern	Asteraceae		S	MH 188
Vernonia hymenolepis A. Rich.	Asteraceae	Gudet	S	MH 199
Vernonia leopoldi (Sch. Bip. ex Walp.) Vatke	Asteraceae		H	MH 201
Vernonia rueppellii Sch. Bip. ex Walp.	Asteraceae		S	MH 107
Withania somnifera (L.) Dunal	Solanaceae	Gulho	S	MH 082

Scientific name	Family	Vernacular name	Habit	Coll. No.
Xanthium spinosum L.	Asteraceae	Melhas ansti	H	MH 081
Zehneria scabra (L. f) Sond.	Cucurbitaceae	Hareg resha	HC	MH 070
Ziziphus mucronata Willd.	Rhamnaceae	Qunqura	T	MH 125
Ziziphus spina-christi (L.) Desf.	Rhamnaceae	Qunqura	S	MH 126

Appendix 2. Endemic species recorded from the study area, their IUCN status and geographical distributions, (LC = Least Concern; NT = Near Threatened).

Scientific name	Family	Habit	IUCN status	Altitude	Floristic Region
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	S	NT	1600-3100 m.	TU, GD, WU, SU, WG, SD
Gomphocarpus purpurascens A. Rich.	Asclepiadaceae	S	LC	1500-2500 m.	EW, TU, GD, GJ, SU, AR, KF, HA
Kniphofia foliosa Hochst.	Asphodelaceae	H	LC	2500-4000 m	TU GD GJ WU SU AR BA,HA
*Laggera tomentosa (*Sch. Bip. ex A. Rich.) Oliv. & Hierm	Asteraceae	S	LC	2345-2950 m.	TU, GD,GJ, WU, SU, HA
Leucas abyssinica (Benth.) Briq.	Lamiaceae	S	LC	1300-2600 m.	TU, GD, GG, SD, BA
Lippia adoensis Hochst. ex Walp.	Verbenaceae	S	LC	1900-2450 m.	TU, GJ, SU, AR, HA, KF, GG
Phyllanthus mooneyi M. Gilbert*	Euphorbiaceae	H	LC	525-2100 m	SU AR IL KF GD,SD
Rhus glutinosa A. Rich.	Anacardiaceae	T	LC	1800-3000 m.	TU, WU, SU, WG, AR, BA, HA
Rhynchosia stipulosa A. Rich.	Fabaceae	WC	LC	1000-800 m	TU,WG, GG
Thymus schimperi Ronniger	Lamiaceae	H	LC	2250-4000 m	EW TU GD WU SU AR SD BA HA
Urtica simensis Steudel	Urticaceae	H	LC	1500-3400m	TU, GD, GJ SU AR BA SD
Vernonia leopoldi (Sch. Bip. ex Walp.) Vatke	Asteraceae	H	LC	1850-2850 m.	TU, GD, GJ, SU, WG, KF, HA
Vernonia rueppellii Sch. Bip. ex Walp.	Asteraceae	S	LC	2150-3000 m.	TU, GD, SU, AR, BA, SD, KF, HA

Source: Hedber et al. (1989,1995,2003,2004,2006,2009a,2009b,; Edwards et al. 1995, 1997,2000)

*1 New records for TU Floristic Region

Appendix 3. Soil seed bank species obtained via germination.

Scientific name	Family	Habit	Coll. No.
Achyranthes aspera L.	Amaranthaceae	H	MH 243
Actiniopteris radiata (Sw.) Link	Actiniopteridaceae	H	MH 325
Aerva lanata (L.) Juss. ex Schultes	Amaranthaceae	H	MH 256
Amaranthus hybridus L.	Amaranthaceae	H	MH 252
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	S	MH 262
Cadia purpurea (Picc.) Ait.	Fabaceae	S	MH 303
Chenopodium murale L.	Chenopodiaceae	H	MH 240
Chenopodium opulifolium Schrader ex Koch & Ziz.	Chenopodiaceae	H	MH 250
Chloris virgata Sw.	Poaceae	H	MH 245
Commelina africana L.	Commelinaceae	H	MH 263
Conyza sp. = Smeds	Asteraceae	H	MH 313
Crassula schimperi Fisch. & Mey.	Crassulaceae	H	MH 324
Cynodon dactylon (L.) Pers.	Poaceae	H	MH 323
Cyperus bulbosus Vahl	Cyperaceae	H	MH 266
Cyperus flavescens L.	Cyperaceae	H	MH 274
Cyperus polystachyos Rottb.	Cyperaceae	H	MH 265
Cyperus pulchellus R.Br.	Cyperaceae	H	MH 264
Cyperus rubicundus Vahl	Cyperaceae	H	MH 254
Digitaria nuda Schumach.	Poaceae	H	MH 247
Digitaria velutina (Forssk.) P. Beauv.	Poaceae	H	MH 242
Dodonaea angustifolia L. f.	Sapindaceae	S	MH 321
Eragrostis cilianensis (All.) Vign. ex Janch.	Poaceae	H	MH 246
Eragrostis cylindriflora Hochst.	Poaceae	H	MH 241
Eragrostis schweinfurthii Chiov.	Poaceae	H	MH 305
Erucastrum abyssinicum (A. Rich.) R.E. Fries	Brassicaceae	H	MH 253
Ficus palmata Forssk.	Moraceae	S	MH 304
Galinsoga parviflora Cav.	Asteraceae	H	MH 238
Galium scioanum Chiov.	Rubiaceae	H	MH 258
Geranium arabicum Forssk.	Geraniaceae	H	MH 261
Harpachne schimperi Hochst. ex A. Rich.	Poaceae	H	MH 249
Helichrysum sp. Mill.	Asteraceae	S	MH 312

Scientific name	Family	Habit	Coll. No.
Hypoestes forskaolii (Vahl) R. Br.	Acanthaceae	H	MH 244
Hypoestes triflora (Forssk.) Roem & Schult.	Acanthaceae	H	MH 317
Kalanchoe petitiana A. Rich.	Crassulaceae	H	MH 315
Laggera crispata (Vahl) Hepper & Wood	Asteraceae	H	MH 307
Ochthochloa compressa (Forssk.) Hilu	Poaceae	H	MH 316
Ocimum lamiifolium Hochst. ex Benth.	Lamiaceae	S	MH 260
Opuntia ficus-indica (L.) Miller	Cactaceae	H	MH 319
Oxalis procumbens Steud. ex A. Rich	Oxalidaceae	H	MH 259
Plectranthus sp. L Her.	Lamiaceae	H	MH 310
Poa leptoclada Hochst. ex A. Rich.	Poaceae	H	MH 322
Polycarpon tetraphyllum (L.) L.	Caryophyllaceae	H	MH 308
Rostraria cristata (L.) Tzvelev	Poaceae	H	MH 239
Rumex nervosus Vahl	Polygonaceae	S	MH 256
Senecio sp. L.	Asteraceae	H	MH 314
Solanum adoense Hochst. ex A. Rich.	Solanaceae	S	MH 311
Solanum nigrum L.	Solanaceae	H	MH 320
Solanum villosum Mill.	Solanaceae	H	MH 248
Sonchus oleraceus L.	Asteraceae	H	MH 306
Tagetes minuta L.	Asteraceae	H	MH 251
Trifolium campestre Schreb.	Fabaceae	H	MH 255
Verbascum sinaiticum Benth.	Scrophulariaceae	H	MH 318
Vernonia sp. Schreb.	Asteraceae	S	MH 321
Zehneria scabra (L. f) Sond.	Cucurbitaceae	HC	MH 309

Appendix 4. Medicinal plants used to treat human ailments (L = Leaf; R/L = Root and Leaf; B= Bark; R = Root; La = Latex; YS = Young Shoot; F = Fruit; L/B = Leaf and Bark; S =Stem; WP = Whole plant; WC = Woody climber; HC = Herbaceous climber)

Scientific name	Family name	Tigrigna name	Habit	Part used	Used for	Preparation and application
Abutilon longicuspe Hochst. ex A. Rich.	Malvaceae	Sa'da buwak	S	L	Cholera	Crush and drink
Acacia etbaica Schweinf.	Fabaceae	Seraw	T	R/L	Cancer	Crush and tie on the infected part
				L	Gulhay*	Crush and drink
Acacia senegal (L.) Willd.	Fabaceae	Sewansa	T	B	Troma	Crush, boil, smoke and drink a cup of glass
Achyranthes aspera L.	Amaranthaceae	Machelo	H	R/L	Gulhay*	Chew, swallow and drink
				L	Tonsillitis	Chew and swallow
				R	Snakebite	Chew
Acokanthera schimperi (A. DC.) Schweinf.	Apocynaceae	Merenz	T	L	Malaria	Crush, drink juiceand apply to nose
				L	Degehabe*	Crush and drink
Aloe camperi Schweinf.	Aloaceae	Ere	S	L	Malaria	Crush, drink juice in a cup of glass
Argemone mexicana L.	Papaveraceae	Medafe	H	La.	Wound	Smearing latex to the affected part
Artemisia abyssinica Sch. Bip. ex A. Rich.	Asteraceae	Chena baria	H	L	Headache	Crush and apply to nose
Asparagus africanus Lam.	Asparagaceae	Kestenosto	WC	R/L	Dandruff	Crush, mix with butter and rub on the head
Balanites aegyptiaca (L.) Del.	Balanitaceae	Bedeno	T	L	Cholera	Crush and drink in cup of glass
				L	Gulhay*	Crush and drink
				L	Hangnail	Crush, mix with butter and tie on the infected part
				L	Dandruff	Crush, mix with butter and rub on the head
				R	Anthrax	Crush, mix with honey and tie on the infected part
				R	Tonsillitis	Chew and swallow
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	Tebeb	S	L	Blood clotting	Crush, immediate tie with fresh juice
				YS	Febrile illness	Crush and drink in cup of glass

Scientific name	Family name	Tigrigna name	Habit	Part used	Used for	Preparation and application
Bidens pilosa L.	Asteraceae	Tselim Teneg	H	L	Anthrax	Crush, mix with *Commicarpus pedunculosus* leaf, *Heliotropium strigosum* leaf with with honey and rub/tie on the infected part
Calpurnia aurea (Ait.) Benth.	Fabaceae	Chrenchah	S	L	Evil eye	Crush, mix with fresh water taken at the morning from the source and wash the whole body
Capparis tomentosa Lam.	Capparidaceae	Harengama	WC	R	Evil eye	Crush and smoke
Carissa spinarum L.	Apocynaceae	Egam	S	R	Febrile illness	Crush and smoke
Clematis simensis Fresen.	Ranunculaceae	Hareghazo	HC	R/L	Chibti*	Crush and drink in cup of glass
				R	Cancer	Crush, mix with butter and tie on the infected
				R/L	Kidney	Crush, mix with honey and drink in small amount
				L	Cancer	Crush and tie
				L	Dislocated	Crush and tie
				R	Paralyze	Mix with *Kniphophia pumila* root, *Plectranthus punctatus* leaf and stored together for three days and wash the damage person
Clerodendrum myricoides (Hochst.) Vatke	Lamiaceae	Shewha	S	R	Snakebite	Chew, crush and drink
Clutia lanceolata Forssk.	Euphorbiaceae	Hirtmtmo	S	L	Berle*	Crush, mix *Olea europaea* subsp. *cuspidata* bark, *Asparagus africanus* fruit and mix with butter and rub on the infected part
Commicarpus pedunculosus (A.Rich.) Cufod.	Nyctaginaceae	Ezni anchwa	H	L	Swollen	Crush and rub/tie on the infected part
Crotalaria incana L.	Fabaceae	Shamto amrakut	S	L	Bullet	Crush, dried, mix with butter and rub on the affected part
				L	Anthrax	Crush, mix with honey and tie in the infected part

Scientific name	Family name	Tigrigna name	Habit	Part used	Used for	Preparation and application
Cyphostemma adenocaule (Steud. ex A. Rich.) Descoings ex Wild and Drummond	Vitaceae	Aserkuka	HC	R	Fumigation	Crush and smoke
Datura stramonium L.	Solanaceae	Mestenagr	H	L	Hemorrhoid	Crush and tie on the infected part
				L	Tuberculosis	Crush and tie on the infected part
				L	Werchi*	Crush, mix with butter and rub
				L	Wound	Crush and tie on the infected part
				F	Toothache	Burn, mix with butter and smoke
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	L	Swollen	Crush and drink
				L	Hibri semay*	Crush, mix with honey and rub on the infected part
Echinops pappi Chiov.	Asteraceae	Dander	S	R	Headache	Chew
Eucalyptus globulus Labill.	Myrtaceae	Tseada bahirzaf	T	L	Asthma	Boil and smoke
				L	Febrile illness	Boil and smoke
Euclea racemosa subsp. *schimperi* (A. DC.) White	Ebenaceae	Kuleo	S	R	Goiter	Chew
Euphorbia petitiana A. Rich.	Euphorbiaceae	Hinzuqzuq	H	R	Jaundice	Crush, mix with butter and drink
Grewia mollis A. Juss.	Tiliaceae	Rewey	T	L	Toothache	Crush and tie
				L	Bonbelea*	Crush and drink with cup of glass
Heliotropium strigosum Willd.	Boraginaceae	Amam gmel	H	L	Wound	Crush and tie in fresh on the affected part
Juniperus procera Hochst. ex Endl.	Cupressaceae	Tshdi adi	T	L	Amoeba	Crush, mix with water, filter and drink
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	Shmeda	S	L	Jaundice	Crush, filter and mix with cheese and drink small cup of glass
					Jaundice	Crush and drink with small amount
Kalanchoe petitiana A. Rich.	Crassulaceae	Awo awo zbei	H	L	Swollen	Crush and drink
					Evulitis	Crush and apply to nose, drink, mix with butter and tie

Scientific name	Family name	Tigrigna name	Habit	Part used	Used for	Preparation and application
*Laggera tomentosa (*Sch. Bip. ex A. Rich.) Oliv. and Hiern	Asteraceae	Kaskanso	S	L	Satan	Crush, mix with water and wash every monrning
Leucas abyssinica (Benth.) Briq.	Lamiaceae	Shiwa qerni	S	L	Wekei*	Crush and drink with cup of glass
				L	Snakebite	Crush and drink
Myrica salicifolia A. Rich.	Myricaceae	Shinet	T	B	Cancer	Crush, dried and smoke through nose
				B	Cough	Crush, dried/fresh and smoke
Myrsine africana L.	Myrsinaceae	Qechemo	S	F	Tapeworm	Crush and drink in cup of glass
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	L	Febrile illness	Crush and smoke
				L/B	Cholera	Crush and drink
				S	Typhus	Burn and smoke
				L	Shanbu*	Crush and drink
				L	Fnfan*	Curl the leaf and insert through anus
				L	Eye infection	Crush and smoke
				L	Stomachache	Crush, mix with water and drink
Phytolacca dodecandera L 'Herit.	Phytolaccaceae	Shibti	S	R	Jaundice	Crush, filter and drink with small cup
Podocarpus falcatus (Thunb.) R. B. ex. Mirb.	Podocarpaceae	Zigba	T	L	Evil eye	Crush, mix with water and wash the body
				L	Intelligence	Crush, mix water and wash the whole body
				S	Evil eye	Tie on the neck
				L	Satan	Crush, mix with water and wash
				B	Evil eye	Crush, mix with *Rumex nervosus and* wash
Rhus natalensis Krauss	Anacardiaceae	Atami	S	YS	Hebri semay*	Crush, mix white shiny stone and butter and then rub on the infected part
Rubus apetalous Poir.	Rosaceae	Mongolil	S	R	Cancer	Crush and tie
Rumex nepalensis Spreng.	Polygonaceae	Dengele	H	R/L	Degehabe*	Crush and drink
				L	Evil eye	Crush, mix with fresh water and

						wash the whole body
				L	Itching	Crush and wash

Scientific name	**Family name**	**Tigrigna name**	**Habit**	**Part used**	**Used for**	**Preparation and application**
Solanum marginatum L.f.	Solanaceae	Engule dogae	S	R	Typhus	Crush and drink every three days in small amount
Verbascum sinaiticum Benth.	Scrophulariaceae	Trnake	H	R	Jaundice	Crush, filter and drink a cup of glass
				R	Jaundice	Crush and drink
				L/R	Bullet	Crush and tie
				R	Jaundice	Crush, mix with cheese and drink one cup of glass for every three morning
Withania somnifera (L.) Dunal	Solanaceae	Gulho	S	R	Malaria	Burn and smoke
				L/R	Satan	Crush and smoke
				L	Wound	Crush and rub
				R	Febrile	Crush and smoke
				R	Dislocated	Crush, mix with butter and rub on the affected part
Zehneria scabra (Linn. f) Sond.	Cucurbitaceae	Hareg resha	HC	L	Febrile illness	Crush and smoke

Appendix 5. Medicinal plants used to treat livestock

Scientific name	**Family name**	**Tigrigna name**	**Habit**	**Part used**	**Used for**	**Preparation and application**
Achyranthes aspera L.	Amaranthaceae	Machelo	H	R	Eye infection	Chew and smear droplet in to the infected part
Aloe camperi Schweinf.	Aloaceae	Ere	S	L	Dislocated	Tie on the tail of the infected animal
Balanites aegyptiaca (L.) Del.	Balanitaceae	Bedeno	T	WP	Degehabe*	Tie the animal on the stem of the live plant of *Balanites aegyptiaca*
Buddleja polystachya Fresen.	Loganiaceae	Metere	S	L	Leeches	Crush and apply to the nose
Clutia lanceolata Forssk.	Euphorbiaceae	Hirtmtmo	S	F	Shanbu*	Crush, drink juice and apply to to the nose
Cyphostemma adenocaule (Steud. ex A. Rich.) Desc. ex	Vitaceae	Aserkuka	HC	R	Leeches	Crush, filter and apply to the nose

Wild and Drummond						
Ehretia cymosa Thonn.	Boraginaceae	Aulaga	T	S	Dislocated	Part of stem that have formed circle hole at the center and insert in to metal and hold the stem and burn the affected part through the hot metal
Scientific name	**Family name**	**Tigrigna name**	**Habit**	**Part used**	**Used for**	**Preparation and application**
Heliotropium strigosum Willd.	Boraginaceae	Amam gmel	H	L	Dislocated	Tie on the tail of the affected animal
Hypoestes forskoalii (Vahl) R. Br.	Acanthaceae	Girbia	H	R	Eye infection	Chew and smear in to the infected part
Leucas abyssinica (Benth.) Briq.	Lamiaceae	Shiwa qerni	S	L	Eye infection	Chew and smear droplet in the infected part
Plectranthus punctatus (L. f.) L'Her.	Lamiaceae	Karewo-awalid	H	L	Zgag*	Crush and apply to the nose
Rhus natalensis Krauss	Anacardiaceae	Atami	S	L	Fnfan*	Curl the leaves and tie via fiber and insert through its anus
Verbascum sinaiticum Benth.	Scrophulariaceae	Trnake	H	R/L	Pancreas	Crush, drink and apply to the nose

Appendix 6. Medicinal plants used to treat both human and livestock

Scientific name	Family name	Tigrigna name	Habit	Part used	Used for	Preparation and application
Acacia etbaica Schweinf.	Fabaceae	Seraw	S	L/R	Dislocated	Crush and tie
Achyranthes aspera L.	Amaranthaceae	Machelo	H	R	Eye infection	Crush, juice and smear drop of juice on the infected part
Clematis simensis Fresen.	Ranunculaceae	Hareghazo	HC	L	Efni*	Crush, apply fresh without additives, mix with butter and tie for human. For livestock surge and insert it
Datura stramonium L.	Solanaceae	Mestenagr	H	L	Dislocated	Crush and tie
Erica arborea L.	Ericaceae	Hasti	T	P/N	Anas*	Swallow honey collected from *Erica arborea*, rub on the infected part
Grewia mollis A. Juss.	Tiliaceae	Rewey	T	L	Dislocated	Crush and tie
Heliotropium strigosum Willd.	Boraginaceae	Amam gmel	H	L	Dislocated	Crush and tie
Malva verticillata L.	Malvaceae	Enkftha	H	L	Anthrax	Crush, mix with honey and tie on the affected part

Appendix 7. Significance test between gender groups

Group Statistics

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Medicinal Plants	Male	200	4.21	9.203	0.651
	Female	139	0.32	1.395	0.118

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Medicinal Plants	69.799	0.000	4.937	337	0.000	3.886	0.787	2.338	5.435
			5.876	212.035	0.000	3.886	0.661	2.582	5.190

Appendix 8. Significance test between age groups

Group Statistics

	Age	N	Mean	Std. Deviation	Std. Error Mean
Medicinal plant	Young members (<50)	252	1.61	5.990	0.377
	Old members (>50)	87	2.66	6.220	0.667

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Medicinal plants	4.683	0.031	-1.388	337	0.166	-1.044	0.752	-2.524	0.436
			-1.363	144.792	0.175	-1.044	0.766	-2.559	0.470

Appendix 9. Significance test between education groups

Group Statistics

	Education	N	Mean	Std. Deviation	Std. Error Mean
Medicinal plants	Literate	140	1.63	4.265	0.360
	Illiterate	199	3.55	8.289	0.588

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Medicinal plant	15.527	0.000	-2.521	337	0.012	-1.924	.763	-3.425	-0.423
			-2.791	312.114	0.006	-1.924	.689	-3.281	-0.568

Appendix 10. Significance test between informant categories

Group Statistics

	Informant	N	Mean	Std. Deviation	Std. Error Mean
Medicinal	Key	30	14.57	13.736	2.508
	General	309	.34	1.107	0.063

Independent Samples T- Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Medicinal plants	392.793	.000	17.858	337	0.000	14.227	0.797	12.660	15.794
			5.671	29.037	0.000	14.227	2.509	9.097	19.357

Appendix 11. Wild edible plants (F = Fruit)

Scientific name	Family name	Tigrigna name	Habit	Part used
Balanites aegyptiaca (L.) Del.	Balanitaceae	Bedeno	S	F
Carissa spinarum L.	Apocynaceae	Egam	S	F
Dovyalis abyssinica (A. Rich) Warb.	Flacourtiaceae	Mongolhats	S	F
Dovyalis verrucosa (Hochst.) Warb.	Flacourtiaceae	Teumtegna	S	F
Ficus sur Forssk.	Moraceae	Shamfa	T	F
Ficus sycomorus L.	Moraceae	Sagla	T	F
Grewia mollis A. Juss.	Tiliaceae	Rewey	S	F
Myrsine africana L.	Myrsinaceae	Qechemo	S	F
Opuntia ficus-indica (L.) Miller	Cactaceae	Beles	S	F
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	S	F
Rhus natalensis Krauss	Anacardiaceae	Atami	S	F
Rosa abyssinica Lindley	Rosaceae	Qega	S	F
Rubus apetalous Poir.	Rosaceae	Mongolil	S	F
Rumex nervosus Vahl	Polygonaceae	Hehot	S	YS
Sageretia thea (Osbeck) M.C. Johnston	Rhamnaceae	Qenchil egam	S	F
Solanum nigrum L.	Solanaceae	Alamo	S	F
Ziziphus mucronata Willd.	Rhamnaceae	Qunqura	S	F

Appendix 12. Fuelwood (St. = Stem)

Scientific name	Family name	Tigrigna name	Habit	Part used
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Chea	T	St.
Acacia etbaica Schweinf.	Fabaceae	Seraw	S	St.
Acacia senegal (L.) Willd.	Fabaceae	Sewansa	S	St.
Acokanthera schimperi (A. DC.) Schweinf.	Apocynaceae	Mrenz	S	St.
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	Tebeb	S	St.
Cadia purpurea (Picc.) Ait.	Fabaceae	Shilean	S	St.
Carissa spinarum L.	Apocynaceae	Egam	S	St.
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tselim om	S	St.
Celtis africana Burm. f.	Ulmaceae	Beto Koma	T	St.
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	St.
Dovyalis verrucosa (Hochst.) Warb.	Flacourtiaceae	Teumtegna	S	St.
Ekebergia capensis Sparrm.	Meliaceae	Kot	S	St.
Erica arborea L.	Ericaceae	Hasti	S	St.
Juniperus procera Hochst. ex Endl.	Cupressaceae	Tshdi adi	T	St.
Maytenus arbutifolia (A. Rich.) Wilczek	Celastraceae	Ats Ats	S	St.

Scientific name	Family name	Tigrigna name	Habit	Part used
Nuxia congesta R.Br. ex Fresen.	Loganiaceae	Tekarea	T	St.
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	St.
Podocarpus falcatus (Thunb.) R. B. ex. Mirb.	Podocarpaceae	Zigba	T	St.
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tsehag	S	St.
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	S	St.
Rhus natalensis Krauss	Anacardiaceae	Atami	S	St.
Rumex nervosus Vahl	Polygonaceae	Hehot	S	St.
Teclea nobilis Del.	Rutaceae	Selah	T	St.

Appendix 13. Farm implements

Scientific name	Family name	Tigrigna name	Habit	Part used
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Chea	T	St.
Acacia etbaica Schweinf.	Fabaceae	Seraw	S	St.
Balanites aegyptiaca (L.) Del.	Balanitaceae	Bedeno	S	St.
Cadia purpurea (Picc.) Ait.	Fabaceae	Shilean	S	St.
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tselim om	S	St.
Celtis africana Burm. f.	Ulmaceae	Beto Koma	T	St.
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	St.
Dovyalis verrucosa (Hochst.) Warb.	Flacourtiaceae	Teumtegna	S	St.
Ehretia cymosa Thonn.	Boraginaceae	Aulaga	S	St.
Ekebergia capensis Sparrm.	Meliaceae	Kot	S	St.
Eucalyptus globulus Labill.	Myrtaceae	Tseada bahirzaf	T	St.
Euclea racemosa subsp.*schimperi* (A. DC.) White	Ebenaceae	Kuleo	S	St.
Ficus sycomorus L.	Moraceae	Sagla	T	St.
Grewia mollis A. Juss.	Tiliaceae	Rewey	S	St.
Maytenus undata (Thunb.) Blakelock	Celastraceae	Qfei	S	St.
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	St.
Podocarpus falcatus (Thunb.) R. B. ex. Mirb.	Podocarpaceae	Zigba	T	St.
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tsehag	S	St.
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	S	St.
Rhus natalensis Krauss	Anacardiaceae	Atami	S	St.
Teclea nobilis Del.	Rutaceae	Selah	T	St.
Ziziphus mucronata Willd.	Rhamnaceae	Qunqura	S	St.

Appendix 14. Building materials

Scientific name	Family name	Tigrigna name	Habit	Part used
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Chea	T	St.
Acacia etbaica Schweinf.	Fabaceae	Seraw	S	St.
Acacia senegal (L.) Willd.	Fabaceae	Sewansa	S	St.
Asparagus racemosus Willd.	Asparagaceae	Kestenosto	S	St.
Balanites aegyptiaca (L.) Del.	Balanitaceae	Bedeno	S	St.
Cadia purpurea (Picc.) Ait.	Fabaceae	Shilean	S	St.
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tselim om	S	St.
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	St.
Dombeya torrida (J.F.Gmel.) P. Bamps	Sterculiaceae	Buyak	S	St.
Ekebergia capensis Sparrmn.	Meliaceae	Kot	S	St.
Eucalyptus globulus Labill.	Myrtaceae	Tseada bahirzaf	T	St.
Ficus sur Forssk.	Moraceae	Shamfa	T	St.
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	Shmeda	S	St.
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	St.
Podocarpus falcatus (Thunb.) R. B. ex. Mirb.	Podocarpaceae	Zigba	T	St.
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tsehag	S	St.
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	S	St.
Teclea nobilis Del.	Rutaceae	Selah	T	St.
Ziziphus mucronata Willd.	Rhamnaceae	Qunqura	S	St.

Appendix 15. Livestock fodder / forage (L = Leaf; P = Pod)

Scientific name	Family name	Tigrigna name	Habit	Part used
Acacia etbaica Schweinf.	Fabaceae	Seraw	S	L/Pod
Achyranthes aspera L.	Amaranthaceae	Machelo	H	L
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	Tebeb	S	L
Cadia purpurea (Picc.) Ait.	Fabaceae	Shilean	S	L
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tselim om	S	L
Celtis africana Burm. f.	Ulmaceae	Beto Koma	T	L
Clerodendrum myricoides (Hochst.) Vatke	Lamiaceae	Shewha	S	L
Cynodon dactylon (L.) Pers.	Poaceae	Tehag	Gr.	L
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	L
Erica arborea L.	Ericaceae	Hasti	S	L
Hyparrhenia hirta (L.) Stapf	Poaceae	Saeri geza	Gr.	L
Hypoestes forskoalii (Vahl) R. Br.	Acanthaceae	Girbia	H	L
Leucas abyssinica (Benth.) Briq.	Lamiaceae	Shiwa qerni	S	L

Scientific name	Family name	Tigrigna name	Habit	Part used
Maytenus arbutifolia (A. Rich.) Wilcz	Celastraceae	Ats Ats	S	L
Maytenus undata (Thunb.) Blakelock	Celastraceae	Qfei	S	L
Myrica salicifolia A. Rich.	Myricaceae	Shinet	T	L
Myrsine africana L.	Myrsinaceae	Qechemo	S	L
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	L
Opuntia ficus-indica (L.) Miller	Cactaceae	Beles	S	L
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tsehag	S	L
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	S	L
Rhus natalensis Krauss	Anacardiaceae	Atami	S	L
Rumex nervosus Vahl	Polygonaceae	Hehot	S	L
Sageretia thea (Osbeck) M.C. Johnston	Rhamnaceae	Qenchil egam	S	L
Sida schimperiana Hochst. ex A. Rich.	Malvaceae	Tsfrer	S	L
Teclea nobilis Del.	Rutaceae	Selah	S	L

Appendix 16. Honeybee forage (N/P = Pollen/Nectar)

Scientific name	Family name	Tigrigna name	Habit	Part used
Abutilon longicuspe Hochst. ex A. Rich.	Malvaceae	Sa'da buwak	S	N/P
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Chea	T	N/P
Acacia etbaica Schweinf.	Fabaceae	Seraw	S	N/P
Aloe camperi Schweinf.	Aloaceae	Ere	S	N/P
Becium grandiflorum (Lam.) Pic.Serm.	Lamiaceae	Tebeb	S	N/P
Cadia purpurea (Picc.) Ait.	Fabaceae	Shilean	S	N/P
Carissa spinarum L.	Apocynaceae	Egam	S	N/P
Dodonaea angustifolia L. f.	Sapindaceae	Tahses	S	N/P
Ekebergia capensis Sparrm.	Meliaceae	Kot	S	N/P
Erica arborea L.	Ericaceae	Hasti	S	N/P
Grewia bicolor Juss.	Tiliaceae	Rewey	S	N/P
Hypoestes forskoalii (Vahl) R. Br.	Acanthaceae	Girbia	H	N/P
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	Shmeda	S	N/P
Leucas abyssinica (Benth.) Briq.	Lamiaceae	Shiwa qerni	S	N/P
Maytenus arbutifolia (A. Rich.) Wilcz	Celastraceae	Ats Ats	S	N/P
Myrica salicifolia A. Rich.	Myricaceae	Shinet	T	N/P
Olea europaea subsp. *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	Awlie	T	N/P
Opuntia ficus-indica (L.) Mill.	Cactaceae	Beles	S	N/P
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Tsehag	S	N/P
Pterolobium stellatum (Forssk.) Brenan	Fabaceae	Qonteftefe	S	N/P

Scientific name	Family name	Tigrigna name	Habit	Part used
Rhus glutinosa A. Rich.	Anacardiaceae	Tetaelo	S	N/P
Rhus natalensis Krauss	Anacardiaceae	Atami	S	N/P
Rosa abyssinica Lindley	Rosaceae	Qega	S	N/P
Rumex nervosus Vahl	Polygonaceae	Hehot	S	N/P
Senecio hadiensis Forssk.	Asteraceae	Sehum atali	S	N/P
Sida schimperiana Hochst. ex A. Rich.	Malvaceae	Tsfrer	S	N/P
Teclea nobilis Del.	Rutaceae	Selah	T	N/P

Appendix 17. Interview items for ethnobotanical information collection.

Informant # ______

1 Name of Informant: ____________

2 Occupation of Informant:__________

3 Educational status:____________

4 Marital status:____________

5 Gender of Informant:__________

6 Village (Forest Village):__________

7 District :____________

Semi structured interview

General questions:

1. What is the local name of the forest? What does the name refer to?
2. What are the traditional sayings, songs, poems and beliefs associated with the forest?
3. Are you aware of the population growth in the area? If yes, what do you think is the consequence of the population growth?
4. What type of environmental change have you observed in your localities for the past 10 years?
5. Do you own livestock? If yes, when and where do you graze them?
6. Where do you get the main source of fuel for your household?
7. Have you experienced any change in fuel availability during the last 10 years? If yes, what do you think is the reason?

Key informants

I. Cognitive domain on Biodiversity

1. How do you compare a natural and plantation forest and which one do you think is more important to your household?
2. Do you know the indigenous tree/shrub species available in your community? What are they?
3. What do you think are the most destructive activities to *Wejig-Mahgo-Waren* massif forest?
4. Which plant species have been threatened in the forest? What do you think is the reason?

II. Forest product utilization

1. What type of forest products do you use in your household?

2. Can you please tell us if your household is involved in trading some of the forest products? If yes, what type of products?
3. Can you please mention plants used for medicine?
7. What are the main human ailments at your locality?
8. What are the main livestock ailments at your locality?
9. How do you diagnose each ailment?
10. What are the major symptoms of the ailment?
11. How do you control ailments?
12. How do you treat human ailments?
13. How do you treat livestock ailments?
14. Which plant(s) do you use for treating that particular ailment?
15. Local name (vernacular) of the reported plant
16. Morphological description of the plant
17. Plant part/parts of the medicinal plant used
18. Used alone, mixed with water or other materials
19. How plant parts are used
20. Detailed preparation of the remedy
21. Amount of the remedy used (dose)
22. Does the dose differ among men, women, pregnant and children?
23. Any noticeable adverse effect(s)
24. Any antidotes for adverse/side effect(s)
25. Any restriction or taboo in collecting medicinal plants
26. Are there any threats to the medicinal plants?
27. Who are the source of traditional medicine for your practice?
28. How is the knowledge on traditional medicine passed to a family member/younger generation?
29. How does modernization interfere with traditional medicinal knowledge?
30. Can you please mention plants used for food, fuelwood, farm implements, building materials, livestock and bee forage.

Focus group discussion

I. Cognitive domain on Forest management Issues

1. Before the demarcation of the *Wejig-Mahgo-Waren* massif forest as a biodiversity hotspot area, how did people of the local community traditionally manage the forest resources?
2. Were there any community laws preventing people from entering the forest for:

   2.1 Beekeeping

   2.2 Grazing

   2.3 Fuel wood collecting

   2.4 Building material collection

4. How do you compare traditional forest management with the current rules used in managing the forest?

4. Are you satisfied with current rules in managing the forest?

5. Have you ever requested permission to harvest forest products from the forest?

6. Have you ever been involved in making suggestions or decisions towards forest management?

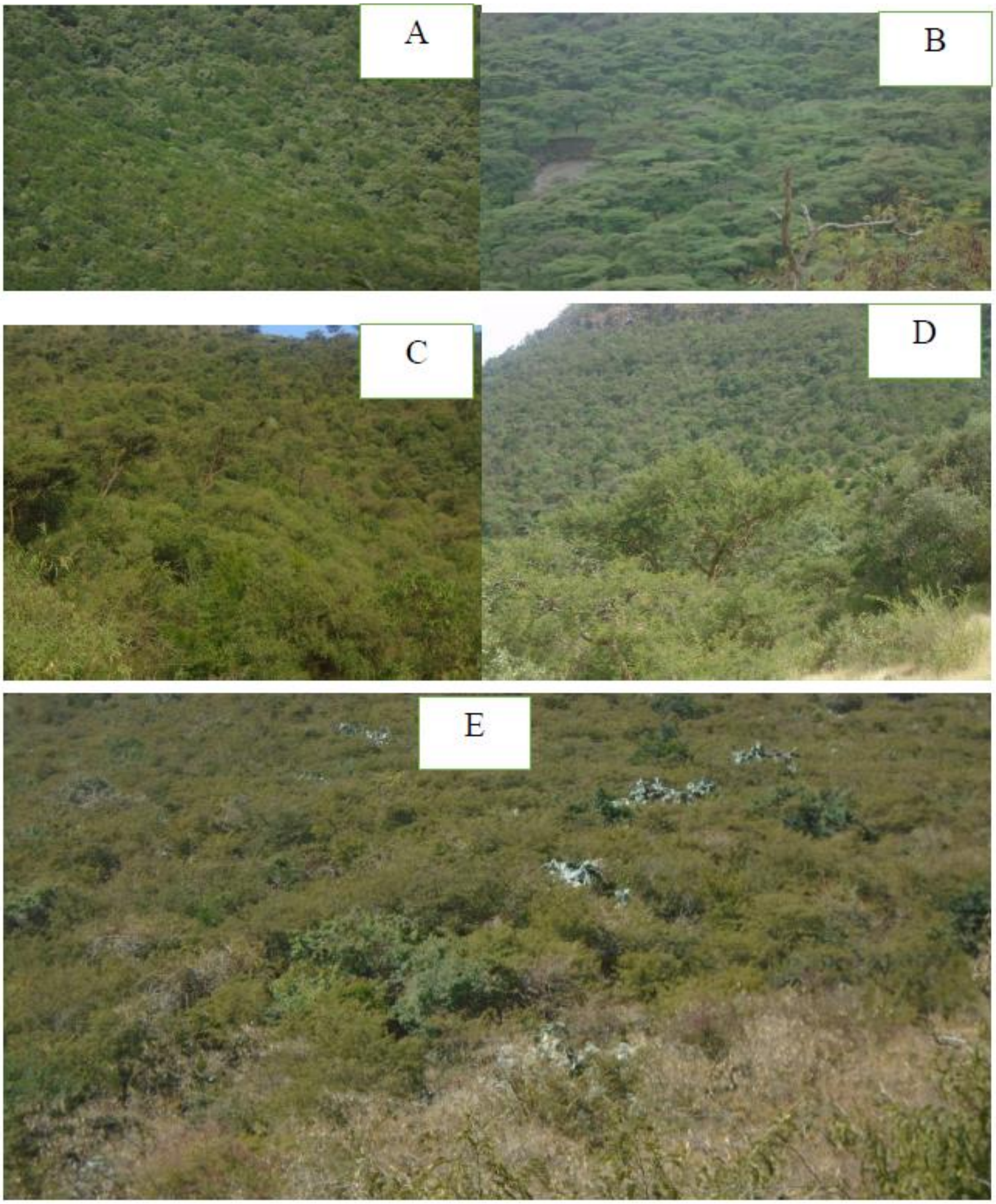
7. How best do you think you participate in forest management activities?

8. Which local institution can work with government in managing the forest for the benefit of the people?

9. Would you please give us any additional information and suggestion?

I thank you very much for your cooperation!

Appendix 18. Plants communities found in *Wejig-Mahgo-Waren* massif forest.

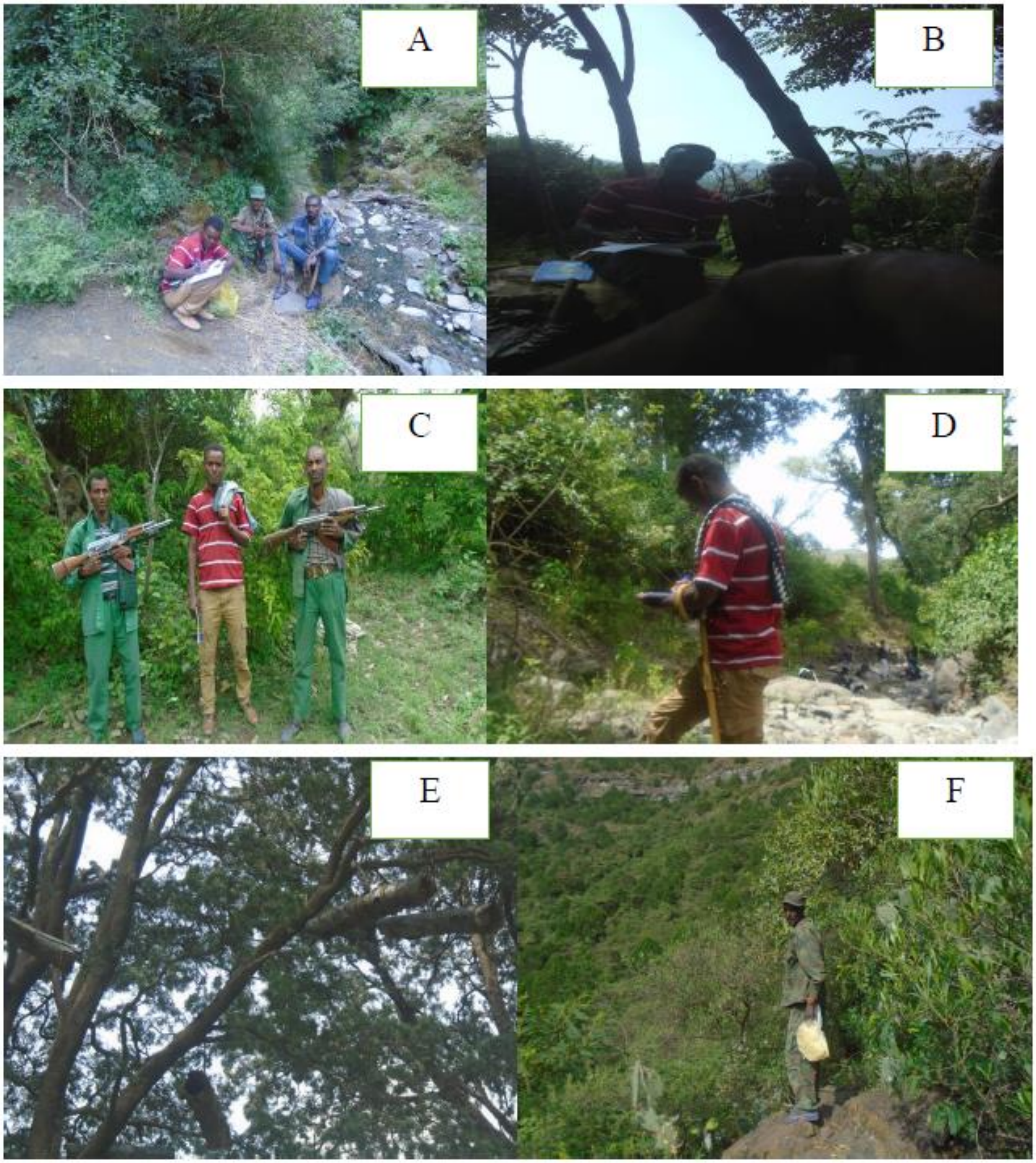


Key: Plant communities found at the study area, (A) *Olea europaea* subsp. *cuspidata – Juniperus procera* (B) *Acacia etbaica – Acacia tortilis* (C) *Dodonaea angustifolia – Acacia abyssinica* (D) *Erica arborea – Myrsine africana* (E) *Cadia purpurea – Carissa spinarum*.

Appendix 19. Some disturbances factors photos

Key: (A) Fuelwood collection, (B) *Olea europaea* subsp. *cuspidata* sold in the market, (C) Illegal cutting of *Olea europaea* subsp. *cuspidata,* (D) Grazing without permission inside the forest, (E- F) Deforestations for agricultural expansion

Appendix 20. Data recording in the field



Key: (A) Interview with guards inside the forest, (B) Interview with key informant, (C) Guards in Waren forest, (D) Data recording along the riverine forest, (E) *Podocarpus falcatus* with honeybee hive, (F) Guard in Wejig forest.

Appendix 21. Soil seed bank germination from the green house

Key: (A) First sieved soil sample placed on stray, (B) Emerging seedlings, (C) Mature seedlings ready for identification, (D) Visual identification using reproductive structures, (E) Stirring for further germination, (F) Pressed specimens brought to the National Herbarium.

Declaration

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

Name: ___________________________ Signature: _______________ Date: ________________