



*Vegetation Ecology and Carbon Stock of Wof-Washa Forest, North
Shewa Zone, Amhara Region, Ethiopia*

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***Vegetation Ecology and Carbon Stock of Wof-Washa Forest, North
Shewa Zone, Amhara Region, Ethiopia***

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This is to certify that the Dissertation prepared by Abiyou Tilahun Ayalew, entitled: *Vegetation Ecology and Carbon Stock of Wof-Washa Forest, North Shewa Zone, Amhara Region, Ethiopia*, and submitted in partial fulfillment of the Requirements for the Degree of Doctor of Philosophy (Biology: Botanical Sciences) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Vegetation Ecology and Carbon Stock of Wof-Washa Forest, North Shewa Zone, Amhara Region, Ethiopia

Abiyou Tilahun Ayalew, PhD Dissertation,
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Dry Afromontane forest in Ethiopia including Wof-Washa Forest is the most altered, exploited and fragmented vegetation type. Thus, the purpose of this study is to investigate plant species diversity and structure, natural regeneration potential, carbon stock and extent of land use land cover change of Wof - Washa forest. Systematic sampling design following transect lines of 1000 meter intervals and 100 m altitudinal drop were used. Vegetation data were collected from 95, 20 x 20 m² plots for tree species and 5, 5 x 5 m² and 1 x 1 m² subplots for sapling and herb species respectively. All plant species were recorded and voucher specimens were collected. Height, DBH, and cover abundance values were measured. Regeneration status of woody species was analyzed by using total count of seedling and saplings. Topographic variables such as aspect slope, altitude, and geographical coordinates were measured at each plot. Soil samples for soil seed bank analysis and carbon stock estimate were taken from 9 cm and 30 cm depth at five sub plots in each plot. Hierarchical cluster analysis was computed to identify plant community types. Shannon Wiener diversity index was used to compute the plant species richness, and evenness. Jaccard and Sorensen's similarity coefficients were used to measure species similarities among community types and soil seed bank layers. Basal area, frequency, density and importance value index were computed. Allometric model equation was used to estimate carbon stocks. Canonical correspondence analysis (CCA) was used to analyze the relationship between plant community types and environmental variables. Three satellite images (TM - 1985, ETM⁺ - 2000 and OLI - 2015) were acquired for land use land cover change analysis. SPSS, R, Arc GIS, Past softwares and Microsoft Excel sheet were used for data analysis. A total of 394 plant species were identified. Asteraceae (62 species) Poaceae (30 species) and Fabaceae (29 species) were the dominant families. 46 endemic plant species to Ethiopia and 13 new records for Shewa Floristic region were identified. Five plant communities were identified and named after the first two species with high synoptic values. The result of CCA reveals that altitude, disturbance, and slope were among the main environmental variables determining plant species distribution pattern and community type formation. The density of mature woody species with DBH > 2.5 cm, > 10 and > 20 cm accounted for 1046.6 stems ha⁻¹, 569.5 and 303.4 stem ha⁻¹ respectively. The total basal area per hectare of woody plant species was 153.26 m²ha⁻¹. Juniperus procera was the most frequent species (79.95 %). The highest IVI value (46.07%) was recorded for six of the most frequent woody species. The overall Shannon-wiener diversity and evenness values were 4.37 and 0.8 respectively. DBH and Height class distribution shows relatively inverted J-shape distribution. 5549 seedlings (76 plant species) were recovered from soil seed bank of Wof-Washa Forest. About 51 % and 34 % of carbon stock were contributed by the aboveground vegetation and soil respectively while the rest of the carbon pools accounted to 11.37 %. Higher carbon stock 298.9 ± 117.8 t/ha were obtained at lower altitudes followed by middle altitude 287.6 ± 192.5 t/ha. Landsat image analysis revealed a continuous expansion of agricultural land and settlement area. In addition, field survey identified that human-induced pressures especially free grazing and human encroachment are the most pressing and persistent driving forces. Therefore, owing to the high biodiversity, carbon stock and anthropogenic pressure, Wof-Washa Forest requires urgent interventions that reduce the threat levels for the maintenance of forest ecosystem services and functioning.

Keywords: Biomass, Carbon sequestration, land use land cover, plant community, regeneration, soil seed bank

Dedication

This research work is dedicated to the memories of Prof. Ensermu Kelbessa, a generous scientist who kindly shared the wealth of his wisdom and knowledge he has gained as a systematic botanist over the last 40 years to his students, colleagues in Ethiopia and beyond. May the almighty God rest his soul in peace.

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List of Acronyms

AAU	Addis Ababa University
AGB	Aboveground Biomass
AGC	Aboveground Carbon Stock
BGC	Below Ground Carbon
CCA	Canonical Correspondence Analysis
DBU	Debre Birhan University
DCA	Detrended Correspondence Analysis
ENVI	Environment for Visualization of Image
ERDAS	Earth Resource Data Analysis System
ETH	The National Herbarium
ETM +	Enhanced Thematic Mapper
FAO	Food and Agricultural Organization
FRC	Forest Research Center
GHG	Green House Gasses
GIS	Geographic Information System
GPS	Global Positioning System
HA	Hectare
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Converging Zones
KM	Kilo Meter
LSD	Least Significant Difference
LULC	Land Use Land Cover
M	Meter
NMSA	National Meteorological Services Agency
REDD	Reducing Emissions from Degraded and Degradation forest
REDD+	Reducing Emission from Deforestation and Forest Degradation, Conservation Forest for Sustainable forest management and Enhancing forest carbon stocks
SOC	Soil Organic Carbon

SPSS	Statistical Package for Social Sciences
SSB	Soil Seed Bank
SS	Sørensen's Similarity Coefficient
TCS	Total Carbon Stock
TM	Thematic Mapper
UTM	Universal Transverse Mercator
WGS	World Geodetic System
CDM	Clean Development Mechanisms
NAMA	Nationally Appropriate Mitigation Actions
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER ONE

1. INTRODUCTION

1.1. Background

The highly rugged and impressive mountain chains of Ethiopia occupy the interior of the horn of Africa stretching between 3⁰ and 15⁰N and 33⁰ and 48⁰ E with a wide range of agro-ecological zones reflecting the wide variations in rainfall, temperature, altitude, topography, and edaphic properties (Badege Bishaw, 2001). Ethiopia covers a total area of 1.13 million km² (CSA, 2000) that expands over a wide range of altitude that comprises rugged mountains, flat-topped plateau, deep gorges with river and rolling plains (FAO, 2005). Internal movement of the earth resulted in the opening up of the rift valley (Mohr, 1971). The Great Rift Valley runs from northeast to southwest of the country and separates the country into Northwestern and Southeastern highlands. The highlands on each side of the rift valley give way to extensive semi-arid lowlands to the east, south, and west of the country (Friis, 1986 and Tamrat Bekele, 1993). The altitudinal variation ranges from the highest peak, 4532 meters above sea level (m.a.s.l.) at Mount Ras Dejen in North Gondar to the lowest altitude 110 meters below sea level at Dalol Depression in the Afar Region (Demel Teketay, 1999; Taye Bekele *et al.*, 1999 and Zerihun Woldu, 1999). Ethiopia harbors two of the 34 global biodiversity hotspots, namely the Eastern Afromontane and Horn of Africa biodiversity hotspots (Myer *et al.*, 2000).

Ethiopia is one of the most pronounced mountain systems in Africa in which altitudinal gradients, steepness, and slope characteristics could be recognized as primordial parameters for the richness of biodiversity (Hurni, 1998). The heterogeneity of the land resource endowments has resulted in diverse ecological conditions that have contributed to the formation of diverse ecosystems inhabited with a great diversity of life forms of flora and

fauna (Taye Bekele *et al.*, 1999 and Zerihun Woldu, 1999) with high endemism. The richness in flora and fauna is the result of diverse ecological settings, complex relief, climate and topography of the country (Hillman, 1993; Hurni, 1998). Thus, the country is home for diverse flora and fauna (Demel Teketay, 1996) and comprises about 6000 species of higher plants, of these about 10% are endemic (Sebsebe Demissew and Nordal, 2010; Ensermu Kelbessa and Sebsebe Demissew, 2014). The diversity of endemism in Ethiopia is known for the high mountain regions and Ogaden area (Teshome Soromessa *et al.*, 2004).

The highlands of Ethiopia over 2, 500 m above sea level, covers 40 % of the country (Zerihun Woldu, 1999) as well as more than 50 % of the area of Afromontane forests (Tamrat Bekele, 1994). Eastern Afromontane forests are recognized as a hotspot for biodiversity conservation because of the exceptionally high concentration of endemic species and habitat loss (Myer *et al.*, 2000). Highlands of Ethiopian contribute large coverage with Afromontane vegetation, of which dry evergreen Afromontane forests (DAF) form the largest proportion. It occurs in an altitudinal range of 1200-2900 m.a.s.l. with average annual temperature and rainfall of 14-25°C and 700 - 1700 mm respectively (Friis, 1992; Friis *et al.*, 2011).

Forest ecosystems play multiple roles at local, national and global levels. They provide complex array of goods and services and economically valued products and in terms of the ecological aspect they regulate local and global climate, ameliorate weather events, regulate the hydrological cycle, protect watersheds and their vegetation, water flows and soils, and provide a vast store of genetic information much of which has yet to be uncovered (UNEP, 2007; FAO, 2005).

Human beings are an integral and inseparable part of the natural world. Our existence and health ultimately depend on the integrity and functioning of ecosystems. Human beings have deliberately managed and converted the landscape to utilize and exploit natural resources

mainly to derive basic needs such as food, shelter, fresh water, and pharmaceutical products (Goldewijk and Ramankutty, 2004).

Despite the economic contribution and ecosystem services provided by forest resources, it has been subjected to intensive human pressure, severe degradation of natural resources, particularly vegetation and soil resources due to the lack of sustainable utilization, proper management strategies (Badege Bishaw, 2001). The loss of vegetation and soil implies losses in the valuable genetic materials and carbon storage capacity (Ethiopian Panel on Climate Change, 2015). Temporal population increment has brought a proportional increase in the demands for resources leading to the conversion of natural environmental conditions and depletion of natural resource sustainability. In most parts of the world including Ethiopia, agriculture is the primary driver of deforestation. It is one of the most serious global environmental problems in recent years. It has become an issue of global concern because of the relevance of tropical forests in biodiversity conservation and in mitigating greenhouse effects (FAO, 1996).

A substantial proportion of the Ethiopian highlands were once believed to have been covered by forests having wide coverage than at present, but has gradually been cleared and exploited (Friis, 1992). Forests have been fragmented into small patches and forest structure and species composition have been influenced by such fragmentation and habitat loss (Alemayehu Wassie *et al.*, 2010). Thus, isolated mature trees in some farmlands areas and remnant patches of forests around churchyards and religious burial grounds showed vast expanse of forests in the past (Tamrat Bekele, 1993). Most of the remaining forests of the country are confined to south and south-west with few small patches in the central and northern parts of the country around the churches and inaccessible areas (Alemayehu Wassie and Demel Teketay, 2006).

The complex biological diversity of Ethiopia which has a high degree of endemism (Ensermu Kelbessa *et al.*, 1992) is under serious threat from anthropogenic disturbances (Badege Bishaw, 2001) and natural pressures (IBC, 2009). Natural factors are associated with the country's broad geological, climatic, altitudinal and edaphic variations. Human beings have changed landscapes to improve the amount, quality, and security of natural resource critical to their wellbeing. The increased use of innovation has provided benefits for human beings, and human populations progressively increase the ability to derive resource from the environment. Anthropogenic pressure related to the diverse population groups and their needs who lived for millennia inhabiting these diverse environmental settings exerted an impact on the already available diversity through a variety of cultural practices (Adane Girma, 2011; Ensermu Kelbessa and Teshome Soromessa, 2008). In addition, forests are also susceptible to natural factors such as insects, pests, diseases, fire and extreme climatic events (UNEP, 2007).

Deforestation in a global perspective is taking place primarily due to the conversion of tropical forest to agricultural land (FAO, 2010). Forest cover in Ethiopian highlands has reduced substantially due to overexploitation for fuelwood, construction and agricultural purposes (Eshetu Yirdaw, 2001).

Ethiopian highlands being the oldest settlement regions of the country (Zerihun Woldu, 1999; Friis *et al.*, 2011). Thus, the forest resources are strongly impacted by anthropogenic and natural factors. Furthermore, the demands of increasing human populations additional pressure on these natural resources (FAO, 2010).

Deforestation in Ethiopia imposed several socio-economic and environmental challenges that have strongly affected the capacity of forests to provide ecosystem services and other benefits (Badege Bishaw, 2001; Demel Teketay, 2001). A number of wild endemic species are reported to be critically endangered in Ethiopian highlands (Vivero *et al.*, 2005). The

highlands of Ethiopia have high livestock density and are the area of greatest land degradation (Hurni, 1987). This high rate of deforestation would result in loss of biodiversity, land degradation and consequently to the erosion of flora and fauna in Ethiopia highlands (Battles and Fahey, 2000). The human-induced pressure in combination with environmental conditions including soil moisture, slope, elevation, and aspect explains the spatial and temporal vegetation distribution patterns and dynamics (Walter, 1985; Woodward, 1987; Ellenberg, 1988). Loss of forest resources would have great implication for the environment, climate change, biological diversity and socio-economic setup of the communities in and around the forest (Sisay Nune *et al.*, 2010). The decimation of natural forests results in the loss of biodiversity, habitat fragmentation, decline in species density and composition, disruption of water flow, declines in land productivity and in turn leading to exacerbation of misery and poverty of the rural people (Ethiopian Panel on Climate Change, 2015).

Land-use change is one of the greatest environmental issues today resulted from the natural and anthropogenic pressure that affect the sustainability of natural resources, carbon storage capacity, biodiversity and ecosystem services and wildlife habitat (Sisay Nune *et al.*, 2016). Different natural and anthropogenic factors lead Ethiopia to experience climate change effects reflected by change in rainfall pattern and quantity, sudden and heavy flooding, recurrent drought and food insecurity (Talemos Seta, 2017). However, Ethiopia has a potential to mitigate the climate change impacts by applying climate change mitigation strategies, strengthening the green economy strategies and watershed management approaches. Nevertheless, lack of carbon stock data for carbon market and related environmental benefits is one of the most critical issues of the country. For effective REDD+ initiative participation and nationwide carbon stock inference are the most pressing issues. Dry Afromontane forests of Ethiopia including Wof-Washa Forest are the most altered and threatened ecosystem and

almost all the forests have been converted to agricultural lands except small pockets left in the most inaccessible areas of the country (Tamrat Bekele, 1993; Demel Teketay, 1996). Furthermore, the present study area is within the two biodiversity hotspot areas which contain threatened and endemic species (Myer *et al.*, 2000). Although the area is under high conservation priority area, updated and basic information on forest status, carbon stock potential, land use change with their respective impacts which can give in lights to develop, improve and implement resource management strategies are lacking.

The frequent anthropogenic impacts and droughts have contributed to the further deterioration of the natural resource and genetic erosion of the area. The effects of the progressive deforestation of Wof-Washa Forest impose threats to the conservation of forest genetic resource. The attention given to biodiversity conservation and sustainable use of natural resources are inadequate and inconsistent. Such limitations of current conservation and management strategies require current and baseline information coupled with integrated application efforts from all the immediate stakeholders. To reduce the threats to the forest area and improve management practice and conservation of biological resources, the current resource conservation must be integrated and expanded at rates that proportionate the growing human population.

Wof-Washa Forest is surrounded by agricultural land in the South, East, and North East part and the North-South stretched terrains detach the forest from the upper highlands which might lead to limited cross-pollination and inbreeding. This, in turn, might have a contribution to the low numbers of seedlings and saplings in some species of trees and shrubs than the density of the mature individuals of the same species and might influence plant species density and diversity. Thus, natural regeneration potential of the woody species is indispensable for sustainability of this fragile forest ecosystem. There are no published documents and work

that has been done on carbon stock estimation and land use land cover change so far. However, some work has been done on the vegetation ecology before 25 years (Tamrat Bekele, 1993; Demel Teketay and Tamrat Bekele, 1995) and soil seed bank except (Demel Teketay and Anders Granström, 1995). Therefore, this study is aimed at investigation of floristic diversity, soil seed banks, carbon stock and land use and land cover change of Wof-Washa Forest. The resulting information is important for policymakers to improve the management strategies and protect the forest ecosystems and to maintain their ecological values (Addo-Fordjour *et al.*, 2009). The knowledge and information of temporal land use land cover change is crucial to understand the current status and to predict the consequences of forest degradation and habitat loss which enable to develop applicable conservation strategies (Schmitt *et al.*, 2010). Thus, findings of this research would serve as the main input for policy and decision makers to redress the challenges, solve environmental problems and to provide the basis for prediction of possible future changes in the sustainability of biodiversity linked to impacts imposed by climate change and other natural and anthropogenic pressures.

1.2. Research Questions and hypotheses

1.2.1. Research Questions

1. What are the major plant communities and dominant plant species found in Wof-Washa Forest?
2. Which environmental factors are the most important in determining the species distribution?
3. What are the potential capacity of soil seed bank for species regeneration and rejuvenation of Wof-Washa Forest?
4. What are carbon sequestration capacity of the Wof-Washa Forest?
5. Which land use type showed significant LULC changes in the study area?

1.2.2. Research Hypothesis

- Hypothesis I: The most abundant woody plant species of Wof-Washa Forest have good regeneration status;
- Hypothesis II: Soil seed bank has better contribution to the regeneration of aboveground woody species of the forest;
- Hypothesis III: The aboveground vegetation of Wof-Washa Forest had stored more carbon stock than the other carbon pools to contribute to the carbon credits;
- Hypothesis IV: Land use land cover change has a significant impact on biodiversity of Wof-Washa Forest.

1.2.3. Objectives of the research

1.2.3.1. General objective

The general objective of this study is investigating plant diversity, carbon storage potential and LULC dynamics of Wof-Washa Forest in North Shewa Zone of Amhara Region, Ethiopia.

1.2.3.2. Specific objectives

- To assess the floristic diversity and identify plant community types in the study area
- To determine the plant population structures and regeneration status of selected woody species;
- To identify the basic environmental variables that determine species distribution and community type formation;
- Analyze the relationships between the soil seed banks and the aboveground vegetation;
- To estimate carbon stock in the soil, above and below ground biomass, LHG (litter, herb, and grass) and dead wood of Wof - Washa Forest; and
- Assess the extent and direction of changes in the LULC pattern of Wof-Washa Forest and the surrounding areas over a period of three decades using GIS and RS.

CHAPTER TWO

2. REVIEW OF RELATED LITERATURES

2.1. Ethiopian vegetation

Natural vegetation is shaped by physical and other environmental influences, including climatic, geomorphological, edaphic, and ecological components and disturbance regimes which interact simultaneously and continuously over extended periods of time. Vegetation tends to integrate these environmental effects to produce vegetation structures adapted to and reflecting environmental conditions. Thus, vegetation can be defined as, the aggregate or assemblage of all populations of plant species of the local flora growing in an area that involves different genetic, migration, historical or ecological elements (Van der Maarel and Franklin, 2013). Vegetation structure can be defined as the organizational orientation of individuals in space that constitute stands of plant species. Vegetation structure may reflect the invasion and modification to the community caused by disturbance and potential implications for the community function and regeneration (Bredenkamp and Theron, 1980). The building blocks of vegetation are individual plants. Individuals of a species form a species population within a given area and groups of plant species population that are found growing together form plant communities or plant species assemblages (Kent, 2012).

The wide variation in geology, physiography and agro-ecological zones of Ethiopia indicates the wide variations of rainfall in quantity and distribution, temperature, altitude, climate and edaphic resources. These enable Ethiopia to have various vegetation types ranging from afro-alpine to desert and semi-desert (Sahle Gebre Kirstos, 1984) which provides economic, socio-cultural and environmental benefits to human well-being and livelihoods. This floristic wealth makes Ethiopia as one of the Vavilov's centers of origin and diversity for many domesticated

plants and their wild relatives (Vavilov,1951; Zerihun Woldu, 1999; Zewge Teklehaimanot and Healey, 2001).

Attempts to describe the vegetation types of Ethiopia were made by different authors, such as Logan (1946); White (1983), Friis and Mesfin Tadesse (1990); Friis (1992), EFAP (1994); Zerihun Woldu (1999); Friis *et al.* (2001) and Friis *et al.* (2011). Most classifications are based on climate and/or physiognomy with some account of species composition. The oldest and overall survey of the vegetation of Ethiopia was made by Pichi-Sermolli (1957), where he recognized 24 vegetation types. He laid the crucial foundation for systematic studies of vegetation and environmental factors in Ethiopia (Zerihun Woldu, 1999). Studies made by Sebsebe Demissew (1988), Hailu Sharew (1982), Friis *et al.* (1982), Zerihun Woldu *et al.* (1989), Zerihun Woldu and Mesfin Tadesse (1990), Tamrat Bekele (1993), Tesfaye Awas *et al.* (2001) are among the main works in vegetation study in different parts of Ethiopia.

Results of the aforementioned authors' study provided a description of specific vegetation types and their floristic composition in different parts of Ethiopia. These authors put considerable contributions towards the understanding of the vegetation of Ethiopia. Thus, the various vegetation types of Ethiopia have been grouped into eight vegetation types (Sebsebe Demissew *et al.*, 1996; Zerihun Woldu, 1999; Friis and Sebsebe Demissew, 2001). To improve the limitations of the previous vegetation maps, to locate and mark vegetation maps precisely, the use of GIS technologies, Digital Elevation Model (DEM) and higher resolution SRTM (Shuttle Radar Topographic Mission) is indispensable.

According to (Friis *et al.*, 2011), the vegetation maps of Ethiopia were divided into the following twelve major types:

Desert and Semi-Desert Scrubland, *Acacia-Commiphora* Woodland bushland, Wooded grassland of the Western Gambela region, *Combretum-Terminalia* Woodland and wooded grassland, Dry Evergreen Montane Forest and Grassland complex, Moist Evergreen Montane Forest, Transitional rainforest, Ericaceous belt, Afroalpine belt, Riverine vegetation, Freshwater Lakes, Lakeshores, Marsh and floodplain vegetation and Saltwater lakes, salt-lake shores, marsh and pan vegetation (Friis *et al.*, 2011).

2.1.1. Dry evergreen Afromontane forest and grassland complex

Dry Evergreen Montane forest (DAF) is a part of Afromontane vegetation characterized by a very complex vegetation type and a complex system of succession involving extensive grasslands rich in legumes on heavy black clay soils that are periodically inundated areas, shrubs, and small to large size trees to closed forest with canopy of several strata on slopes (Friis *et al.*, 2011).

This vegetation is largely characterized by *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, *Podocarpus falcatus*, and *Prunus africana*. Important grass genera in this vegetation type are *Hyparrhenia*, *Eragrostis*, *Panicum*, *Sporobolus* and *Pennisetum* (Tewolde Berhan Gebre Egziabher, 1988) while legumes include species of *Trifolium*, *Indigofera*, *Tephrosia* and *Crotalaria* (Friis *et al.*, 2011). Lianas include *Urera hypselodendron*, *Embelia schimperi* and *Jasminum abyssinicum* (IBC, 2009). The prominent features of tropical dry forests are their seasonality of rainfall compared with the rainforests where the environment is stable throughout the year. Dry evergreen montane forests experience long dry seasons (4-8 months) and the rainy period is unreliable. During the dry season, not only moisture stress but also temperature increases and daytime humidity and watercourses reduce (Demel Teketay, 1996). The dry Afromontane forests occur in both northwestern and southeastern highlands,

especially on the plateau of Oromia, Tigray, Amhara, and Southern Nations, Nationalities, and Peoples (SNNP) the Regional States (Friis, 1992).

2.1.2. Threats of dry evergreen Afromontane forest

Biodiversities are under severe threat as a result of human activities and their livelihood demands. The Afromontane areas of eastern Africa, including the Ethiopian highlands, constitute vivid examples of tropical forest ecosystems that have exceptional species richness, high concentrations of endemic species, and internationally recognized as the Eastern Montane Biodiversity Hotspot (White, 1983). The concept of Biodiversity hotspot focuses on species richness, endemism, and threat (Mittermeier *et al.*, 2005). Based on species richness, endemism and level of threats, 34 biodiversity hotspots have been identified from which two are in Ethiopia (Mittermeier *et al.*, 2005). The dry evergreen Afromontane forest areas are inhabited by the majority of the Ethiopian population and represent a zone of sedentary cereal-based mixed agriculture for centuries (Anonymous, 1994). Although the remnants of dry afro-montane forests are found in the highlands, the majority of these forests are exploited and deforested due to anthropogenic activities (Badege Bishaw 2001). The rapid population growth and their demands for natural resources have put great pressure on the biodiversity of the country. Thus, deforestation led to acute shortage of fuelwood, charcoal, construction wood, timber and non-wood forest products together with disturbed ecosystem services (soil erosion, hydrological imbalance, loss of biodiversity etc...), in both highlands and lowlands (Mulugeta Lemenih and Habtemariam Kassa, 2014). The soil has become shallow due to the persistent erosion that has been taking place for centuries (Zerihun Woldu, 1999). Most parts of the vegetation and soil in highland areas are degraded and diminished due to excessive soil erosion, human interference and are mainly replaced by bushlands (Friis *et al.*, 2011). Human-induced pressure on the Ethiopian highlands coupled with agricultural expansion and

extensive traditional cattle herding activities has resulted in ecosystem deterioration, deforestation, habitat fragmentation, the decline in soil fertility and overexploitation of resources (Eshetu Yirdaw, 2002). Forest degradation and deforestation increase socio-economic and environmental challenges that have strongly affected the capacity of the forest to provide ecosystem services (Badege Bishaw, 2001). Thus, forest disturbances are sensitive to climate and aggravate the current climate change impacts observed in the country. It is known that climate change has potential to adversely affect the natural resources and disrupt the socioeconomic frameworks of all countries of the world; its adverse effects in sub-Saharan Africa including Ethiopia are clearly imposed problems (Chidumayo *et al.*, 2011).

2.2. Plant community and species diversity

2.2.1. The concept of plant community

The principles of plant communities are based either on the continuum or on individualistic theories. Clements (1916) in his plant succession theory considered plant communities as one big organ (organismic 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 perspective is the individualistic concept of the plant community. Although differences still exist among ecologists on the concepts of plant communities (Callaway, 1997). Plant ecologists who favor vegetation classification follow the approach of Clements and thus, group species into communities. 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). Thus, there is a need to integrate the two different concepts and reconcile by third alternative to resolve this issue. Collins *et al.* (1993) have proposed the hierarchical continuum concept of plant community to incorporate the dynamic nature of vegetation and the variation in environmental gradients (Roberts, 1987). The hierarchical continuum concept of Collins *et al.* (1993) can be viewed as a modern synthesis that recognizes the validity and combination of both views and their complementarities in their application for different aspects of community analysis. Thus, a plant community with a hierarchical continuum concept can be understood as a combination of plants that are dependent on their environment, influence one another, and modify their environment (Mueller-Dombois and Ellenberg, 1974).

A plant community consists of a combination of plant species associated with each other and is restricted to a particular physical environment determined by climate, sunlight, nutrients in the soil, geology, and topography and water availability for plants (Kent and Coker, 1992). The distribution of plant communities is closely related to environmental conditions (Daubenmire, 1968 and Gauch, 1982). To understand the distribution of plant communities, it is inevitable to consider the environmental variables such as geology, topography, and climate. Plant communities differ visibly by general physiognomy and growth habits of the plant species found in a particular area (Van der Maarel and Franklin, 2013).

2.2.2. Measures of species diversity

Biodiversity measures such as species richness and evenness have been widely used as indicators of ecosystem status, and play a critical role in the assessment of human impact on ecological systems (Leitner and Turner, 2001). However, since the biodiversity of an ecosystem is far too complex to be comprehensively quantified, indicators of biodiversity are needed (Duelli and Obrist, 2003). Species diversity is a multidimensional concept (Purvis and

Hector, 2000) which focus mainly on the two fundamental parameters, the number of species and the number of individuals in each species (Hamilton, 2005). Thus, species diversity is a function of the number of species present and the evenness with which the individuals are distributed among these species (species evenness, species equitability or abundance of each species) (Spellerberg, 1991). Species richness is the simplest way to describe community and diversity (Magurran, 1988), and thus, species richness forms the basis of many ecological models of community structure (MacArthur and Wilson, 1967). In this case, the numbers of individuals' tree/shrub species encountered across the whole sampled plots were used as a representation of species richness. Conceptually, species richness appears as the most intuitive and straightforward parameter to measure biodiversity and provides an extremely useful and comprehensible expression of diversity (Magurran, 1988; McCune and Grace, 2002 and Kent, 2012). Evenness (sometimes equitability) is quantifying the unique representation of a given species against a hypothetical community in which all species are equally common, such that when all species have equal abundance in the community (Kent and Coker, 1994).

Species richness, evenness, and other biodiversity entities are computed using different diversity indices (Peet, 1974). The basic idea of a diversity index is to obtain a quantitative estimate of biological variability that can be used to compare biological entities which contain discrete components in space and time. A diversity index is a statistic which is intended to measure the differences among members of a set consisting of various types of objects and it provides important information about rarity and commonness of species in a community (Pitkanen, 1998). Diversity indices compute the species richness, evenness, alpha or beta diversity, where alpha diversity refers to species richness within an area and beta diversity to the rate of species turnover along a complex environmental gradient (Whittaker, 1972). Biodiversity in landscape level can also be described in terms of gamma diversity; the number

of species of different communities in an area and the level of differentiation of the communities (Whittaker, 1972; Pitkanen, 1998). The most commonly used diversity indices include the Simpson and Shannon-Wiener index. The Shannon diversity and Simpson's index are commonly used to characterize species diversity in a community and to account both abundance and evenness of the species present (Peet, 1974).

2.2.3. Multivariate data analysis

Plant community data are multivariate in nature and hence their analysis requires multivariate techniques to study the complex nature of plant community structures (Stephane *et al.*, 2008). Currently, wide varieties of multivariate techniques are available to study the complex nature of the plant communities. Classification and ordination are the two main and basic techniques to analyze the nature of plant communities (Mueller-Dombois and Ellenberg, 1974; Whittaker, 1975).

Ordination

Ordination is a multivariate method that expresses the relationships between samples, species and environmental variables in a low-dimensional space using ordination diagrams (ter Braak, 1995; McCune and Grace, 2002). The aim of ordination is to arrange the points such that points that are close together correspond to sites that are similar in species composition, and points that far apart correspond to sites that are dissimilar in species composition (Jongman *et al.*, 1995). In ordination analysis, variation in species composition is related to variation in associated environmental and /or biotic factors that can usually be represented by environmental/biotic gradients (Jongman *et al.*, 1995). Primarily ordination methods are descriptive and enable to formulate ideas about plant community structure, as well as possible casual relationships between variation in vegetation and its environment (Kent, 2012). Thus, ordination methods focus on species and their degrees of similarity to each other and on how

the order of the individuals is correlated with underlying environmental variables. Correlation analyses between environmental factors and ordination axes scores can be used to identify and describe environmental factors that influence species distribution pattern and species response to these variables (Kent and Coker, 1992 and McCune and Grace, 2002).

In ordination analyses, the basic models that currently in use: are the linear response model (Principal Correspondence Analysis (PCA) and /or Redundancy Analysis (RA)) and unimodal response model (Detrended Correspondence Analysis (DCA), Correspondence Analysis (CA), Canonical Correspondence Analysis (CCA)). The choice of either of the two models depends on the property of the data set being analyzed. The application of linear response model and /or unimodal for analysis depends on the nature of the dataset.

Among unimodal models, a canonical correspondence analysis (CCA) was the most appropriate for the present study in assessing the relationship between vegetation and environmental data. CCA differs from other ordination methods because it incorporates the correlation and regression between floristic and environmental data within the ordination analysis (ter Braak and Prentice, 1988). CCA can be defined as a method of direct ordination with the resulting ordination being a product of the variability of the environmental data as well as the variability of the species data (Kent and Coker, 1992). CCA is best suited to the community data sets where species response to the environment is unimodal and the important underlying environmental variables have been measured (McCune and Grace, 2002). The resulting ordination diagram expresses not only patterns of vegetation in floristic composition but also demonstrates the principal relationship between the species and each of the environmental variables. The gradient length measures the beta diversity in a community composition along the individual independent gradients (ordination axes). If the longest value (longest gradient) is greater than four, the unimodal model is preferred to be used for analysis.

On the other hand, if the longest gradient is shorter than three the linear model is a better choice (ter Brakk, 1995). In the range between three and four, both models work well (Lepš and Smilauer, 1999).

Classification

Classification is to group together a set of vegetation samples (study plots of vegetation) based on their attributes, floristic or plant species composition (Kent, 2012). The analysis end product of a classification should be a set of groups derived from the individuals, where, ideally, every individual within each group is more similar to the other individuals in that group than to any individuals in any other group (Kent and Coker, 1992; McCune and Grace, 2002 and Kent, 2012).

Vegetation classification attempts to identify discrete, repeatable classes of relatively homogeneous communities or association. Classification helps to group together a set of vegetation samples for similarity analysis (Kent, 2012). The community types identified from the cluster analysis were further refined in a synoptic table and species occurrences are summarized as synoptic-cover abundance values. Synoptic values are the product of the species frequency and average cover abundance values (van der Maarel *et al.*, 1987).

2.3. Soil seed bank flora

Plant populations are represented not only by growing individuals aboveground but also by a number of dormant propagules forming seed reserves in the soil (Harper, 1977; Thompson, 1987; Baskin and Baskin, 1998). Soil seed bank includes both viable as well as non-viable seeds buried in the soil, which is composed of seeds partly produced in the area and partly brought from elsewhere (Harper, 1977; Bakker *et al.*, 1996). Seeds incorporated into the soil under a plant community represent not only the present vegetation growing in the area but also a memory of the past vegetation that occurred nearby (Bakker *et al.*, 1996).

The seed bank dynamics indicates the continuous addition of seeds to the soil by the seed rain (Harper, 1977), forming a dormant seed reservoir from which seeds are lost by germination, predation, and death (Bakker *et al.*, 1996). Seed banks are highly variable in characteristics such as size, species composition, seed longevity, seed viability, germination strategies and depth distribution of seeds in the soil (Warr *et al.*, 1993; Bakker *et al.*, 1996).

Forests are known to be subjected to both natural and anthropogenic disturbances, which disrupt the process of plant regeneration. A good understanding of natural regeneration requires information on the presence and absence of persistent soil seed banks quantity and quality and longevity of seeds in the soil, losses of seeds to predation and deterioration, triggers for germination of seeds and sources of regrowth after disturbances. Tropical forest plant species regenerate from one or more pathways, seed rain, soil seed bank, seedling bank or advance regeneration, and coppice (Demel Teketay, 2005).

2.3.1. Seed distribution in the seed bank flora

Although seeds are usually more abundant near the soil surface with numbers declining with increasing depth, each vegetation type has its own characteristic distribution of seeds in the soil profile (Warr *et al.*, 1993; Bonis and Lepart, 1994; Bakker *et al.*, 1996). Small seeds tend to be dispersed deeper into the soil than larger seeds that are more abundant in the topsoil layers and litter debris on the soil surface. A number of small seeds are buried by the activities of soil-living organisms and other herbivores (Willson, 1985; Warr *et al.*, 1993; Bonis and Lepart, 1994; Bakker *et al.*, 1996). Soil seed density, species diversity, and seed longevity might vary in different soil depth (Holmes and Moll, 1990; Demel Teketay and Granström, 1995). Effective seed germination might be hindered due to large numbers of small seeds that are deeply buried (> 50 mm) and lack the necessary resources to reach the soil surface where environmental conditions are more favorable (Harper, 1977). Another very important

germination requirement with regard to soil depth is deficient light exposure. Light penetrates only a few millimeters into the topsoil layers so that, light-sensitive seeds will not germinate from greater soil depths (Jankowska-Blaszczuk *et al.*, 1998). The accumulation of seeds both in vertical and horizontal seed distribution might be caused by animal activity, wind and rainwater runoff (Bigwood and Inouye, 1988; Matlack and Good, 1990).

Spatial and temporal seed dispersal together with seed characteristics such as mass, size, shape, and viability will determine the success of management in restoring and rehabilitating a target plant community (Henderson *et al.*, 1988). Successful regeneration and establishment rely on seed dispersal mechanisms, available germination sites, and seed-dispersing agents creating germination niches by disturbing vegetation structure and soil surface (Fenner, 1985). Soil seed banks play a significant role in plant succession to determine the composition and structure of existing vegetation and in the restoration and regeneration of native vegetation following disturbance (Van der Valk and Pederson, 1989). However, there is extreme variation among species. Seed density and viability are responsible for the relationship between the aboveground vegetation and soil seed bank flora (Harper, 1977). Soil seed banks, in general, are dominated by herbaceous species such as grasses, forbs, and sedges than woody species (Roberts, 1986).

2.3.2. The role of soil seed bank in above ground vegetation restoration

Human-induced factors are the greatest threat to the remaining natural forests in Ethiopia that require conservation priority and great concern by researchers, especially fragmented remnant patches and biological hotspots (Edwards and Ensermu Kelbessa, 1999). Rare and endangered plant species, in particular, are in need of protection against extinction. Deforestation by farmland expansion, fuelwood production, and local consumption of forest products require rehabilitation and restoration of plant communities after disturbance (Van der Valk and

Pederson, 1989; Warr *et al.*, 1993). Thus, the soil seed bank of some vegetation types can be used to re-establish plant species lost from the original plant community (Bakker *et al.*, 1996). Restoration of vegetation into its original and natural state from soil seed bank depends on the viability and abundance of the soil seeds (Bakker and Berendse, 1999). However, many vegetation types do not produce long-lived seeds. In these cases, restoration of the vegetation after disturbance cannot be successfully accomplished from the soil seed bank. The most common and applicable techniques to investigate soil seed bank are seedling emergence and manual seed extract methods for identification and isolation of seed bank (Demel Teketay and Granstrom, 1997; Feyera Senbeta and Demel Teketay, 2001). These methods were used to determine and compare seed density and species composition in the soil of natural forests. The utility of these approaches varies with community and habitat type. Despite large divergence between the two approaches, seedling emergence is the most commonly used method (Johnson and Anderson, 1986).

2.4. Carbon storage role of forest

Global temperatures increase from 0.3 to 0.6°C in the last 100 years and an expected increment in the next 100 years, is expected to bring regional and global changes in climate that would have significant impacts on human well-being and natural systems and alter the earth's radiation capacity (IPCC, 2001). IPCC, 2000 defines carbon sequestration as an increase in carbon stock in any non-atmosphere reservoir and the net removal of CO₂ from the atmosphere into long-lived pools of carbon (living aboveground biomass dead biomass, living biomass in soils, and/or recalcitrant organic and inorganic carbon in soils and deeper subsurface environments). Carbon sequestration removes carbon in the form of CO₂ from the atmosphere, combustion or industrial processes. Carbon dioxide and greenhouse gasses removed from the atmosphere are either stored in growing plants in the form of biomass or

absorbed by oceans. Climate change impacts will affect everyone everywhere in general and sub-Saharan African countries in particular where developing countries are most vulnerable and have least capacity to respond to the climate variability (IPCC, 2007). The main carbon pools in forest ecosystems are the living biomass above and below ground vegetation and dead wood of litter, woody debris, and soil organic matter (Pearson *et al.*, 2005 and FAO, 2010). Rehabilitation and restoration of ecosystem, and watershed, implementing conservation and management strategies, and minimizing deforestation might slow the accumulation of atmospheric carbon (Brown, 2002; Houghton, 2005).

Thus, forests have the potential to form a major component in the mitigation of global warming and adaptation to climate change. According to IPCC (2001), forest stores about 80 % of all aboveground and 40 % of all belowground terrestrial organic carbon. During the productive season, carbon dioxide from the atmosphere is taken up by vegetation and stored as plant biomass (Phat *et al.*, 2004). However, accumulated carbon would be lost as forest is cleared and is released into the atmosphere as carbon dioxide (Houghton, 2005). The soil is the largest carbon store globally, storing twice as much carbon as vegetation (Bellamy *et al.*, 2005). Climate change affects soil carbon turnover as increases in temperature increase rates of organic matter decomposition. As an increasingly important source of carbon emissions, it is important to evaluate soil carbon levels to determine the impacts of climate change on soil chemistry and decomposition, as well as to elucidate the potential contributions of soils to greenhouse gas emissions. REDD (Reducing Emissions from deforestation and degradation forest) has emerged as a means to create an incentive for developing countries to protect, manage and wisely use their forest resources, contributing to the global fight against climate change. The response of tropical forest ecosystems to both natural and anthropogenic environmental changes is a crucial issue in ecology. Tropical forest comprises large amount

of carbon stock, yet uncertainty remains regarding their quantitative contribution to the global carbon cycle as part of climate change mitigation, conservation of forest carbon stocks and enhancement of forest carbon stocks (UNREDD, 2012). Forests play an important role in regional and global carbon cycles (Brown *et al.*, 1996). REDD⁺ is a climate change mitigation mechanism with many initiatives, and strategies beyond deforestation and forest degradation including the role of conservation, sustainable management of forests and enhancement of forest carbon stocks by reducing emissions (Sedjo *et al.*, 1998). Thus, estimating forest biomass and quantifying carbon stocks provides baseline information for policymakers.

2.5. Land use land cover dynamics

The surface of the earth is not static and showed rapid land use land cover (LULC) change due to various natural and anthropogenic phenomena (Qian *et al.*, 2007). Land use is never static and is continuously changing in response to dynamic interaction between underlying drivers and proximate causes (Lambin *et al.*, 2003). Changes in LULC impose severe impacts on biological diversity, forest fragmentation, aggravate opportunities for ecosystem service change, disruption of socio-cultural practice, increase the natural disasters and other attributes of the terrestrial and aquatic surface of the earth (Mengistie Kidanu *et al.*, 2013).

Accelerated deforestation during recent decades has resulted in the conversion of hundreds of hectares of forests to other land uses. Ethiopia is experiencing a vast and wide range of LULC changes from natural vegetation and grassland to agricultural land and settlement area (Girma Hailu, 2000 and Mengistie Kidanu *et al.*, 2013). The problem of land cover dynamics is more severe in the Ethiopian highlands accounting for nearly 44% of the country's land area (Hurni *et al.*, 2005). The main reason for shrinkage in areas of tropical forests is human-induced (anthropogenic) pressure and their activities (Barraclough and Ghimire, 2000). Many interrelated processes contribute to tropical deforestation. Agricultural expansion is prominent

factor that led to drastic loss in biodiversity and change in the composition of species in the area. In addition to biodiversity values of the forest, it is imperative to recognize the ecosystem services natural habitats provide including genetic diversity, carbon sequestration, water cycling, climate regulation, and many other non-timber products (Constanza *et al.*, 1997).

Therefore, the knowledge and current information on LULC change in local, zonal, regional and/or national level is essential in decision making owing to negative impacts and mitigation policy interventions to reverse into sustainable resource conservation and utilization (Ellis and Pontius, 2007). Recent LULC dynamics information could lead to forecast the future LULC change and to apply appropriate mitigation strategies for achieving better land resource management (Lambin *et al.*, 2001). Thus, remote sensing and GIS are beneficial tools for assessing, monitoring and evaluating temporal and spatial LULC dynamics.

2.5.1. Role of RS and GIS in LULC change

Remote sensing (RS) is the practice of obtaining information about the Earth's surfaces using images taken from an overhead perspective by using electromagnetic radiations reflected (Campbell and Wynne, 2011). RS measures the reflective response of the earth's surface and observes directly the land cover for a given pixel. Remote sensing detects the surface cover type and condition and provides a number of landscape attributes that can be used by LULC models (Giri, 2012). On the other hand, Geographic information system (GIS) is a computer-based system that can deal with any type of information referenced by geographical location; and capable of handling both location data and attribute data (Lillesand *et al.*, 2004). GIS offers the integration of geospatial data sets from different sources such as surveys, remote sensing, and recycled paper maps. The combination of RS and GIS technology provides sufficient information and efficient methods for the analysis of land use issues and tools for

land use planning and modeling (Bakker *et al.*, 2001). Thus, GIS databases are used to improve the extraction of relevant information from remote sensing imagery, whereas RS data provide periodic pictures of geometric and thematic characteristics of objects and improving ability to detect changes (Janssen, 1994). Remote sensing brings together a multitude of tools to better analyze the scope and rate of deforestation and provides multi-temporal data for change detection analysis. In recent years, remote sensing techniques have been providing immense value for preparing accurate LULC maps and monitoring changes at regular intervals.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

This study was conducted at Wof-Washa Forest in North Shewa Zone of Amhara Region, in central Ethiopia on the eastern escarpment of Northwestern highlands (Figure 1). The forest is one of the state-owned natural forests of the country and is currently administered by Amhara Forest Enterprise (AFE). Wof-Washa Forest is within the Eastern Afromontane hotspot, a region extending across much of Ethiopian highland, characterized by high levels of biodiversity, species endemism and habitat threat (Mittermeier *et al.*, 2005). The forest extends between 9°43' 46.3" N to 9°46'26.2" N latitude and between 39°01'10.78 " E to 39°47'15.8" E longitude. The overall altitude range of Wof-Washa Forest is 1900-3700 m.a.s.l. and has ~ ca. 3197 ha total forest area.

Wof-Washa Forest is found in the Districts of Tarmaber, Ankober and Bassona Werena. The spatial distribution of Wof-Washa Forest spreads over 14 subdistricts: under Basonawerena district: Baso Dengora, Gudo Beret, Aba Mote, Keyt, Goshu Hager, Debele; in Ankober District the sub districts are: Lay Gorebella, Mahel Wenz, Zego, Eme-Mehret, Mescha, and Zembo and sub districts such as Wof-Washa and Debre Meaza are in Tarmaber District.

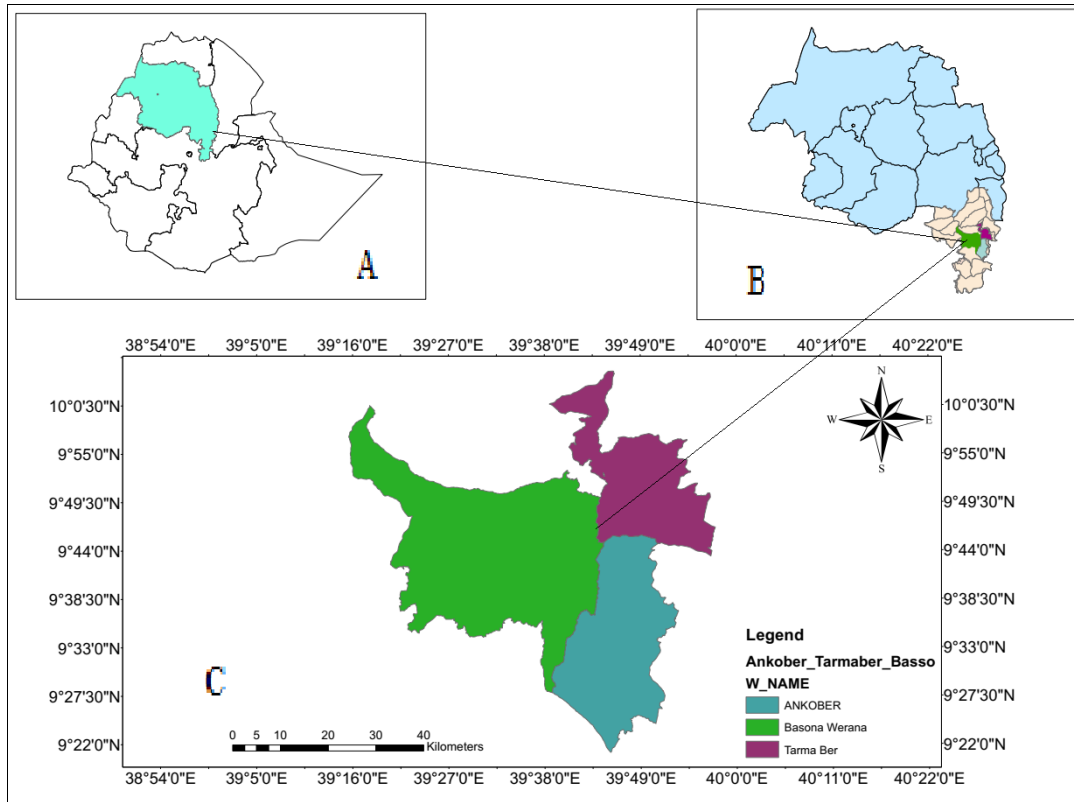


Figure 1. Map of Ethiopia showing the Regional States (A), Amhara region with North Shewa Zone (B), and Study districts(C)

3.1.2. Geology

Volcanic rocks constitute the basic parent material of the Ethiopian highlands. These are mainly alkali basalt and tuffs with rare rhyolites (Chaffey, 1979). The lava plateau of central highlands in Ethiopia, to which Wof-Washa Forest belongs, is characterized by two principal types of soils originating from the disintegration of the volcanic substratum intermingled with sand and limestone formations. These are the black compact clay soil on the flat highlands as well as on the bottoms of wide valleys and the reddish-brown (red soils) on the mountain and valley slopes and on better-drained highlands (Von Breitenbach, 1961). While the latter are soils of a complex mineral composition, the former are calcareous and, during the dry period, are liable to desiccation and superficial accumulation and precipitation of iron, aluminum and sodium hydroxide (Mohr, 1971). At times of heavy precipitation, these soils are affected by siltation and leaching as well as to silting and leaching. The lithology of the area is very

heterogeneous (Zanettin *et al.*, 1974, cited in Tamrat Bekele, 1993). It comprises ferric basalts, fine-grained basalts, zeolitized basalts, phonolites, alkali trachyte, trachyphonolites and subordinate alkaline and peralkaline rhyolites. The basaltic assemblage is reported to be alkaline. It is worth noting that the alkaline character of the Tarmaber rocks is essentially due to the high level of Na₂O (Merla *et al.*, 1979, cited in Tamrat Bekele, 1993).

3.1.3. Climate

Climate determines the formation, establishment, and distribution of natural vegetation (Craweley, 1986). The rainfall patterns in Ethiopia relies on the prevailing winds governed by inter tropical converging zones (ITCZ), and local reliefs (Friis *et al.*, 2011). In the summer season (“Kiremt” in Ethiopia) from late June to earlier September when the ITCZ is north of the equator, the wind in most areas of Ethiopia is Southwesterly. This moisture loaded wind produces rainfall over large areas of Western Highlands and most escarpments whereas in the winter season (“Bega” in Ethiopia from November to April) the ITCZ is far well south of Ethiopia. Thus, the prevailing winds are North easterlies that bring little moisture from the Red Sea and rains over Eritrea and Afar Alps. Only small amount of rain falls on the highlands during this season (Friis *et al.*, 2011). Thus, Wof-Washa Forest area has a double growing season locally known as “Belg” and “Meher” using the two rainy seasons, a bimodal type of rainfall.

According to the climate data (1990-2016) obtained from the National Meteorological Services Agency, the mean annual rainfall of Tarmaber district is 1530 mm (falling in two wet rainy seasons spring, from December to early March, and summer season from July to September (Figure 2) (Daniel Gemechu, 1977; Friis *et al.*, 2011). The first season includes the so-called ‘small rains’ which have a peak around January, while the latter season includes the ‘big rains’ with high concentrations in July and August (Figure 2). The big rain last from late

June to early September, with a peak in August. The mean monthly maximum temperature at Debre Sina is 27.1°C, and the corresponding mean monthly minimum temperatures are 6.0 °C. Thus, the average, mean monthly temperature of the area is 16.5°C. Debre Sina (at which the nearest meteorological station found) is located around 15 km northeast of Wof-Washa Forest at 9°51' 00" N and 39°45'41" E and 190 km northeast of Addis Ababa. There are often dry winds during the day, frosts may occur at night, and snow sometimes settles on the summit of Eme Mihret, Kundi, Gosh Meda, Ayir and Wutti.

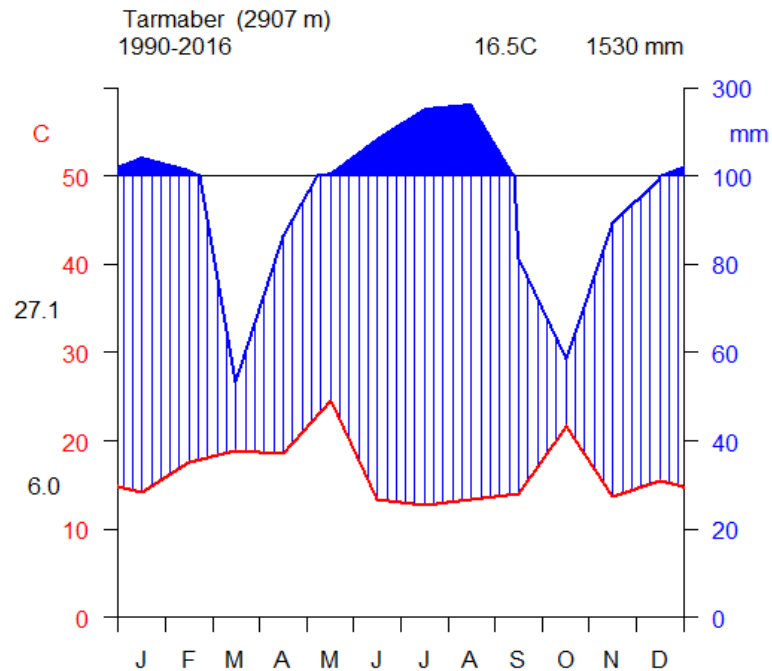


Figure 2. Climate diagrams showing Annual rainfall and temperature data from 1990-2016 (Source: National Meteorological Services Agency (NMSA) (2016).

3.1.4. Vegetation

Wof-Washa Forest can best be described as dry evergreen afromontane forest in the eastern escarpment of the NW Highlands with clear Ericaceous belt at the higher altitude (Friis *et al.*, 2011). The main characteristic species at the higher altitudes are *Hagenia abyssinica*, *Juniperus procera*, *Maesa lanceolata* and *Ilex mitis*. *Podocarpus falcatus*, *Allophylus*

abyssinicus, *Halleria lucida*, *Euphorbia abyssinica*, *Polyscias fulva*, *Prunus africana* and *Olinia rochetiana* occupy the middle altitude. At and above 3,000 m, *Erica arborea*, *Hypericum revolutum*, and *Lobelia rhynchopetalum* are the most dominant species with a few individual trees of *Hagenia abyssinica* and *Pittosporum viridiflorum* on the inaccessible cliffy and steep slopes. In the open areas, on rocks and on cliffs, there are also extensive patches of the endemic *Kniphofia foliosa*, clumps of *Helichrysum* and *Festuca* grass species that are adapted to the extreme cold climate. Plantation was done in the western, northern and southwestern edge using exotic species such as *Eucalyptus globulus*, *Cupressus lucitanica*, and *Pinus patula* to rehabilitate the most affected and degraded part of the forest.

3.1.5. Fauna

Wof-Washa Forest provides shelter, food and breeding areas for a number of wild animals including avifauna. Spotted hyena (*Crocuta crocuta*), Common jackal (*Canis aureus*), Guereza (*Colobus guereza*), Geladababoon (*Theropithecus gelada*), Klipspringer (*Oreotragus oreotragus*), Rock hyrax (*Procavia capensis*), Menelik's Bushbuck (*Teragelaphus scriptus meneliki*), East African Red Duiker (*Cephalophus harveyi*), and Bird species, like Thick-billed Raven (*Corvus crassirostris*), Black francolin (*Francolinus hildebranti*), Abyssinian Woodpecker (*Dendropicos abyssinicus*), and Ankober Serin (*Serinus ankoberensis*) and other small wild animals are among the most frequently observed wild animals in Wof-Washa Forest (Fasil Demeke, 2003). However, illegal hunting is a common practice in the forest and contributes to the ongoing genetic erosion and eventual local extermination of some species, particularly Menelik's Bushbuck, East African Red Duiker and Klipspringer (Demel Teketay and Tamrat Bekele, 1995).

3.1.6. Human population and their means of subsistence

The people living in and around Wof-Washa Forest belong to the Amhara people, one of Ethiopia's largest ethnic groups in Ethiopia as well as Argoba, Oromo and Afar people. The total population density of the three districts is summarized in Table 1.

Table 1. Population of the three districts bordering Wof-Washa Forest

District	Year (1994)			Year (2007)			Difference
	Total	Male	Female	Total	Male	Female	Total
Tarmaber	74522	37197	37323	84481	42812	41669	9959
Ankober	67,361	33,791	33,570	76,510	38,790	37,720	9149
Bassonaworena	112,173	56868	55305	120,930	61924	59006	8757
Total	254056	127856	126198	281921	143526	138395	

Source: Central Statistical Agency, 2017 (census result of 1994 and 2007 E.C.)

Agriculture: Subsistence agriculture and livestock production are the major livelihoods in the three Districts with a low level of specialization of crop production. The most widely cultivated crops are *Hordeum vulgare*, *Triticum* species, *Solanum tuberosum*, *Vicia faba*, *Pisum sativum*, and *Eragrostis tef*. Declining landholding sizes because of population growth and deteriorating soil fertility are among the biggest challenges facing the local communities. *Rhamnus prinoides* known locally as “Gesho”, is grown in the wild and as a plantation crop in home gardens both for sale (income generating alternatives) and domestic use. It is used as a flavoring agent in a locally produced beverage (“Tella, Tej and Areki”). *Thymus schimperi* (“Tosign” in Amharic) is collected from the wild by the local people and sold as an alternative income generating option. The well-dried leaves are boiled and used as a spice for tea preparation. The cultivation of *Hordeum vulgare* has now expanded onto the steepest slopes around to edge of the forest.

Beekeeping: There are large number of beehives in Wof-Washa Forest, especially inside the Ericaceous belt (Figure 12). The forest provides bee forage, nesting habitat for bees, and

materials to make beehives. However, the ongoing apiary is traditional and illegal activity around Wof-Washa Forest and honey and related products are harvested from fixed beehives using fire smokes. *Juniperus procera* and *Erica arborea* are the most preferred tree species to make beehives due to the durability of the beehives. The tree/shrub species preferred for bee fodder in Wof-Washa Forest are *Erica arborea* and *Ilex mitis*, *Allophylus abyssinicus*, and *Hagenia abyssinica*. Farmers favor these species due to the attractive odor, abundance and long flowering periods and the good nature of the honey that is produced from these flowers (Fasil Demeke, 2003). Hanging of beehives is carried out mainly in September and collects honey in February. However, in the lower part of Wof-Washa Forest, hanging of beehives and collection of honey take place in July and October respectively following the flowering season of most species used for apiary (Fasil Demeke, 2003).

Forest products are mainly used by local people (as local house construction, grazing land, apiary, fuelwood, and charcoal, farm implements and fencing backyard) and illegal selective cutting of timber trees (particularly *Juniperus procera* and *Podocarpus falcatus*) are the common activities practiced in Wof-Washa Forest.

3.1.7. Topography

Wof-Washa Forest occupies the side of a curved ridge and stream incisions with steep slopes of the escarpment ranging from 1900 to about 3700 m. a.s.l. (Figure 4). The escarpment is broken up by a number of valleys and rivers that penetrate the forest and form nearly a trapezoid accordion-like appearance of the escarpment. There are several peaks covered by forest and ericaceous shrubs mostly in the northwestern part of Wof-Washa Forest. The extreme slope in the north and west part and extended North-south cliff around 10-15 km make Wof-Wash forest played a role for the inaccessibility of the forest but, in the east and south part, roads are improved even for vehicle and small hamlets increased. Thus, such road

accessibility and settlement expansion impose more anthropogenic pressures and aggravate the threats to this remnant forest ecosystem.



Figure 3. Partial view of the undulated nature of Wof-Washa Forest (Photo by Abiyou Tilahun, 2016)

3.1.8. Water catchment

Wof-Washa Forest is on the eastern side of high ground forming the point at which the two big river basins divide: The Blue Nile and the Awash in Ethiopia. The forest lies within the catchment of the Awash watershed (Chaffey, 1979) which drains into the Danakil plains in the Northern section of the Rift Valley. There are more than seven streams flowing out from Wof - Washa forest and forming tributaries of the Awadi River, which itself is one of the main tributaries of the Awash River (Demel Teketay and Tamrat Bekele, 1995). The tributaries of Awash River such as Awadi, Buchin, and Kebena have their source in Wof - Washa Forest. Among the smaller streams sourced in the forest and that drain to join Awadi river are “Mescha jiret”, “Tikurit jiret”, “Sebat weyra”, “Lam washu”, “Misilenae kilkil”, “Qil Matebia”, “Ashosho jiret”, “Aroge Beret”, “Phila”, “Qechinit”, “Borbor”, “Qechamo jiret”, and “Astakel”.

Historical background of Wof - Washa forest

Wof-Washa Forest carries huge environmental significance and historical interest. Wof - Washa forest has a historical connection with Emperor Zera Yacob in the 14th century, it was believed that Emperor Zera Yacob was tried to grow *Juniperus procera* seeds in the forest for the future fuelwood and construction demands. It was also believed that the Emperor cultivated some of the gentle slopes and bottom hills with *Juniperus procera* seeds. The Emperor Zera Yacob was ordered the preservation of this forest as "Crown forest" and the forest was used as sources of seeds to establish Menagesha Suba forest (Sebsebe Demissew, 1988; Demel Teketay, 1995).

Since the 16th century, Wof-Washa Forest served as a source of timber for construction of nearby churches, villages, and urban centers. In the era of Menelik II in the late 19th century, the area was indicated to have high forest cover. Later, with the establishment of the first forest policy in the country by Emperor Menelik II (in the 1880's), Wof-Washa Forest was declared to be a State Reserve Forest (Anonymous, 1994).

At the peak of mount Wutti, approximately to the center of Wof-Washa Forest, there is a map of Ethiopia engraved By the Italian Geographer Orazio Anthinory (Personal communication with religious leaders particularly Like Kahinat Kalehiwot Habtewold). Even though, the exact period of the carving of the map is difficult to estimate, the local religious leaders and elders said that it was done around the 18th century before their invasion of Ethiopia to serve as a reference point to the Palace of Ankober in the near distance (Figure 5).



Figure 4. Map of Ethiopia engraved by the Italian on the peak of mount Wutti (left)

In 1950, about 200 ha of the forest area was destroyed due to a forest fire. In line with this, honey extraction activity frequently caused a forest fire that led to a significant decline of forest resource of the area.

During the Era of Emperor HaileSELLASIE, Wof-Washa Forest area was preserved and excessive tree cutting was not allowed. During the Derg period, although the population had increased, excessive tree cutting for expansion of farmland was not also allowed. However, the villagization program that was carried out in the area in 1986, without the willingness of the community, used forest resources for the construction of their residences. Thus, the forced resettlement and villagization results in negative impact on fragile local resources, particularly on the forest, water, and grazing land. The current government ended the villagization programme in 1991 replaced once the regime and farmers returned to their homestead and forest resources were again used to re-construct their residences (Fasil Demeke, 2003).

3.2. Materials

During data collection, Garmin GPS 62, Compass and Suunto Clinometer were used to measure altitude, aspect, and slope respectively. Digital photo camera was used to document photos of microhabitats, landscapes and plant specimen. Rope, wooden frame, and measuring tape were used to collect vegetation data in every plot. Plant press was used to pack plant

specimens from the field to the Herbarium. Soil auger and core sampler were used for collecting soil samples, polyethylene bags for holding the soil and temporally putting the plant specimens, newspapers for preserving the plant specimens and markers for coding specimens were also used.

3.3. Methods

3.3.1. Vegetation study

3.3.1.1. Reconnaissance survey

A reconnaissance survey was carried out from March 20 to 30, 2014. During the survey, sampling method was determined, accessibility of the study area, altitudinal gradient, and topography of the study area were assessed and general information was collected. Generally, reconnaissance survey provides an impression on the general vegetation physiognomy, landscape and sampling sites of Wof-Washa Forest.

3.3.1.2. Sampling design

A systematic sampling design with the first plot being established by simple random sampling technique was used to collect overall vegetation and environmental data following the techniques of Mueller-Dombois and Ellenberg (1974). Since the study area is extremely undulated terrain, transects were set along elevation gradients and plots were established at 100 m intervals along the predetermined transects. Ten transects were laid systematically and the distribution was made in such a way that, representative data from all aspects of Wof-Washa Forest would be included. The lengths of each transect line, the number of plots in each transects, aspect, and range of altitude vary among transects (Table 2).

Table 2. General description of transects laid in the study area

Transect no	Length (km)	Direction	No of plots	Altitude ranges (m.a.s.l)	Aspect
1	2.66	NW to SE	10	2836-3392	SE
2	1.98	NW to SE	10	2825-3321	SE
3	1.61	NW to SE	11	2803-3376	E
4	1.62	W to E	7	2887-3498	N
5	2.72	S to N	10	2529-3271	NE
6	2.16	E to W	11	2338-2667	E
7	1.02	W to E	10	2423-2498	S
8	2.57	SE to NW	12	2706-2815	S
9	1.49	W to E	6	2604-2650	SE
10	1.85	E to E	8	3083-3167	E

Ninety-five (20 m x 20 m) study plots for the tree species and, five (5 m x 5 m) subplots for shrub species, saplings, and seedlings, and 1 m x 1 m for herb species were established within each major study plots. Similar sample sizes and shapes in the different Afromontane forests in Ethiopia have been used (Lisanework Nigatu and Mesfin Tadesse, 1989; Demel Teketay, 1996; Kumlachew Yeshitela, 1997; Feyera Senbeta and Demel Teketay, 2003; Tadesse Woldemariam, 2003 and Motuma Didita *et al.*, 2010).

3.3.1.3. Vegetation Data collection

Vegetation data were collected (Late September to October 30, from January first to earlier February, end of May to end of June) before and after the onset of both small and big rainfall seasons (spring and summer) respectively. A complete list of herbs, shrubs, lianas, and trees was made inside each plot and voucher specimens were collected. Woody species with a diameter at breast height (DBH at 1.30 m above ground) > 2.5 cm were measured in caliper. Moreover, the DBH of some species which are out of the range of the Caliper was derived from circumference ($D = C/\pi$, where D = diameter at breast height, C = Circumference, and π = constant with value 3.14) of each woody species measured by a measuring tape. The height of woody individual's species with > 2 m height was measured using Suunto Clinometers, but

wherever sometimes the use of this instrument was constrained, due to limited visibility, graduated sticks were used (Feyera Senbeta *et al.*, 2002). The cover abundance of each species inside each plot was estimated following the Braun-Blanquet scale as modified by van der Maarel (1979). Species occurring outside the plots were also recorded to obtain a complete floristic list of the study area. However, exotic species data were excluded from the analyses as the objective of the paper was to deal with indigenous plant species. In this study, woody species clustered as seedlings (when height less than 0.5 m), saplings (as the height ranged 0.5 - 2 m) and tree when the height > 2 m.

Topographic variables such as altitude, latitude, and longitudes were recorded at the center of each study plot using Garmin 62 GPS (Global Positioning System). An aspect of each plot was measured using a compass. Values for aspect were codified based on Zerihun Woldu *et al.*, (1989), where North = N = 0, North East-NE = 1, East - E = 2, South East - SE = 3, South - S = 4, South West - SW = 3.3, West - W = 2.5 and North West - NW = 1.3.

Each plant specimen was coded, labeled, pressed, dried in the heater, deep-frozen, identified and finally deposited at ETH. Plant species identification was done at the National Herbarium (ETH) using taxonomic keys, Flora of Ethiopia and Eritrea (Edwards *et al.*, 1995; Edwards *et al.*, 1997; Edwards *et al.*, 2000; Hedberg *et al.*, 1989; Hedberg *et al.*, 2003; Hedberg *et al.*, 2004; Hedberg *et al.*, 2006; Mesfin Tadesse, 2004) and by comparisons with authenticated herbarium specimens in the National Herbarium, Addis Ababa University.

3.3.1.4. Vegetation data analysis

3.3.1.4.1. Community Classification

Agglomerative hierarchical cluster analysis was used to identify plant community types from entire vegetation dataset of Wof-Washa Forest. Species-wise cover abundance values were used to classify vegetation communities. Each cluster represents a specific community type

with characteristic and dominant species. Synoptic values were calculated to identify dominant species for naming plant communities. Each community type was named by the first two species with the highest synoptic cover values using the free statistical software R Version 3.0.2 (R Development Core Team, 2014). Frequency, density, DBH, height and basal area per ha of woody species were computed to characterize the vegetation structure. Importance value indices of woody species were calculated using relative density, relative frequency and relative dominance of the respective species to identify ecologically and environmentally important plant species in Wof-Washa Forest.

3.3.1.4. 2. Diversity analysis

Diversity measures

Measures of diversity are indicators of the wellbeing of ecological systems. The Shannon-Wiener diversity (H') and evenness (E') indices were computed following Magurran (1988) to measure the diversity of species in Wof-Washa Forest. Thus, Shannon-Wiener diversity index was computed to measure species diversity in Wof-Washa Forest, using the following formula;

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

Where, S = total number of species; P_i = the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of total cover and \ln = log base n .

The values of Shannon –Wiener diversity index are usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5 (Magurran, 1988). Evenness or equitability (E') is a measure of similarity of the abundances of the different species in the sampled sites. Evenness was calculated from the ratio of observed diversity to maximum diversity as a measure for evenness of spread using the equation:

$$E' = \frac{H'}{H \max} = \frac{H'}{\ln S}$$

Where, $H \max$ is the maximum level of diversity possible within a given population and S is species richness. The values of evenness lay between 0 and 1, and with 1 representing a situation in which all species are equally abundant or complete evenness (Magurran, 2004).

Similarity indices

The similarity in species composition among plant communities in the forest was analyzed using the widely used and classical similarity indices Sorensen Similarity Index. The following formula was used to determine the similarity of the plant species in the community types:

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

where a = number of species common in two community types; b = number of species recorded only in one community type to be compared; and c = the number of plant species recorded only in the other community type.

In addition, the Simpson's Index of Diversity (D) was computed using the formula:

$$D = \sum \left(\frac{ni(ni-1)}{N(N-1)} \right)$$

where ni = the number of individuals in the i^{th} species and N = the total number of individuals. As D increases, diversity decreases and Simpson's index is, therefore, usually expressed as $1-D$. Simpson's index is heavily weighted towards the most abundant species in the sample while being less sensitive to species. The values of D ranges between 0 and 1 (Magurran, 1988).

3.3.1.4.3. Species composition and richness among communities

Sørensen's Similarity Index was used to compare the degree of floristic similarity and differences among the community types. Data matrix of all species present/absent in each

community type was used for the analysis. Species composition analyses were complemented by calculating the floristic dissimilarity between all pairs of sites using β -diversity. Therefore, pairwise comparison of β -diversity between community types was computed in Microsoft Office Excel (2007) spreadsheet using the formula:

$$\beta\text{-diversity} = a + c/2a + b + c \text{ (Whittaker, 1972),}$$

Where, a is the number of shared species in two sites, and b and c are the numbers of species unique to each site.

β -diversity is the rate of change in species composition from one community to another along gradients. High species turnover would, indicate high β -diversity. A high β -diversity index indicates a high level of species heterogeneity among study plots and /or community types. The species turnover between clusters would be higher than the species turn over between the sample plots of the original data (Whittaker, 1967 and 1969).

3.3.1.4.4. Ordination of vegetation and environmental data

Both the vegetation data and the environmental variables were analyzed with canonical correspondence analysis (CCA) using the free statistical software R Version 3.0.2. The CCA analysis identified the correlation between vegetation and environmental variables and hence the major environmental variable that determine species distribution pattern were identified. Results of the preliminary Detrended Correspondence Analysis (DCA) was done to detect the appropriate model for analysis and the longest gradient for the Wof-Washa Forest data set was 4.65. Hence a unimodal model, Canonical Correspondence Analysis (CCA) was used for the present study in assessing the relationship between vegetation and environmental data (Palmer, 1993).

Before the application of CCA, thirteen environmental variables were tested using a Monte Carlo permutation test was used to test the significance of environmental variables in determining patterns of community formation and species distribution.

Hence, nine variables were found to be statistically significant and CCA analysis was done using 95 sample plots, 365 species and nine environmental variables from Wof-Washa Forest. DCA, CCA, and Adonis test were computed by using the free statistical software R version 3.0.2 (R Development Core Team, 2014).

3.3.1.4.5. Species composition, structure and regeneration data analysis

For each species, values of frequency, density and dominance were calculated following the methods of Curtis and McIntosh (1951). Woody species recorded in all plots of Wof-Washa Forest were used in the analysis of vegetation structure. The diameter at breast height was classified into seven DBH classes: 1) <10, 2) 10.01- 20, 3) 20.01- 30, 4) 30.01- 40, 5) 40.01- 50, 6)50.01- 60, 7) > 60 cm. The percentage of individuals in each DBH class was calculated to assess the structural patterns of Wof-Washa Forest. In addition, tree heights of all adult plants were classified into seven height classes: 1) ≤ 5, 2) 5.01 - 10, 3) 10.01 - 15, 4) 15.01 - 20, 5) 20.01-25, 6) 25.01 - 30, 7) > 30 m and the percentage number of each height class for Wof-Washa Forest was calculated.

Frequency (F) - refers to the degree of dispersion of individual species in an area and usually expressed in terms of percentage occurrence. it can also have defined as the proportion of sample units where a species was found compared to the number of sample units measured and is expressed as either an absolute (number of plots in which the respective species occurs) or a relative number (the ratio of absolute frequency of a species to the total number of plots multiplied by 100).

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

Where F is expressed as a percentage for each species and then sorted in increasing order and grouped into five classes (in %): 1) 0-20, 2) 21-40, 3) 41-60, 4) 61-80, 5) 81-100. The percentage distribution of individuals of species in each class is used to assess and compare the distributional patterns of species of each forest patches within the forest.

Density (D) - is the count of individuals per unit area. It is calculated from the count of all the individuals from the study area per ha basis (Mueller-Dombois and Ellenberg, 1974).

$$D = \frac{\text{Number of stems of a species counted}}{\text{Sample area in hectare}} \times 100$$

Where, D is expressed as a percentage for each species and then sorted in increasing order and grouped into seven classes (Density classes: 1) ≤ 5 , 2) 5.01 - 10, 3) 10.01 - 20, 4) 20.01 - 40, 5) 40.01 - 60, 6) 60.01 - 80, 7) > 80 %. The ratio described as a/b (where, a = dbh > 2.5 and b = dbh > 10 and c = dbh > 20 cm is taken as the measure of size class distribution (Grubb *et al.*, 1963).

Basal Area (BA) - The cross-sectional area of tree stems in diameter at breast height (at 1.3 m above ground) is usually expressed as basal area (BA). Basal Area (in m² per hectare) of trees was computed using $(d/200)^2 \times 3.14$ to measure dominance (degree of coverage of a species as an expression of the space it occupies) (Barbour *et al.*, 1987).

$$BA = (d/200)^2 \times \pi$$

Where: BA = Basal Area in m² per ha, d = diameter at breast height in meter and $\pi = 3.14$

Important value index (IVI) indicates the relative ecological importance of a given species at a particular site (Kent and Coker, 1992). It is determined from the summation of the relative values of density, frequency, and dominance of each woody species. Relative Frequency (RF) - is the frequency of a species per sum of frequencies of all species X 100.

Relative Density (RD) - is the total number of individuals of a species per total number of

individuals of all species X 100. Relative Dominance (RDO) - is the total basal area of a species per total basal area of all species x 100; where dominance is the mean basal area per species multiplied by a number of individuals of the species. Therefore,

$$IVI = RDO + RD + RF \text{ (Mueller-Dombois and Ellenberg 1974 and Kumar, 1981).}$$

Based on their IVI values, tree and shrub species of Wof-Washa Forest were grouped into five classes (in %) for conservation priority following Simon Shibru and Girma Balcha (2004).

IVI classes: 5) <1, 4) 1-5, 3) 5.01-10, 2) 10.01-15, 1) >15.

The population structure of each woody species in Wof-Washa Forest was assessed through histograms constructed using the density of individuals of each species and diameters classes (Peters, 1996). Then, based on the profile depicted in the population structures, the regeneration status of each woody species was determined.

The status of regeneration of species of different growth forms was determined as good (when the density of seedlings much larger than the saplings and when the density of saplings are greater than mature individuals), whereas Fair regeneration as the density of seedlings higher than the density of saplings and the density of saplings much higher than the mature individuals, and very poor when the density of seedlings much lower than the saplings and saplings lower than mature individuals) (Pandey and Shukla, 2003). Thus, regeneration status of Wof-Washa Forest was analyzed by comparing saplings and seedlings with the matured trees following Pandey and Shukla (2003).

Vertical stratification: According to Leibungut (1958) cited in Lamprecht (1989), three simplified vertical structures are distinguished in tropical montane forests. The upper layer is comprised of individual tree/shrub species that attain a height greater than two-thirds of the top height of a given forest while the middle stratum is formed by individual tree/shrub species with a height less than two-thirds and greater than one-third of the top height in a

given forest. The lower layer also composed of individual tree/shrub species with a height less than one-third of the top height. Accordingly, the forest vegetation of Wof-Washa Forest was classified into three strata.

3.3.2. Soil seed bank study

3.3.2.1. Sampling design

Soil seed bank samples were collected from each plot (15 cm x 15 cm) length and width with a 9 cm depth in three layers in five replicates four at each corner and one at the center of a square 20 m x 20 m plot established for the vegetation data collection following methods used by Demel Teketay and Granström (1995). The composite sampling provides average and representative values for each respective 20 x 20 m sampled plot for further greenhouse germination work.

3.3.2.2. Data collection methods and procedures

Soil seed bank data were collected at the end of the small rain (May-June, 2015) and at the end of the major rainfall season (October -November 2015). Samples were collected from the 95 plots prepared for vegetation data collection. Three successive layers (0 - 3, 3 - 6, and 6 - 9 cm) and the litter layers as the fourth layer were carefully removed using a 15 cm x 15 cm metal frame at each subplot (Demel Teketay and Granström, 1995); Dalling *et al.*, 1995). Soil layers of each subplot were separated by using a sharp knife and spoon. Soil samples of the corresponding soil layers from the five sub-plots of each plot were mixed in a plastic bag and later divided into three equal parts of which one was randomly taken as the working sample for incubation in a greenhouse (Figure 6). A total of 285 different soil seed layers were sampled and transported to Forest Research Center (FRC) Addis Ababa for germination analysis in the greenhouse. There are various methods used in determining soil seed bank density and composition (Dalling *et al.*, 1995; Bernhardt *et al.*, 2008). Thus, seedling

emergence/germination analyses were used for this study. The collected samples were transported to a green house in FRC (Forest Research Center, Addis Ababa) and spread on trays. The soil samples were first sieved using a mesh size of 1.6 mm, 2.5 mm and 3.15 mm to recover large seeds. The seeds recovered by sieving were collected into paper bags and identified using seed experts from FRC. The viability of seeds was determined by germination (Feyera Senbeta and Demel Teketay, 2001; Feyera Senbeta and Demel Teketay, 2002). Watering of the samples was done every morning until the incubation had terminated. Seedling germination was checked every seven days and seedlings identified in the greenhouse were recorded and removed from the trays to reduce shade effect following the methodology by Ter Heerd *et al*, (1996).

The germination process and emerging seedlings were kept for eleven months from October 2015 to September 2016 since a shorter period of study could result in an underestimation of the persistent seed bank (Baskin and Baskin, 1998). Even after 11 months, when there was no further seed germination, there was watering the samples for another two months, no new seedlings emerged. Nevertheless, the residual soil was checked for remaining seeds by viewing small random samples taken from the trays under a microscope and probing seeds with a needle in order to distinguish between the firm and empty seeds. Since there were no seeds that remained in the investigated soil samples, germination process completed. The maximum number of seedlings emerged in the first four months of examination. Earlier in the fifth month onwards, the emerging rate gradually decreased until the end of the germination period. There was no germination of new seedlings for the last two months in both phases. Species identification was done in the greenhouse by the supervision of advisors (Figure 6). Unidentifiable seedlings were transplanted into pots and let to grow until species

identification is possible using Flora volumes and authenticated voucher specimens (Diaz-Villa *et al.*, 2003).



Figure 5. Species identification in the Greenhouse (Photo by Abiyou Tilahun, December 2016)

3.3.2.3. Soil seed bank data analysis

Species composition (number of species germinated per sample) and density (number of germinated seeds per sample) of the soil seed banks among the study sites and soil depths were compared using Pearson correlation methods. As compared with other similarity indices, Sorensen Similarity Index has been recognized as robust and unbiased even with small sample sizes (Ludwig and Reynolds, 1988). Total species diversity, richness, evenness, and total value for the similarity between the aboveground vegetation and the soil seed bank of the study area were calculated taking the pooled seeds from three layers of 95 study plots.

To analyze the density of seeds in each soil layer, the sum of numbers of seeds recovered in similar layers were divided by the area in meter square sample area (15 cm x 15 cm), and then multiplied by sample size (number of study plots), so that the density of seeds (number/m²) at

that particular soil depth was determined following the methodology used by Getachew Tesfaye *et al.*, (2004) and Taye Jara (2006).

3.3.3. Biomass and carbon stock study

Estimation of Wof-Washa Forest carbon stock enables to assess the amount of carbon loss by deforestation and related anthropogenic pressures. The principal element for the estimation of forest's carbon stocks is the estimation of forest biomass.

3.3.3.1. Sampling design

Non- destructive sampling method was used for the above-ground biomass estimation using diameter at breast height, the height of the tree and wood density (Chave *et al.*, 2005; Reyes *et al.*,1992). The design of the plot depends on the sizes of different species in the forest. In this study, 1 m x 1 m subplots were used for litters, herbs, and saplings (with DBH < 2 cm) while, 5 m x 10 m plots were used for live woody plants with 2-20 cm DBH and dead wood. Trees with DBH \geq 20 - 50 cm were counted in the 10 m x 30 m, while larger tree species with DBH > 50 cm DBH were measured and counted from 20 m x 50 m plots following Pearson and Brown (2005).

3.3.3.2. Carbon stock data collection

Aboveground Biomass (AGB): The major activities of carbon measurement during the field data collection were above-ground tree biomass, leaf litter, dead wood (dead standing and dead fallen) and soil organic carbon measurements. The first plot was established 100 m away from the edge of the forest using random sapling method. The DBH (at 1.3 m) of individual trees \geq 2.5 cm were measured in each plot using a caliper and measuring tape. Species on the border of a plot were included when more than 50 % of their basal area falls within the plot and excluded if more than 50 % of their basal area falls outside the plot. In addition, species overhanging into the plot were excluded, but trees with their trunks inside the sampling plot

and branches outside are included (Karky and Banskota, 2007 and MacDicken, 1997). Below ground biomass (BGB) is estimated from above ground measurements, i.e. belowground biomass is 20 % of the above-ground biomass (MacDicken, 1997). Individuals of woody plants with dbh < 2.5 cm were included using method applied for LHGs below.

Litter, herbs, and grass (LHGs): The litter layer is defined as all dead organic surface material on top of the mineral soil. For the collection of litter, five rectangular subplots of 1x1 m were established at the four corners and center of each main plot. Where the sample is large, the fresh weight of the total sample was recorded in the field and a subsample of manageable size (100-200 g) evenly mixed subsamples (95 total samples) were brought to the laboratory to determine dry biomass and percentage carbon (Pearson *et al.*, 2005). Likewise, the plot design and number of subplots for herbs (grasses, sedges, and all other non-woody plants within the plots) were similar to litter sample design. Samples were collected by clipping all the vegetation and weighing it and then placing in a sample weighing bag and brought to the laboratory to determine the oven dry weight of the biomass.

Carbon in dead Wood: Standing dead trees, fallen stems and fallen branches with a DBH ≥ 10 cm were measured in each nested plot with their respective DBH. Branches with 2-20 cm dbh were measured within the 5 x 10 m² plots and thinner branches were only measured within the 1 m² plot.

Standing Dead Wood: standing dead trees were measured within each nested respective to their DBH. The DBH of stumps > 1.3 m in height were measured as standing dead trees. However, when the height of the stump is less than 1.3 m in height, the diameter was measured as close as possible to the top. In addition, the height of the stump and the state of the dead wood (alive or dead) was measured (Pearson *et al.*, 2005).

Fallen Dead Wood: Fine pieces of fallen dead wood (logs and branches between 1 cm and 10 cm diameter were measured in litter while coarse objects (DBH >10 cm) were measured along the entire lines. Fallen dead woods were sampled using the line intersecting method (Harmon and Sexton, 1996, Pearson *et al.*, 2005) in which two 50 m lines are bisecting each sample plot at the center (UNFCCC, 2015). The diameters of the fallen dead wood (≥ 10 cm diameter) were measured at the perpendicular lines of the transects (on the two major axes) and the dead fallen woods crossing the transects using designed plot accordingly. Measurement starts at one end of the transect line and traverses along it until a piece of dead wood (≥ 10 cm diameter) crosses the line. At the point where the piece intersects the transect line, measure the diameters of the piece (UNFCCC, 2015).

The fallen dead woods were assigned into three density classes as sound (S), intermediate (I) and rotten (R) using the machete test (IPCC, 2003 and REDD methodological module, 2009).

Soil Organic Carbon (SOC): Soil samples were collected from two successive layers, 0-15 and 15-30 cm using a core sampler of 5 cm diameter and composited for laboratory analysis in pre-weighed sampling bags. Fresh wet weights of soils from 15 x 15 cm were measured in the field using kitchen balance with 0.1 g precision. Composite sampling was used, where sub-samples are collected from the selected plots in Wof-Washa Forest and the sub-samples are composited for analysis. To have an accurate inventory of organic carbon stocks in organic soil, three types of variables (depth, bulk density and the concentrations of organic carbon within the sample) must be measured (Pearson *et al.*, 2005).

Model selection for AGB: Previously single or multi-species allometric equations were not developed for woody species and forest types in Ethiopia except for few exotic species. In order to compute AGB of Wof-Washa Forest, the appropriate model that can estimate the biomass accurately were selected by reviewing and testing developed multi-species model

(Allometric equations) for the broader ecological zone (wet, dry and moist) and forest types (Tropical, Sub-Saharan African). As a result, after exhaustive and expanded reviewing of published allometric equations for the tropical region and dry tropical forests, we have selected one which uses more parameters to estimate the biomass and corresponding carbon stock of the current study forest. Baker *et al.* (2004) have shown that ignoring variations in wood density results in poor overall prediction of above ground biomass. Therefore, wood density is an important variable in the regression model. Based on such recommendation Chave *et al.* (2014) model that used wood density was selected among other biomass estimating equations. The unit of the AGB estimated from allometric models is the kilogram (kg).

3.3.3.3. Carbon stock Data Analysis

3.3.3.3.1. Aboveground biomass (AGB) and carbon stock

The analysis of carbon stock in different carbon pools of Wof - Washa forest was computed using (Chave *et al.*, 2014) model and described below:

$$AGB = 0.0673x (pD^2H)^{0.976} \dots\dots\dots (eq.1)$$

Where, AGB = (kg/ha), P= Density of species (g/cm³), D = Diameter at breast height (cm) and H-height (m).

The following procedures were used to estimate both aboveground biomass and carbon stock:

1. Calculating AGB (kg) of each woody species (DBH > or = 2.5 cm) measured from all study plots and then converting the AGB (kg) into AGB (ton) by using the expansion factor (10000 m²/area of a sample plot m²), i.e. AGB (ton) = AGB (kg) x 10000 m²/area of a sample plot m²;
2. Convert the AGB in to AGC (AGC = AGB x 0.5) (Pearson *et al.*, 2005)
3. Aggregate carbon stocks of all species in each study plots;

4. Convert carbon stock (ton) to hectare basis using carbon stock (ton/hectare) = carbon stock (ton) x 10,000/Area of plot), and
5. Calculate the mean aboveground carbon stock of the plot in carbon dioxide equivalent AGC (t/ha) in CO₂ equivalent (ton/hectare CO₂ equivalent = Carbon stock in ton/ha x 44/12 or 3.67).

3.3.3.3.2. Below-Ground Biomass (BGB) and carbon stock (BGC)

According to Mac Dicken (1997), the standard method for estimation of belowground biomass can be obtained as 20% of aboveground tree biomass i.e., the root-to-shoot ratio value of 1:5 is used.

$$\text{Thus, BGB} = \text{AGB} \times 0.2 \dots \dots \dots \text{(eq.2)}$$

Where BGB is below ground biomass, AGB is above ground biomass, 0.2 is conversion factor (or 20 % of AGB).

3.3.3.3.3. Litter biomass and carbon stocks

Laboratory analyses:

The 200 g of mixed sub-samples of wet weight were oven dried at 105⁰C for 24 hours (Figure 7). The oven dried samples were ground and 20 g samples were combusted in pre-weighted crucibles in the furnace at 550⁰C for two hours to ignite. And the then, the cooled crucibles with ash were weighted to determine the percentage of organic carbon in the litter using the loss on ignition method following Allen *et al.* (1986). The weight loss is assumed to be proportional to the amount of organic carbon contained in the sample.

Litter biomass was calculated using the following formula;

$$\text{LHG} = \frac{W_{field}}{A} \times \frac{W_{sub-sample\ dry}}{W_{sub-sample\ wet}} \times \frac{1}{10,000} \dots \dots \dots \text{(eq.3)}$$

Where, LHG = biomass of litter, herb and grasses (ton/ha); W_{field} = weight of the fresh field sample of litter, herb and grasses collected destructively from a sample size of A(g); A = size

of the area in which leaf litter, herb, and grasses were collected (ha); Wsub-sample, dry = weight of the oven dry subsample of leaf litter, herb and grasses took to the laboratory to determine moisture content (g); and Wsub-sample wet = weight of the fresh sub-sample of leaf litter, herb and grasses taken to the laboratory to determine moisture content (g).

Loss of ignition (LOI) method was applied to determine the percent carbon of LHGs Allen *et al.*, 1986). Organic matter content was calculated as the difference in weight between the oven dried at 105⁰C and the ash created following ignition at 550⁰C within a furnace following Heiri *et al.* (2001):

$$\% \text{ Organic Matter} = (\text{Weight of Post } 550^{\circ}\text{C Ash} / \text{Weight Post } 105^{\circ}\text{C Dry Sample}) \times 100$$

$$\% \text{ C} = \% \text{ Organic Matter} \times 0.58$$

$$\text{Or } \% \text{ Ash} = \frac{W_c - W_a}{W_b - W_a} \times 100 \dots \dots \dots (\text{eq.4})$$

$$\% \text{ C} = (100 - \% \text{ Ash}) \times 0.58 \dots \dots \dots (\text{eq.5})$$

Where, %C = carbon fraction determined in the laboratory, Wa = weight of crucible (g); Wb = weight of oven dried grind sample and crucible (g); and Wc = weight ash and crucible (g).

Thus, Carbon stocks in litter biomass (LHG) were calculated by multiplying LHG with the IPCC (2006), default carbon fraction (carbon fraction determined in the laboratory) using the following equation:

$$TC = LHG \times \% \text{ C} \dots \dots \dots (\text{eq.6})$$

Where, TC = Total carbon stock in the leaf litter (ton/ha) and % C- carbon fraction determined following Pearson *et al.* (2005).



Figure 6. Partial view of litter data collection and laboratory works

3.3.3.3.4. Deadwood carbon stocks

Standing dead trees: The carbon content in dead wood was calculated by multiplying total biomass of dead wood with the IPCC (2006) default carbon fraction of 0.47. The height and the DBH of each tree above 2 m height and above 2 cm thickness in dbh were measured and recorded. For standing dead wood which has branches, it is recommended (Pearson *et al.*, 2005) to measure and quantify using the allometric equation selected for estimation of aboveground biomass. Volume was calculated using DBH and height measurements and the estimate of the top diameter. It is then estimated as the volume of a truncated cone.

$$\text{Volume (cm}^3\text{)} = \frac{1}{3}\pi h (r_1^2 + r_2^2 + (r_1 \times r_2)) \dots\dots\dots (\text{eq.7})$$

Where, h = the height in (cm); r1 = the radius at the base of the tree (cm); r2 = the radius at the top of the tree (cm); and $\pi = 3.14$.

Volume is converted to dry biomass using an appropriate wood density.

Thus, Biomass of dead wood (g) = Volume (cm³) x wood density (g/cm³), where Density was calculated from the volume of the disk using flotation method and mass of the disk (IPCC, 2006).

Fallen Dead Wood: Wood density for each density class was calculated from the pieces of dead wood collected and then the density is calculated by the following formula:

$$\text{Density (g/m}^3\text{)} = \frac{\text{Mass(g)}}{\text{Volume(m}^3\text{)}} \dots\dots\dots (\text{eq.8})$$

Where: Mass= the mass of the oven-dried sample (g) and

Volume = $\pi \times (\text{average diameter}/2)^2 \times \text{average width of the fresh sample}$.

The volume was calculated separately for each density class (sound, intermediate, and rotten), as follows:

$$\text{Volume (m}^3/\text{ha)} = \pi^2 * (d_1^2 + d_2^2 \dots d_n^2 / 8L) \dots \dots \dots (\text{eq.9})$$

Where d_1, d_2 , etc = diameters of intersecting pieces of dead wood in cm and L = length of the line in m (50 m in our case).

3.3.3.3.5. Soil organic carbon and some other parameters

Samples from each depth were composted and well mixed per sampling plot and then prepared for analysis by removing stones and plant residue > 2 mm as well as by grinding. The carbon stock density of soil organic carbon was calculated from volume and density following Pearson *et al.* (2007):

$$V = h \times \pi r^2 \dots \dots \dots (\text{eq.11})$$

Where; V = Volume of the soil in the core sampler (cm^3), h = the height of the core sampler (cm) and r = the radius of the core sampler (cm).

$$P = W_{av, dry} / V \dots \dots \dots (\text{eq.12})$$

Where; P = Bulk density of the soil sample per plot, $W_{av, dry}$ = the average air-dry weight of soil sample per plot (g), V = Volume of the soil in the core sampler (cm^3) (Pearson *et al.*, 2005).

Laboratory analysis:

Soil samples from each subplots were air dried and dry weights of each sample were taken. Five equal weight of each sample were mixed homogeneously and carbon fraction of each homogenous sample were done in the laboratory using Walkley-Black Method (Walkley, A. and Black I. A.1934). Then, the soil carbon stock of Wof-Washa Forest was computed using

Pearson *et al.*, (2005) from the soil depth, bulk density and carbon concentration (%) as follows:

$$SOC = P \times d \times \% C \dots\dots\dots (eq.13)$$

Where, SOC = soil organic carbon stock per unit area (ton/ha); P = soil bulk density (g cm⁻³);

d = the total depth at which the soil sample was taken (30 cm); and % C = carbon concentration (%) determined from the laboratory (Pearson *et al.*, 2005; Kflay Gebrehiwot and Kitessa Hundera, 2014).

Finally, the total carbon stock density of Wof-Washa Forest was calculated by summing the carbon stock densities of the individual carbon pools using the Pearson *et al.* (2005) formula:

$$TCS = AGC + BGC + LC + DWC + SOC \dots\dots\dots (eq.14)$$

Where: TCS = Total Carbon Stock (t/ha); AGC = Aboveground Carbon (t/ ha); BGC = Belowground Carbon (t/ ha); LC = Litter Carbon (t/ ha); DWC = Dead Wood Carbon (dead fallen and standing) (t/ ha); and SOC = Soil Organic Carbon (t/ ha).

Soil analysis

Soil samples were analyzed for soil pH using pH-Meter in suspension at 1:1 water: soil ratio (Schofield and Tailor, 1955). The texture was determined following Hydrometer method with the categories sand, silt and clay (expressed as % weight) using sodium hexametaphosphate as particle dispersing agent (Gee and Bauder (1986). Percent of total nitrogen was determined following the macro-Kjeldahl method (Keeny and Nelson, 1982). Percent total organic carbon was determined by oxidation with acid dichromate and spontaneous heating by dilution of sulfuric acid according to Walkley-Black’s method (Bremner and Jenkinson, 1960). Available phosphorus (ppm) was determined using Olsen’s method (Olsen and Sommers, 1982), by spectrophotometer at 660 nanometers (nm). Cation exchange capacity (meq/100g) was

determined on the basis of NH₄Oac (extraction with ammonium acetate at pH 7) (meq/100 g) and Exchangeable acidity was determined using a flame photometer

3.3.4. Land use/Land cover dynamics

Data Acquisition and source

Landsat satellite images (Landsat5 Thematic Mapper (TM), Landsat7 Enhanced Thematic Mapper (ETM⁺) and Landsat8 Operational Land Imager (OLI)) of the study area were acquired for three periods: 1985, 2000, and 2015 from United States Geological Survey (USGS) (Table 3). To have adequate and proper datasets, the selection of sensor, relevant wavelength, bands, and dates of acquisition are most important requirements. For easier analysis, dry season and cloud-free images were used. The satellite images cover 185 × 185 km with a spatial resolution of 30 m, i.e., a single pixel in the image represents 30 × 30 m on the ground. The acquisition dates of the satellite images were December, January, and February. Arc GIS 10.2, ERDAS imagine 2014 and ENVI 5.1 software were used during image processing, classification, and change detection as well as the production of the final land use and land cover maps.

Table 3. Data Source characteristics of LULC change

Acquisition date	Imagery type	Sensor	Resolution	Path/ raw	Spectral resolution/bands	Source
02-01-1985	Landsat 5	TM	30 x 30 m	168/53	Band 2 (green) 520–600 nm Band 3 (red) 630–690 nm Band 4 (near IR) 760–900 nm	USGS
05-12-2000	Landsat 7	ETM ⁺	30 x 30 m	168/53	Band 2 (green) 520–600 nm Band 3 (red) 630–690 nm Band 4 (near IR) 760–900 nm	USGS
06-02-2015	Landsat 8	OLI	30 x 30 m	168/53	Band 3 (green) 520–600 nm Band 4 (red) 630–690 nm Band 5 (near IR) 760–900 nm	USGS

Image pre-processing and classification

Image classification is an important part of the remote sensing, image analysis, and pattern recognition. After the images were geo-referenced and subset on the basis of Area of Interest (AOI), all satellite data were studied by assigning per-pixel signatures and differentiating the study area into six classes on the bases of the specific digital number value of different landscape elements. The delineated classes were Settlement, Agricultural land, Natural Forest, Plantation, Grassland and Bareland (Table 4). Each class was given unique identity and assigned a particular color to make them separate from each other. Training samples for image classification were selected for each predetermined land cover type by delimiting polygons around representative sites. Spectral signatures for the respective land cover types derived from the satellite imagery were recorded by using the pixels enclosed by these polygons. A satisfactory spectral signature is the one ensuring that there is 'minimal confusion' among the land covers to be mapped (Gao and Liu, 2010). After that, a supervised classification was performed by applying maximum likelihood algorithm on the images. Maximum likelihood classification is a statistical decision criterion to assist in the classification of overlapping signatures; pixels are assigned to the class of highest probability. This is the most accurate of the classifiers of the ERDAS system (Renuka *et al.*, 2001). It is the type of image classification that is mainly controlled by the analyst as the analyst selects the pixels that are representative of the desired classes.

Image Processing

The major image processing steps used are image layer stacking, and image enhancement techniques of the image dataset. Layer stacking is a method to build a new multiband file from geo-referenced images of various pixel sizes, extents, and projections. For accurate image classification, band selection is also crucial since one feature, which is not discriminated apparently, may be clearly differentiated on another band. Accordingly,

selected bands were stacked for each year to form one full image with all bands to help the interpreter understand all features in the study area. Enhancement techniques were applied on satellite image in order to increase visual distinctions between features and increase the amount of information that can be visually interpreted from the data. All the three images were geo-referenced (Universal Transverse Mercator-UTM, (WGS84) to the map. After correcting all the images, they were then subset into the same AOI (area of interest).

Image classification

Simple random sampling was employed to collect training points after a preliminary LULC map was produced for each year. For training and testing, 20 samples per LULC class (120 sample areas) were randomly assigned using Global Positioning System (GPS). The actual classification and post-classification overlay were carried out after the training data had been established and thematic land-cover maps for the year 1985, 2000 and 2015 were produced for the study area by supervised classifications using a maximum likelihood classification. Maximum likelihood classification (Scott and Symons, 1971) is widely used in remote sensing where a pixel with the maximum likelihood is classified into the corresponding class. The data collected during the ground truthing were stored in Excel, converted to shapefiles using Arc GIS 10.2 Software, and used for LULC classification, analysis, and accuracy assessments. A total of six land use and land cover classes were identified. All six classes were identified in all images representing the years under investigation in a consistent manner except plantation in 1985.

Accuracy assessment

Because of the increased chances for error presented by digital imagery, however, accuracy assessment has become more important than ever (Congalton, 1991). A common tool to assess accuracy is the error matrix. Error matrices compare pixels or polygons in a classified

image against ground reference data (Jensen, 2005). Thus, assessment of classification accuracy of 1985, 2000 and 2015 images were carried out to determine the quality of information derived from the data. For the accuracy assessment of land cover maps extracted from satellite images, the stratified random method was used to represent different land cover classes of the area. The accuracy assessment was carried out using 60 points, based on ground truth data and visual interpretation. The comparison of reference data and classification results were carried out statistically using error matrices. In addition, a nonparametric Kappa test was also performed to measure the extent of classification accuracy (Rosenfield and Fitzpatrick-Lins, 1986). Kappa is used to measure the agreement or accuracy between the remote sensing derived classification map and the reference data. A value > 0.80 (80%) are strong agreement, a value b/n 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value < 0.40 (40%) represents poor agreement (Congalton, 1991).

Table 4. General description of LULC classes

LULC Classes	General description
Grassland	All areas covered with mainly natural pasture, but also other small sized plant species.
Agricultural land	Crop fields and fallow lands areas of land plowed/prepared for growing rainfed or irrigated crops. This category includes areas currently under crop, fallow and land under preparation
Bare land	Land surface devoid of vegetation, Bare soil/ rock, rock outcrops, gravel and barren area and quarries influenced by human.
Natural forest	Areas covered by trees forming closed or nearly closed canopies; predominant species are <i>Juniperus procera</i> and <i>Podocarpus falcatus</i>
Settlement	Areas composed of small villages and/or scattered hamlets; mostly located on the slopes or at the foot of the highlands and include open areas near homesteads

The rate of land use and land cover change

Change statistics were computed by comparing values of the area of one dataset with the corresponding value of the data set in each period following the designed flowchart (Figure 8). The values were presented in terms of hectare and percentage. Quantification of the rate of

change has been applied to generate information about the land use/land cover change of the study area.

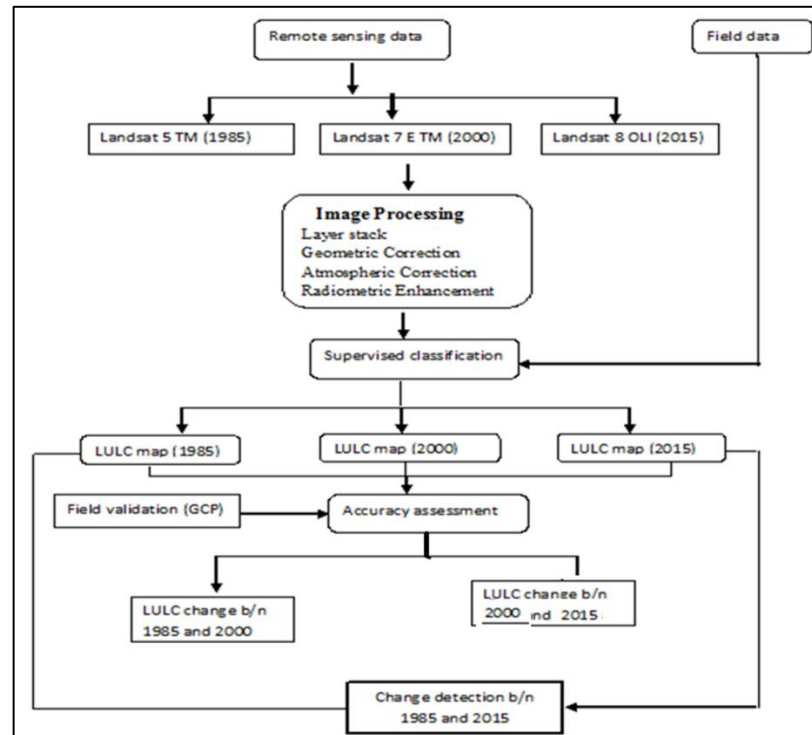


Figure 7. The general workflow of the LULC changes data analysis procedure

Change detection matrix

Pixel-based classified images were used to produce change information on the land classes and observed changes taking place. Classified image pair was compared using cross-tabulation to determine qualitative and quantitative aspects of the changes for the periods from 1985 (initial) and 2015 (final state) data. Thus, change matrix was produced with the help of ENVI Imagine software. Quantitative areal data of the overall land use/cover changes as well as gains and losses in each category between 1985 and 2015 were then compiled (Rawat and Kumar, 2015). This analysis is very much helpful to identify various changes occurring in different classes of land use like an increase in agricultural land or decrease in natural forest and so on (Rizk and Rashed, 2015).

The rate of change of each land use and land cover calculated using the following formula.

$$\text{Rate of change (ha/year)} = (X-Y)/Z$$

Where, X = Recent area of the land use and land cover in ha, Y = Previous area of the land use and land cover in ha and Z = Time interval between X and Y in years. It should be noted that the negative values for rate of change indicate the magnitude of the decline in that particular land use and land cover type.

CHAPTER FOUR

4. RESULTS

4.1. Vegetation Study

4.1.1. Floristic Composition of Wof-Washa Forest

The floristic analysis of Wof-Washa Forest generates a total of 394 species of flowering plants, conifers, and ferns belonging to 288 genera and 99 families (Table 5 and Appendix 1).

Out of these, 381 species were angiosperms, 4 species were gymnosperms and 9 species pteridophytes. Fifty-five percent of the families were represented by more than one species.

The highest numbers of species were recorded in families: Asteraceae (35 genera, 62 species), Poaceae (22 genera, 30 species), Fabaceae (18 genera, 29 species), Lamiaceae (12 genera, 17 species), Cyperaceae (4 genera, 15 species) and Apiaceae (13 genera, 13 species). Rubiaceae and Brassicaceae were represented with 9 species each. Euphorbiaceae, Malvaceae, Ranunculaceae, Rosaceae, and Scrophulariaceae were also represented by seven species while Acanthaceae, Crassulaceae, Polygonaceae, and Solanaceae were represented by six species each. Among the reported families (Asclepiadaceae, Geraniaceae, Urticaceae) contributed five species each whereas families (Amaranthaceae, Aspleniaceae, Boraginaceae, Caryophyllaceae, Celastraceae, Oleaceae) were represented by four species each.

Aloaceae, Anacardiaceae, Asphodelaceae, Balsaminaceae, Commelinaceae, Convolvulaceae, Dipsacaceae, Hypericaceae, Lobeliaceae, and Plantaginaceae were represented by three species each. The following families: Araceae, Araliaceae, Chenopodiaceae, Cucurbitaceae, Cupressaceae, Ericaceae, Iridaceae, Loganiaceae, Meliaceae, Myricaceae, Myrsinaceae, Myrtaceae, Orchidaceae, Pteridaceae, Rutaceae, Sapindaceae, Tiliaceae, and Vitaceae were represented by two species. Families represented by single species were Adiantaceae, Amaryllidaceae, Apocynaceae, Aquifoliaceae, Asparagaceae, Berberidaceae, Cactaceae,

Campanulaceae, Casuarinaceae, Colchicaceae, Cuscutaceae, Dracaenaceae, Dryopteridaceae, Ebenaceae, Flacourtiaceae, Gentianaceae, Haloragaceae, Hyacinthaceae, Linaceae, Melianthaceae, Menispermaceae, Moraceae, Oliniaceae, Onagraceae, Orobanchaceae, Oxalidaceae, Papaveraceae, Phytolaccaceae, Pinaceae, Piperaceae, Pittosporaceae, Podocarpaceae, Polygalaceae, Polypodiaceae, Primulaceae, Rhamnaceae, Rhizophoraceae, Salicaceae, Santalaceae, Sinopteridaceae, Smilacaceae, Sterculiaceae, Ulmaceae, Verbenaceae and Violaceae (Appendix 4).

Table 5. Taxonomic classification of the identified plant species

Taxa	Pteridophytes	Gymnosperms	Angiosperms		Total
			Dicots	Monocots	
Family	4	3	74	16	99
Genera	5	3	236	42	288
Species	9	4	314	67	394

The eight species' richest families (Asteraceae, Poaceae, Fabaceae, Lamiaceae, Cyperaceae, Apiaceae, Rubiaceae, and Brassicaceae) in their descending order and contributed 46.7 % of the total species, and the five species-richest genera were in family Asteraceae, Poaceae, Fabaceae, Apiaceae, and Lamiaceae contributed 34.7 % of the total genera of plant species collected from Wof-Washa Forest. The most species-rich genus was *Cyperus* with nine species, followed by *Helichrysum*, *Trifolium*, and *Vernonia* each with six species (Table 6 and Appendix 4).

Table 6. Families of plant species with more than 10 species in Wof-Washa Forest

No	Family	Number of genera	Number of Species	%
1	Asteraceae	35	62	15.7
2	Poaceae	22	30	7.6
3	Fabaceae	18	29	7.4
4	Lamiaceae	12	17	4.3
5	Cyperaceae	4	15	3.8
6	Apiaceae	13	13	3.3

Based upon plant species growth habit, 49 (12.5%) were tree species followed by 72 (18.3%), shrubs, 18 (4.6%) lianas and 255 (64.7%) herbaceous plant species (Figure 9). Nine ferns and two epiphytic species were identified among the 255 herbaceous plant species collected.

Four gymnosperm species (*Podocarpus falcatus*, *Juniperus procera*, *Pinus patula* and *Cupressus lucitanica*) were recorded in Wof-Washa Forest. Many species are rare in their occurrence and hence, only 365 species, representing 78 families were recorded in the 95 study plots while the remaining 29 species were collected outside the study plots. Hence, the vegetation analyses were done by using 365 species.

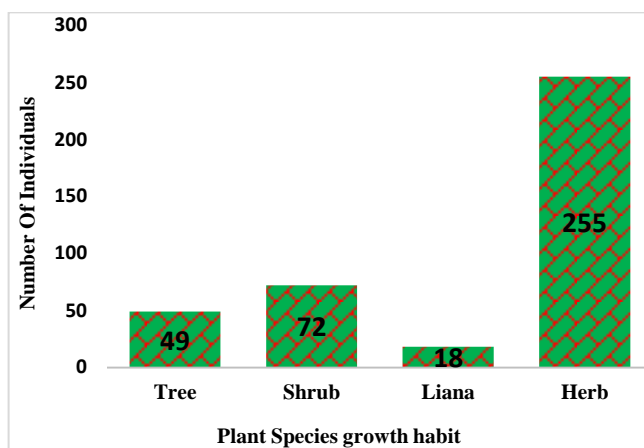


Figure 8. The proportion of growth form of plant species in Wof-Washa Forest

About 11.68 % (46 species) of all species identified in Wof-Washa Forest were endemic (Appendix 2). The most dominant of endemic species were recorded from Asteraceae (41.6%) followed by Fabaceae (16.6%) of the total endemic species in Wof-Washa Forest. Thirteen species were newly recorded for Shewa floristic region in the study area (Appendix 3).

Few species of trees, shrubs, and lianas dominate the forest vegetation and most of the species were rare and have a low frequency of occurrence. About 50 % of the total abundance is contributed by only three species *Juniperus procera*, *Erica arborea* and *Podocarpus falcatus* and nearly 99 % of the total abundance is accounted by half of the species recorded in Wof-

Washa Forest (Appendix 5). Only 10 species occur in more than 50 % of the study plots. At the other extreme, 81 species were recorded only once (0.25 % frequency each), while 191(48.5%) of species occurred in fewer than five plots (Appendix 9). The five most abundant and common trees in the upper canopy layer were *Juniperus procera*, *Podocarpus falcatus*, *Erica arborea*, *Maesa lanceolata* and *Ilex mitis*. *Urera hypselodendron*, *Embelia schimperi*, *Smilax aspera*, *Toddalia asiatica*, *Rubus apetalus*, *Rubus volkensii* and *Periploca linearifolia* were among the most dominant lianas in Wof-Washa Forest.

4.1.2. Plant community types of Wof-Washa Forest

Based on the floristic composition, hierarchical cluster analysis and synoptic table values of the entire data set of Wof-Washa Forest were identified five plant community types (Figure 10). The communities identified were *Erica arborea* - *Pittosporum viridiflorum* Community (C1), *Juniperus procera* - *Alchemilla pedata* (C2), *Maytenus arbutifolia* - *Olea europaea* subsp. *cuspidata* (C3), *Maesa lanceolata* - *Bersama abyssinica* (C4) and *Podocarpus falcatus* – *Olinia rochetiana* (C5). The number of study plots vary among the community types and ranged from 8 to 30 plots. The community types were named by the first two plant species with the highest cover abundance values (Table 7).

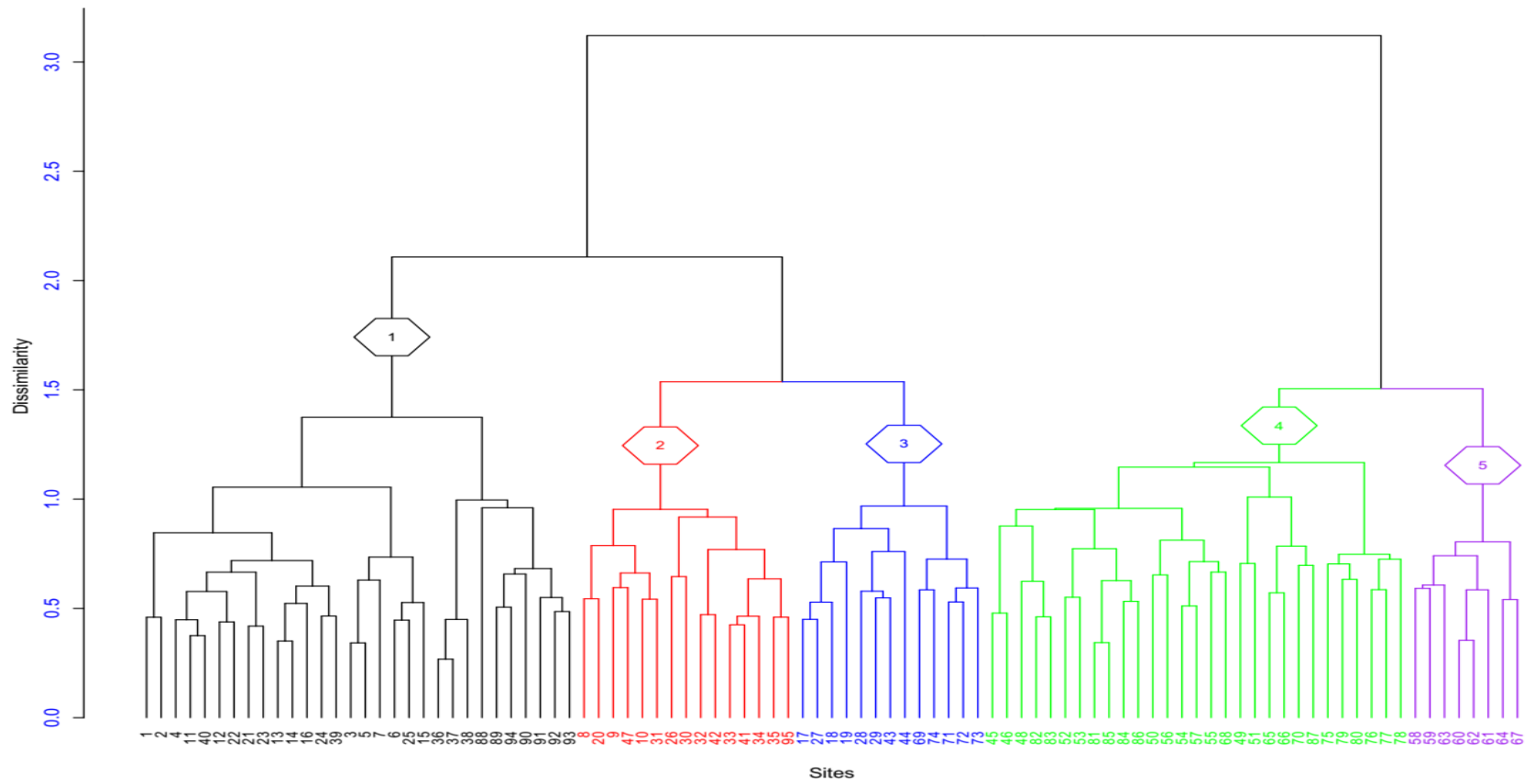


Figure 9. Hierarchical cluster analyses result of species abundance data of Wof-Washa Forest

Table 7. Synoptic table value for species of Wof-Washa Forest

No	Species	Cluster	C1	C2	C3	C4	C5
No of Plots							
1	<i>Erica arborea</i>		5.97	0.33	2.92	0.17	0.00
2	<i>Pittosporum viridiflorum</i>		4.47	2.00	3.46	1.03	1.25
3	<i>Hypericum revolutum</i>		4.17	2.73	1.92	0.69	0.00
4	<i>Thymus schimperi</i>		4.07	0.00	0.46	0.24	0.00
5	<i>Inula confertiflora</i>		3.93	3.47	3.15	2.34	0.00
6	<i>Myrsine Africana</i>		3.70	4.33	5.46	2.17	3.13
7	<i>Rosaabyssinica</i>		3.63	3.40	2.77	1.62	4.13
8	<i>Hagenia abyssinica</i>		2.87	3.07	0.38	0.10	0.00
9	<i>Osyris quadripartite</i>		2.77	0.33	3.23	0.72	2.50
10	<i>Oxalis corniculata</i>		2.63	2.13	1.00	0.34	1.38
11	<i>Helichrysum splendidum</i>		2.60	0.00	2.31	0.00	0.00
12	<i>Kniphofia foliosa</i>		2.53	1.93	0.62	1.10	0.00
13	<i>Clematis simensis</i>		1.97	1.07	1.92	0.21	0.00
14	<i>Satureja punctate</i>		1.53	0.00	0.00	0.31	2.00
15	<i>Festuca macrophylla</i>		1.17	0.00	0.38	0.00	0.00
16	<i>Solanum benderianum</i>		1.07	0.87	0.38	0.00	0.00
17	<i>Juniperus procera</i>		4.27	5.47	5.32	3.52	4.50
18	<i>Alchemila pedata</i>		4.30	4.60	3.69	1.97	0.75
19	<i>Cynoglossum amplifolium</i>		3.90	4.33	2.31	1.69	0.00
20	<i>Hypoestes triflora</i>		1.33	4.13	0.00	1.66	1.63
21	<i>Discopodium penninervium</i>		1.23	3.00	0.38	3.00	0.00
22	<i>Ilex mitis</i>		0.00	3.80	1.92	1.66	0.00
23	<i>Galiniera saxifrage</i>		0.00	3.60	1.77	2.52	0.00
24	<i>Lobelia goberroa</i>		0.23	2.93	1.38	0.83	0.00
25	<i>Berberis holstii</i>		2.00	2.13	4.15	0.21	0.00
26	<i>Dovyalis abyssinica</i>		0.13	1.40	2.08	2.10	2.50
27	<i>Phalaris paradoxa</i>		0.40	1.40	2.15	1.03	0.13
28	<i>Asparagus africanus</i>		1.87	1.67	2.23	2.07	1.63
29	<i>Maytenus arbutifolia</i>		0.73	4.53	5.15	3.59	4.13
30	<i>Olea europaea L.subsp. cuspidata</i>		0.53	1.07	4.23	1.59	2.25
31	<i>Clutia abyssinica</i>		0.10	0.20	3.38	3.00	3.00
32	<i>Rumex nervosus</i>		1.30	0.47	2.38	0.45	0.00
33	<i>Halleria lucida</i>		0.00	0.00	1.46	1.45	1.00
34	<i>Festuca abyssinica</i>		0.10	0.00	1.46	0.00	0.00
35	<i>Tephrosia interrupta</i>		0.17	0.00	1.08	0.00	0.38
36	<i>Leonotis ocyimifolia</i>		0.40	0.67	1.38	0.00	0.00
37	<i>Helichrysum nudifolium</i>		0.17	0.33	1.62	0.17	0.00
38	<i>Smilax aspera</i>		0.17	0.00	1.15	1.48	2.13

No	Species	Cluster	C1	C2	C3	C4	C5
39	<i>Galium simense</i>		1.00	0.53	1.31	0.38	0.25
40	<i>Adiantum poiretii</i>		0.00	0.73	1.38	0.34	0.00
41	<i>Nuxia congesta</i>		0.00	0.53	1.54	1.00	1.75
42	<i>Olea capensis</i> subsp. <i>macrocarpa</i>		0.00	0.27	1.38	0.28	0.00
43	<i>Maesa lanceolate</i>		0.00	2.07	1.85	4.83	2.38
44	<i>Bersama abyssinica</i>		0.00	0.20	0.77	4.17	4.25
45	<i>Embelia schimperi</i>		0.00	0.00	0.38	3.03	0.00
46	<i>Jasminum abyssinicum</i>		0.00	0.53	1.00	2.66	0.00
47	<i>Rubus volkensii</i>		0.90	0.20	0.69	2.41	0.00
48	<i>Phytolacca dodecandra</i>		0.00	0.00	0.85	1.17	0.00
49	<i>Psudrax schimperiana</i>		0.00	0.00	0.38	1.93	1.38
50	<i>Rhus glutinosa</i>		0.00	0.67	0.38	1.48	0.50
51	<i>Oplismenus hirtellus</i>		0.20	0.60	0.69	1.48	0.25
52	<i>Urera hypselodendron</i>		0.00	0.87	0.38	1.66	0.00
53	<i>Tacazzea conferta</i>		0.00	0.00	0.00	1.55	0.00
54	<i>Dryopteris lewalleana</i>		0.43	0.07	1.00	1.31	0.00
55	<i>Ficus sur</i>		0.00	0.00	0.00	1.59	0.63
56	<i>Periploca linearifolia</i>		0.00	0.20	0.23	2.31	0.13
57	<i>Podocarpus falcatus</i>		0.00	0.67	0.77	4.20	6.13
58	<i>Olinia rochetiana</i>		0.00	0.20	2.69	1.31	5.25
59	<i>Hypoestes forskaolii</i>		0.37	1.80	0.38	4.10	5.18
60	<i>Allophylus abyssinicus</i>		0.00	0.20	3.85	2.38	4.75
61	<i>Ekebergia capensis</i>		0.00	0.00	0.00	1.79	4.00
62	<i>Dodonea angustifolia</i>		0.00	0.00	0.38	0.00	3.75
63	<i>Polyscias fulva</i>		0.00	0.00	0.38	1.41	3.75
64	<i>Jasminum grandiflorum</i>		0.00	0.00	0.38	0.17	2.63
65	<i>Premna schimperi</i>		0.00	0.00	0.00	0.00	2.63
66	<i>Rhus retinorrhoea</i>		0.00	0.00	0.00	0.00	2.50
67	<i>Euphorbia ampliphylla</i>		0.00	0.00	0.00	0.38	2.50
68	<i>Carissa spinarum</i>		0.00	0.00	0.38	0.66	2.50
69	<i>Nuxia congesta</i>		0.00	0.53	1.54	1.00	1.75
70	<i>Cyathula cylindrical</i>		0.00	0.00	0.00	0.00	1.25
71	<i>Maytenus undata</i>		0.33	0.07	0.15	0.31	1.25
72	<i>Hyparrhenia hirta</i>		0.00	0.00	0.00	0.52	1.13
73	<i>Laggera tomentosa</i>		0.00	0.00	0.00	0.62	1.00
74	<i>Rhamnus prinoides</i>		0.00	0.00	0.00	0.10	1.00

Note: Species having a value of >1.25 in at least one community type and values in bold refer to the species used to name community types.

The description of plant community types identified using hierarchical cluster analysis were done and explained mainly by their altitude ranges, dominant plant habits and plant species, species richness, evenness and similarity between community types as follows:

4.1. 2.1. *Erica arborea*-*Pittosporum viridiflorum* Community Type (C1)

This community type was distributed over the altitudinal ranges between 3048 to 3498 m.a.s.l. The community was represented by 30 plots (1.2 ha) and 88 plant species. The community consists both the *Ericaceous belt* and sub afro-alpine plant species such as *Lobelia rhynchopetalum* and *Helichrysum citrispinum* (Figure 11 B and C). This community type is mainly found on the steep slope area of the forest with an average of 35.12% and about 60.44% of the study plots are east facing and are inaccessible for grazing and anthropogenic factors. The soil depth was remained shallow and with exposed rocks. *Erica arborea* is the most prominent and dominant species in this cluster and covers 504.2 individuals /ha (Figure 11 A). The tree layer was dominated by *Erica arborea*, with scattered *Hagenia abyssinica*, *Hypericum revolutum*, *Osyris quadripartita* and *Pittosporum viridiflorum* while the shrub layer was dominated by *Inula confertiflora*, *Myrsine africana*, *Rosa abyssinica* and *Helichrysum citrispinum*. The ground layer was covered by *Cynoglossum amplifolium*, *Oxalis corniculata*, *Alchemilla pedata*, *Haplocarpha rueppelli*, *Festuca abyssinica*, *Festuca macrophylla* and *Haplocarpha schimperi*. *Asplenium protensum* and *Asplenium aethiopicum* represent the fern species. *Clematis simensis* and *Solanum benderianum* were the common lianas in this community type. *Kniphofia foliosa*, *Thymus schimperi*, and *Lobelia rhynchopetalum* were characteristic species of the community. Traditional apiary is a common practice of the local people in this community type (Figure 12).

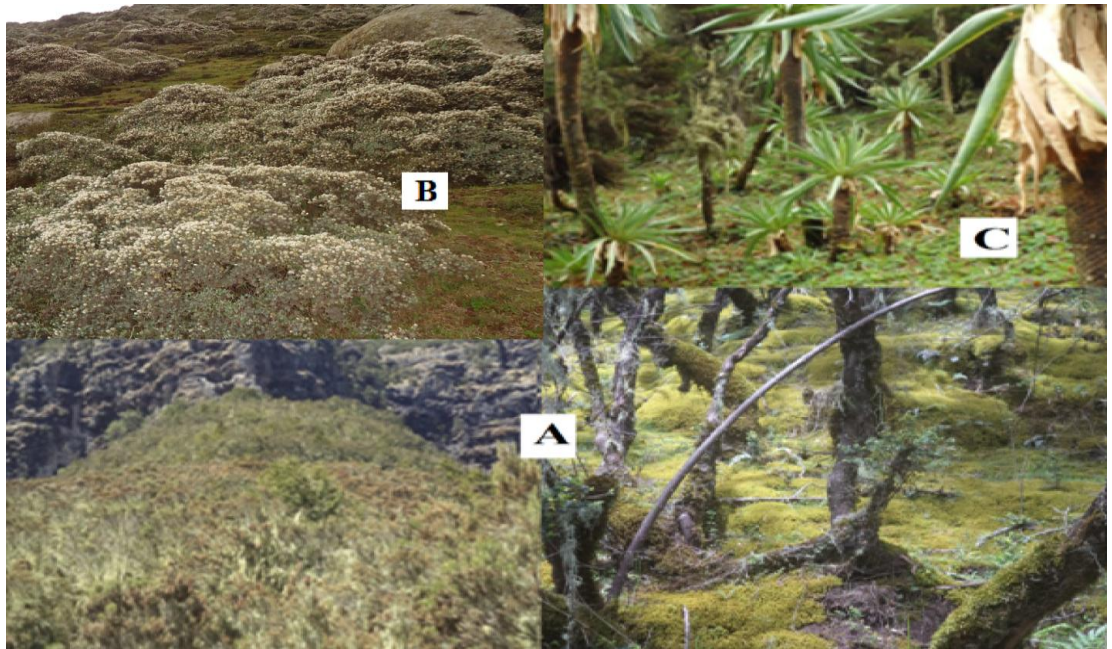


Figure 10. Community type dominated by *Erica arborea* (A), *Helichyris citrispinum* (B) and *Lobelia rhynchopetalum* (C) in Wof-Washa Forest

Apiary in the form of traditional beehives and beekeeping within the forest were common in this community type (Figure 12) and is one of the potential threats of fire to the forest.



Figure 11. Traditional beehive and apiary practice in the ericaceous belt of Wof-Washa Forest (Photo by Abiyu Tilahun, 2016)

4.1.2.2. *Juniperus procera* –*Alchemila pedata* Community Type (C2)

This community type was distributed between 2583-3104 m.a.s.l. Plots in this cluster were dispersed over medium altitude areas of the forest and slopes are mostly facing towards the East and Northeast. The community consists of 15 plots and 104 plant species. The dominant species in this community were *Galiniera saxifraga*, *Hagenia abyssinica*, *Hypericum revolutum*, *Ilex mitis*, *Juniperus procera*, *Maesa lanceolata*, *Maytenus arbutifolia* and *Pittosporum viridiflorum* in the tree layers. Shrub species such as *Rosa abyssinica*, *Myrsine africana*, *Inula confertiflora*, *Lobelia giberroa* and *Berberis holstii* were found to be the most dominant in the forest. The ground flora was dominated by *Adiantum poiretii*, *Alchemilapedata*, *Cynoglossum amplifolium*, *Plectranthus lanuginosus* and *Oplismenus hirtellus*. The most common woody climbers distributed in this cluster were *Rubus volkensii* and *Urera hypselodendron*. Eleven barns together with small rooms for shepherds were found in this community type. Grazing and trampling by domestic animals were evident and recurrent in most part of this community type.

4.1.2.3. *Maytenus arbutifolia* - *Olea europaea* subsp. *cuspidata* Community Type (C3)

Thirteen plots and 87 species represent this cluster. The altitudinal range of this type stretched from 2498 to 3031 m.a.s.l. Most of the study plots were at the gentle slope and 46.37% of the study plots in this community type were south facing. The dominant tree species were *Juniperus procera*, *Osyris quadripartita*, *Maesa lanceolata*, *Pittosporum viridiflorum* and *Galiniera saxifraga*. *Myrsine africana*, *Discopodium penninervium*, *Leonotis ocyimifolia*, *Berberis holstii*, *Dovyalis abyssinica* and *Maytenus arbutifolia* were the most dominant shrubs in this community type. The field layer was dominated by *Oplismenus hirtellus*, *Oenanthe palustris*, *Hypoestes triflora* and *Plectranthus lanuginosus*. The most common

woody climbers in this type were *Jasminum abyssinicum*, *Embelia schimperi*, and *Rubus volkensii*. From 19 barns (room for housing domestic animals in Wof-Washa Forest, those are functional throughout the year) recorded eight of them were found in this community type (Figure 14).



Figure 12. Figure 14. Barn, shelters of the shepherds, heat and light source (A, B and C) Photo by Abiyou Tilahun, 2016)

On some inaccessible areas of this community type epiphyte on *Juniperus procera* (*Diaphananthe schimperiana*) and *Aeonium leucoblepharum* are the characteristic species in this community type that have been observed (Figure 15).



Figure 13. The most common and Unique species (*Diaphananthe schimperiana* on *Juniperus procera* (on the left, A) and *Aeonium leucoblepharum* (to the right, B) (Photo by Abiyou Tilahun, 2016)

4.1.2.4. *Maesa lanceolata* - *Bersama abyssinica* Community Type (C4)

This community type consists of 29 plots (1.16 ha) and 115 plant species. The study plots representing this community were found between 2338-2786 m.a.s.l. The dominant plant species in the tree and shrub layer were *Galiniera saxifraga*, *Dovyalis abyssinica*, *Podocarpus falcatus*, *Polyscias fulva*, *Allophylus abyssinicus*, *Ficus sur*, *Halleria lucida*, *Ekebergia capensis*, *Rhus natalensis*, *Olinia rochetiana* and *Bersama abyssinica*. The ground flora of Wof-Washa Forest was dominated by *Plantago major*, *Kalanchoe densiflora*, *Peperomia abyssinica*, *Asplenium protensum* and *Hypoestes forskalii*. The dominant woody climbers in this type were *Urera hypselodendron*, *Periploca linearifolia*, *Smilax aspera*, *Taccazea conferta* and *Embelia schimperi*. *Prunus africana* is the unique plant species to this community type.

4.1.2.5. *Podocarpus falcatus* – *Olinia rochetiana* Community Type (C5)

This community was found relatively at lower altitudinal ranges of 2348-2483 m.a.s.l. and in sheltered valleys that contain more broad-leaved species. This association can be described as lower altitude community type of Wof-Washa Forest. The slope gradient varies between 20-35%) and all plots were South facing.

This cluster consists of 8 study plots and 102 plant species. *Polyscias fulva*, *Allophylus abyssinicus*, *Olinia rochetiana*, *Ekebergia capensis*, *Ficus sur*, *Rhus retinorrhoea*, *Carissa spinarum*, *Psydrax schimperiana*, *Halleria lucida*, *Euphorbia ampliphylla*, *Celtis africana*, *Rhus glutinosa* and *Clusia abyssinica* were the dominant species in the tree and shrub layers. *Embelia schimperi*, *Rubus volkensii*, *Toddalia asiatica*, *Smilax aspera* and *Periploca linearifolia* were the dominant woody climbers in this type. The ground layer was dominated by *Hypoestes forskalii* and *Oplismenus hirtellus*. *Dodonea angustifolia*, *Toddalia asiatica*, *Turraea holstii* and *Premna schimperi* were characteristic species. *Hyparrhenia hirta* was the dominant grass on the edge of Wof-Washa Forest towards the lower altitude areas (1900 - 2300 m.a.s.l.) and in some inaccessible areas of this community type.

4.1.3. Species composition among community types

The largest number of individual trees, shrubs and lianas were recorded in community type one at the higher altitude (3046-3498 m.a. s. l) and community type four near to the lower altitude. On the other extreme, the least number of individuals in all the growth habits were found in community type five that stretch to the lower part of Wof-Washa Forest with 2348-2483 m.a. s.l. altitudinal range (Table 8).

Table 8. Community types and the respective plant growth habit, number of plots and altitudes

Community type	Altitude range(m)	Number of individuals				Plot		List of plots in each community type
		Tree	Herb	Liana	Shrub	N*	%	
C1	3046-3498	1173	310	68	223	30	31.6	1-7 11-16 40 21-25

								36-39 88-94
C2	2583-3104	516	149	21	116	15	15.8	8-10 20 47 26 30-35 42 41 95
C3	2498-3031	518	116	25	112	13	13.7	17 27 18 19 28 29 43 44 69 71-74
C4	2338-2786	1182	241	139	167	29	30.5	45 46 48 50-68 49 65 66 70 75-87
C5	2348-2483	371	41	13	13	8	8.4	58-64 67

Key: N* = Cluster size

Results of Sørensen's similarity coefficient indicated that the highest floristic similarity was found between community type three (C3) and community type four (C4) with and (SS = 0.768) values followed by community type two and three with (SS = 0.733) values (Table 9). These communities' types share more species than the rest of the identified community types. The lowest species similarity was also found between community type one and five (SS = 0.389) (Table 9). The pairwise Similarity coefficients of all communities were ranged from 0.389 to 0.768. On the contrary, the highest β -diversity value was recorded between communities' type two and five while the lowest β -diversity was between communities type one and four (Table 9). The maximum β -diversity value was recorded between communities' type two and five while the lowest was between community one and four.

Table 9. Species composition among community types using β -diversity and Sørensen's Similarity Coefficient

Community type	C1	C2	C3	C4	C5
C1	1	0.381	0.376	0.288	0.422
C2	<i>0.639</i>	1	0.463	0.358	0.649
C3	<i>0.6</i>	<i>0.733</i>	1	0.457	0.577
C4	<i>0.562</i>	<i>0.652</i>	<i>0.768</i>	1	0.529
C5	<i>0.389</i>	<i>0.474</i>	<i>0.56</i>	<i>0.629</i>	1

Key: Values in bold show (β -diversity) and Italics to (SS) Sørensen's Similarity Coefficient

4.1.4. Species Diversity: Species Richness and Evenness

The result of vegetation data analyses showed heterogeneity in species richness, evenness, abundance among communities in Wof-Washa Forest. As shown in (Table 10), all the community types had relatively high species richness. The highest value of species richness (4.37) was found in community type four and the lowest (3.95) was recorded in community type two (Table 10). In this analysis, the highest values of species richness, sapling and mature tree density and total basal area were identified in community type four whereas the maximum tree abundance and individual's density was found in community five (Table 10). The highest and the lowest species richness (46 species and 12 species respectively) were recorded at middle elevation (2815 m) and higher elevation (3332 m) respectively.

Table 10. Species richness and diversity among plant communities

Vegetation parameters	Community types				
	C1	C2	C3	C4	C5
No of sample	30	15	13	29	8
Area in hectare	1.2	0.6	0.52	1.16	0.32
Richness	88	104	87	115	102
H	4.02	3.95	4.14	4.37	3.98
Simpson index	0.73	0.91	0.92	0.9	0.88
Evenness	0.79	0.86	0.89	0.87	0.9
Tree abundance (n/ha)	975	765	992.3	1015.5	1162.5
Basal area (m ² /ha)	35.42	31.4	17.45	55.51	13.48
Density (n/ha)	1477.5	1336.7	1484.6	1490.5	1550
Seedling density	5348	3318	3733	5327	2025
Sapling density	2754	1500	1763	4223	1249
Mature trees species	1170	459	516	1178	372

The maximum species evenness (0.9) was recorded from community type five followed by community type three (0.89) and the least species evenness was recorded in community type one (0.73) (Table 10). The species richness of the five community types of Wof-Washa Forest reveals that the highest species richness was found in community type four (115 species)

whereas the lowest plant species richness was recorded for community type three (Table 10). The Shannon diversity index of community type four (C4) is higher than the rest community types

4.1.5. Physical aspects of soils in Wof-Washa Forest

The soil within Wof-Washa Forest is generally shallow with high rock fragments mixed with gravel content particularly at higher altitude (>3000 m.a.s.l) and the steep slopes where rock outcrops are much frequent. On the flat plateaus and wide valley bottoms, heavy and black clay soils are observed. In the higher altitude areas of Wof-Washa Forest (> 3000 m.a.s.l) areas of Wof-Washa Forest, the color of the soil is reddish-brown or gray (Demel Teketay and Tamrat Bekele, 1995). The pH value of the soil varies from 5.2-7 and the mean pH value is 5.9 (Table 11 and Appendix 15). Total nitrogen determined by Kjeldahl method (a wet oxidation procedure) ranged from 0.1 to 0.8 % and the mean value was 0.3) % (Table 11). The values of cation exchange capacity (CEC) ranges from 7.2 to 60.9 Meq/100 g and the average values were 29.9 Meq/100 g.

Table 11. Average values of soil parameters across community types

CT	Sand%	Silt%	Clay%	pH	C	CEC	Exacid	TN	P
C1	54.3	20.7	25	6	10.9	32.6	1.2	0.3	8.8
C2	50.5	21.9	27.6	6.1	12.4	31.8	1	0.4	5.4
C3	50.9	21.2	27.8	5.8	10	29.5	0.9	0.4	6.9
C4	50.4	23.8	25.8	5.8	9.7	27.8	1.4	0.3	10.1
C5	52.3	18.5	29.3	5.9	8.7	24.2	0.9	0.2	6.9
Mean	51.9	21.7	26.4	5.9	10.4	29.9	1.2	0.3	8.2
Max	82	42	42	7	27.2	60.9	2.6	0.8	46.9
Min	20	10	4	5.2	2	7.2	0	0.1	0.6

Note: CT= Community types, TN = Total Nitrogen, CEC = Cation Exchange Capacity, Exacid = Exchangeable acidity, pH = Measure of Acidity or Alkalinity, C = Organic carbon, P = Phosphorus, Meq = Milliequivalent, ppm = Parts per million, Max = maximum and Min = minimum.

As shown in Table 11, the average sand, silt, and clay were 51.9, 21.7 and 26.4 % respectively. Community type one shows the highest mean sand percentage while community types four has the lowest. The maximum mean organic carbon was found in community type two (12.4) followed by community type one (10.9) while the lowest average organic carbon was observed in community type five. The maximum and minimum average CEC were exhibited in community type one (32.6) and five (24.2) respectively (Table 11).

Table 12. Average values of soil parameters along altitudinal gradients (m.a.s.l)

Altitude	Sand%	Silt%	Clay%	pH	C	CEC	Exacid	TN	P
A	49.6	22.5	27.8	5.8	8.6	25	1.3	0.3	8.9
B	51.4	22.4	26.2	5.9	11.1	31.5	1	0.3	7.1
C	54.9	20	25.1	6	11.5	32.9	1.3	0.3	9
Mean	51.9	21.7	26.4	5.9	10.4	29.9	1.2	0.3	8.2
Maximum	82	42	42	7	27.2	60.9	2.6	0.8	46.9
Minimum	20	10	4	5.2	2	7.2	0	0.1	0.6

Note: A = Lower altitude (2000-2500 m.a.s.l), B = Middle altitude (2501-3000 m.a.s.l) and C = Upper altitude (3001-3500 m.a.s.l)

As indicated in Table 12, the maximum average sand percentage (54.9) was shown in upper altitude followed by middle altitude (51.4). The lower altitude comprises the lowest average percentage of sand. On the contrary, the highest average clay percentage (27.8) was found in higher altitude followed by the middle altitude areas (26.2). The maximum average organic carbon and CEC were also shown in upper altitude with the values of 11.5 and 32.9 Meq/100g respectively.

Table 13. Average values of soil parameters along the eight aspects

Row Labels	Sand%	Silt%	Clay%	pH	C	CEC	Exacid	TN	P
East	51.5	21.8	26.7	5.7	12.5	36.6	0.8	0.4	6.7
North	54.5	20.6	24.8	6	8.8	28.5	1.3	0.3	7.5
North East	57.3	16.2	26.5	5.9	14.4	28.4	1.3	0.4	8.3
South	50.8	23.3	26	5.8	8.9	24.2	1.1	0.2	7.1
South East	49.9	22.4	27.7	6	9.3	31.9	1.4	0.3	8.9
South West	28	42	30	5.3	9.1	42	1.3	0.2	17.7

West	53.7	22.3	24	6.1	11.7	24.1	0.9	0.3	13
Mean	51.9	21.7	26.4	5.9	10.4	29.9	1.2	0.3	8.2
Max.	82	42	42	7	27.2	60.9	2.6	0.8	46.9
Min.	20	10	4	5.2	2	7.2	0	0.1	0.6

The highest sand percentage (57.3) was observed in Northeast aspects followed by the north (54.5). The maximum average silt and clay percentage were found in Southwest aspects of Wof-Washa Forest. The maximum CEC values were recorded in the Southwest aspects (42) followed by East (36.6 Meq/100g). Average pH value ranges from 5.7 - 6.1 and the maximum average values of phosphorus (17.7) were shown in Southwest aspects of Wof-Washa Forest while the minimum average (6.7) was observed in the East aspect (Table 13).

4.1.6. Ordination of vegetation and environmental variables

The choice between the two models the linear response model and unimodal response model depends on the property of the data set being analyzed. Therefore, working on the data the heterogeneity of the vegetation data was detected using Detrended Correspondence Analysis (DCA) to select the appropriate model for analysis. The length of the first axis of DCA indicates species heterogeneity in the vegetation as a result of environmental variables (Table 14).

Table 14. Detrended correspondence analysis result of Wof-Washa Forest vegetation

DCA Axes	DCA1	DCA2	DCA3	DCA4
Eigenvalues	0.4537	0.265	0.1693	0.1419
Decorana values	0.5681	0.2771	0.2277	0.1518
Axis lengths	4.6537	2.5532	3.2172	2.0919

In this data set, the longest gradient was greater than 3 which is around 4.65 in the DCA test. Thus, CCA was selected to show the effect of environmental gradient on the patterns of plant distribution. The principal theme is to assess the relative importance of environmental gradient to the distribution patterns of plant species of Wof-Washa Forest. The eigenvalues of

the first axis (0.47) were much higher than all the successive axes. The first four CCA axes explain 85.93 % of the variation in species data whereas the first two axes account 62.07 % of the variation (Table 15).

Table 15. Biplot scores for constraining variables and their correlation with the CCA axes, eigenvalues and proportion of variance explained

Axes	I	II	III	IV
Eigenvalue	0.4663	0.15436	0.12405	0.11462
Prop. Explained	0.0648	0.02145	0.01724	0.01593
Cumulative Prop.	0.0648	0.08625	0.10349	0.11942

The distribution pattern of most species in the species-plot biplot was highly concentrated around the center of ordination space where the two axes cross each other. The result of ordination diagram (Figure 18) showed that the distribution of study plots along the first and the second axes of variation allowed them to be divided into five groups representing patterns of forest vegetation. Environmental variables are often represented by lines radiating from the centroid of the ordination; axes are also ranked by their eigenvalues. Thus, the first axis has the highest eigenvalues, the second axis contains the second highest eigenvalues and shows a gradual decreasing pattern. Ordination diagram of the data set exhibits five groupings that are well differentiated but not perfectly discrete (Figure 18). Thus, CCA strengthens and confirms the result of hierarchical cluster analysis, showing similar distribution patterns with respect to CCA axes. This indicates that the two methods are complementary to each other. Except community type one and five, the rest of the plant communities share species with adjacent ones as the environmental gradient changes. Thus, the over-lapping of plots among community types enables the species to tolerate a wide range of habitat conditions.

Community type one is negatively correlated with CCA1, while some plots of this group are correlated positively and the rest negatively correlated with CCA2. Most plots in community type two correlate negatively and only one plot correlates positively to CCA1 (Figure 18).

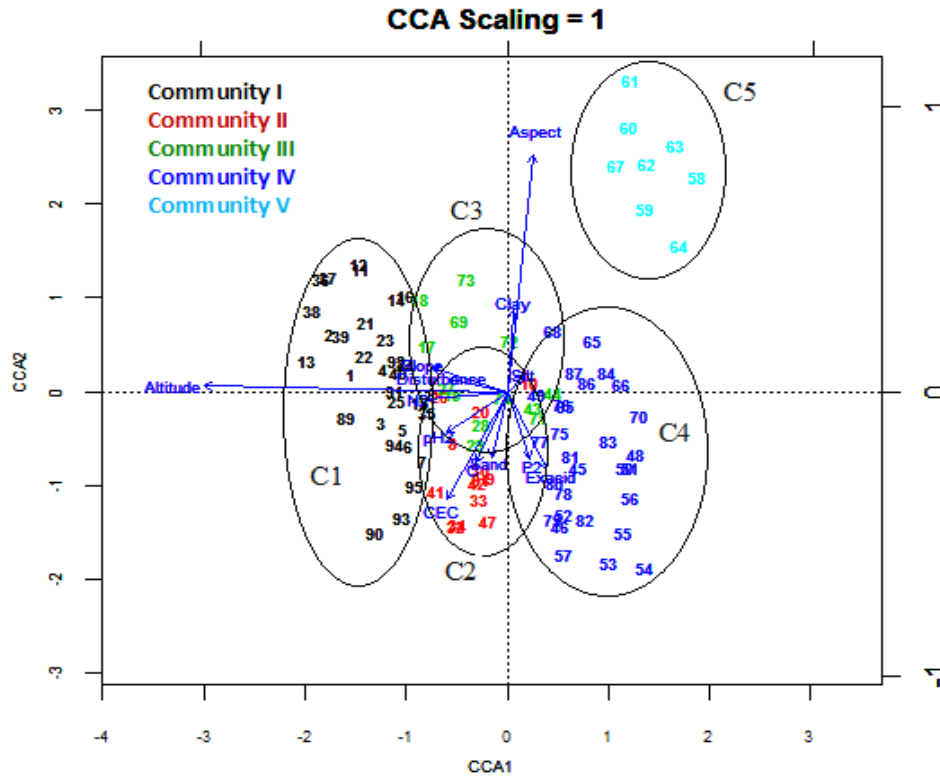


Figure 14. Canonical Correspondence Analysis (CCA) ordination diagram of 95 plots and 13 environmental variables, Number represents plot distribution in the five community types

The magnitude and direction of the vectors in the species-environment biplots represent the degree of correlation between the species and environmental variables (Figure 18). Communities type two and three were more closely related to each other while community type five is more distantly related to other three community types. Altitude, Disturbance, slope, Total nitrogen and pH axes strongly influenced the distribution of species in community type one. Species distribution pattern in community type two was highly influenced by CEC, sand, and pH. Phosphorous and exchangeable acidity influence the

distribution of plant species in community type four. The effect of slope, disturbance, clay, sand, and pH was exhibited in the cluster three species distribution (Figure 18).

Table 16. Scores of constraining variables and Correlation between environmental variables and CCA axes

Parameters	Axis1	Axis2	Axis3	Axis4
Altitude	-0.99	0.021	-0.018	-0.018
Slope	-0.247	0.083	0.128	-0.04
Aspect	0.085	0.831	-0.2	-0.029
Disturbance	-0.193	0.044	0.131	0.109
Sand	-0.051	-0.228	0.152	0.07
Silt	0.053	0.055	-0.068	-0.186
Clay	0.018	0.282	-0.156	0.096
pH	-0.198	-0.145	-0.165	0.054
C	-0.1	-0.246	-0.257	0.271
CEC	-0.196	-0.378	-0.412	0.156
Exacid	0.128	-0.269	0.296	-0.116
TN	-0.261	-0.025	-0.445	-0.013
P	0.075	-0.235	0.071	-0.188
Eigenvalue	0.4663	0.15436	0.12405	0.11462
Prop. Explained	0.0648	0.02145	0.01724	0.01593
Cumulative Prop.	0.0648	0.08625	0.10349	0.11942

Where, C-organic carbon, TN-Total nitrogen, P-phosphorus, and CEC- cation exchange capacity, Exacid-exchangeable acidity

Altitude is a constraining variable that showed a strong negative correlation with CCA1 of the ordination diagram ($r = 0.99$; $p < 0.05$) while aspect has strong positive correlation with the second ordination axis (CCA2) ($r = 0.83$; $p < 0.05$). However, CEC showed a negative correlation with the second axis (Table 16). Thus, altitude was extremely important constraining variable in weighting axis one of the ordination results followed by the slope, disturbance, and pH. CCA2 explains the influences of aspect ($r = 0.83$) and cation exchange capacity ($r = 0.378$) to the distribution of plant species of Wof-Washa Forest (Table 16). Among the constraining variable altitude contributed significantly in explaining patterns of variation in the species distribution and community type formation.

Table 17. Pearson's correlation coefficient matrix for the thirteen environmental variables

Altitude	1													
Slope	0.73***	1												
Aspect	-0.08 ^{ns}	-0.27*	1											
Disturb	0.12 ^{ns}	0.08 ^{ns}	0.14 ^{ns}	1										
Sand	0.14 ^{ns}	-0.13 ^{ns}	-0.19 ^{ns}	-0.02 ^{ns}	1									
Silt	-0.12 ^{ns}	-0.03 ^{ns}	0.20 ^{ns}	-0.03 ^{ns}	-0.75***	1								
Clay	-0.07 ^{ns}	0.23*	0.06 ^{ns}	0.06 ^{ns}	-0.67***	0	1							
pH2	0.17 ^{ns}	-0.01 ^{ns}	-0.08 ^{ns}	-0.25*	0.12 ^{ns}	0.02 ^{ns}	-0.2 ^{ns}	1						
C	0.17 ^{ns}	0.15 ^{ns}	-0.12 ^{ns}	-0.01 ^{ns}	0.29*	-0.2 ^{ns}	-0.21*	0.15 ^{ns}	1					
CEC	0.26*	0.06 ^{ns}	-0.08 ^{ns}	-0.07 ^{ns}	0.28*	-0.21*	-0.18 ^{ns}	0.23*	0.61***	1				
Exacid	0.00 ^{ns}	-0.31**	0.00 ^{ns}	-0.09 ^{ns}	0.17 ^{ns}	-0.1 ^{ns}	-0.14 ^{ns}	0.05 ^{ns}	0.08 ^{ns}	0.13 ^{ns}	1			
TN	0.23*	0.27*	-0.16 ^{ns}	0.11 ^{ns}	-0.07 ^{ns}	-0.12 ^{ns}	0.23*	-0.15 ^{ns}	-0.06 ^{ns}	-0.07 ^{ns}	-0.29*	1		
P	-0.03	-0.14 ^{ns}	0.02 ^{ns}	-0.03 ^{ns}	0.23*	-0.11 ^{ns}	-0.23*	0.31**	0.29*	0.47***	0.27*	-0.15 ^{ns}	1	
	Altitude	Slope	Aspect	Disturb	Sand	Silt	Clay	pH2	C	CEC	Exacid	N2	P2	

Key: The magnitude indicates the degree of correlation. Positive signs indicate positive correlation and negative signs indicate inverse relation. *p < 0.05, **p < 0.01, ***p < 0.001 and ns = no significance.

Pearson's correlation analysis showed a strong positive correlation between altitude and slope (0.73) and strong negative correlation between percent silt and sand (-0.75) followed by clay and sand (-0.67). CEC and Carbon also showed positively correlated with each other (0.61) (Table 17).

4.1.7. Vegetation Structure

4.1.7.1. Tree and shrub density

Table 18 represents the density of forest tree and shrub species individuals per hectare with DBH greater than 2.5 cm, 10 cm, and 20 cm. The overall tree and shrub density with DBH greater than 2.5 cm were 1046.6 stems ha⁻¹ and those individuals with DBH >10 cm and with DBH greater than 20 cm were 584.2 stems ha⁻¹ and 303.7 stems ha⁻¹ respectively (Table 18). Over 95.12 % of the total stem encountered were < 50 cm in DBH.

Table 18. Density woody species in Wof-Washa Forest; a = for trees > 10 cm DBH; b = for trees > 20 cm DBH; a/b = ratio between a and b

DBH (cm)	Density (No. of individuals/ha)
>2.5 cm	1046.6
>10 cm	584.2
>20 cm	303.7
a/b	1.923

Thus, the ratio of the density of trees and shrubs with DBH greater than 10 and 20 cm (a) to DBH > 20 cm (b) was 1.923 for Wof-Washa Forest. The proportion of medium-sized individuals (DBH between 10 and 20 cm) was 280.5 individuals/ha which is smaller than the large-sized individuals (DBH > 20 cm (303.7 individuals/ha)) while the proportion of small-sized individual (DBH < 10.01 cm (462.4 individuals/ha)) was also smaller than DBH > 10 cm (584.2 individuals/ha) (Table 18). Hence, overall tree and shrub density comes from species

with DBH > 2.5 cm was 1046.6 individuals per hectare whereas those with DBH > 10 and 20 cm contributed 55.8 % and 29.02 % of the overall tree and shrub density of the forest.

Species were classified into seven density classes where species belong to class one has lower density and those belong to class seven have a higher density (Table 19). Some of the species belong to class one (low density species) are *Prunus africana*, *Rhus retinorrhoea*, *Dombeya torrida*, *Schefflera abyssinica*, *Celtis africana*, *Olea capensis* subsp. *macrocarpa*, *Myrica salicifolia*, *Teclea nobilis*, *Rhus vulgaris*, *Buddleja polystachya* and *Premna schimperi*. High density species in the forest that reach to the last class were *Erica arborea*, *Juniperus procera*, *Podocarpus falcatus*, *Maesa lanceolata*, *Hypericum revolutum* and *Pittosporum viridiflorum*.

Table 19. Density class distribution of species

Density Class	Density intervals	Total density	%
1	<5	153.3	14.6
2	5.01-10	211.4	20.2
3	10.1-20	171.3	16.4
4	20.1-40	186.9	17.9
5	40.01-60	95.2	9.1
6	60.01-80	73.9	7.1
7	>80	154.7	14.8
Total		1046.7	100.0

The top ten densest woody species contributing about 70.1 % of the total density in Wof-Washa Forest were *Erica arborea*, *Juniperus procera*, *Podocarpus falcatus*, *Maesa lanceolata*, *Hypericum revolutum*, *Pittosporum viridiflorum*, *Maytenus arbutifolia*, *Galiniera saxifraga*, *Hagenia abyssinica* and *Allophylus abyssinicus*. The least density (0.30 % of the total density) was contributed from woody species *Embelia schimperi*, *Euphorbia abyssinica*, *Dracaena steudneri*, *Urera hypselodendron*, *Buddleja polystachya*, *Maytenus obscura*, *Hypericum quartinianum* and *Toddalia asiatica* (Table 20).

Table 20. Density/ha of most common tree species with DBH > 2 cm, 10 cm and 20 cm

Species	DBH > 2 cm		DBH > 10 cm		DBH > 20 cm	
	Density	%	Density	%	Density	%
<i>Erica arborea</i>	175.8	16.8	55.3	9.7	9.7	3.2
<i>Juniperus procera</i>	122.4	11.7	97.4	17.1	74.2	24.5
<i>Podocarpus falcatus</i>	97.1	9.3	30.8	5.4	18.9	6.2
<i>Maesa lanceolata</i>	67.1	6.4	49.2	8.6	25.5	8.4
<i>Hypericum revolutum</i>	58.9	5.6	38.2	6.7	13.2	4.3
<i>Pittosporum viridiflorum</i>	56.6	5.4	41.6	7.3	25.8	8.5
<i>Maytenus arbutifolia</i>	48.7	4.7	19.5	3.4	6.1	2
<i>Galiniera saxifraga</i>	40.3	3.8	22.9	4	11.8	3.9
<i>Hagenia abyssinica</i>	35	3.3	25.5	4.5	15	4.9
<i>Allophylus abyssinicus</i>	32.9	3.1	21.3	3.7	12.1	4
<i>Olea europaea</i> subsp. <i>cuspidata</i>	28.9	2.8	22.1	3.9	14.5	4.8
Subtotal	763.7	72.9	423.8	74.3	226.8	74.7
Other species	282.9	27.1	145.7	25.7	76.6	25.3
Total	1046.6	100	569.5	100	303.4	100

The total density of mature woody plant species in each of the five community types were (323.9, and 323.4) for (community type one, community type four) respectively while other community types contained a smaller density of woody species (Table 21).

The highest woody species density was contributed by community type one and four each with 30.9 % and the least density (9.8%) was recorded from community type five. Community type two and three contained the medium density distribution (14.8 % and 13.5%) in Wof-Washa Forest (Table 21).

Table 21. Relative density of woody species at each respective community type;

Density Class	C1	Spp.	C2	Spp.	C3	Spp.	C4	Spp.	C5	Spp.	Total density
1	19.2	11	30.5	17	31.5	20	37.1	24	35	24	153.3
2	23.3	3	18.7	3	46.5	6	89.7	13	33.2	5	211.4
3	19.7	1	56.2	4	36.1	3	45.6	3	13.7	1	171.3
4	64.2	4	49.2	2	27.9	1	24.5	1	21.1	1	186.9
5	42.6	0	0	0	0	0	52.6	1	0	0	95.2
6	0	0	0	0	0	0	73.9	1	0	0	73.9
7	154.7	1	0	0	0	0	0	0	0	0	154.7
Total	323.9	20	154.6	26	142	30	323.4	43	103	31	1046.7

Key: C1= community type one, C2 = community type two, C3 = community type three, C4 = community type four and C5 = community type five, and Spp.= number of species, (Density classes: 1) ≤ 5 , 2) 5.01 - 10, 3) 10.01 - 20, 4). 20.01 - 40, 5) 40.01 - 60, 6) 60.01 - 80, 7) >80 .

The density distribution of woody species in Wof-Washa Forest shows significant variation among the five community types (Appendix 8). The highest density of mature trees and shrubs was found in the last density class (154.7) of community type one followed by 4th and 5th (64.2 and 42.6) density classes respectively. Density class seven was not represented by species except in the first community type (Table 21). A single species (*Juniperus procera*) reached to the 7th density class. In community type two, the maximum density was found in the 3rd class (56.2) followed by the 4th and 1st density classes (49.2 and 30.5) respectively while higher density classes (density class five, six and seven) were no represented by species. The second density class of the third cluster consisted of the maximum density (46.5) of that community followed by the 3rd, 1st and 4th density classes with 36.1, 31.5 and 27.9 values respectively in a decreasing order. The higher density classes were not represented in this cluster. In community type three, *Juniperus procera*, *Erica arborea*, *Allophylus abyssinicus*, and *Olea europaea* subsp. *cuspidata* density rich species than the rest species of the cluster.

The second density class of community type four contained the highest density among other density classes of community type four followed by density class six. *Podocarpus falcatus*, *Maesa lanceolata*, *Juniperus procera*, *Bersama abyssinica*, *Allophylus abyssinicus*, *Galiniera saxifraga*, *Ficus sur*, *Pittosporum viridiflorum*, *Ilex mitis* and *Polyscias fulva* were the first top ten species in community type four (Table 22).

In the last cluster, the first three density class was represented in smaller densities and the remaining higher density classes were not represented. Species showing relatively higher density in this community type were *Podocarpus falcatus* and *Juniperus procera* (Table 22 and Appendix 6).

Table 22. Density of dominant species along community types (Number of individuals/ha)

Species	Density of dominant species				
	C1	C2	C3	C4	C5
<i>Erica arborea</i>	504.2	10	101.9	4.3	-
<i>Juniperus procera</i>	108.3	145	201.9	79.3	159.4
<i>Pittosporum viridiflorum</i>	104.2	43.33	53.8	24.1	25
<i>Maytenus arbutifolia</i>	6.67	166.67	70.1	24.1	43.8
<i>Olea europaea</i> subsp. <i>cuspidata</i>	11.67	36.67	140.4	13.1	43.8
<i>Maesa lanceolata</i>	-	25	50	148.3	43.8
<i>Bersama abyssinica</i>	-	3.33	5.8	44	81.3
<i>Podocarpus falcatus</i>	-	8.33	7.7	242.2	781.3
<i>Hagenia abyssinica</i>	7.5	80	5.8	2.6	-
<i>Ilex mitis</i>	-	81.67	26.9	25.9	-

As indicated in Table 22, the density of dominant tree species distribution along community types showed variations. *Juniperus procera*, *Pittosporum viridiflorum*, *Maytenus arbutifolia*, and *Olea europaea* subsp. *cuspidata* were distributed in all the community types. However, the density of each species vary greatly across community types. Species such as *Maesa lanceolata*, *Bersama abyssinica*, *Podocarpus falcatus* and *Ilex mitis* were not recorded in

community type one whereas *Erica arborea*, *Hagenia abyssinica*, and *Ilex mitis* were not found in community type five.

4.1.7.2. Height and diameter class distribution

The measured DBH and height (3977 individual woody species) showed 93.16% accounts less than 20 m of height and 71% of the total woody species accounted for individuals of DBH < 20 cm.

4.1.7.2.1 Tree height

The highest proportions of individuals (80.2 %) were found in the lowest height class (5-15m). The most dominant species in this height class interval were *Erica arborea*, *Hypericum revolutum*, *Osyris quadripartita*, *Myrsine africana*, *Maytenus arbutifolia*, *Rosa abyssinica* and *Discopodium penninervum*. Particularly 39.8 % of the tree density was found in the second tree height class (5.01-10 m) and few individuals (2.4 %) laid in the largest height class distribution (> 25 m). Only a few species < 0.7 % reached a height of more than 30 m (Table 23).

Table 23. Height class distribution of woody species of Wof-Washa Forest

No	Height class(m)	Values	% values
1	≤ 5	393	9.9
2	5.01-10	1532	38.5
3	10.01-15	1165	29.3
4	15.01-20	566	14.2
5	20.01-25	229	5.8
6	25.01-30	64	1.6
7	>30	28	0.7
		3977	100

The highest height class distribution of woody plant species was recorded in community type one (32.1 %) followed by community type four (30.6 %) (Table 24). Height classes two and

three contributed maximum height density distribution (40.1 % and 30 %) respectively. The minimum woody species distribution was recorded in the last height classes (six and seven) with 1.4 % and 0.5 % respectively. The last height class (>30 m) was attained by *Juniperus procera*, *Podocarpus falcatus*, and *Polyscias fulva*. The highest height of species (47 m) in Wof Wash forest was attained by *Juniperus procera* followed by *Podocarpus falcatus* (32 m).

Table 24. Height class (m) distribution of woody species across community types in Wof-Washa Forest

Height class	C1	C2	C3	C4	C5	Sum of value	Sum of %
1	163	56	39	37	23	318	8.0
2	639	210	194	382	168	1593	40.1
3	319	146	187	428	115	1195	30.0
4	117	102	74	234	49	576	14.5
5	30	43	22	97	28	220	5.5
6	1	7	11	34	4	57	1.4
7	7	6	0	5	0	18	0.5
Total value	1276	570	527	1217	387	3977	100.0
Total in %	32.1	14.3	13.3	30.6	9.7	100	

Key: C1 = community type one, C2 = community type two, C3 = community type three, C4 = community type four and C5 = community type five.

4.1.7.2.2 Tree Diameter at breast height (DBH)

DBH measurements reveal a similar trend to the height distribution except that, the highest density of DBH has recorded in the first class as opposed to the height (Figure 21). The overall species DBH class distribution was computed and showed an inverted J-shape distribution where most of the individuals of woody species (70.56%) were in the lower DBH class (< 20 cm) (Table 23). The distribution of individuals in the lower DBH was higher with declining trend to the higher successive DBH classes. However, the trend of decreasing the density of individuals towards higher DBH class revealed variation among the community types of Wof-Washa Forest. The highest number of individuals were found in the first (< 10 cm) DBH class followed by the second (10.01-20 cm) and third (20.01-30 cm) with

decreasing tendency (Figure 20 and Table 25). About 70.56 % of the individual species were found in the first two lower DBH classes (< 20 cm) while a very small proportion of the stem density (i.e. ≤ 1.23 %) attained DBH classes between 50-60 cm. The biggest diameter in Wof-Washa Forest was recorded from *Juniperus procera* with a DBH of 226 cm (710 cm circumferences).

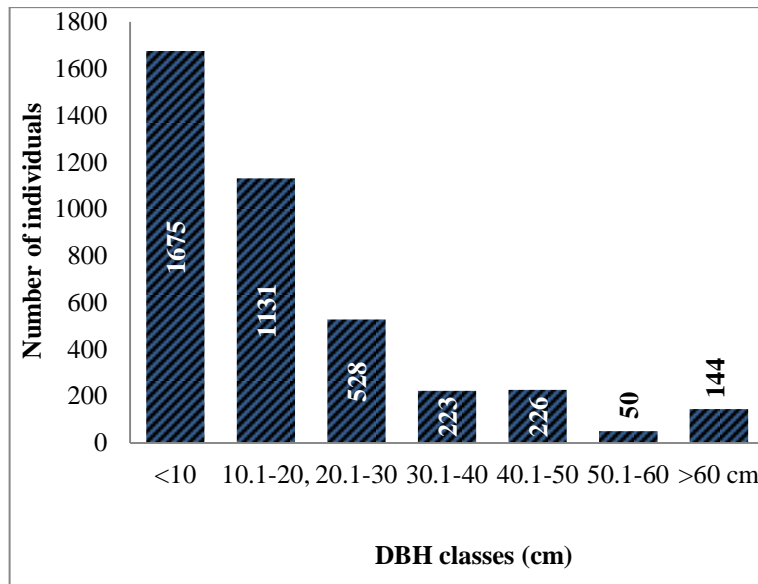


Figure 15. Diameter-class (cm) distribution of trees in Wof-Washa Forest

The distribution patterns of individual species in DBH classes for each community types were shown that a large number of individuals were found in the lower diameter classes with a gradual decline towards the higher DBH classes in all the five communities (Figure 20 and Table 25).

About 83.8 % of the total individuals were obtained in DBH classes (< 30 cm), DBH < 10 cm accounted of 42.1 %, DBH between 10.01-20 cm contained 28.44 % and DBH between 20.01-30 of 13.3 %) (Table 25).

At the community level, the number of individuals in DBH < 20 cm were 81.3 %, 60 %, 69.9 %, 69.5 % and 70.5 % in community type one (C1), community type two (C2), community

type three (C3), community type four (C4), and community type five (C5) respectively. Community type one and four contained the highest number of total individuals than the rest community types (Table 25).

Table 25. Diameter-class (cm) distribution of trees in Wof-Washa Forest

DBH class (cm)	C1	C2	C3	C4	C5	Total value	Value in %
	No. of Indiv.	No. of indiv	No. of indiv	No. of indiv	No. of indiv		
<10	640	204	218	433	180	1675	42.1
10.1-20,	397	138	150	357	89	1131	28.4
20.1-30	119	73	87	196	53	528	13.3
30.1-40	51	49	16	83	24	223	5.7
40.1-50	33	48	33	84	28	226	5.7
50.1-60	13	8	3	23	3	50	1.2
>60 cm	23	50	20	41	10	144	3.6
Mean	182.29	81.43	75.29	173.86	55.29	568.14	100.00
Max	640	204	218	433	180	1675	
Min	13	8	3	23	3	50	

4.1.7.3. Basal area

The total basal area per hectare of woody plant species of Wof-Washa Forest is 153.26 m²ha⁻¹. About 72.74 % of the total basal area came from ten tree species, i.e. *Juniperus procera*, *Podocarpus falcatus*, *Pittosporum viridiflorum*, *Olea europaea* subsp. *Cuspidata*, *Hagenia abyssinica*, *Maesa lanceolata*, *Ilex mitis*, *Hypericum revolutum*, *Erica arborea* and *Allophylus abyssinicus*. From the total basal area per hectare of woody plant species of Wof-Washa Forest 25.42 % (38.96 m²ha⁻¹) was contributed by only a single species (*Juniperus procera*) followed by *Podocarpus falcatus* of 10.05 % (15.41 m² ha⁻¹) (Table 26).

Table 26. Basal area (BA) (m²ha⁻¹) and percentage contribution of ten most dominant trees

Tree Species	BA (m ² ha ⁻¹)	Percent contribution
<i>Juniperus procera</i>	38.96	25.42
<i>Podocarpus falcatus</i>	15.41	10.05

<i>Pittosporum viridiflorum</i>	11.09	7.24
<i>Olea europaea</i> subsp. <i>cuspidata</i>	6.01	3.92
<i>Hagenia abyssinica</i>	6.15	4.01
<i>Maesa lanceolata</i>	9.47	6.18
<i>Ilex mitis</i>	6.82	4.45
<i>Hypericum revolutum</i>	5.81	3.79
<i>Erica arborea</i>	7.06	4.61
<i>Allophylus abyssinicus</i>	4.7	3.07
Subtotal	111.48	72.74
Other species	41.78	27.26
Total	153.26	100.00

The maximum values of basal area (98.99 %) were contributed by tree species of Wof-Washa Forest whereas the least amount (0.09 m²/ha) was occupied by lianas (Figure 21). More than 52.56 % (80.55 m²ha⁻¹ of the total basal area was contributed by higher DBH (> 40 cm) whose density was only 10.56 % of the total individuals in Wof-Washa Forest. The lower DBH class (<10 cm) contributes only 3.77 % of the total basal area but, they are represented as 42.11% of the total density (Table 26).

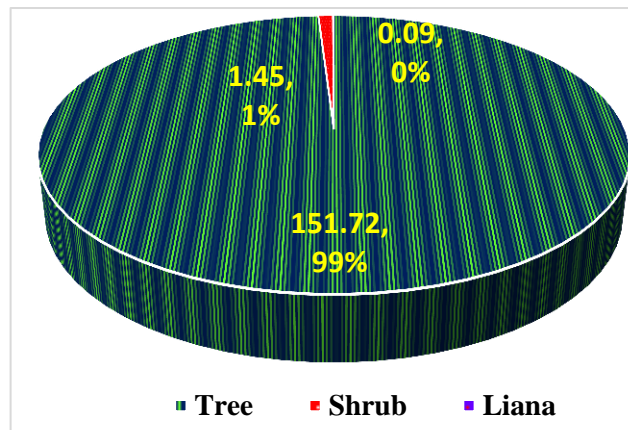


Figure 16. Basal area distribution among woody plant habits of Wof-Washa Forest

The highest contribution to the total basal area was by those tree species attaining higher DBH (> 40 cm). A typical example of this class is *Juniperus procera*, *Podocarpus falcatus*, *Pittosporum viridiflorum*, *Olea europaea* subsp. *cuspidata*, *Hagenia abyssinica*, *Maesa lanceolata* and *Ilex mitis*. *Juniperus procera* was the only species with both high density and

high-frequency distribution. Species with high density, low frequency, and low dominance include *Myrsine africana* and *Discopodium penninervium*. Tree species accounted low density, low frequency, and low dominance were *Prunus africana*, *Dombeya torrida*, *Polyscias fulva*, *Ekebergia capensis*, *Schefflera abyssinica*, *Olea europaea* subsp. *cuspidata* and *Cassipourea malosana* (Appendix 11).

Table 27. The contribution of DBH classes for the Basal Area (BA) in Wof-Washa Forest

Diameter class(cm)	BA (m ² /ha)	BA (%)	Number of individuals	(%)
<10	5.79	3.8	1675	42.1
10.01-20,	18.87	12.3	1131	28.4
20.01-30	26.22	17.1	528	13.3
30.01-40	21.83	14.2	223	5.6
40.01-50	36.3	23.7	226	5.7
50.01-60	10.7	7.0	49	1.2
>60 cm	33.55	21.9	145	3.6
Total	153.26	100.0	3977	100.0

The total basal area per hectare contributed by each community types (community type one, community type two, community type three, community type four and community type five) were 35.42, 31.4, 17.45, 55.51 and 13.48 (m²/ha) respectively. As indicated in Figure 22, the basal area per hectare of community type four is much higher (55.51), 36.2 % than the rest community types of Wof-Washa Forest while, community type five accounted much lower (13.48), 8.8 % than the other four clusters (Figure 22).

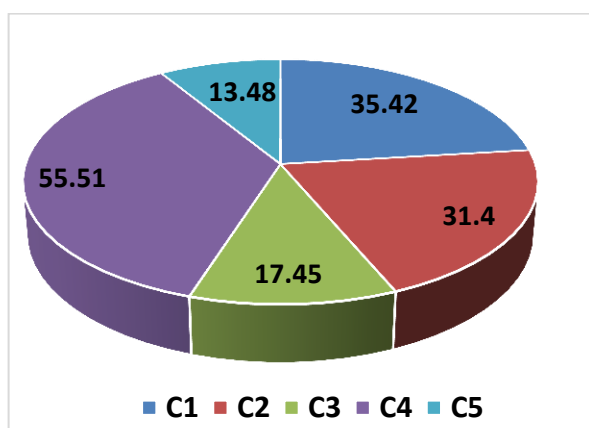


Figure 17. Basal Area distribution among community types

The basal area contribution of dominant species of the forest showed variations among community types (Table 28). *Juniperus procera*, *Pittosporum viridiflorum*, *Olea europaea* subsp. *cuspidata* and *Maytenus arbutifolia* were contributed different values of basal area in all the five community types. However, *Maesa lanceolata*, *Bersama abyssinica*, *Podocarpus falcatus* and *Ilex mitis* were not recorded in community type one as *Erica arborea*, *Hagenia abyssinica* and *Ilex mitis* in community type five. The highest basal area values (6.28) of *Erica arborea* was found in community type one community where as *Juniperus procera* contributed the highest basal area in community type four. *Juniperus procera* and *Podocarpus falcatus* accounted high basal area in community type five while *Podocarpus falcatus*, *Juniperus procera*, and *Maesa lanceolata* contributed high values of basal area in community type four (Table 28).

Table 28. Basal area of dominant woody speies

Species	Basal area of dominnt species (m ² /ha)					Total
	C1	C2	C3	C4	C5	
<i>Erica arborea</i>	6.28	0.31	0.38	0.09	0	7.06
<i>Juniperus procera</i>	6.43	11.32	8.91	9.2	3.1	38.96
<i>Pittosporum viridiflorum</i>	5.9	1.6	1.3	1.4	0.9	11.1
<i>Maytenus arbutifolia</i>	0.09	1.64	0.46	0.47	0.23	2.89
<i>Olea europaea</i> subsp. <i>cuspidata</i>	0.15	0.55	4.11	1.1	0.1	6.01

<i>Maesa lanceolata</i>	0	0.49	0.7	8.11	0.63	9.93
<i>Bersama abyssinica</i>	0	0.23	0.08	1.39	1.32	3.02
<i>Podocarpus falcatus</i>	0	2.37	0.25	10.04	2.75	15.41
<i>Hagenia abyssinica</i>	1.4	5.34	0.46	0.1	0	7.3
<i>Ilex mitis</i>	0	4.75	1.72	3.13	0	9.6

4.1.7.4. Species Frequency

Based on the frequency values, woody species of the five community types were classified into five frequency classes (in %): 1) 0 - 20, 2) 21 - 40, 3) 41 - 60, 4) 61 -80, 5) 81-100. At the species level, the analysis of frequency distribution of woody species revealed that *Juniperus procera* was found to be the most frequent species in Wof-Washa Forest, occurring in 75 study plots (79.95 %). *Myrsine africana* (68.42 %), *Maytenus arbutifolia*, *Rosa abyssinica* (61.05 %), *Pittosporum viridiflorum* (51.58 %), *Maesa lanceolata* (38.95 %), *Erica arborea* (40 %), and *Podocarpus falcatus* (35.79 %) were the most frequent species in Wof-Washa Forest (Table 29). *Rhus vulgaris*, *Cordia africana*, *Teclea nobilis*, *Turraea holstii*, *Toddalia asiatica*, *Schefflera abyssinica*, *Rhoicissus tridentata*, *Pavetta abyssinica*, *Pentas schimperiana*, *Calpurnea aurea*, *Prunus africana*, *Rhus retinorrhoea* and *Hypericum quartinianum* were found to be the least frequent species (< 4.2 % each) in Wof-Washa Forest (Appendix 9). A list of most frequent woody species occurring at least in 30 % of the study plots sampled was shown in Table 29.

Table 29. Most frequent woody species in Wof-Washa Forest

Woody species	Frequency	%
<i>Juniperus procera</i>	75.0	78.95
<i>Myrsine africana</i>	65.0	68.42
<i>Maytenus arbutifolia</i>	61.0	64.21
<i>Rosa abyssinica</i>	58.0	61.05
<i>Inula confertiflora</i>	55.0	57.89
<i>Pittosporum viridiflorum</i>	49.0	51.58
<i>Hypericum revolutum</i>	39.0	41.05

<i>Erica arborea</i>	38.0	40.00
<i>Clematis simensis</i>	37.0	38.95
<i>Maesa lanceolata</i>	37.0	38.95
<i>Osyris quadripartita</i>	36.0	37.89
<i>Bersama abyssinica</i>	35.0	36.84
<i>Podocarpus falcatus</i>	34.0	35.79
<i>Allophylus abyssinicus</i>	33.0	34.74

The frequency distribution of species in each cluster also showed different patterns. The largest proportions of species were distributed in the first frequency class in all community types followed by an irregular decline in the successive higher frequency classes. However, community type four showed a relatively increasing trend from the second frequency class towards the higher, community type one also revealed relatively similar distribution to community type four (Figure 23). The distribution of species in frequency classes at community type three and five showed an inverted J-shape with the highest frequency in the first class and show gradual decline towards the higher frequency classes Figure 23).

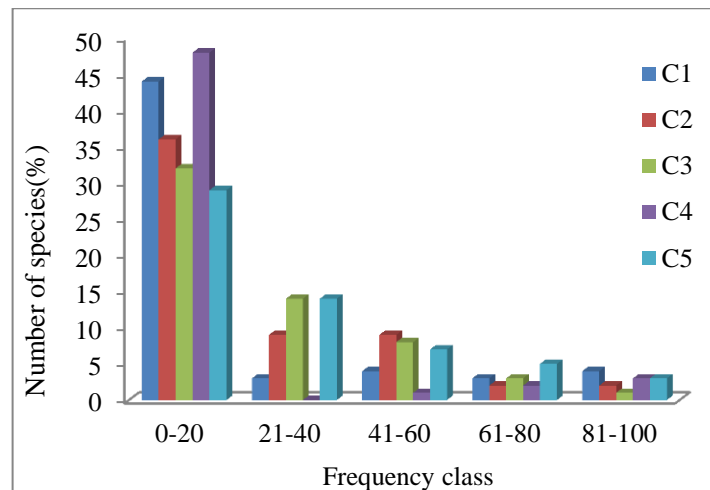


Figure 18. Frequency distribution of woody species in Wof-Washa Forest community types. The frequency of species in each community type showed different distribution patterns. As indicated in Table 28, *Juniperus procera* has a frequency of 72.7 %, 82.4 %, 81.1 %, 83.3 % and 72.2 % in community type one, two, three, four and five respectively. *Erica arborea* also showed 96.7 % in community type one and not recorded in community type five (Table 28).

Juniperus procera, *Myrsine africana*, *Maytenus arbutifolia*, *Rosa abyssinica*, *Pittosporum viridiflorum*, *Maesa lanceolata*, and *Osyris quadripartita* are among the common species to all the five community types (Table 28).

4.1.7.5. Importance Value Index (IVI)

The important values of woody species of the forest ranged from 0.1 to 43.8 (Appendix 11). The highest IVI value (46.07 %) was recorded from six frequent woody species of Wof-Washa Forest. The highest IVI value was recorded for *Juniperus procera* (43.8) followed by *Erica arborea* (25.9) (Table 30). *Podocarpus falcatus*, *Pittosporium penninervum*, *Maesa lanceolata*, *Hypericum revolutum*, *Olea europaea* subsp. *cuspidata*, *Maytenus arbutifolia*, *Hagenia abyssinica*, *Galiniara saxifraga*, *Ilex mitis* and *Allophylus abyssinica* were abundant, frequent and dominant that contributes more to the IVI value (Appendix 11).

The remaining tree and shrub species i.e. *Pavetta abyssinica*, *Premna schimperi*, *Celtis africana*, *Euphorbia abyssinica*, *Pentas schimperiana*, *Maytenus undata*, *Cupressus lusitanica*, *Hypericum quartinianum*, *Buddleja polystachya*, *Teclea nobilis*, *Diospyros abyssinica*, *Erythrina brucei*, *Maytenus obscura* and *Debregeasia saeneb* had IVI values less than 0.5 each (Appendix 11).

Table 30. IVI values of eleven most frequent trees in Wof-Washa Forest

Species	Basal Area	RBA	Dens	RD	Ferq %	RF	IVI	Rank	Priority
<i>Juniperus procera</i>	38.96	25.4	122.4	11.7	78.9	6.4	43.5	1	1
<i>Erica arborea</i>	7.06	4.6	175.8	16.8	42.1	3.4	24.8	2	1
<i>Podocarpus falcatus</i>	15.41	10.1	97.1	9.3	35.8	2.9	22.2	3	1
<i>Pittosporum viridiflorum</i>	11.1	7.2	56.6	5.4	52.6	4.2	16.9	4	1
<i>Maesa lanceolata</i>	9.47	6.2	67.1	6.4	43.1	3.5	16.1	5	1
<i>Hypericum revolutum</i>	5.81	3.8	58.9	5.6	42.1	3.4	12.8	6	1
<i>Hagenia abyssinica</i>	7.3	4.8	36.1	3.4	29.5	2.4	10.6	7	1
<i>Maytenus arbutifolia</i>	2.89	1.9	48.7	4.7	63.2	5.1	11.6	8	1
<i>Ilex mitis</i>	9.6	6.3	24.5	2.3	28.4	2.3	10.9	9	1
<i>Olea europaea</i>	6.01	3.9	28.9	2.8	33.7	2.7	9.4	10	1

<i>subsp.cuspidata</i>									
<i>Galiniere saxifraga</i>	4.58	3	40.3	3.9	33.7	2.7	9.6	11	1
Subtotal	118.19	77.2	756.4	72.3	483.1	39	188.4		
Other species	35.14	22.8	290.2	27.7	755.4	61	111.6		
Total	153.33	100	1046.6	100	1238.5	100	300		

4.1.7.6. Species Population structure

Height class distribution of woody species

The height class distribution of tree and shrub species reveals that 92.6 % of the individuals had less than 20 m in height (Height class1- 4) followed by 7 % of the population reaches (20-30 m) and the 0.45% reached above 30 m, indicating that the dominance of low stature individuals. The population structure of most dominant and frequent woody species shows five major patterns of height dynamics (Figure 24 (a-f)).

The first group was exhibited with irregular distribution with a higher value in the highest height classes and the lowest individual density at the first and third classes. This pattern was represented by *Juniperus procera* and *Halleria lucida* (Figure 24 (a)).

The second group consists of species that showed an inverted J-shaped pattern that had the highest density of individuals in the lowest height class and progressively declining numbers with increasing height classes. Species belonged in this group includes *Allophylus abyssinicus*, *Myrsine africana* and *Discopodium penninervium* (Figure 24 f).

The third group shows a similar pattern with the second group except for very small density of individuals in the first class and highest density at the second class with gradual declining towards the highest height classes. This group was exemplified by the species *Podocarpus falcatus*, *Oliniarochetiana*, *Maytenus arbutifolia* and *Dovyalis abyssinica* (Figure 24 c).

The fourth group was exhibited nearly “n”- shaped pattern with maximum height density at the middle classes (10-20 m) with a gradual decline in both directions and no values in the

highest height classes (> 25 m). This group was represented by *Maesa lanceolata*, *Olea europaea* subsp. *cuspidata*, *Ilex mitis* and *Pittosporum viridiflorum* (Figure 24 d and e).

The fifth group was represented by species with the highest height density at the second class with progressive decline towards the higher height class density and individuals are missing at the highest classes (class 6 and 7). To this group, *Hagenia abyssinica*, *Erica arborea* and *Galiniera saxifraga* were categorized (Figure 24b).

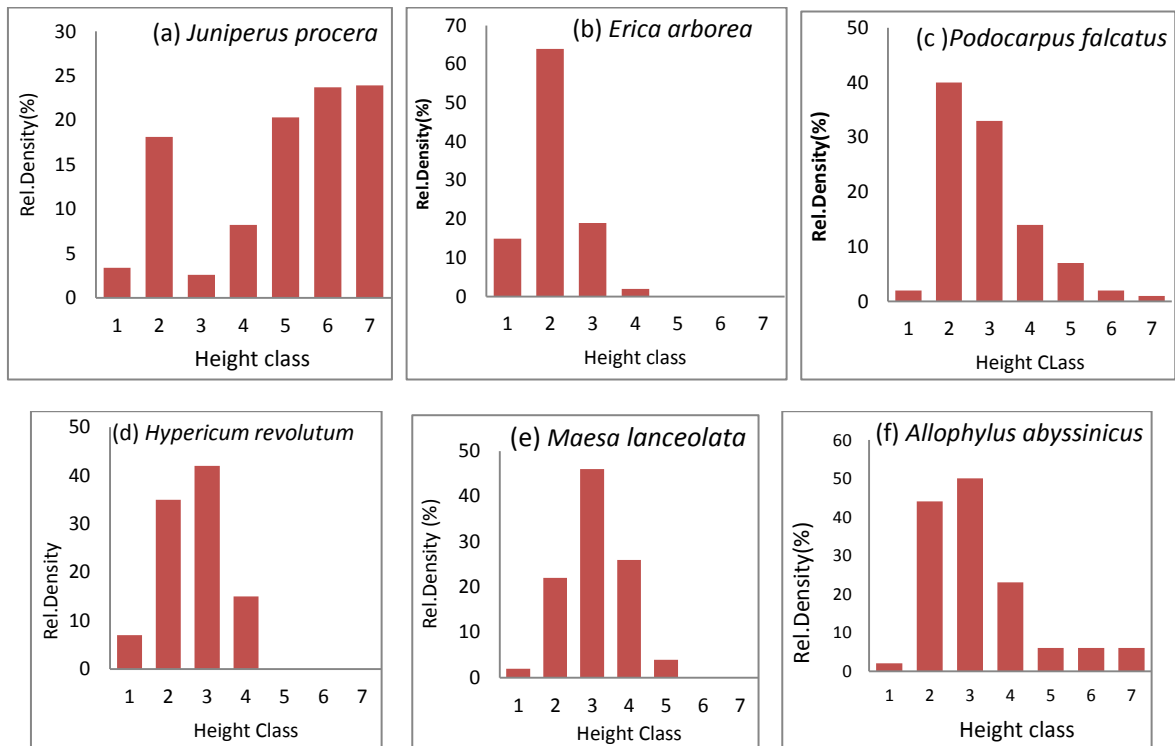


Figure 19. The pattern of height class distribution of twelve top tree species based on IVI values

DBH class distribution of woody species

Population structure dictates the general trends of population dynamics and recruitment processes of each species. Based on the diameter class distribution, Woody species recorded from Wof-Washa Forest reveals variation in patterns of population structures. The analysis of DBH class density distribution of woody species at Wof-Washa Forest show five distinct

patterns of population structure that exhibit the population dynamics among species (Figure 25 (a-l)).

The first group shows reversed J-shaped pattern of population structure with the highest density of individuals at the lowest DBH class (< 10 cm) followed by a gradual decline with increasing diameter class. Species belonged this cluster are *Ericaar borea*, *Podocarpus falcatus*, *Galiniera saxifraga*, *Olinia rochetiana* and *Allophylus abyssinicus* (Figure 25 b).

The second group reveals irregular diameter class density with the highest value of second diameter class and an intermediate value at diameter class 3-5(20-50 cm DBH) and the lowest value at the sixth class (50-60 cm). This group was exemplified by *Hagenia abyssinica* and *Olea europaea* subsp. *cuspidata* (Figure 25 d).

The third group shows reversed irregular diameter class density distribution with the maximum diameter density at the higher DBH class (> 50 cm) and low values in the middle DBH classes (20-40 cm) whereas the lower DBH classes (<20 cm) were relatively represented in well manner. This cluster is typically represented by *Juniperus procera* (Figure 25 a).

The fourth group represents a J-shaped pattern of woody species individual density distribution, which had the highest individual density at the highest DBH class. This pattern progressively declines towards the lower DBH class distributions with the smallest value at the first DBH class. *Ilex mitis*, *Ekebergia capensis*, *Croton macrostachyus*, *Euphorbia ampliphylla* and *Polyscias fulva* are categorized in this group (Figure 25 e).

The fifth group is similar to the first group except the maximum individuals' density is found at the second DBH class and subsequently decrease towards the higher DBH class. *Hypericum revolutum* and *Maesa lanceolata* belong to this cluster (Figure 25 c).

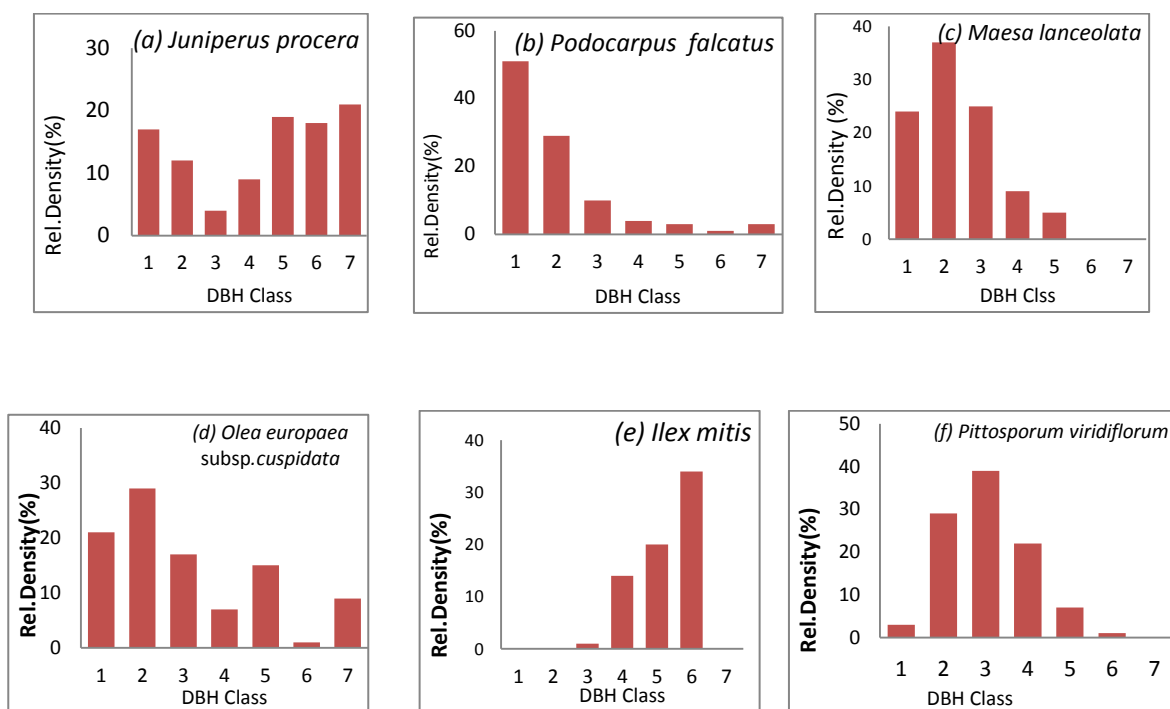


Figure 20. Diameter class frequency distribution of selected tree species in Wof-Washa forest

4.1.7.7. Vertical Stratification

According to Lamprecht (1989), the vegetation of Wof-Washa Forest was clustered into three strata. The upper layer includes those species with height exceeds 31.33 m, the middle stratum in between 15.66 to 31.33 m and the lower stratum comprises species lower than 15.66 m in height. The height distribution of woody species reflects the highest point of the upper canopy (47 m) was attained *Juniperus procera* stand at 3116 m. a.s.l. About 72.8 % of the total individuals were recorded in the lower strata which contained broad-leaved herbs, grasses, lianas, strangling epiphytes, ferns, and bryophytes. The herb layer is patchy and the patches are variable in size and density. Tree species with highest stem density in the lower strata were *Erica arborea*, *Podocarpus falcatus*, *Juniperus procera*, *Hypericum revolutum*, *Maesa lanceolata*, *Maytenus arbutifolia* and *Pittosporum viridiflorum* with the corresponding number of individuals (651, 279, 211, 190, 178, 177 and 151) respectively.

A few trees (3.5 % of the total individuals) of the upper stratum are raised well above the middle tree stratum and have a large number of branches. The most common emergent trees above 30 m height were *Juniperus procera*, *Podocarpus falcatus*, and *Polyscias fulva*. Intermediate number and density of species were found in the middle storey but, the height of the canopy varies between 15 and 20 m. The most common species of the middle stratum include *Maesa lanceolata*, *Rhus vulgaris*, *Hagenia abyssinica*, and *Pittosporum viridiflorum*. The lower tree stratum usually forms a dense canopy and consists of small trees and shrubs with dense crowns between 2 and 15 m. *Erica arborea*, *Dovyalis abyssinica*, *Maytenus arbutifolia*, *Myrsine africana* and *Galiniera saxifraga* are among the dominant tree species in Wof-Washa Forest (Table 31).

Table 31. Vertical layer of woody species in Wof-Washa Forest vegetation

Strata/strata	Height (m)	No of individuals	Density(stem/ha)	%	No. of spp.	%
Lower	< 15.66 m	3155	830.3	79.3	59	72.8
Middle	15.66-31.33 m	808	212.6	20.3	19	23.5
Upper	>31.33 m	15	3.9	0.4	3	3.5

4.1.7.8. Regeneration status of woody species

The density of seedlings, saplings and mature stems of woody species showed variation among community types. A total of 119 woody species, belonging to 96 genera and 52 families were recorded as seedlings in Wof-Washa Forest. The total seedlings, sapling, and mature tree individuals were 19,751 (56.1 %), 11,489 (32.6 %) and 3,977(11.3 %) and showed a reversed J-shaped pattern of decreasing trend with increasing height and DBH (Figure 26 and Appendix 10). The seedling population was dominated by few woody species such as *Maytenus arbutifolia*, *Myrsine africana*, *Podocarpus falcatus*, *Inula confertiflora* and *Hypericum revolutum*.

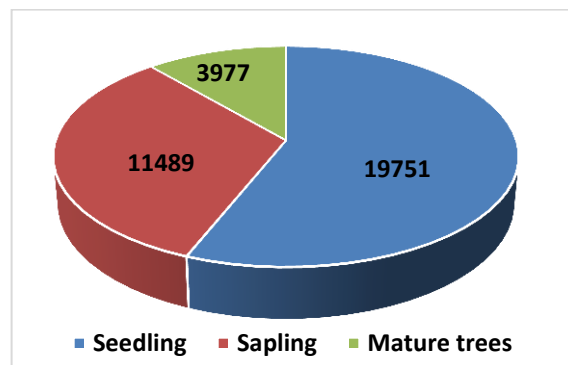


Figure 21. Size class distribution of woody species

Note: Individuals considered as seedlings as the height <0.5 m, saplings when the size is $0.5 < x < 2$ m and mature individuals when > 2 m.

Seedling Density

The seedling density of Wof-Washa Forest species was found to be the highest compared to saplings and mature tree species (Figure 26). The five most abundant tree species represented in the seedling bank were *Maytenus arbutifolia*, *Podocarpus falcatus*, *Hypericum revolutum*, *Bersama abyssinica* and *Osyris quadripartita* represented in 70.8 % of the seedlings. *Maytenus arbutifolia* is the most dominant tree species (360.8 seedlings per ha) followed by *Podocarpus falcatus* and *Hypericum revolutum* 345.3 and 299.5 seedlings per ha respectively (Figure 26 and Appendix 10). The highest seedling density of shrub is due to the presence of *Myrsine africana*, *Inula confertiflora*, *Berberis holstii*, *Helichrysum citrispinum*, *Rosa abyssinica*, *Asparagus Africanus*, *Colutia abyssinica*, *Dodonea angustifolia* and *Dovyalis abyssinica*.

Table 32. Families represented by four or more species in the seedling population of Wof-Washa Forest

Family	No. of species	No. of genera	No. of seedlings	No. of saplings	No. of mature plant
Fabaceae	14	11	926	146	55
Asteraceae	9	6	2814	898	70
Euphorbiaceae	6	3	47	51	52
Lamiaceae	5	5	295	55	5
Rosaceae	5	4	1606	919	184
Malvaceae	5	5	63	8	0

Oleaceae	4	2	202	155	110
Solanaceae	4	2	128	36	2
Rubiaceae	4	4	248	333	210

As indicated in Table 32, large number of individuals were recorded from few families and their respective species. Asteraceae, Rosaceae and Fabaceae were the first three families with large number of individuals of seedlings and saplings in their species recorded in Wof-Washa Forest. The first 20 seedling rich species comprised 84.6 % of the seedling population while the remaining species consisted only the 15.4% of the seedlings (Appendix 10).

Ecologically important tree species (*Juniperus procera*, *Erica arborea*, *Ilex mitis* and *Polyscias fulva*) were less represented in seedlings and saplings (Appendix 10). *Acacia negrii*, *Agarista salicifolia*, *Clerodendrum myricoides*, *Cordia africana*, *Diospyros abyssinica*, *Dracaena steudnerii*, *Erythrina brucei*, *Euphorbia abyssinica* and *Grewia ferruginea* were not represented in seedlings (Appendix 10).

Sapling density- The total density of saplings was 3030.53 ha⁻¹ (32.4 %) recorded in all sampled study plots of Wof-Washa Forest (Appendix 10). 60.27 % of the total sapling density was contributed by eleven woody species (*Podocarpus falcatus*, *Myrsine Africana*, *Maytenus arbutifolia*, *Hypericum revolutum*, *Inula confertiflora*, *Rosa abyssinica*, *Discopodium penninervium*, *Erica arborea*, *Maesa lanceolata*, *Bersama abyssinica* and *Juniperus procera*) (Appendix 10). The five most abundant tree species represented in the saplings were *Maytenus arbutifolia*, *Podocarpus falcatus*, *Hypericum revolutum*, *Bersama abyssinica* and *Osyris quadripartita* represented in 52.2 %. *Jasminum grandiflorum*, *Acacia abyssinica*, *Agarista salicifolia*, *Cordia africana*, *Diospyros abyssinica* and *Grewia ferruginea* were not represented by sapling stages in this size class type.

Tree density- the mature tree species was the lowest in density of individuals and number of species as compared to seedlings and saplings (Figure 27). The higher density in the mature

tree species was contributed by few species such as *Erica arborea*, *Juniperus procera*, *Podocarpus falcatus*, *Maesa lanceolata* and *Hypericum revolutum* (46.6 %) of the total mature tree species (Appendix 10).

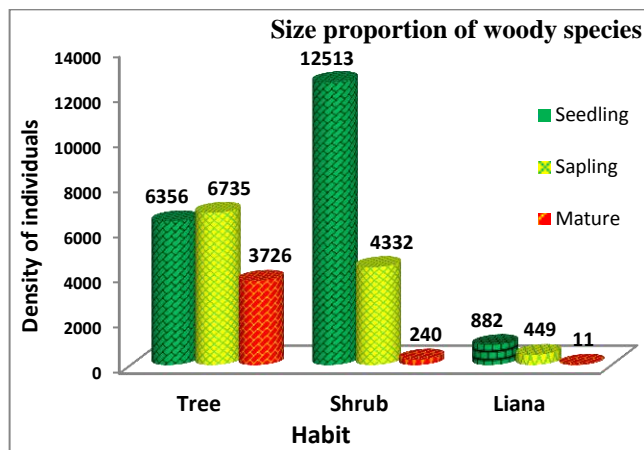


Figure 22. The seedling and sapling proportion in the respective habit in Wof-Washa Forest. At the species level, 58 species such as *Osyris quadripartita*, *Podocarpus falcatus*, *Hypericum revolutum*, *Bersama abyssinica*, *Dovyalis abyssinica*, *Inula confertiflora*, *Toddalia asiatica*, *Rosa abyssinica*, *Vernonia auriculifera*, *Myrica salicifolia* and *Helichrysum citrispinum* etc showed good regeneration with both the ratio of the seedling to sapling and sapling to mature tree > 1 (Table 33). However, *Halleria lucida*, *Olea europaea* subsp *cuspidata*, *Celtis africana*, *Ficus sur*, *Juniperus Procera*, *Psydrax schimperiana*, *Allophylus abyssinicus*, *Pittosporum viridiflorum*, *Maesa lanceolata*, *Turraea holstii*, *Croton macrostachyus*, *Ekebergia capensis*, *Prunus africana*, *Cassipourea malosana*, *Polyscias fulva*, *Ilex mitis*, *Erica arborea*, *Acacia negrii* and *Euphorbia ampliphylla* exhibited poor regeneration (Appendix 10 and Table 33).

Table 33. Proportion of species in regeneration category along community types

Community types	Number of Seedlings	Number of Saplings	Number of Tree	Se: Sa	Sa: Te	Se: Te
C1	5311	2597	1176	2.05	2.2	4.5
C2	3536	1545	566	2.29	2.7	6.2

C3	3763	1763	578	2.13	3.1	6.5
C4	5116	4223	1282	1.21	3.3	4.0
C5	2025	1361	375	1.49	3.6	5.4

Note: Se- seedlings, Sa -Saplings and Te-tree individuals

As indicated in Table 33, the number of individuals of seedlings were much larger than the number of sapling and tree individuals in all the community types. The number of saplings also larger than the number of tree individuals. The highest seedling population were recorded in community type three and two with (19.05 and 17.9 %) respectively. However, the highest sapling individuals (36.8 %) were found in community type four followed by community type one (22.6 %) (Table 34). *Myrsine africana*, *Inula confertiflora*, *Berberis holstii*, *Maytenus arbutifolia* and *Podocarpus falcatus* are the first five woody species contributing the highest seedling density (736.6, 513.7, 457.1, 360.8 and 345.3 individuals /ha) respectively. The maximum numbers of sapling individuals among the tree species were found in *Podocarpus falcatus* and *Maytenus arbutifolia* with 319.7, and 253.2 ha⁻¹ respectively (Appendix 10).

Analysis of the population structure of dominant tree species in Wof-Washa Forest showed four general patterns of regeneration (Figure 28). The first pattern is represented by medium densities in saplings and maximum densities in the mature plant with no seedlings at all. Species in this category are *Prunus africana*, *Ilex mitis*, *Cordia africana*, *Diospyros abyssinica*, *Grewia ferruginea*, *Dracaena steudnerii*, *Acacia negrii*, *Agarista salicifolia* and *Clerodendrum myricoides* (Figure 28 a). The second type is a J-shaped pattern, where the number of individuals of mature plant larger than the saplings and the number of individuals of saplings higher than the number of seedling individuals. This pattern is exemplified by *Erica arborea*, *Juniperus procera*, *Pittosporum viridiflorum*, *Cassipourea malosana*, *Maytenus undata*, *Teclea nobilis* and *Vernonia amygdalina* (Figure 28 b). The third type is represented by positively skewed distribution (reversed J-shaped pattern), where the

maximum density was observed in the seedling stage, intermediate in the sapling size and few numbers in the mature plant. *Podocarpus falcatus*, *Hypericum revolutum*, *Premna schimperi*, *Osyris quadripartita*, *Bersama abyssinica*, *Vernonia auriculifera*, *Toddalia asiatica*, *Dovyalis abyssinica*, *Dodonea angustifolia*, *Rosa abyssinica*, *Maytenus arbutifolia*, *Myrsine africana* and *Inula confertiflora* were categorized in this pattern (Figure 28 d). The fourth pattern is exemplified by *Olinia rochetiana*, *Hagenia abyssinica*, *Discopodium penninervum* and *Dombeya torrida* where saplings accounted the maximum density while both seedling and mature plant density is in an intermediate value (Figure 28 c).

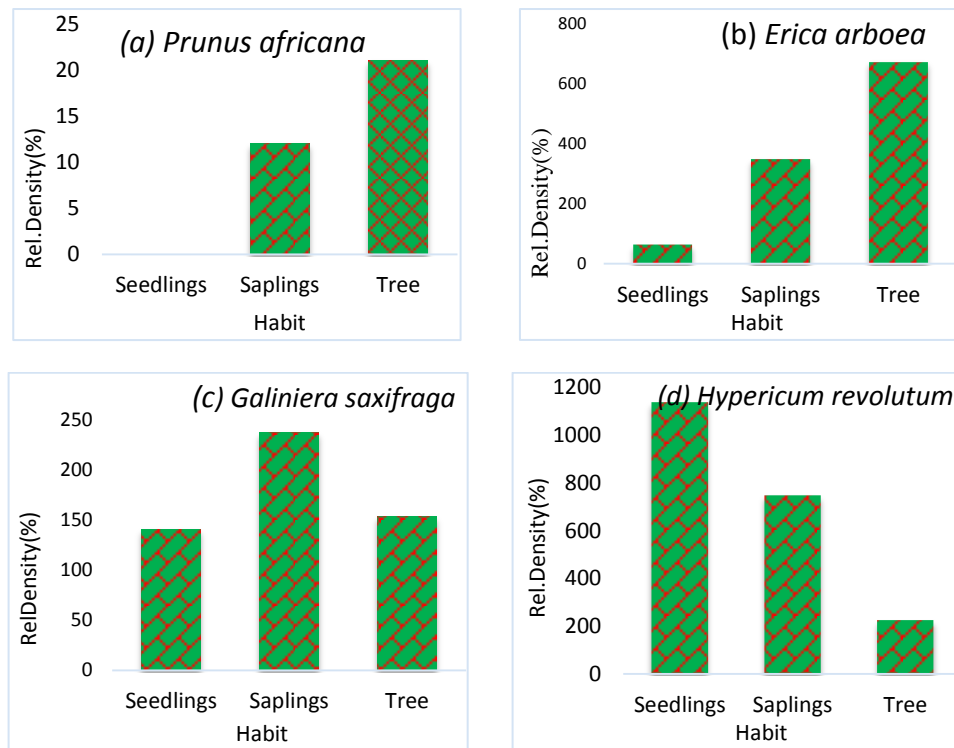


Figure 23. Size class distribution of selected woody species of Wof-Washa Forest

Based on the density of seedlings and saplings, woody species of Wof-Washa Forest were classified into three groups. Species which are totally absent in regeneration (species without seedlings or saplings or both) were grouped under regeneration class one, while those species whose seedling and/ or sapling density greater than zero and less than 50 were underclass two. The remaining species having more than 50 seedlings, saplings, or both were classified under

class three. Species such as *Ilex mitis*, *Prunus africana*, *Ekebergia capensis*, *Halleria lucida*, *Polyscias fulva*, *Croton macrostachyus*, *Schefflera abyssinica*, *Nuxia congesta*, *Myrica salicifolia*, *Teclea nobilis*, *Celtis africana*, *Acacia abyssinica*, *Cassipourea malosana* and *Cordia africana* were categorised under class one while *Erica arborea*, *Ficus sur*, *Psydrax schimperiana*, *Maytenus obscura*, *Sparmannia ricinocarpa*, *Embelia schimperii*, *Turraea holstii* and *Toddalia asiatica* were in category two (Table 34). Most of the shrubs (*Berberis holstii*, *Dodonea angustifolia*, *Inula confertiflora*, *Maytenus arbutifolia*, *Myrsine africana* and some of the dominant tree species (*Juniperus procera*, *Podocarpus falcatus*, *Maytenus arbutifolia*, *Maesa lanceolata*, *Olinia rochetiana* *Osyris quadripartita* were under the last category that exhibits better regeneration than the other classes (Table 34).

Table 34. List of species under regeneration status classes in Wof-Washa Forest

Class one :(species no seedlings or saplings or both), Class two: species with Seedling and/ or sapling density > 0 and < 50 and Class three: species with >50 seedlings or saplings or both)

No	Class one	Class two	Class three
1	<i>Acacia abyssinica</i>	<i>Embelia schimperii</i>	<i>Berberis holstii</i>
2	<i>Cassipourea malosana</i>	<i>Erica arborea</i>	<i>Bersama abyssinica</i>
3	<i>Cordia africana</i>	<i>Ficus sur</i>	<i>Cupressus lusitanica</i>
4	<i>Debregeasia saeneb</i>	<i>Maytenus obscura</i>	<i>Discopodium penninervium</i>
5	<i>Diospyros abyssica</i>	<i>Psydrax schimperiana</i>	<i>Dodonea angustifolia</i>
6	<i>Ilex mitis</i>	<i>Rhus retinorrhoea</i>	<i>Dovyalis abyssinica</i>
7	<i>Erythrina brucei</i>	<i>Sparmannia ricinocarpa</i>	<i>Galiniera saxifraga</i>
8	<i>Euphorbia ampliphylla</i>	<i>Toddalia asiatica</i>	<i>Hagenia abyssinica</i>
9	<i>Grewia ferruginea</i>	<i>Turraea holstii</i>	<i>Hypericum revolutum</i>
10	<i>Grewia ferruginea</i>	<i>Vernonia hochstetteri</i>	<i>Inula confertiflora</i>
11	<i>Lobelia rhynchopetalum</i>		<i>Juniperus procera</i>
12	<i>Maytenus undata</i>		<i>Maesa lanceolata</i>
13	<i>Prunus africana</i>		<i>Maytenus arbutifolia</i>
14	<i>Rhoicissus tridentata</i>		<i>Myrsine africana</i>
15	<i>Salix mucronata</i>		<i>Olinia rochetiana</i>
16	<i>Schefflera abyssinica</i>		<i>Osyris quadripartita</i>
17	<i>Teclea nobilis</i>		<i>Podocarpus falcatus</i>
18	<i>Vernonia amygdalina</i>		<i>Taczazea conferta</i>

No	Class one	Class two	Class three
19	<i>Croton macrostachyus</i>		
20	<i>Polyscias fulva</i>		
21	<i>Myrica salicifolia</i>		
22	<i>Nuxia congesta</i>		
23	<i>Olea hochsteteri</i>		
24	<i>Halleria lucida</i>		
25	<i>Celtis africana</i>		
26	<i>Dombeya torrida</i>		
27	<i>Ekebergia capensis</i>		

4.1.7.9. Floristic similarity between Wof-Washa Forest and some other montane forests

Sorensen's coefficient of similarity analysis generates the floristic similarity between Wof-Washa Forest and other montane forests of Ethiopia were summarized in Table 35.

Table 35. Comparison of Wof-Washa Forest and some montane forests in Ethiopia

Forest	Altitude(m.a.s.l)	N	a	b	c	Ss
Jibat ^a	2200-2900	53	27	109	26	0.286
Chilimo ^a	2400-2800	31	22	114	9	0.263
Wof-Washa ^a (1993)	2400-3000	28	24	112	4	0.293
Menagesha ^a	2400-3000	30	27	109	3	0.325
Dense ^b	2125-2921	84	65	71	19	0.591
Wof-Washa ^c (1995)	2400-3000	59	56	60	3	0.65
Wof-Washa ^d (2018)	2348-3498	134	132	0	0	1

Data source: ^aTamrat Bekele (1993), ^bErmias Lulekal (2014) and ^cDemel Teketay and Tamrat Bekele (1995), and (N = Number of species included in comparison; a = species common to both forests to be compared; b = species available only in Wof-Washa^d; c = species available only in the other forest including Wof-Washa^a and c compared, Ss = Sorensen's coefficient of similarity)

Table 37 showed that Wof-Washa Forest (2018) has the highest values of Sorensen's similarity with the previous study of the same forest or Wof-Washa (1995)^c with 65 % species similarity followed by Dense (59 %) and Menagesha Suba State Forest (32.5 %). The low

species similarity value was recorded from Chilimo forest (26.3 %) followed by Wof-Washa Forest itself (1993) (Table 35).

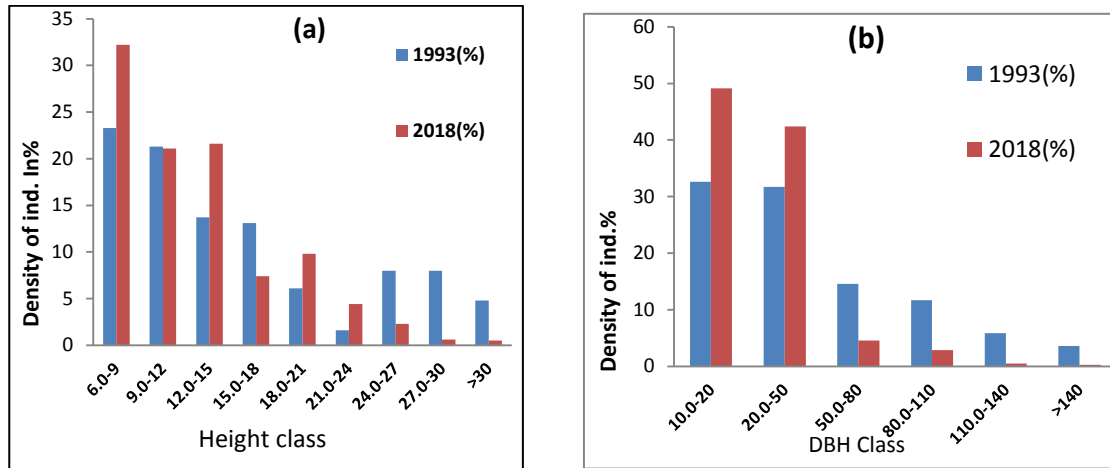


Figure 24. Comparison of percentage distribution of individuals in height and DBH classes in Wof-Washa Forest (1993 and 2018)

The highest height and DBH class distribution of woody species of Wof-Washa Forest both in 1993 and 2018 showed similar patterns with large species population density in the lower height and DBH classes with progressive decline towards the high height and DBH classes (Figure 31). As indicated in Figure 29 a and b, the higher DBH and height classes were contributed a significant number of individuals in the population structure of the previous study (1993). In the current study, the population structure indicated that the higher DBH and height classes were highly declined whereas the lower DBH and height classes were contributed large number of individuals.

Table 36 showed that *Juniperus procera* accounted the highest basal area in both study periods (1993 and 2018) whereas *Podocarpus falcatus* was ranked second in 1993 but in 2018, *Erica arborea* accounted the second basal area contribution of Wof-Washa forest. The basal area contribution of the subsequent ranks of *Ilex mitis*, *Euphorbia ampliphylla* and *Hagenia abyssinica* (1993) were replaced by *Pittosporum viridiflorum*, *Maesa lanceolata*, and *Hypericum revolutum* respectively.

Table 36. Basal area and density of the five most important tree species for the two periods (1993 and 2018)

Woody Species	Year (1993)					Year (2018)				
	Basal area		density		Species rank	Basal area		density		Species rank
	m ² /ha	%	stems/ha	%		m ² /ha	%	stems/ha	%	
<i>Juniperus procera</i>	62.9	61.8	78	7.7	1	38.6	25.2	122.4	11.7	1
<i>Podocarpus falcatus</i>	16.3	16.0	144	14.0	2	15.41	10.1	97.1	9.3	3
<i>Ilex mitis</i>	8.4	8.3	83	8.1	3	9.6	6.3	24.5	2.3	8
<i>Euphorbia ampliphylla</i>	5.2	5.1	50	4.9	4	1.61	1.1	5.3	0.5	32
<i>Hagenia abyssinica</i>	2.3	2.3	3	0.3	5	7.3	4.8	35	3.3	9
Total	95.1	93.5	358	35.0		72.52	47.3	284.3	27.1	

4.2. Soil seed bank study

4.2.1. Species composition of soil seed flora

A total of 76 plant species, 5549 seedlings (2596 per m²) (2948 in the 0-3 cm surface layer, 1494 seedlings in the 3-6 cm layer and 1107 seedlings in the 6-9 cm layer) were recovered from soil samples of Wof - Washa Forest. Herbs dominate the soil seed flora, represented by 63 species (82.9 %) followed by 8 tree species (10.53 %), Liana species 3 (3.95 %), and shrub species with 2(2.63 %) (Appendix 12). Of the tree species, six were indigenous (*Olea europaea* subsp. *cuspidata*, *Ficus sur*, *Juniperus procera*, *Maesa lenceolata*, *Hypericum revolutum* and *Vernonia amygdalina*) and two were exotic species (*Eucalyptus globulus* and *Eucalyptus camaldulensis*). The dominant families were Poaceae and Asteraceae with seven species each followed by Brassicaceae (5 species), Apiaceae and Polygonaceae with four species each while Caryophyllaceae, Commelinaceae, Crassulaceae, Geraniaceae, Lamiaceae,

and Solanaceae consists three species each. The rest 24 families were represented by either one or two species (Appendix 15).

Table 37. Seedling composition of woody species in the seed bank layers in Wof-Washa Forest

<i>Species</i>	0-3 cm	3-6 cm	6-9 cm	Total
<i>Maesa lanceolata</i>	18	0	3	21
<i>Solanum bundrianum</i>	4	0	5	9
<i>Vernonia amygdalina</i>	4	1	3	8
<i>Eucalyptus camaldulensis</i>	1	0	5	6
<i>Juniperus procera</i>	1	3	0	4
<i>Calpurnia aurea</i>	3	0	1	4
<i>Ficus sur</i>	3	0	0	3
<i>Smilax aspera</i>	1	2	0	3
<i>Eucalyptus globulus</i>	2	0	0	2
<i>Hypericum revolutum</i>	2	0	0	2
<i>Clusia abyssinica</i>	1	1	0	2
<i>Urera hypselodendron</i>	1	1	0	2
<i>Olea europaea</i> subsp. <i>cuspidata</i>	1	0	0	1
Total	42	8	17	67

Thirteen woody species with 67 seedlings were identified from soil seed flora of Wof-Washa Forest. *Maesa lanceolata*, *Solanum bendrianum*, and *Vernonia amygdalina* were represented by 21, 9 and 8 seedlings respectively. About 62.68 % seedlings of the woody species identified from soil seed bank were found in the upper layer (0-3 cm) and 22.37 % from the bottom layer (6-9 cm) (Table 39).

Table 38. Density of seeds identified by seed count method from woody species

Woody Species	Number of seeds in the litter layer
<i>Juniperus procera</i>	192
<i>Discopodium penninervum</i>	36
<i>Maesa lanceolata</i>	15
<i>Galiniara saxifraga</i>	11
<i>Rosaabyssinica</i>	7
<i>Osyris quadripartita</i>	2
Total	263

4.2.2. Soil seed density

A total 5549 seedlings (2596 seedlings/m²) and 263 seeds were recovered from the upper nine centimeters and litterfall assessed using seedling emergence and direct seed counting methods respectively. The highest density of seeds (52.5 % of the seed densities in the soil seed banks of Wof-Washa Forest) was contributed by the five most abundant species of herbs (*Crasula alsinoides*, *Nephrophyllum abyssinicum*, *Oxalis corniculata*, *Eragrostis schweinfurthii* and *Callitriche oreophila*) (Table 39).

Table 39. Species with abundant seedlings germinating from soil seed bank in Wof-Washa Forest

Species	Soil seed bank layers(cm)			
	0-3	3-6	6-9	Total
<i>Crasula alsinoides</i>	495	445	427	1367
<i>Nephrophyllum abyssinicum</i>	322	175	112	609
<i>Oxalis corniculata</i>	177	84	97	358
<i>Eragrostis schweinfurthii</i>	132	96	78	306
<i>Callitriche oreophila</i>	213	47	14	274
<i>Agrocharis melanantha</i>	189	34	21	244
<i>Dichondra repens</i>	144	75	10	229
<i>Eragrostis racemosa</i>	117	41	54	212
<i>Spilanthes costata</i>	151	34	8	193
<i>Trifolium repense.</i>	74	48	53	175
<i>Cyperus costatus</i>	86	33	27	146
<i>Cotula abyssinica</i>	57	19	35	111
<i>Galinsoga quadriradiata</i>	73	30	5	108
<i>Silene burchellii</i>	87	15	0	102
Subtotal	2317	1176	941	4434
Other species	631	318	166	1115
Total	2948	1494	1107	5549

Seedling density was variable among community types. The highest number of seedlings were observed community type one (C1) with 1949 seedlings respectively. At the species level, *Crasula alsinoides* contributes the maximum seedlings; i.e 1367 (24.64 %) followed by

Nephrophyllum abyssinicum with 609 seedlings (10.97 %) and *Oxalis corniculata* 359 seedlings (6.45 %) (Table 39).

4.2.3. Spatial distribution of seeds in the soil

There were great differences in the spatial (horizontal and vertical) distribution in both the number of species and seed densities in the soil seed bank.

Vertical distribution of seeds in the soil profile

Seed densities and number of species in soil seed bank showed the similar depth distribution pattern in all community types with the highest number of seed densities and number of species in the upper three centimeters of the soil and gradually declining with increasing soil depth (Figure 30). About 51 % of the recorded seedlings were identified in the upper three centimeters of soil followed by the second soil depth (3-6 cm) with 26% while the deeper layer (6-9 cm) contributed only 19 % of the total seed bank of Wof-Washa Forest. At the species level, the highest densities and number of seeds were identified in the upper three centimeter of soil seed bank layer, particularly *Crasula alsinoides*, *Nephrophyllum abyssinicum*, *Callitriche oreophila*, *Eragrostis schweinfurthii*, *Eragrostis racemosa*, *Agrocharis melanantha*, *Silene burchellii*, *Cyperus costatus*, *Oxalis corniculata*, *Galinsoga quadriradiata*, *Uebelina abyssinica*, *Cotula abyssinica* and *Spilanthes costata*.

The following species *Umbelicus botroides*, *Ajuga integrifolia*, *Stellaria media*, *Geranium arabicum*, *Crepis rueppellii* and *Datura stramonium* were represented highest seedling density at 3-6 cm soil depth (with 29, 23, 23, 22, 9, and 8) seedlings respectively (Appendix 12 and 13). *Cardamine trichocarpa*, *Plectranthus lanuginosus*, *Arabis thaliana*, *Sonchus bipontini*, *Plantago lanceolata* and *Conyza bonariensis* were represented in the deepest layer (6-9 cm) (Appendix 12).

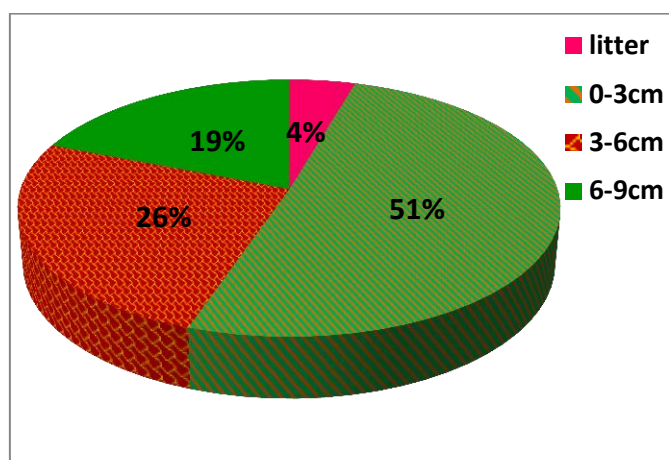


Figure 25. The density of seeds (number of seeds/ m²) recorded from the four layers

The vertical distribution of seedling densities exhibit variation among identified community types. Seeds of *Discopodium penninervum*, *Galiniara saxifraga*, *Rosa abyssinica* and *Osyris quadripartita* were entirely confined to the litter layer only. On the other hand, seedlings of *Crasula alsinoides*, *Nephrophyllum abyssinicum*, *Oxalis corniculata*, *Eragrostis schweinfurthii*, *Callitriche oreophila*, *Agrocharis melanantha*, *Dichondra repens*, *Eragrostis racemosa*, *Spilanthes costata*, *Trifolium repense* were relatively well distributed in all the three soil seed bank layers. The seedlings of *Conyza bonariensis*, *Plantago lanceolata*, *Arabis thaliana*, *Plectranthus languinosus* and *Cardamine trichocarpa* were distributed in the deeper soil seed bank layers.

In all community types, the litter layers had a lower number of species and densities of seeds compared with the top six centimeters of soil layers. Seed densities and number of species exhibit similar patterns of distribution in all the community types with minor variation. The upper three-centimeter soil layer shows the highest seed density in community type 1 followed by community type 4, community type 2, community type 3 and community type 5 with decreasing order (Figure 31). The seedling quantities decrease from the middle to the bottom layer in each community types. The seed density distribution in the litter layer varies from the three soil seed layers with the highest number of seeds in community type 3

followed by community 4. The lowest number of seeds was contributed by community type 2 (Figure 31).

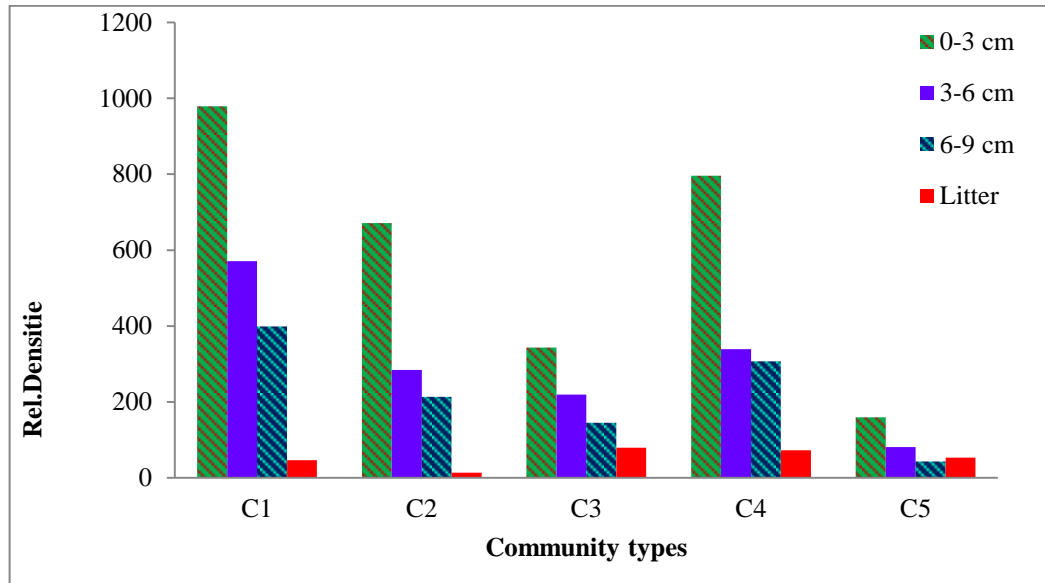


Figure 26. Vertical distribution of seedling densities with the respective community types. As indicated in Table 40, the pairwise correlation between community type showed significant variations among the compared community type pairs. Community type two and community type four accounted the highest soil seed bank species similarity (83%) followed by pairs between community types two and three. The lowest species similarity was observed between pairs community type two and five and community type four and five (Table 40).

Table 40. Pearson correlation results from Soil seed bank flora along the community types

CT	C1	C2	C3	C4	C5
C1	1				
C2	0.67	1			
C3	0.62	0.74	1		
C4	0.71	0.83	0.52	1	
C5	0.28	0.05	0.45	0.05	1

Horizontal distribution

Horizontal distribution of seeds showed considerable variations among community types. The highest seed density 1956 (35.2 %) was recorded from community type (C1) followed by community type four (C4) with a density of 1439 (25.9 %). The least soil seed density 283(5.1 %) was recorded from community type five (C5) (Figure 32).

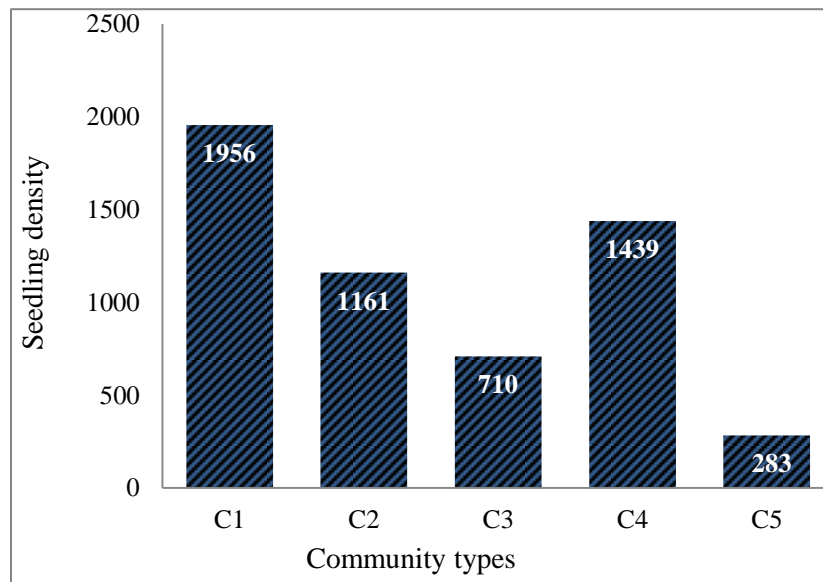


Figure 27. Density of seedlings along the respective community types

Jaccard's and Sørensen's similarity coefficient were used to compare the soil seed bank composition among community types. The result of the JSC and SS similarity coefficient indicates that the highest seed bank species similarity was found between community type one (C1) and community type four (C4) with JSC = 0.553, and SS = 0.712 followed by community type C2 and C4 with JSC = 0.473, and SS = 0.642 values. The lowest soil seed bank species similarity was also found between community type C2 and C5 with JSC = 0.213, and SS = 0.351 (Table 41). The similarity in species composition was generally low among community types.

Table 41. Jaccard's (JSC) and Sørensen's (SS) similarity coefficient of soil seed species composition among community types

Community type	C1	C2	C3	C4	C5
C1	1	0.449	0.453	<u>0.553</u>	0.407
C2	<i>0.619</i>	1	0.367	0.473	0.213
C3	<i>0.624</i>	<i>0.537</i>	1	0.373	0.268
C4	<i><u>0.712</u></i>	<i>0.642</i>	<i>0.543</i>	1	0.308
C5	<i>0.578</i>	<i>0.351</i>	<i>0.423</i>	<i>0.471</i>	1

Key: Values indicated in light blue and italicized refer to the Jaccard's (JSC) and Sørensen's (SS) similarity coefficient respectively

4.2.4. Relation between aboveground vegetation and soil seed bank of Wof-Washa

Forest

A total of 405 species were recognized in the vegetation and soil seed banks of Wof-Washa Forest. Of which 65 species (16 %) were present in both above ground vegetation and soil seed bank, 3% were found only in the soil seed bank and 81 % were in aboveground vegetation (Figure 33). Wof-Washa Forest plant diversity was mostly represented by herbaceous species confined to different families. Asteraceae (48 species), Poaceae (30 species), Cyperaceae (15 species), Fabaceae and Lamiaceae (each 14 species), Apiaceae (13 species) Brassicaceae (9 species) and Polygonaceae (8 species) among other families and contributed, the highest species richness (64.7 and 82.9 %) in both above ground and soil seed bank species of Wof-Washa Forest respectively. The least species richness was recorded from shrub species in soil seed bank (2.6 %) and liana in aboveground vegetation (4.6 %) (Table 42).

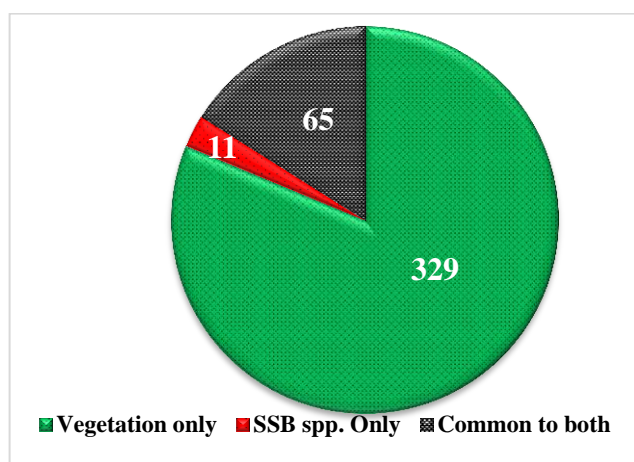


Figure 28. Proportion of vegetation, Soil seed bank and common species in Wof-Washa Forest

Sixty-five soil seed species were common to both soil seed bank and above-ground vegetation, only 12 (15.8 %) were recorded only in the soil seed bank species. Among the woody species (*Juniperus procera*, *Maesa lanceolata*, *Olea europaea* subsp. *cuspidata*, *Ficus sur*, *Vernonia amygdalina*, *Urera hypselodendron*, *Sparmannia ricinocarpa*, *Hypericum revolutum*, *Calpurnia aurea* and *Eucalyptus globulus* were found both in the aboveground vegetation and soil seed banks (Table 42).

Table 42. Growth habit classification of soil seed bank and above-ground vegetation based on their habit

No	Habit	Soil seed bank		Above ground Vegetation	
		Number of species	%	Number of species	%
1	Tree	8	10.5	49	12.4
2	Shrub	21	2.6	72	18.3
3	Herb	63	82.9	255	64.7
4	Liana	3	3.9	18	4.6
Total		76	100	394	100

Moreover, among the most abundant species in the above ground vegetation *Erica arborea*, *Myrsine africana*, *Podocarpus falcatus*, *Ilex mitis* and *Galiniera saxifraga* are not represented

in the soil seed bank and vice versa for (*Callitriche oreophila*, *Centella asiatica*, and *Eragrostis racemosa*) (Appendix 1 and 12).

Table 43. Jaccard's and Sørensen's coefficient of similarities JSC and SS of soil seed bank and above-ground vegetation species

CT	SSB species richness	Only in SSB	Vegetation species richness	Only to Vegetation	Common to both (a)	JSC	SS
C1	50	42	88	67	10	0.08	0.16
C2	36	30	104	63	8	0.08	0.15
C3	29	23	87	78	7	0.06	0.12
C4	44	35	115	101	10	0.07	0.13
C5	23	21	102	62	6	0.07	0.13

Species similarity between the soil seed bank and above-ground flora was very low (ranging from values of 0.06 to 0.08 in JSC, and 0.12 to 0.16 in SS). The lowest species similarity was recorded in community type three (C3) and the highest was in community type one (C1) (Table 43). Although there are more common species in soil seed bank and above-ground vegetation, high species richness of above ground vegetation reduces the species similarity between the soil seed bank and above-ground flora.

4.3. Carbon stock study

4.3.1. Carbon stock in the different carbon pools

The carbon stock contribution of Wof - Washa Forest showed variation in storage capacity among the carbon pools (above ground and below ground, soil, litter and dead wood biomass) showed different carbon stock sequestration capacity. The largest carbon stock fraction of the forest (51 % of the carbon stock) was accounted by the above ground carbon stock. About 34 % of the carbon stock was comprised in soil organic carbon. Below ground carbon comprised the third share (10 %) of the total carbon stock of Wof - Washa Forest. The least amount of carbon (0.1 ± 0.1 t/ha) was accounted for litter biomass followed by dead wood carbon pool

(3.9 %) (Table 44). The carbon sequestration potential of Wof-Washa Forest was about 1042.99 ± 869.22 t CO₂ eq /ha (Table 44). The forest level carbon sequestration potential in CO₂ equivalence would be $3,334,439 \pm 2,778,896.34$ t CO₂. Thus, Wof-Washa Forest has a high carbon stock (284.19 ± 236.83 t/ha) potential that enables the country to generate more money from carbon trade using REDD+ initiatives and CDM.

Table 44. Carbon stock and the corresponding carbon dioxide values of the carbon pools of Wof-Washa Forest (\pm SD) in t/ha, CO₂ in t/ha and CO₂ t/forest

Carbon Pools	Mean carbon stock(t/ha)	CO ₂ eq. in t/ha	CO ₂ eq. in t/ total forest area
AGC	143.5 ± 139.4	526.7 ± 511.6	$1,683,859.9 \pm 1,635,585.2$
BGC	28.7 ± 27.8	105.3 ± 102.0	$336,644.1 \pm 326,094$
SOC	97.19 ± 54.53	356.69 ± 200.12	$1,140,337.9 \pm 639,783.64$
LC	0.1 ± 0.1	0.4 ± 0.4	$1,278.8 \pm 1,278.8$
DWC	14.7 ± 15.0	53.9 ± 55.1	$172,318.3 \pm 176,154.7$

Note: AGC: Aboveground carbon, BGC: Below ground carbon, LC: Litter carbon, SOC: Soil organic carbon and DC: Deadwood carbon.

The carbon stock potential of Wof-Washa Forest distribution varies among community types. Community type two (C2) accounted the highest carbon stock (t/ha) in above ground, below ground and soil carbon (Table 45). The least carbon stock (t/ha) in the AGC was contributed by community type one (C1) whereas the least carbon stock in the soil carbon was obtained from community type five (C5). The maximum and minimum carbon stock of dead wood carbon was recorded from community types three (C3) and four (C4) respectively.

Table 45. Carbon stock among the five community types (t/ha)

	AGC(t/ha)	BGC(t/ha)	SOC(t/ha)	LC(t/ha)	DC(t/ha)
C1	108.30 ± 196.75	21.66 ± 39.35	105.16 ± 53.62	0.06 ± 0.05	19.00 ± 12.61
C2	189.75 ± 160.72	37.95 ± 32.14	113.23 ± 54.39	0.05 ± 0.03	17.24 ± 18.31
C3	114.73 ± 46.64	22.95 ± 9.33	90.02 ± 53.92	0.04 ± 0.04	20.90 ± 21.64
C4	169.33 ± 77.09	33.87 ± 15.42	88.46 ± 55.84	0.10 ± 0.09	7.86 ± 10.38
C5	141.87 ± 84.17	28.37 ± 16.83	80.55 ± 55.61	0.11 ± 0.05	8.49 ± 7.93

Note: CT=community type, C1= community type one, C2 = community type two, C3 = community type three, C4 = community type four, and C5 = community type five

4.3.1.1. Aboveground carbon biomass and stock

Carbon stocks in the dominant tree species

Wof-Washa forest is characterized by few high-density tree species including *Juniperus procera*, *Erica arborea*, *Podocarpus falcatus*, *Pittosporum viridiflorum*, *Maesa lanceolata*, *Hypericum revolutum*, *Hagenia abyssinica* and *Maytenus arbutifolia*. The highest aboveground carbon stock per hectare was contributed by *Juniperus procera* (32.48 %) followed by *Podocarpus falcatus* (11.07 % t/ha) and *Pittosporum viridiflorum* (7.24%). About 86.32 % of the above ground carbon stock was contributed by fifteen woody species of the forest while the rest plant species were accounted only 13.68 % of the above ground carbon stock (Appendix 16).

The high carbon stock was contributed by, *Juniperus procera*, *Podocarpus falcatus*, *Rhus natalensis*, *Teclea nobilis*, *Ilex mitis*, *Polyscias fulva* and some others (Table 46).

Table 46. The above and below ground carbon stock of 16 woody species

Species name	AGC (t/ha)	BGC (t/ha)
<i>Allophylus abyssinicus</i>	2.98 ± 4.5	0.6 ± 0.91
<i>Bersama abyssinica</i>	3.35 ± 4.25	0.55 ± 0.85
<i>Erica arborea</i>	1.8 ± 2.88	0.07 ± 0.18
<i>Euphorbia abyssinica</i>	9.94 ± 8.7	1.99 ± 1.74
<i>Ficus sur</i>	7.07 ± 15.6	1.41 ± 3.13
<i>Galiniera saxifraga</i>	1.53 ± 2.38	0.31 ± 0.48
<i>Hagenia abyssinica</i>	4.48 ± 7.77	0.9 ± 1.55
<i>Ilex mitis</i>	7.96 ± 14.6	1.59 ± 2.92
<i>Juniperus procera</i>	9.5 ± 40.62	1.9 ± 8.12
<i>Maesa lanceolata</i>	3.5 ± 4.47	0.7 ± 0.89
<i>Olea europaea</i> subsp. <i>cuspidata</i>	5.47 ± 6.8	1.09 ± 1.36
<i>Pittosporum viridiflorum</i>	4.59 ± 6.19	0.92 ± 1.36
<i>Podocarpus falcatus</i>	4.09 ± 14.19	0.82 ± 2.84

<i>Polyscias fulva</i>	7.14 ± 9.66	1.43 ± 1.93
<i>Rhus natalensis</i>	9.59 ± 12.58	1.92 ± 2.52
<i>Schefflera abyssinica</i>	3.81 ± 3.97	0.76 ± 0.79

Carbon stock in different DBH classes

The amount of above ground carbon stock increased with increasing the DBH with some irregularities around 50-60 DBH. The density of individuals in DBH classes and above ground vegetation carbon stock showed a strong negative correlation in which as the DBH increase aboveground carbon stock increase while the density of individual showed a clear decline with correlation coefficients ($r = - 0.7$ and $P = 0.05$).

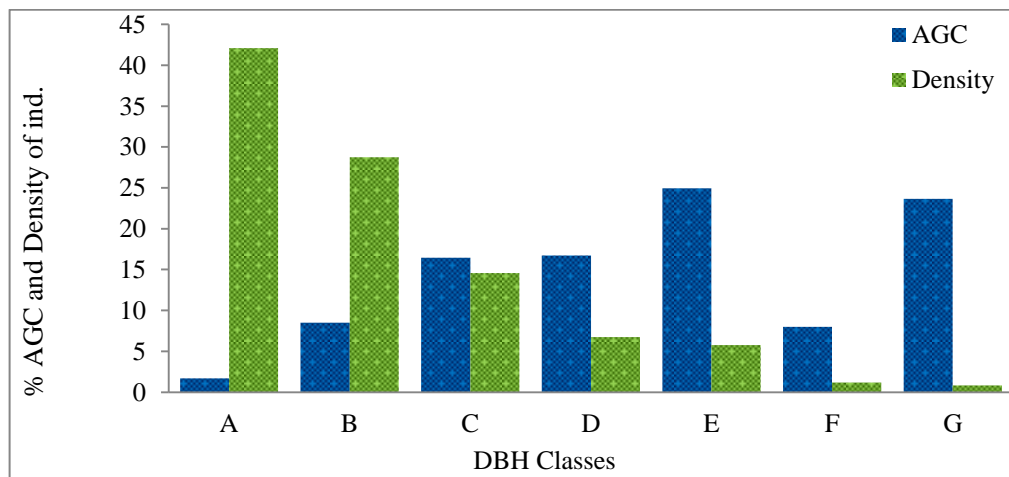


Figure 29. Density and % aboveground carbon stock of Wof-Washa Forest across DBH Classes

Note: A = < 10, B = 10.1-20, C = 20.1-30, D = 30.1-40, E = 40.1-50, F = 50.1-60 and G = > 60 cm

The highest aboveground carbon stock was found in community type two (189.75 ± 160.7 t/ha) followed by community type four (169.33 ± 77.1 t/ha). The smallest aboveground carbon stock was also found in community type one (108.30 ± 196.7 t/ha) (Table 47). The basal area distribution showed a similar pattern with aboveground biomass with the highest value in community type two and the smallest value in community type one (Table 47). The

highest above ground carbon was found in community type two followed by community type four and the smallest value was found in community type one.

Table 47. Aboveground carbon stock (t/ha) and basal area (m²/ha) among the community types (\pm SD)

Community types	BA(m ² /ha)	AGC(t/ha)
C1	1.18 \pm 1.27	108.30 \pm 196.7
C2	2.091 \pm 0.57	189.75 \pm 160.7
C3	1.34 \pm 0.45	114.73 \pm 46.6
C4	1.91 \pm 0.81	169.33 \pm 77.1
C5	1.68 \pm 0.87	141.87 \pm 84.2

4.3.1.2. Below Ground carbon stock

The contribution of belowground carbon stock (28.7 \pm 27.8 t/ha) is higher than litter (0.1 \pm 0.1t/ha) and dead wood (14.7 \pm 15.0 t/ha) carbon stock and less than both the soil organic carbon stock (194.4 \pm 109.1 t/ha) and above ground (143.5 \pm 139.4 t/ha) carbon stock (Table 45). The distribution patterns of belowground carbon stock showed similar trends with the aboveground carbon stock and biomass densities with the maximum values (37.95 \pm 32.14 t/ha) and the minimum values (21.66 \pm 39.35 t/ha) found in community type two and one respectively (Table 48).

Table 48. Below ground carbon stock across community types

Community type	BGC(t/ha)	CO ₂ equi. t/ha
1	21.66 \pm 39.35	79.49 \pm 144.41
2	37.95 \pm 32.14	139.28 \pm 117.95
3	22.95 \pm 9.33	84.23 \pm 34.24
4	33.87 \pm 15.42	124.30 \pm 56.59
5	28.37 \pm 16.83	104.12 \pm 61.77

4.3.1.3. Deadwood and litter carbon stock

The carbon stock of dead wood was computed from both dead fallen and dead standing carbon pools and accounted 7.94 \pm 11.85 and 6.75 \pm 8.96 respectively (Table 50). Among the

95 study plots fallen dead wood were not recorded in 16 study plots and no data from 18 plots for standing dead wood were taken. Among the three categories of dead wood, sound dead wood has accounted higher carbon stock (10.9 ± 13.05) than both the rotten and intermediate classes (Table 49).

Table 49. Density classes of fallen dead wood in Wof-Washa Forest

LDW class	density(g/cm^3)	Carbon(t/ha)
Rotten	0.56 ± 0.0	5.63 ± 7.2
Intermediate	0.86 ± 1.4	8.98 ± 14.13
Sound	1.05 ± 4.01	10.9 ± 13.05

At the community level, the highest dead wood carbon stock was contributed by community type three (20.90 ± 21.60 t/ha) and the lowest was at community type four (7.86 ± 10.40 t/ha). Community type five contains relatively the higher values of litter carbon stock among other community types (Table 50).

Leaf litter of Wof-Washa Forest has contributed the lowest carbon stock (0.1 ± 0.1 t/ha) of the forest that comprises 0.4 ± 0.4 CO₂ equivalent t/ha and $1,278.8 \pm 1,278.8$ CO₂ eq. in t/total forest area (Table 44).

Table 50. Dead wood and litter carbon stock (t/ha) in Wof-Washa Forest (\pm SD)

Community Types	Deadwood carbon(t/ha)	Litter carbon(t/ha)
C1	19.00 ± 12.60	0.06 ± 0.06
C2	17.24 ± 18.30	0.05 ± 0.03
C3	20.90 ± 21.60	0.04 ± 0.04
C4	7.86 ± 10.40	0.10 ± 0.09
C5	8.49 ± 7.90	0.11 ± 0.05

4.3.1.4. Soil organic carbon

The soil carbon pool had a significant contribution to the total carbon stock of Wof-Washa Forest. The soil carbon stock of Wof-Washa Forest was 97.19 ± 54.53 t/ha (Table 44). The corresponding carbon dioxide equivalent values sequestered by the soil would be

356.69 ± 200.12 CO₂ t/ha and 1,140,337.9 ± 639,783.64 CO₂ t/forest. The soil organic carbon of Wof-Washa Forest showed variation among community types in which community two contributed the highest soil organic carbon (113.23 ± 54.39 t/ha) followed by community type one (105.16 ± 53.62 t/ha). The least amount of soil carbon was obtained from community type five (80.55 ± 55.61 t/ha) (Table 44 and Figure 36).

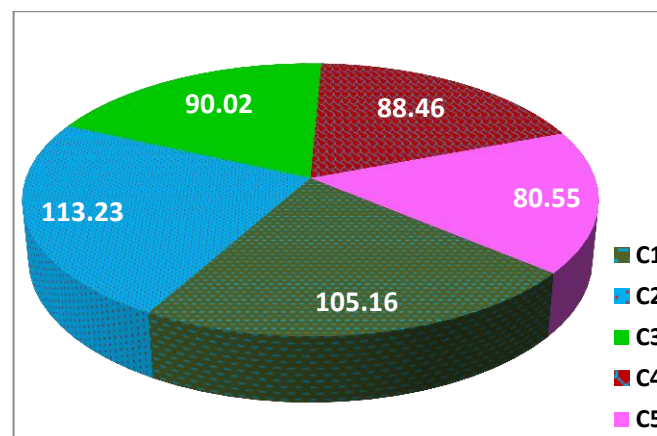


Figure 30. Carbon stock values of soil organic carbon in the five community types

4.3.2. Carbon Stocks variation along topographic variables

Carbon Stocks variation of the major Pools along altitude

The presence of variation in altitudinal gradient affects the carbon stock of different pools in Wof-Washa Forest. The lower altitude has high above ground carbon stocks while the middle and the upper altitude have moderate and low carbon stocks in aboveground carbon. The aboveground carbon stock recorded at the lower, middle and upper altitude were 178.6 ± 99.8, 139.5 ± 98.6 and 111.3 ± 203.7 (t/ha) respectively (Table 51). Similar patterns of carbon stock distribution were shown in below ground and litter carbon pools with the highest value found in the lower altitude followed by the middle and upper altitude (Table 51).

Table 51. Carbon stock (t/ha) in different pools along altitudinal gradient

Altitude class	AGC	BGC	SOC	LC	DC
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Lower	178.6 ± 99.8	35.7 ± 20.0	77.56 ± 50.12	0.1 ± 0.1	6.9 ± 7.8
Middle	139.5 ± 98.6	27.9 ± 19.7	103.23 ± 55.63	0.05 ± 0.0	16.9 ± 18.6
Higher	111.3 ± 203.7	22.3 ± 40.7	110.26 ± 53.6	0.06 ± 0.1	19.9 ± 12.5

Where, altitude range for lower altitude class = 2000-2500, Middle altitude class = 2501-3000 and Higher altitude class=3001-3500.

In contrast to the aboveground and belowground biomass, the soil organic carbon density shows the reverse pattern with above and below ground carbon along the altitudinal gradient. The maximum and minimum soil carbon stock density was found in higher and lower altitude with 110.26 ± 53.6 and 77.56 ± 50.12 t/ha respectively. In general, the cumulative carbon stock of the five carbon pools showed that the maximum carbon stock was found in the higher altitude among the altitude classes followed by the middle altitude class (Table 51).

Carbon Stocks of pools along the aspects

Aspect is another parameter that affects the carbon stocks of different pools. Seven major aspects were recorded in Wof-Washa Forest during data collection (East-E, North-N, North East-NE, South-S, South East-SE, South-West-SW, and West-W). Based on the result of this study, the aboveground carbon stock value was lowest in SE (76.5 ± 76.5 t/ha) and highest in the SW (234.9 ± 0.0 t/ha). A similar trend was observed for carbon stocks in belowground carbon pool with the lowest and highest value of 15.3 ± 15.3 and 47.0 ± 0.0 t/ha in SE and SW direction respectively. On the other hand, the highest carbon stocks in soil organic carbon were recorded in the NE with 276.0 ± 91.0 t/ha and the minimum in SW 153.3 ± 0.0 t/ha. The lowest and the highest carbon stocks of litter were also recorded in SW (0.03 ± 0.1 t/ha) and North (N) (0.1 ± 0.1 t/ha) respectively. Maximum carbon stocks of the dead wood were recorded from E, NE and SE with 18.5 ± 17.0 , 18.0 ± 21.5 and 17.4 ± 14.7 t/ha respectively. Carbon stock from litter fall was not recorded in SW and W aspects of the forest. In general, soil organic carbon has higher than aboveground carbon stocks in most aspects except in the North, South and Southwest aspects of the forest (Table 52).

Table 52. The (\pm SD) carbon stock (t/ha) in the major pools along the identified the aspects

Aspect	AGC	BGC	SOC	LC	DC
E	126.5 \pm 91.8	25.3 \pm 18.4	115.32 \pm 49.02	0.1 \pm 0.1	18.5 \pm 17.0
N	228.0 \pm 107.5	45.6 \pm 21.5	83.85 \pm 42.6	0.1 \pm 0.1	7.9 \pm 7.6
NE	153.3 \pm 137.1	a 30.7 \pm 27.4	138.00 \pm 45.5	0.1 \pm 0.1	18.0 \pm 21.5
S	186.8 \pm 219.4	37.4 \pm 43.9	82.64 \pm 54.9	0.1 \pm 0.1	10.8 \pm 10.6
SE	76.5 \pm 76.5	15.3 \pm 15.3	83.53 \pm 55.1	0.1 \pm 0.1	17.4 \pm 14.7
SW	234.9 \pm 0.0	47.0 \pm 0.0	76.65 \pm 0.0	0.0 \pm 0.0	0.5 \pm 0.0
W	132.4 \pm 78.6	26.5 \pm 15.7	113.37 \pm 70.5	0.0 \pm 0.0	16.0 \pm 19.6

Carbon stock estimated in Wof-Washa Forest revealed that the average total carbon stock was relatively similar to other forests in Ethiopia. Similar studies were done in different forests of Ethiopia and showed different amounts of total carbon stock estimated. Hamere yohannes *et al.* (2015) estimated an average carbon stock (523.6 t/ha) of Gedo forest. Talemso Seta (2017) also found out 392.3 t/ha average carbon stock for Boter Becho forest in Gibe Watershed. Mesfin Sahle (2011) estimated the average total carbon stock of Menagesha Suba State Forest (286.53 t/ha) (Table 53).

Table 53. Carbon stock estimates of different carbon pools by different Authors

Authors name	AGC	BGC	Soil C	L C	DWC	Name of Forests
Abel Girma <i>et al.</i> (2014)	237.2	47.6	57.6	6.5	-	MZMF
Adugna Feyissa <i>et al.</i> (2017)	278.08	55.62	277.56	3.47	-	Egdu
Belay Melese <i>et al.</i> (2014)	414.7	83.48	83.8	1.27	-	AMGW
Hamere Yohannes <i>et al.</i> (2015)	281	56.1	183.69	0.41	-	Gedo
Mesfin Sahile (2011)	133	26.99	121.28	5.26	-	MSSF

Mohammed Gedefaw <i>et al.</i> (2014)	306.37	61.52	274.32	0.9	-	Tara Gedam
Tamene Yohannes(2017)	466.08	93.22	155.75	2.51	-	Gergeda
Telemos seta (2017)	189.4	43.98	159.31	0.3	-	Boter Becho
Tulu Tolla (2011)	122.85	25.97	135.94	4.95	-	AACF
Present study	143.5	28.7	97.19	0.1	14.7	Wof-Washa

Note: MZMF- Mount Zequalla Monastery Forest, AMGW - Ariba Minch Ground Water Forest, AACF-Addis Ababa selected Church Forests, MSSF- Menagesha Suba State Forest

4.4. Land use land cover dynamics

The classified images (Figures 37, 38 and 39) obtained after pre-processing and supervised classification of the multi-temporal satellite images and Table 54 depicts the LULC status of Wof-Washa Forest in three decades (1985 – 2015). Part of the forest and most areas of bare land existed in 1985 map showed a progressive decline in 2000 and 2015 maps (Table 54 and Figure 37-39). The map of 2000 and 2015 also showed expansion of agricultural land and settlement areas. Plantation showed relatively larger area coverage in 2000 map and reduced in 2015 map (Table 54).

The classification result of the Land sat TM 1985 image revealed that natural forest accounts the largest proportion of study area (area of interest) with a value of 3395 ha (35 %), followed by Bare land contributes 2933 ha (30.2 %) and grassland 2266 ha (23.4 %). The least coverage was attributed to agricultural land that accounted 437 ha (4.5) while there was no plantation record in this period. From overall land use land cover classes, 58.4 % (5661 ha) of the study area was covered by green vegetation such as natural forest and grassland while the remaining 41.6 % (4032 ha) was covered by the settlement, bareland and agricultural land (Table 54).

Table 54. Area coverage and classification results of LULC type (ha)

LULC Classes	1985		2000		2015	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area(%)

Agricultural land	437	4.5	3,565	36.8	3,710	38.3
Bare land	2,932	30.2	1,435	14.8	1,137	11.7
Grass land	2,266	23.4	512	5.3	534	5.5
Natural forest	3,395	35.0	3,223	33.3	3,197	33.0
Plantation	0	0	145	1.5	61	0.6
Settlement	663	6.8	813	8.4	1,054	10.9
Total	9,693	100	9,693	100	9,693	100

In 2000, the dominant LULC classes were agricultural land, Natural forest and bareland with 3565 ha (36.8 %), 3223 ha (33.3 %) and 1435 ha (14.8 %) respectively. Plantation covers 1.5 % of the land use land cover classes. Settlement and grassland accounted 813 ha (8.4%) and 512 ha (5.3 %) respectively. Of all land use land cover classes, 3880 ha (40.03 %) was covered by green vegetation due to natural forest, plantation, and grassland while the remaining 59.97 % (5813 ha) was covered by agricultural land, bare land, and settlement in 2000.

The 2015 image analysis of Wof-Washa Forest revealed that agricultural land is the dominant LULC class, 3,710 ha (38.3%) followed by natural forest that accounted 3,197 ha (33 %). Bare land and settlement also cover 1,137 ha (11.7%) and 1,054 ha (10.9 %) respectively. The least LULC class was accounted by plantation that covers only 0.6 %. About 3,792 ha (39.12 %) of the study area (area of interest) was covered by green vegetation such as forest, plantation, and grassland but the remaining 5901 ha (60.88 %) was covered by agricultural land, bare land, and settlement (Table 54). In general, over the whole study period natural forest, grassland and bare land showed a progressive decline while settlement and agricultural land showed steady increment from 1985 to 2015.

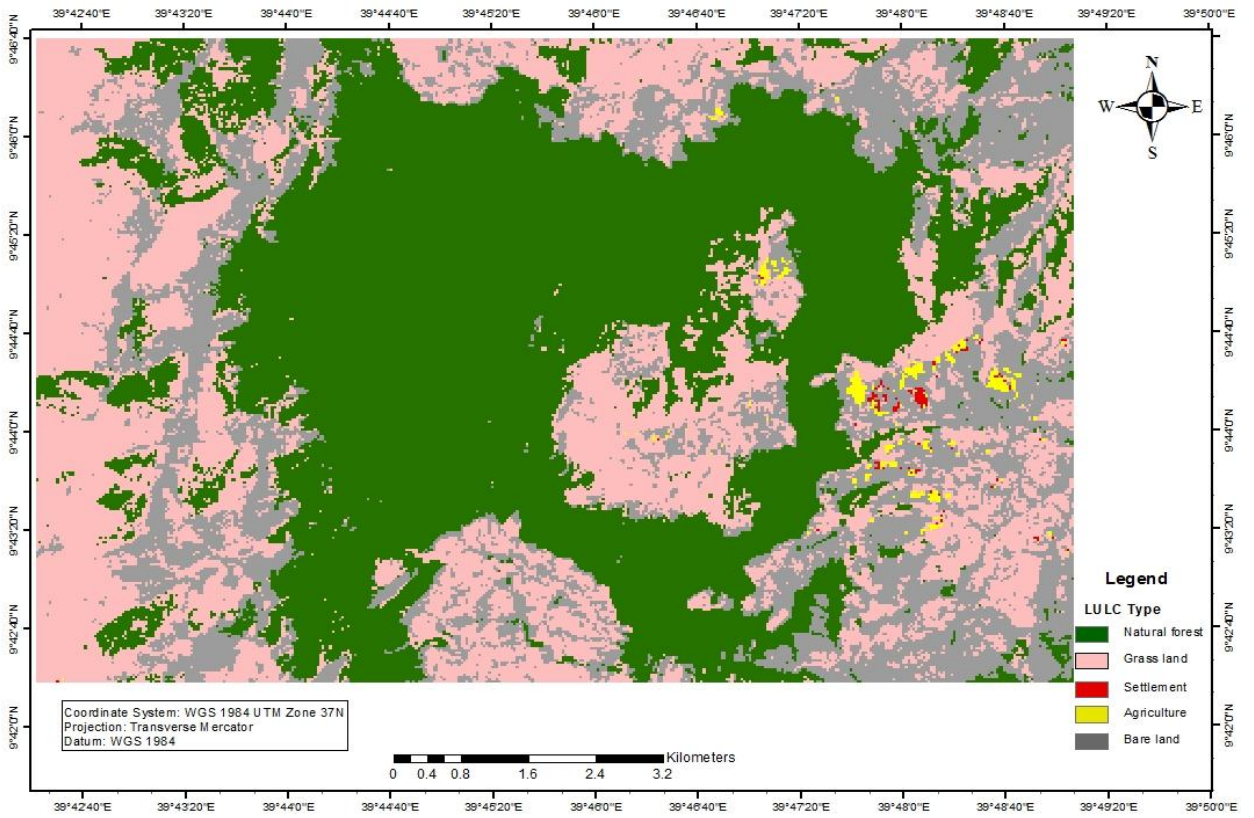


Figure 31. Land use /land cover map of Wof-Washa Forest (1985)

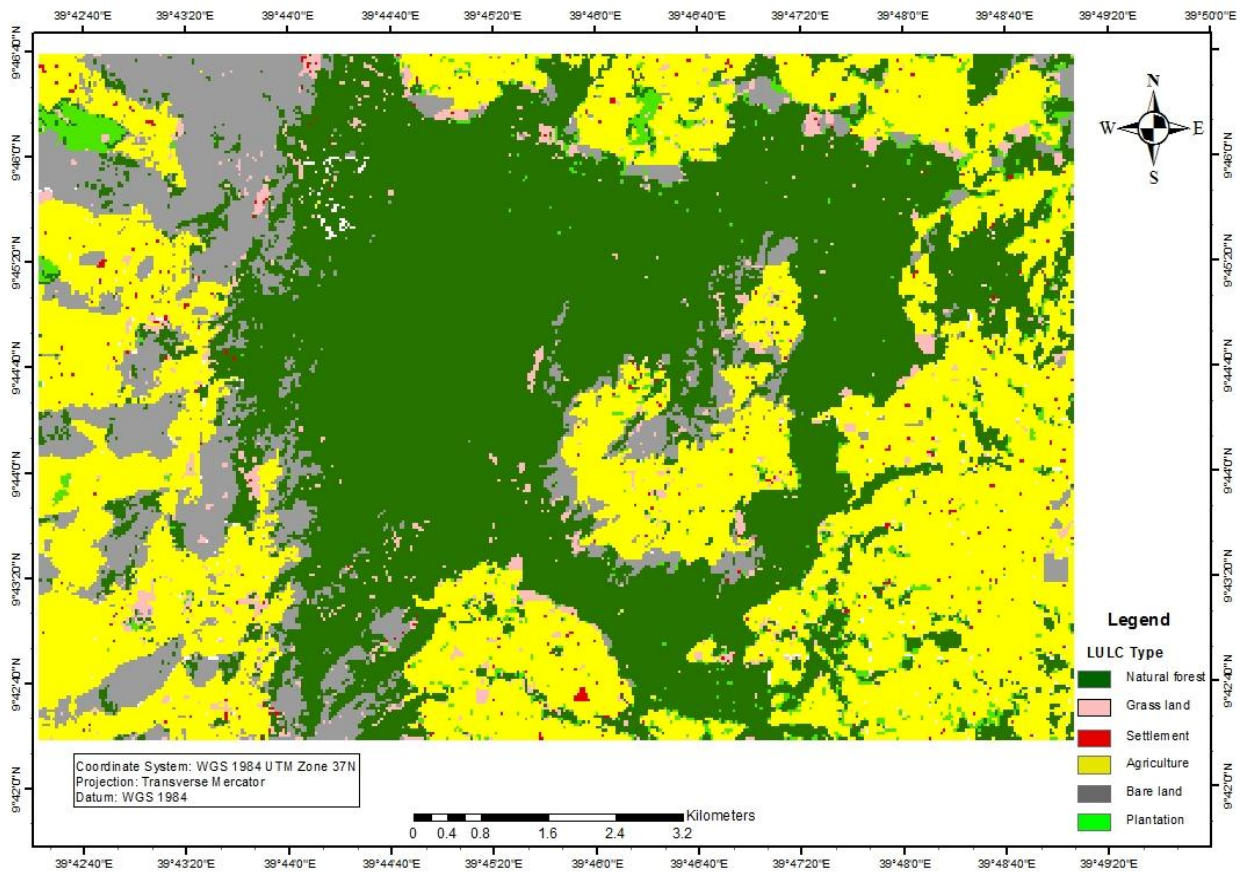


Figure 32. Land use /land cover map of Wof-Washa Forest (2000)

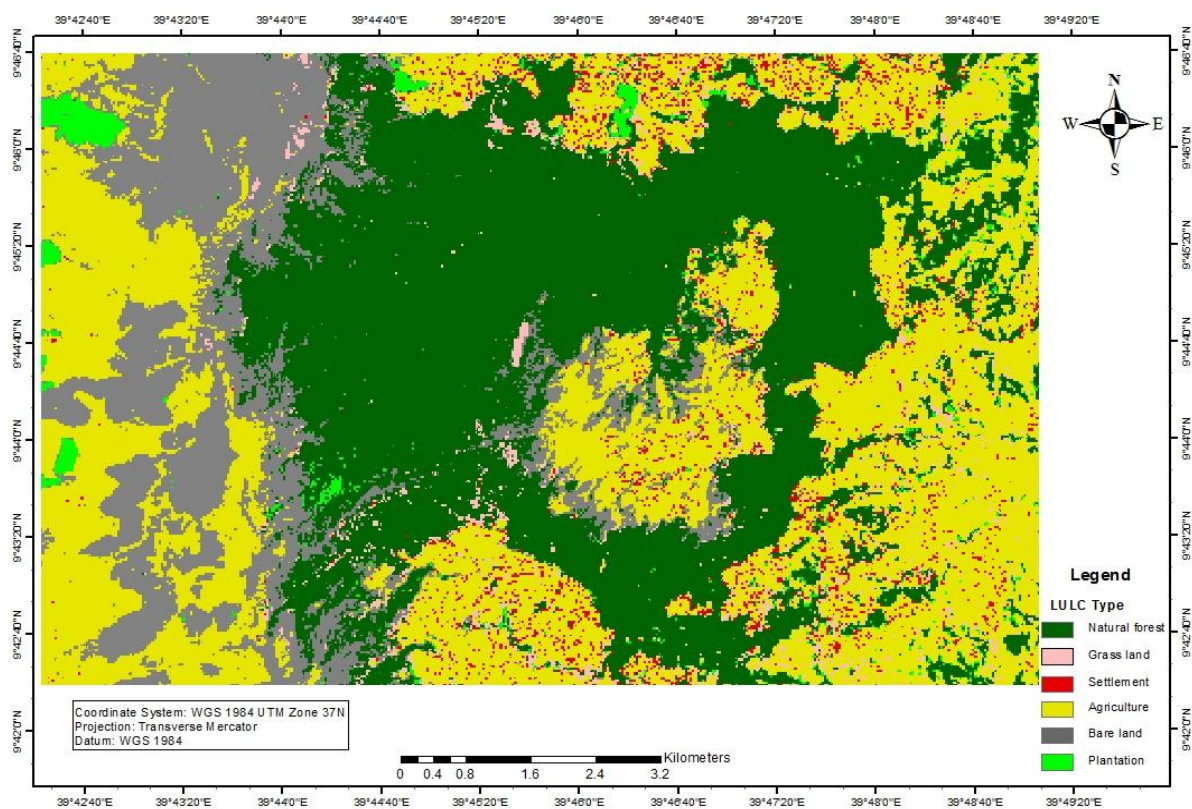


Figure 33. Land use /land cover map of Wof-Washa Forest (2015)

Accuracy Assessment

One of the most important final steps in classification process is accuracy assessment. The overall classification accuracy assessment and Kappa coefficient values of the three reference year's i.e. 1985, 2000 and 2015 is indicated below in (Table 55).

Table 55. Classification accuracy assessment of Wof-Washa Forest for the year (1985, 2000 and 2015)

Year	Overall accuracy (%)	Kappa coefficient
1985	83.87	0.7683
2000	83.33	0.7835
2015	80.95	0.7688

Land use/land cover change from 1985 to 2015

The post-classification change detection analysis was done using ENVI 5.1. The cross-tabulation matrices (Figure 40) indicated the direction of change and change extent from 1985 to 2015 among land use land cover classes. As results (Figure 40) showed, from 3,395 ha of forest area in 1985, 2,955 ha was still forest area in 2015 but, 267 ha was converted to agricultural land, 158 ha was converted to bare land and 16 area of the forest was converted to grassland. At the same time the expansion of agricultural land from 1985 to 2015, was mainly from bare land (1,334.6 ha) and grassland (1,063). During this time interval, more forest areas (179 ha) were converted to bare land. About 61 ha of the plantation was done on the grassland (45 ha) and bareland (16 ha) and the plantation has no expansion towards the natural forest, agricultural land and settlement areas in 2015. Grassland class retained only 336 ha from the total 2,266 ha in 1985 and was reduced to 534 ha and mainly replaced to agricultural land (1063 ha) and settlement areas (524 ha) and to bareland (257 ha) in 2015 (Figure 40). The expansion of settlement was mainly from grassland (524 ha) and bareland (500 ha).

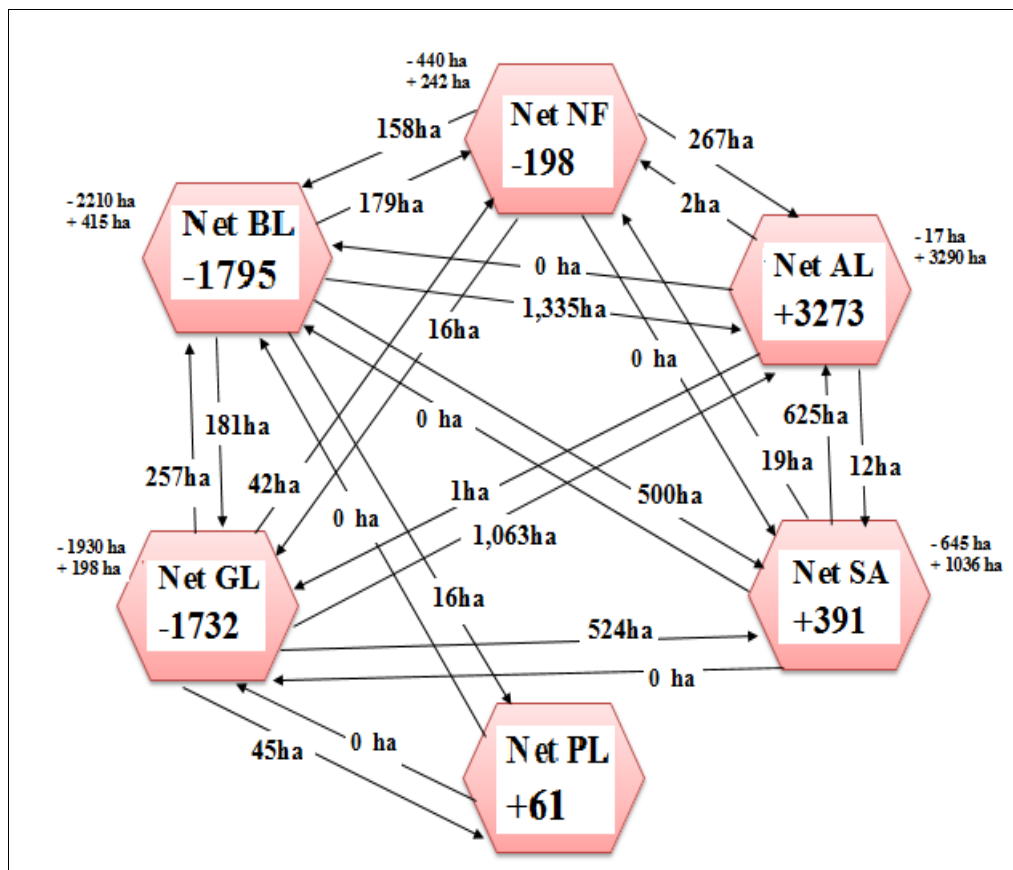


Figure 34. Land use land cover dynamics of 1985-2015 among the land use types

4.4.1. Rate of Land Use/Land Cover Changes

Results presented in Table 54 showed expansion of agricultural land, settlement, and plantation while natural forest, bareland, and grassland were showed a decline with a considerable amount in the whole study period (1985-2015). In 1985-2000 periods, agricultural land was increased by 3128 ha which is around 208.53 ha/year. Settlement and plantation area also increased by 150 ha (10 ha /year) and 145 ha (9.67 ha /year) (Table 54). In contrast, grassland, bare land, and natural forest were reduced by 1754, 1497, and 172 ha respectively. The rate of change (ha/year) of grassland, bareland, and natural forest were 116.93, 99.8, and 11.47 (ha/year) respectively.

During 2000-2015, the settlement was increased by 241 ha (16.07 ha/year), agricultural land also increased by 145 ha which is approximately equivalent to 9.67 ha/year. Grassland

showed smaller increment, 22 ha (1.47 ha /year). On the contrary, Bareland, natural forest and plantation were reduced by 298, 26 and 84 ha respectively. In the whole study period (1985-2015), agricultural land showed the highest increment (3273 ha) which is 109.1 ha/year followed by settlement area 391 ha (13.0 ha/year). Bareland, grassland, and natural forest showed a significant decline with 1795, 1732 and 198 ha respectively. The rate of change of decline in bareland, grassland, and natural forest were 59.8, 57.7, and 6.6 ha/year respectively (Table 54).

4.4.2. Driving forces for LULC change and forest destruction

Anthropogenic disturbance exists in all forest vegetation of Ethiopia (Bonnevillie and Hamilton, 1986). Human disturbance has led to excessive deforestation in the Afromontane zone of Ethiopia (Tesfaye Bekele, 2000). The study area is one of the most intensively cultivated areas with a long history of population settlement coupled with deforestation and cattle grazing that led to intense land use change and biodiversity loss. Population pressure leads to farm steeper slopes, encroachment into the forest with grazing, and looking for additional income generating activities such as timber production and traditional apiary. The type and intensity of disturbances were reflected by trampling, a number of new stumps, browsing and animal trails in each sample plots. The visible indicators of pressures are the presence of a number small functional shades near to each barn for shepherds, the presence of beehives on the trees. Grazing is noted by the occurrence of cropped vegetation and trampled seedlings, the frequent presence of fresh cow dung and presence of more than 19 barns within Wof-Washa Forest. The presence of new stumps and branch debris on the ground confirmed the presence of cutting in Wof-Washa Forest. In general, the combined impact of these variables could increase the threat to the biodiversity of the forest particularly for rare species (*Prunus africanus*, *Hagenia abyssinica*, and *Schefflera abyssinica*) and to ecologically and

economically most significant species of the forest (*Juniperus procera*, *Podocarpus falcatus*, and *Erica arborea*). Thus, such intensive and holistic human influences indicated livestock grazing and fuelwood, agricultural expansion, and timber productions are the most pressing issues in Wof-Washa Forest

The presence and functionality of the number of barns (Appendix 19) in Wof -Washa forest are the visible indicators of anthropogenic pressures and showed that the wild animals competition with domestic animals for food, shelter, and other necessary requirements. From the field observation, we have seen that some wild animals move to the farmland in search of food while the livestock lives in the forest. Thus, it is possible to forecast the future existence of biodiversity of the area. The most common species (*Urtica simensis*, *Chenopodium morale*, *Discopodium penninervum* and *Oenante palustris*) growing around the barns are disturbance indicators those can grow either in the backyard or degraded areas.

CHAPTER FIVE

5. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

5.1. DISCUSSION

5.1.1. Floristic composition

The results of this study showed that Wof-Washa Forest is rich in species composition with the presence of 394 species. The observed rich plant species of the forest might be attributed to topographic heterogeneity that includes deep gorges, a number of peaks, plateau, and rivers, that create a specific multitude of microhabitats and nest different set of organisms which in turn accounted to the distribution patterns and variations in species composition. The higher species diversity of the forest was due to the herbaceous species richness favored by a strong anthropogenic disturbance in the forest. This was evidenced by the frequent prevalence of disturbance indicator species such as *Bersama abyssinica*, *Dodonea angustifolia*, *Croton macrostachyus*, *Phytolacca dodecandra* and *Kalanckoe petitiiana*. The previous study of the same forest by Demel Teketay and Tamrat Bekele (1995) about 23 years ago identified a total of 252 plant species of which 80 % were herbs. In addition, Wof-Washa Forest is within Eastern Afromontane biodiversity hotspot, one of the most diverse and richest in plant species composition (Mittermeier *et al.*, 2011; Ermias Lulekal, 2014). It has higher species richness than other Afromontane forests in Ethiopia such as Jibat (131 species) (Tamrat Bekele, 1994), Zegie (113 species) (Alemnew Alelign *et al.*, 2007), Mena Angetu (212 species) (Ermias Lulekal *et al.*, 2008) and Dense (158 species) (Ermias Lulekal, 2014). The distribution pattern of plant species over different habitats of the forest could be attributed to a number of environmental factors, which impose impacts in both temporal and spatial scales (Shmida and Wilson, 1985). Thus, environmental heterogeneity, regeneration capacity, moderate disturbance, and competition might shape and determine species richness of the forest.

Family Asteraceae has the highest representation of species (62 species) in Wof-Washa Forest and this could be attributed the large number of pollen grains, efficient and successful dispersal strategies and better structural and physiological adaptation to a wide range of ecological conditions. The high dominance of Poaceae might attributed the by the reduced floral structure, ability to produces more seeds and wind pollination have enabled the species in the family to be an extremely successful plant in wide elevation ranges. Furthermore, gramineae are also known to adapt open, marginal and disturbed habitats. Fast germination ability and symbiotic properties might have enabled species in family Fabaceae to easily establish and adapt to different habitat types. Fabaceae is the richest family in species richness followed by Poaceae and Asteraceae in the Flora area of Ethiopia. Thus, the predominance of Asteraceae, Poaceae, and Fabaceae in Wof-Washa Forest could be attributed to their wider ecological and altitudinal adaptation and abundance in the flora area (Hedberg and Edwards, 1989; Hedberg *et al.*, 2006; Mesfin Tadesse, 2004, Ensermu Kelbessa and Sebsebe Demissew, 2014).

The highest representation of herbaceous species in Wof-Washa Forest as compared to other growth forms might be due to high anthropogenic disturbance, low density, and frequency of shrub and tree species with open canopy layer that allow light and poor regeneration of most tree species. Furthermore, human intervention and the opening of forests by selective cutting for different purpose may increase the growth of herbaceous species in the dry Afromontane forest of Ethiopia (Ermias Lulekal *et al.*, 2008; Haile Yineger *et al.*, 2008). This result agrees with similar patterns of the dominance of herbaceous species in other montane forests (Abiyoun Tilahun *et al.*, 2011; Fekadu Gurmessa *et al.*, 2013).

With regard to endemism, 46 (11.68 %) endemic species were identified in Wof-Washa Forest and is within the range of endemic plant species of Afromontane forests of Ethiopia

(10-15 %) (Friis and Sebsebe Demissew, 2001; Teshome Soromessa and Ensermu Kelbessa, 2013). This result agrees with the basic features of Eastern Afromontane forests and Horn of Africa biodiversity hotspots known to harbor diverse endemic species (White, 1978). This high endemism might be due to diverse topographic features and the area is within the two biodiversity hotspots and conservation priority areas known by endemism (Sebsebe Demissew *et al.*, 1996). According to White (1978), the Afromontane region is an important center of endemism housing over 3000 endemic plant species.

5.1.2. Plant community types and species diversity

The observed variation in species diversity could be explained by the difference in altitudinal gradients, the effect of environmental variables, habitat disturbance reflected by cattle barns, the presence of traditional beekeeping, and the presence of roads within the forest and undulated peaks on the western and northwestern part. In addition, Wof-Washa Forest is surrounded by 14 sub districts of the three districts, hence subjected to severe anthropogenic pressure, particularly timber production from *Juniperus procera* and *Podocarpus falcatus*, fuelwood production from *Erica arborea* and *Olea europaea* subsp. *cuspidata*, year-round free grazing has a great contribution to the variation in floristic composition among community types. Similar findings were reported by (Hedberg, 1964; Alemayehu Wassie *et al.*, 2005 and Neelo *et al.*, 2015). The species distribution pattern in a plant community is a reflection of physical gradients (Altitude ranges, soil heterogeneity, and microclimate types), biotic response to these gradient and human-induced factors in the region (Urban *et al.*, 2000).

The lower evenness value in community type one indicates the dominance of few species such as *Erica arborea* (Ericaceous belts) below the cliffs along the terrains and afro-alpine and sub-afroalpine species. Similar general patterns in *Erica arborea* dominated dry Afromontane forest at higher altitudinal ranges were stated by (Demel Teketay and Tamrat

Bekele, 1995; Haile Yineger *et al.*, 2008; Ermias Lulekal, 2014). Apart from such threats, traditional beehives are found with a few meter distances in this community type, which is a potential threat to fire. The low Simpson equitability of this community type indicates the unbalanced distribution of the number of individuals among different species in which few species (*Erica arborea*) were represented by a large number of individuals.

Community type two also showed the overlap of altitude between community one and three in the upper and lower altitude respectively. The overlap of plant communities indicated the presence of shared species between and/or among community types showing similar adaptation tolerance and requirements. High frequency of *Juniperus procera* in the forest indicated the spatial distribution of species, contribution of the species to the carbon stock, ecological and economic benefits of the species to the livelihood of the local communities. Community type two includes most degraded plots in the forest where eleven barns locally known as “Beret” are found and free grazing is extremely persisting. Scattered and few large-sized *Juniperus procera* trees with open grazed fields with rare seedlings, saplings, and larger herbaceous species. From field observation, it was evident that community type two was found heavily affected by the local people who were involved in clearing forest species for farm implements, fuelwood, fence, construction and selective cutting for timber production. Thus, anthropogenic disturbances could be attributed to the low woody species diversity, low seedling, and sapling density as well as low overall woody plant abundance. The lower storey of this community type was invaded by *Chenopodium murale* and *oenanthe palustris* and the shrub layer was dominated by *Solanum marginatum*, *Discopodium penninervium*, *Hypericum revolutum* and *osyris quadripartita*.

Community Type three is known by extreme livestock grazing, trampling both by human and domestic animals and fuelwood collection by the local people contributed to the low diversity

and abundance of only large woody plant species in this community type. In addition, the presence of permanent footpaths that connect the two districts (Ankober and Tarmaber) has played a significant role in illegal timber and charcoal production and transportation (Table 41). Furthermore, the presence of eight barns in this community type exacerbate pressure to the wild animal and plant species diversity and therefore, the area is most vulnerable community type for disturbances due to its close proximity to human settlement areas and accessibility for livestock.

The highest species richness and diversity in community type four would be due to inaccessibility coupled with the presence of more dangerous wild animals that protect the vegetation from human disturbance, free grazing and trampling by domestic animals. The highest basal area, highest species richness, Shannon diversity index, the highest density of sapling and seedling in this community type indicated the need for special conservation and management priority and are urgent issues to the area. Furthermore, the steep slopes surrounding the streams and small rivers might create a microclimate and site-specific productivity that protect the area from dry warm air coming from Afar lowlands as compared to the surrounding slopes of other community types.

The least density of mature tree species, saplings and smallest basal area in this community type might be due to a narrow range of altitude, study plot sites where expansion of agriculture and settlement aggravate the human disturbance indicated by the leftover stumps, footpaths, charcoal kilns and cow dung might lead to such woody species diversity and dominance of few woody species. This community type contains highly disturbed plots by grazing, selective cutting, trampling and agricultural land expansion. Few and scattered woody species such as *Psydrax schimperiana*, *Halleria lucida*, *Euphorbia ampliphylla*, *Celtis africana*, *Dodonea angustifolia*, *Toddalia asiatica* and *Turraea holstii* were recorded in this

community type. *Hyparrhenia hirta* is the dominant grass on the edge of Wof-Washa Forest towards the lower altitude and is in the inaccessible areas of the cluster. The presence of more individuals of *Croton macrostachyus*, *Dodonaea angustifolia* *Discopodium penninervum*, and *Maesa lanceolata* indicated the past anthropogenic disturbance.

This community type showed better species similarity to community types of three and four. This is due to the geographical proximity and overlaps in elevation and climatic conditions led to having shared species, which have similar resource requirement, disturbance resistance, and niche preference.

The highest β -diversity between community's types two and five have indicated the species heterogeneity between the community types or low level of species similarity between the compared community types. This might due to altitudinal variation in which most of the plots of community type five is located in the lower altitude while the plots of community type two are found in the middle and upper altitude of the forest. In addition, the microhabitat productivity, variation in soil type and level of anthropogenic disturbance might accounted for this variation. The low beta diversity value obtained between community type one and four might be associated with habitat homogeneity.

Species diversity

The variation in species richness and evenness among plant communities might be due to habitat productivity, topographic heterogeneity and difference in disturbance intensity. Altitude and slope had a significant contribution to the species distribution pattern in the forest. The lower and middle altitude comprised more plant species than the higher altitude. Low species richness in community type three is due to trampling, browsing in free grazing, fuelwood collection and agricultural expansion. In addition, most of the major roads crossing the forest were found in this community type and some of the plots were towards the Eastern

periphery of the forest where livelihood activities such as farm implements and charcoal making were quite common. The value of species richness has a great importance in assessing the taxonomic, structural and ecological value of the forest (Abiyu Tilahun *et al.*, 2011).

5.1.3. Ordination

Plant species distribution patterns and plant community formation highly influenced by environmental gradients, microclimate, soil physical and chemical heterogeneity, and anthropogenic factors (Hedberg, 1964; Friis, 1992; Tadesse Woldemariam, 2003; Whittaker *et al.*, 2003). CCA analysis result showed the distribution pattern of species among community types, the influence of environmental variables and the response of species to the underlying environmental variables. Thus, CCA ordination biplot diagram exhibits the association of species in the five clusters along the underlying environmental variables. The position of study plots in the ordination diagram reveals that floristically most similar plots with similar adaptation and tolerance projected close to each other while plots that vary differently are projected apart from each other. Thus, the first axis denotes the influence of altitude, disturbance, and slope on plant species distribution and clustering of the five community types into three distinguished groups. The size of each eigenvalue shows how much variance is represented by each axis. This indicates that the first axis is strongly related to the most important environmental variables, altitude in this analysis. Hence, community type one is located in the middle left of the ordination diagram, community type three and two in the middle and community type five and four in the middle right. CCA2 also denotes that aspect and clay influences community type five to be projected far to the top right. CCA1(axis one) significantly negatively correlated with altitude, total nitrogen, slope, and disturbance while CCA2 (axis two) positively correlated with aspect and clay. Altitude and slope are important

environmental variables resulting in major difference among plant community types in Wof-Washa Forest. Similar altitudinal impacts were reported by many authors such as Zerihun Woldu and Ingvar, 1991; Tamrat Bekele, 1994; Feyera Senbeta, 2006; Tadesse Woldemariam *et al.*, 2008 and Motuma Didita *et al.*, 2010. Other environmental factors such as aspect and physical and chemical properties of soil were also related variously with the CCA axes (Axes 1- 4) indicating that each variable has their own share in determining distribution patterns of plant communities and community formation in Wof-Washa Forest (Table 16).

5.1.4. Vegetation Structure

Analysis of results showed that the vegetation structure of Wof-Washa Forest was characterized using Height, DBH size class distribution, density, frequency and basal area (Tamrat Bekele, 1994).

The distribution pattern of woody species along altitudinal gradients depicts gradual decline in woody species diversity and abundance towards the higher altitude. Thus, the highest number of tree species were recorded at the lower altitude (2300-2800 m. a. s. l.) in which community type four and five found. At and above 2900 m. a. s. l both the number of species and their density (except *Erica arborea*) decreases and becomes very few around 3400 m.a.s.l and it is dominated by *Erica arborea*, few individuals of *Pittosporum viridiflorum*, *Hagenia abyssinica* on the shaded area and *Helichrysum citrispinum* species intermingled with *Festuca* grasses and *Kniphofia foliosa* on the shallow soil of the cliffs in the terrains. Thus, elevation gradients showed spatial distribution pattern of plant species in the forest. Results from Beta diversity also exhibited variation in the spatial patterns of species diversity that can provide insights into the selection and protection of conservation priority areas with high species richness and diversity.

Tree and shrub density

The total density of mature woody species with DBH > 2.5 cm in Wof-Washa Forest was 1046.6 individual's ha⁻¹(Table 20). Most plant species were represented only by few individuals in some specific habitats and few species such as *Juniperus procera* dominate most part of the forest. This type of plant species distribution pattern is common to most tropical forests (Valencia *et al.*, 1994 cited in Ermias Lulekal, 2014). The ratio of DBH > 10 cm and >20 cm describes the measure of size class distribution. The ratio of individuals' density with DBH between 10 and 20 cm of Wof-Washa Forest was 1.92. This ratio value indicates a predominance of small-sized individuals and past anthropogenic disturbances and /or excessive cuttings of the higher individuals (Grubb *et al.*, 1963). The number of individual woody species reduces in mature tree species (303.7/ha) as DBH (>20 cm) in all the five community types. The density of individuals in both height and DBH class distribution of species showed inverted -J shape indicating a selective disturbance in the higher height and DBH classes. The ratio of > 10 cm and >20 cm of Wof-Washa Forest is higher than Dodola forest (1.5) (Kitessa Hundera *et al.*, 2007), Komto (1.5) (Fekadu Gurmessa *et al.*, 2012) and Dense (1.5) (Ermias Lulekal, 2014).

Erica arborea, *Juniperus procera*, *Podocarpus falcatus*, *Maesa lanceolata*, *Hypericum revolutum* and *Pittosporum viridiflorum* were found to be the most abundant species in Wof-Washa Forest. Only three species (*Erica arborea*, *Juniperus procera*, and *Podocarpus falcatus*) contribute 395.3 density/ha (37.8 %) in the higher density class. *Juniperus procera* showed similar distribution patterns in all Wof-Washa Forest with more density of individuals in community type four and sparsely distributed at the ericaceous belt. The lowest density (< 5) was recorded from *Prunus africana*, *Dombeya torrida*, *Schefflera abyssinica*, *Celtis africana*, *Olea capensis* subsp. *macrocarpa*, *Myrica salicifolia*, *Teclea nobilis*, *Buddleja*

polystachya and *Premna schimperi*. In general, most species of trees and shrub species were found in the lower density class and few species only reach to the higher density classes in all the five community types. However, these species were the most abundant and contribute more to the total density.

The difference in density might be attributed to the variations and influence of altitude, habitat preferences of species and the degree of anthropogenic disturbances in the forest (Whittaker *et al.*, 2003). The density of mature woody species in Wof-Washa Forest is lower than Dense (1138 individuals' ha⁻¹) (Ermias Lulekal, 2014); Dindin (1750 individuals' ha⁻¹) (Simon Shibru and Girma Balcha, 2004) and Masha Anderacha (1709 individuals' ha⁻¹) (Kumlachew Yeshitela and Tamrat Bekele, 2002).

Diameter and Height class distribution

The inverted J-shaped distribution pattern that contained 80.2 % of individuals in the lowest height class (5-15 m) indicated selective cutting in larger individuals and related human-induced pressures which led to such structural dynamics of species in the forest. Similar height class distribution was observed in all the five community types that revealed the highest height densities were found in the lower altitude (< 15 m) height classes. Thus, seed production for future regeneration would be difficult as mother trees had harvested before seedling and sapling replace them. Species distribution in DBH classes showed similar trends with height class. Most tree species (70.56 % of the total individual woody species) were found in DBH classes (< 20 cm) while a very small proportion (≤ 1.23 %) attain diameters between 50-60 cm. This result and the distributional trend agrees with Dense forest in Ankober district (44.58 % of individuals in < 20 cm DBH), where most species had the highest individuals in the lower DBH class with a gradual decrease towards the higher DBH classes. This kind of pattern was reported in the previous study of Wof-Washa, Chilimo and

Menagesha Suba Forest (Tamrat Bekele, 1993); Dense forest (Ermias Lulekal, 2014). This distribution pattern of species in the forest both in terms of height and DBH was attributed by abundant presentations of few small tree and shrub species such as *Erica arborea*, *Hypericum revolutum*, *Myrsine africana*, *Maytenus arbutifolia*, *Rosa abyssinica* and *Discopodium penninervum* in the lower height and DBH classes. Feyera Senbeta and Demel Teketay (2003) derived a similar type of conclusion for inverted J-shaped distribution pattern. The largest tree found in Wof-Washa Forest is *Juniperus procera* (47 m height and 2.26 m in DBH). Comparable results were recorded for *Juniperus procera* by Tamrat Bekele (1993) with a DBH of 2.00 m for the same forest, Kitessa Hundera *et al.* (2007) with 2.29 m DBH, Hussien Adal (2014) (75 m height and 3.2 m DBH).

Basal area

According to Cain and Castro, 1959 cited in Ermias Lulekal, 2014, basal area provides a better measure of the relative importance of species than simple stem count and is used to measure the relative dominance of woody species in a forest. The total basal area per hectare of woody plant species of Wof-Washa Forest is 153. 26 m² ha⁻¹ which is higher than the previous study of the same forest (101.8 m² ha⁻¹) (Tamrat Bekele, 1993) and Menagesha Amba Mariam forest (84.17m²/ha) (Abiyou Tilahun *et al.*, 2015) and lower than Menagesha Suba (158.68 m² ha⁻¹) reported by Dinkissa Beche (2011). The basal area contribution of the lowest DBH class (<10 cm) was very small (5.79 m² ha⁻¹) while the middle and higher DBH classes contained the higher basal area of Wof-Washa Forest. The forest is dominated and characterized by aged and large-sized *Juniperus procera* almost in all forest areas except the Ericaceous belt and comprised the maximum basal area 38.96 m²ha⁻¹ (25.42 %) followed by *Podocarpus falcatus* 15.41 m²ha⁻¹ (10.05 %). Thus, the high basal area in *Juniperus procera* and *Podocarpus falcatus* showed the contribution of these species in climate change

mitigation to enhance carbon sequestration in the forest. Higher basal area indicates the volume occupied by the plant that in turn reflects the biomass and carbon stock stored. However, the density of other tree species in the higher DBH class is low and their contribution to the total basal area is also low. *Juniperus procera*, *Podocarpus falcatus*, *Pittosporum viridiflorum*, *Olea europaea* subsp. *cuspidata*, *Hagenia abyssinica*, *Maesa lanceolata*, *Ilex mitis*, *Hypericum revolutum*, *Erica arborea* and *Polyscias fulva* were the most important tree species contributing about 72.74 % of the total basal area (Table 26). However, *Erica arborea* accounts the highest density (16.8 %), but its contribution in the basal area was low and ranked 9th. This is due to a large number of smaller sized individuals (Table 26). The total density distribution pattern by DBH classes does not follow the same trend as that of the basal area (Table 20).

The presence of large-sized individuals of *Juniperus procera*, *Podocarpus falcatus*, *Maesa lanceolata*, *Ilex mitis* and *Bersama abyssinica* accounted the highest basal area in community type four. On the contrary, lowest basal area record in community type five was due to dominance of small-sized individuals of woody species. Basal area of Wof-Washa Forest is higher than Masha-Anderacha (81.9 m² ha⁻¹) (Kumelachew Yeshitila and Taye Bekele, 2003); Dodola (129 m² ha⁻¹) (Kitessa Hundera *et al.*, 2007) and Mana Angetu (94 m² ha⁻¹) (Ermias Lulekal *et al.*, 2008).

Frequency

Results of this study showed that the largest proportions of species were distributed in the lower frequency class in all community types with an irregular decline in the successive higher frequency classes. The frequency of most woody species is generally low in Wof-Washa Forest. Thus, the result showed floristic heterogeneity of Wof-Washa Forest. However, *Juniperus procera* was found to be the most frequent tree species in Wof-Washa

Forest followed by *Myrsine africana*. The low frequency of most species indicated the presence of floristic heterogeneity in the forest. However, the degree of heterogeneity varied among the five community types and altitude classes. The high value of frequency in lower frequency class and low-frequency value in the higher frequency class show the floristic heterogeneity whereas high value in higher frequency class and low value in lower frequency class indicates homogenous nature of forest (Simon Shibiru and Girma Balcha, 2004). According to Priya *et al.* (2005), high frequency of few species like *Juniperus procera* in this study revealed a more uniform distribution of such species with a wide range of habitat adaptability, the degree of disturbance tolerance and availability of suitable environmental conditions for the regeneration of such species.

Importance Value Index

According to Lamprecht (1989), high density and high-frequency values coupled with high basal area indicate the overall dominance of a species in vegetation and the relative ecological significance of species in a forest. In this study IVI value indicated that *Juniperus procera*; *Erica arborea*, *Podocarpus falcatus*, *Pittosporum viridiflorum* and *Maesa lanceolata* were ecologically significant species of Wof-Washa Forest and could determine and /or influence the overall community structure. However, the values contributed by IVI components (relative frequency, relative density, and relative dominance) vary greatly among woody species i.e. *Juniperus procera* comprised the highest relative basal area and highest frequency and higher relative dominance while *Erica arborea* had the highest relative density but much lower values of relative basal area and frequency. *Juniperus procera* showed high density and a high frequency indicating the regular horizontal distribution in the forest. High density, low frequency, and low basal area are typical for under strata species indicated by species such as *Myrsine africana* and *Dodonaea angustifolia*. on the other hand, species such as *Ilex mitis* and

Olea europaea subsp. *cuspidata* in the upper strata showed the low contribution to the total basal area (Appendix 11) due to their representation in very few and large-sized individuals. Although some species showed only high values of one of the IVI components raise the overall IVI value and lead to having higher IVI rank, it depends on the nature and growth habit of the species. Therefore, IVI ranks and/ or values might obscure the ecologically significant species by other species.

In general, the analysis result of IVI values in Wof-Washa Forest confirmed that the three species (*Juniperus procera*, *Erica arborea*, and *Podocarpus falcatus*) are the most important/dominant species in Wof-Washa Forest.

5.1.5. Species Population structure

Species-specific population structure analysis of 25 most dominant woody species of the Wof-Washa Forest showed five major representative patterns of density of trees species across the DBH classes. The pattern of population structure reflects variations in population dynamics and regeneration status of species in the forest.

Population structure represented by species such as *Erica arborea*, *Podocarpus falcatus*, *Galiniera saxifraga*, and *Olinia rochetiana* indicates the presence of highest density of individuals at the lowest DBH class (< 10 cm) followed by a gradual decline with increasing diameter class. Such population pattern is an indication of a stable and healthier regeneration status and high potential of reproduction of the species where a large number of seedlings produced with a better proportion of saplings and mature tree species. Similar reports were reported in different afro-montane forests of Ethiopia (Tamrat Bekele, 1994; Demel Teketay and Granström, 1997; Getachew Tesfaye *et al.*, 2010 and Ermias Lulekal, 2014).

Hagenia abyssinica and *Olea europaea* subsp. *cuspidata* (Figure 25 d) showed regular density of individuals of the highest value in 10-20 cm DBH class with a progressive decline in the

higher DBH classes. Such pattern indicates good reproduction but, bad recruitment potential of the species interrupted by the selective cutting, harvesting of intermediate and large size populations and disturbance before reaching reproductive age. Thus, this has resulted in a decline of the species population and might distract regeneration of woody species in the future (Tamrat Bekele, 1993; Getinet Masresha, 2014).

The bell-shaped structure was represented by *Pittosporum viridiflorum* and showed the maximum diameter density at the middle class (30-40 cm) and gradual decrease towards the lower and the higher DBH classes. Such pattern is an indication of poor reproduction and recruitment potential of species. This could be affected by competition between seedlings and /or saplings with other tree species, trampling and grazing by domestic animals, which destruct seedlings and saplings and selective logging. The gradual decline of large-sized individuals is an indication of selective cutting for timber and other purposes. Ermias Lulekal *et al.*, (2008) and Fekadu Gurmessa *et al.*, (2012) reported similar results from various Afromontane forests of Ethiopia. Feyera Senbeta *et al.*, (2007); Woldeyohannes Enkossa (2008) and Getinet Masresha (2014) reported a similar suggestion for bell-shaped population structure.

Species such as *Ilex mitis*, *Ekebergia capensis*, *Euphorbia ampliphylla* and *Polyscias fulva* revealed a J-shaped pattern of distribution with a gradual increase in the density of individuals from the lower to the higher DBH class distributions. This population structure pattern suggests disturbance in the early stage, unfavorable microclimate for germination and regeneration potential and mechanism variation (Demel Teketay and Tamrat Bekele, 1995). *Hypericum revolutum* and *Maesa lanceolata* shown the highest individual density in the second DBH class (10-20 cm) and subsequently decrease towards the higher DBH class. This pattern suggests that the species had better reproduction but a bad recruitment potential. The

observed major population structure of woody plant species in Wof-Washa Forest are indicators and foundations to the identification of conservation priority species of the forest. The observed livestock grazing, stocking cattle in the barn and trampling affects the density of seedlings and saplings under the mother tree. In general, analysis of population structure of most woody species revealed J shaped of distribution while few species showed inverted –J shaped structure with some irregularities. Species under inverted -J shaped structure includes tree and shrubs whose reproduction and recruitment require assisted regeneration whereas J-shaped structure comprises species with relatively better reproduction as well as recruitment but poor in regeneration, indicating the need for conservation activities and priority setting for species with poor reproduction and hampered recruitment.

Vertical Stratification

Three vertical structures were identified in the vegetation of Wof-Washa Forest following Lamprecht (1989). The height distribution of woody species reflects that the highest point of the upper canopy (47 m) was attained by *Juniperus procera* tree. Crown of *Juniperus procera* rises above the general canopy level that enables the species to get full access to sunlight from above and on all sides than other smaller species. Multi-layered nature and height variation of emergent tree species such as *Juniperus procera*, *Podocarpus falcatus* and *Polscias fulva* made the forest to show a rough texture and inconsistent canopy layer. Thus, there is no clear and distinct canopy stratification displayed by the individual species present in the forest. Many species could not attain the middle and upper strata by their nature while others may be due to disturbance and removal before reaching to the middle and upper strata. In this study, the highest density of individuals (79 %) (including herbs, lianas, shrubs and small tree species) were found in the lower strata. The ability of lower storey vegetation to grow under the canopy layer depends on the conditions of the soil nature and the quantity of sunlight

received. All species that have representatives in the upper strata also appear in the middle and lower strata. This observation is in line with that of (Abate Ayalew *et al.*, 2006; Birhanu Kebede, 2010; Dinkissa Beche, 2011 and Abiyou Tilahun *et al.*, 2015). In general, the upper canopy (strata) of Wof-Washa Forest is dominated by *Juniperus procera* in most of the study area and *Podocarpus falcatus* and *Polyscias fulva* in the middle and lower altitude areas of the forest indicating the presence of characteristic species of dry Afromontane forest in the study area.

5.1.6. Regeneration status of woody species

As indicated in reversed J-shaped patterns of distribution, the regeneration status of most species in the forest was low. The main reason for low and poor regeneration status of most dominant species could be due to seed predation by domestic and wild animals, grazing, browsing and trampling, the intensity of herbivore grazing, human encroachment, germination style, seed viability, and regeneration mechanisms and seed dispersal limitations. Ecologically important tree species (*Juniperus procera*, *Ilex mitis*, and *Polyscias fulva*) of Wof-Washa Forest had few numbers of seedlings and saplings. There were no seedling and sapling records for species such as *Agarista salicifolia*, *Clerodendrum myricoides*, *Cordia africana*, *Diospyros abyssinica*, *Dracaena steudnerii*, *Erythrina brucei*, *Euphorbia abyssinica* and *Grewia ferruginea*. In addition, the tree layer of the forest do not form a continuous canopy layer, in such condition, reduced canopy layer would lead to soil desiccation that hampers regeneration potentials of tree species. Furthermore, increase in canopy gaps to the edge of the forest might create conditions for the expansion and rapid seedling establishment of fast growth pioneer shrubs and herbaceous species which have the high competitive capacity to replace the native forest species.

Species such as *Prunus africana* and *Ilex mitis* showed poor regeneration which might be due to disturbance such as grazing and trampling. Low seedling density in *Erica arborea*, *Juniperus procera*, *Pittosporum viridiflorum* and *Cassipourea malosana* might be influenced by biotic, edaphic and other abiotic ecosystem factors including seed predators, grazers, canopy cover for seedling recruitment, nature of seed dormancy breakage in relation to environmental factors, and pathogens could also affect the nature of seed germination, propagation and reproduction (Getinet Masresha, 2011; Abiyou Tilahun *et al.*, 2015).

The reversed J-shaped pattern revealed in *Podocarpus falcatus*, *Hypericum revolutum*, *Osyris quadripartita* and *Myrsine africana* indicating potentials of replacement of mature plants in the future. Hence, such species showed abundance of regenerating individuals in Wof-Washa Forest which guarantees the supply of juveniles necessary to replace adults that would die naturally or harvested for different purpose. This agrees with other works reported in different Afromontane forests of Ethiopia (Simon Shibru and Girma Balcha, 2004; Ensermu Kelbessa and Teshome Soromessa, 2008; Fekadu Gurmessa *et al.*, 2012; Gebremicael Fisaha *et al.*, 2013). Few species such as *Olinia rochetiana*, *Hagenia abyssinica*, *Discopodium penninervum*, *Dombeya torrida* and *Lobelia rhynchopetalum* showed the highest density of saplings with a low density of both seedling and mature individuals. The low number of seedlings may be due to physical damage to seedlings during cuttings of matured trees, grazing and trampling together with other disturbances. The low representation of mature plants might attribute to human-induced disturbance and harvesting for timber production, fuelwood production, construction and other local consumptions.

Species such as *Ilex mitis*, *Euphorbia ampliphylla*, *Halleria lucida*, *Teclea nobilis*, *Polyscias fulva*, *Nuxia congesta*, *Croton macrostachyus*, *Ekebergia capensis* and *Celtis africana* were represented by the high density of mature states with no and few seedlings. Rare species of

Wof-Washa Forest such as *Cordia africana*, *Erythrina brucei*, *Grewia ferruginea*, *Prunus africana*, *Schefflera abyssinica* and *Teclea nobilis*. were not represented by seedlings. Thus, these species might require conservation priority apart from further assisted regeneration following phonological events, seed physiology, seedling survival rate, seed germination and sprouting nature from coppice, and other related man-made and ecological assistance. In general, recurrent disturbance, past and present agricultural expansion to the periphery, unsustainable and illegal cutting of matured trees influences the number of seedlings and saplings by reducing seed sources as the matures are removed and increasing physical damage of seedling and saplings that affect negatively the floristic composition of the plant species of Wof-Washa Forest. Furthermore, anthropogenic disturbance may affect the local environmental condition thereby seedling recruitment would be hampered.

5.1.7. Floristic similarity of Wof-Washa Forest and some Afromontane forests of Ethiopia

Floristic comparison of Wof-Washa Forest with the previous study (Demel Teketay and Tamrat Bekele,1995) indicated that Wof-Washa Forest showed high Sorensen's similarity value with itself than the rest forests compared. This indicates that although there were high anthropogenic pressures on woody species, the decline in forest area and land use change in the forest, the species richness was not strongly affected. This might be due to the more topographic heterogeneity of the forest area that creates microhabitat within a short distance in the forest. In addition, intermediate level of disturbance may promote invasions by non-native and weed species that increase species richness. The second highest floristic similarity was observed between Wof-Washa Forest (2018) and Dense Forest. The two forests are floristically more similar to each other than other montane forests. Dense Forest is found in Ankober district (approximately 20-30 km distance from Wof-Washa Forest towards the

Southwest), North Shewa zone of Amhara region and Wof-Washa Forest is stretched over Ankober, Tarmaber and Bassona Werena Districts. The altitude range and the mean annual rainfall of Dense Forest were 2125-2921 m.a.s.l and 1250 mm whereas Wof-Washa Forest has a mean annual rainfall of (1530 mm) and stretched over 2348-3498 m.a.s.l. Although the highest elevation of Wof-Washa Forest extends up to 3498 m.a.s.l which is higher than Dense and the lowest elevation of Dense 2125 m.a.s.l, both forests have close geographical proximity and share bimodal rain seasons. Thus, overlaps in altitude, geographical proximity and climatic conditions might have resulted in a high floristic similarity between the two forests. The temporal floristic similarity values of Wof-Washa Forest in the two previous studies (Tamrat Bekele,1993 and Demele Teketay& Tamrat Bekele, 1995) with the current study showed that, results of Demele Teketay and Tamrat Bekele (1995) has more floristic similarity than the similarities with the study result of Tamrat Bekele (1993). This variation might come from the number of study plots taken at each study period and altitudinal range difference at which the study plots taken might brought such diversity and structural differences coupled with land use change impacts and, change in population density of the three districts.

The result of land use land cover changes also showed a progressive decline of natural forest area with a corresponding increase in the agricultural land and settlement area which could be attributed to the low temporal woody species similarity of Wof-Washa Forest in the last 25 years.

The general structure of the forest in both DBH and height class showed similar distributional patterns. The observed highest basal area contribution of *Juniperus procera* in both study periods (Tamrat Bekele,1993 and current study (2018)) indicates that it is the most significant and dominant species over the last 25 years. The contribution of *Juniperus procera* as a

carbon store is high (Table 46) in the forest. *Juniperus procera* has shown the highest frequency (79, 95 %) and highest IVI value (43.8) (Table 30) in Wof-Washa Forest. However, agricultural expansion and settlement (Table 54) and anthropogenic pressures coupled with its multipurpose values exposed the species to extreme pressure. The replacement of high basal area species such as *Podocarpus falcatus*, *Ilex mitis*, and *Euphorbia ampliphylla* in 1993 by other species like *Erica arborea* and *Maesa lanceolata* is the reflection of anthropogenic pressure and land use change in the forest area that could expose the area to severe deforestation, climate change impacts and threats to the forest ecosystem.

5.1.8. Soil seed bank study

Among the 76 species identified in soil seed bank of Wof-Washa Forest, *Crasula alsinoides*, *Nephrophyllum abyssinicum*, *Oxalis corniculata*, *Eragrostis schweinfurthii* and *Callitriche oreophila* showed the highest number of seedlings. The dominance of herbs in the soil seed bank of Wof - Washa Forest might be due to the seed sizes that could easily be dispersed by different mechanisms and might require a small amount of resources requirements, their wide ecological adaptation capacity, effective pollination and fast germination capacity may also account for the dominance of herbs. In addition, small seeds have a better chance of becoming buried in deeper layers of the soil while seeds of large trees are susceptible to predation, seed decay and mode of seed dispersal and predation by both wild and domestic animals could be the reasons for the low woody species seed density (Harper, 1977).

Absence or very few woody species in soil seed bank may be due to several factors, some might have seeds that can immediately germinate after the seed shed. Other species might have the capacity to store seeds for several years, exposure of large seeds for predation and species-specific seed dormancy. The high density of herbs and low proportion of woody species in the soil seed bank were reported from different afro-montane forests of Ethiopia

(Demel Teketay and Granstrom, 1995; Kebrom Tekle and Tesfaye Bekele, 2000; Feyera Senebeta and Demel Teketay, 200; Mulugeta Lemenih and Demel Teketay, 2005 and Alemayhu Wassie and Demel Teketay, 2006) in Ethiopia and (Baker, 1989; Halpern *et al.*, 1999; Willson and Traveset, 2000 ; Baider *et al.*, 2001; Korb *et al.*, 2005; Akinyemi and Oke, 2013 and Wang *et al.* , 2017) from abroad.

Vertical and horizontal distribution of seeds in the soil

A clear soil seed distribution pattern was observed in Wof-Washa Forest in which the overall species richness decreases with soil depth. However, few species (*Crassula alsinoides*, *Nephrophyllum abyssinicum*, *Oxalis corniculata*, *Eragrostis schweinfurthii*, *Callitriche oreophila*) were recorded in all the layers, whereas other species (*Discopodium penninervum*, *Galiniera saxifraga*, *Rosa abyssinica* and *Osyris quadripartita*) also obtained in one or two layers. The seedlings of *Conyza bonariensis*, *Plantago lanceolata*, *Arabis thaliana*, *Plectranthus languinosus* and *Cardamine trichocarpa* were distributed well in the deeper soil layer. The low species diversity and abundance with depth would be attributed to the availability of environmental conditions such as oxygen, light, and temperature. Such type of distribution pattern of seeds in the soil was reported in several previous studies in Ethiopia (Mulugeta Lemenih and Demel Teketay, 2005; Tefera Mengistu *et al.*, 2005 and Eyob Tenkir, 2006).

Distribution, abundance, and richness of soil seeds in the soil exhibited spatial variability in Wof-Washa Forest. Site productivity, wind, and sedimentation movement might have attributed to the variation of soil seed density among community types. The highest seed density was identified from community type one and four while least soil seed density was collected from community type five. Most species were found in a few samples and very few species were common and distributed in most samples. The microhabitat differentiation

causes spatial variation in abundance and distribution of soil seeds. Such habitat variation might be attributed to variation in vegetation cover, burial depth, seed density, disturbance levels and predator pressure (Wagner and Mitschunas, 2008).

The low Jaccard and Sørensen's coefficient of similarities values obtained from comparison of soil seed bank and above-ground vegetation species values showed low floristic similarity (Table 43). Only *Juniperus procera*, *Maesa lanceolata*, *Olea europaea* subsp. *cuspidata*, *Ficus sur*, *Vernonia amygdalina*, *Urera hypselodendron*, *Sparmannia ricinocarpa*, *Hypericum revolutum*, *Calpurnia aurea* and *Eucalyptus globulus* among the woody species existed in both the above ground and soil seed bank floras. The low species similarity showed that, the above-ground vegetation is highly represented by most abundant species (*Erica arborea*, *Myrsine africana*, *Podocarpus falcatus*, *Ilex mitis* and *Galiniera saxifraga*) that were absent from the seed bank and vice versa for abundant soil seed species (*Callitriche oreophila*, *Centella asiatica*, and *Eragrostis racemosa*) which were not identified in the aboveground vegetation. Most tree and shrub species had no soil seeds indicating that there is very poor survival, poor reproduction and/ or poor regeneration potential of these species from soil seed bank. Thus, sustainable conservation of these woody species would be the most indispensable strategies to the future regeneration. In woody species having large sized seeds might be targeted to predation by small animals in the forest floor before germination and all the seeds in the soil may not germinate (Thompson and Grime, 1979 and Warr *et al.*, 1993; Mekuria Argaw *et al.*, 1999). Soil seed bank may be derived from a former stage in the succession, seed viability difference (Thompson *et al.*, 1997; Lyarruu and Backeus, 2000) and some seeds such as (*Senna multiglandulosa* and *Senna occidentalis*) may partly be derived from seeds outside of the forest, (Eriksson, 1995; Bekker *et al.*, 1998). This result is consistent with numerous previous studies that have shown a poor correspondence between

species present in the above ground flora and in the soil seed bank (Feyera Senbeta and Demel Teketay, 2002; Abdella Mekonnen *et al.*, 2007; Hopfensperger, 2007). In general, the soil seed bank of Wof-Washa Forest has no significant contribution to the regeneration of above ground vegetation. Thus, regeneration of most significant and dominant woody species of the forest require other alternative regeneration mechanisms for the survival and sustainability of the species.

5.1.9. Biomass and Carbon stock study

Estimation of forest carbon stock is vital to understand the role of forests in national and the global carbon cycle and relationship between changes in land use and Carbon dioxide emissions (Sundarapandian *et al.*, 2013). The estimated carbon stock of the forest differed significantly among the carbon pools, study plots, and community types. Above ground vegetation accounts about 51 % of the total carbon stock of the forest (Table 44 and Appendix 16). The high carbon stock in above ground vegetation might be due to presence of abundant and large sized woody species. Land use change, particularly conversion to agricultural ecosystems disturb the natural conditions of the forest ecosystem that aggravate species loss, soil erosion and depletion of the soil carbon stock. Wof-Washa Forest soils might lost a considerable amount soil organic matter (soil organic carbon) content in the last three decades as the forest was converted to agricultural land with 6.6 t/ha per year for 30 years.

In other words, afforestation and rehabilitation of degraded areas of the forest and applying applicable management strategies can enhance carbon stocks of major carbon pools through carbon sequestration (Lal, 2005). Land use change due to human intervention such as deforestation might have played a significant role in above ground carbon stock, plant species population structure and plant species richness and density.

The observed 51 % carbon stock contribution of above ground vegetation might be attributed by few species with large and abundant presence.

The lowest carbon stock (0.1 t C/ha) was recorded from litter pool (lower than the value reported to tropical dry forests (2.1 t ha⁻¹ IPCC, 2006). This result might be due to the absence of litter layer in most study plots and might be collected for fodder and fuelwood. In addition, this could be due to disturbance specifically grazing, amount of litterfalls dropped from few deciduous woody species (such as *Croton macrostachyus*, *Cordia africana*, and *Ficus sur*). Another suggestion to the low litter carbon stock would be the status and microbial activity of soil organisms that promote the fragmentation of litter and mixing with organic matter in the soil that require further study. In addition, in some intact parts of the forest, closed canopy and the dominance of evergreen and small-leaved tree species such as *Juniperus procera* in middle altitude *Erica arborea* in the upper altitude and *Polyscias fulva* might affect the growth of herbs and grasses in the ground layer of the forest.

The contribution of species to the carbon stock of Wof-Washa Forest was not evenly distributed, some species contributed a large amount of carbon stocks (t/ha) *Juniperus procera*, *Podocarpus falcatus*, *Pittosporum viridiflorum*, *Maesa lanceolate*, and *Ilex mitis* while others are such as *Celtis africana*, *Premna schimperii* and *Euphorbia abyssinica* accounts very small carbon stock (Figure 35). This might be due to the wood density of each species, size of species (height and DBH), abundance of species and, the extent of anthropogenic pressure.

This result is in line with findings from the different Afromontane forest of Ethiopia (Fisher and Binkly, 2000; Mesele Negash, 2013 and Muluken Nega *et al.*, 2015). In general, the average total carbon stock of Wof - Washa Forest was lower than Carbon stocks reported for Menagesha Suba State Forest (286.53 t/ha) (Mesfin Sahle, 2011), Mount Zequalla Monastery

Forest of 348.9 t/ha (Abel Girma *et al.*,2014), (Gedo Forest of 521.2 t/ha (Hamere Yohannes *et al.*,2015), Gergeda Forest in western Ethiopia (717.56 t/ha) (Tamene Yohannes, 2016)) were larger than Wof-Washa Forest. The significant variations of total carbon stocks of different forests in Ethiopia would be due to difference in successional stages of forests, abundance of large sized species, variation in species composition, difference in basal area and wood density of species in different areas of the country. Another major reason for the variation of carbon stock estimate would be the use of different allometric equations by the researchers. This is because species-specific allometric models for all tropical species particularly in Ethiopia are lacking.

The carbon stock density distribution varies along altitude and aspects in Wof-Washa Forest. The middle altitude (2501-3000 m) contributes high total mean carbon stock density (298.86 ± 177.82 t/ha) in (Table 51). This might be the difference in productivity of microhabitat that allows more species to coexist (Hemp, 2006) and low disturbance due to inaccessibility. The high carbon stock density in the middle altitude agrees with other studies in Ethiopia (Mohammed Gedefaw *et al.*, 2014; Muluken Nega *et al.*, 2015 and Fantahun Abere, 2016). As indicated in Table 51 high mean aboveground carbon stock density was found in the lower altitude area and it may be due to few large sized tree species such as *Polyscias fulva*, *Ficus sur*, and *Podocarpus falcatus*. The highest carbon stock density value in litter carbon also found at the lower altitude (Table 51). The presence of deciduous tree species like *Croton macrostachyus*, *Cordia africana*, *Ficus sur* and *Erythrina brucei* may have a significant contribution. The mean total carbon stock density in the five major pools varied differently along the given aspects. The highest mean aboveground carbon stock was in the SW with 359.05 ± 0.0 t/ha.

The maximum total carbon stocks values were accounted in NE and N aspects of the forest (Table 52). This may be due to the difference in solar radiation and higher land surface temperature that promote less evapotranspiration than the East and South East facing part of Wof-Washa Forest, the presence of intact forest part and abundance occurrence of large-sized individuals (Jin *et al.*, 2008; Hamere Yohannes *et al.*, 2015). In addition, inaccessibility of the northern and South Western part of the forest for anthropogenic disturbance (especially, cutting and transportation of wood logs) may contribute to the high mean carbon stocks.

5.1.10. Land use land cover dynamics trend, rate, and magnitude

Major deforestation and conversion of LULC class had taken place in Wof-Washa Forest during the last 30 years. The total area of (58.4 %) covered by green vegetation (forest and grassland) was much greater than the total area covered by the rest LULC class types (agricultural land, settlement and bare land) in 1985. However, in 2000 and 2015 the area accounted by green vegetation (forest, plantation, and grassland) was much lower than the area covered by other LULC class types (Table 54). Due to the expansion of agricultural land and settlement area, natural forest and grassland were highly declined in the area, affected and degraded. During the whole study period (1985-2015), the area covered by natural forest was reduced at a rate of 6.6 ha/year. About 76.4 % of grassland conversion into other LULC class types. This might due to villagization program that collects most rural people and hamlets of the low land area to the highland area especially on the southern, eastern and northern part of the forest and converts the forest edge into agricultural land. A significant amount of natural forest (198 ha) was lost in the last 3 decades (1985-2015). This result agrees with Mengiste Kedanu *et al* (2013) who reported that 11.8 % decline of natural forest in the Munessa-Shashemene landscape. A dramatic expansion of agricultural land (109.1 ha/year) and

settlement area (13 ha/year) where due to the larger area transformation of bareland, grassland and natural forest. Sisay Nune *et al.* (2016) reported a similar research finding where agricultural land and settlement area increment at expense of natural forest, grassland, and bare land. Conversion of such large area into agricultural land and settlement area was mainly due to population expansion. Expansion of population surrounding the natural forest brought increasing demands for agriculture and settlement that enforce the local communities to use all available and marginal land areas. This, in turn, led to rapid increase in the area of agricultural land and settlement. This result agrees with Abate Shiferaw (2011) who reported that agricultural land increased by 18 % due to population growth. In general, this research result identified that agricultural land increased by 33.8 %, whereas bareland, grassland, and natural forest were decreased by 18.5 %, 17.9 %, and 2.04 % respectively in the whole study period (30 years).

5.1.11. Drivers of change in the study area

Understanding factors that cause changes in LULC is a crucial issue in order to design applicable management and conservation strategies as well as to predict future changes and threats with their respective mitigation measures and management options. Based on the Landsat imagery analysis, population pressure, agricultural land expansion, and settlement are found to be the most significant factors causing land use and land cover change of Wof-Washa Forest and its surrounding areas over the last 30 years. Such land use change directly causes perturbation of the ecosystem and can influence the carbon stocks and sequestration capacity.

Population

The total population of the three districts showed a progressive increment from 254,056 in 1994 to 281,921 in 2007 (Table 1) indicating a high rate of population growth with 2786.5

annual rates of change. As the population grows with such rate, the corresponding demands from the local environment increases in a multitude manner. In line with this result from Kibrom Tekle and Hedlund (2000) reported that, population growth is a major driving force in land use/land cover changes and that it has contributed to land degradation and deforestation. As a result of human population growth, human activities such as logging, livestock husbandry, crop cultivation and fuelwood consumption led to the high rate of forest shrinkage and degradation

Agricultural land expansion

As indicated in Table 54 and Figure 40, the agricultural land area was increased by 3128 ha (208.53 ha/year between 1985-2000 periods). In the whole study period (1985-2015), agricultural land showed the highest increment (3273 ha) which is 109.1 ha/year followed by settlement area 391 ha (13.0 ha/year). A progressive decline of forest vegetation indicates the removal of carbon stock. This intentional forest clearing for expansion of agricultural land, settlement, and charcoal production has affected forest biodiversity together with a substantial amount of the carbon that was originally stored and additional carbon would have also been lost by degradation of the standing forest. Thus, conservation of biological diversity and holding large amounts of carbon are being lost and threatened by human-induced pressures. This result agrees with research reported by Sisay Nune *et al.* (2016) and Nogueira *et al.* (2017). The land use change particularly, the conversion of forest to agricultural land destroy soil's aggregation structure and enhance mineralization of soil organic carbon and CO₂ emission (Wei *et al.*, 2014). Thus reduce soil organic carbon stock and increase carbon dioxide concentration in the atmosphere.

5.1.12. Implications of this study

Wof-Washa Forest is found within the eastern Afromontane region that comprise many native indigenous, endemic and endangered species of flora and fauna particularly *Serinus ankoberensis*, *Aloe ankoberensis* are endemic to this area and 46 endemic plants species are also identified in this forest.

Due to the topographical and agroecological heterogeneity, the forest harbors relatively high plant diversity (394 plant species). The south and southeastern part of the forest is highly intact and contain more plant species diversity. However, the current conservation practice is highly influenced by agricultural expansion in its periphery and free year-round grazing and other related anthropogenic pressures in most area of the forest. Thus, this interference led to the reduction of woody species which might influence the microhabitat of the forest and regeneration condition of some species.

The forest stores a mean carbon (284.19 ± 236.83 t/ha) due to its old aged and dominant tree species and high soil organic carbon resulted from decomposition rates and activities of soil microorganisms. Thus, the carbon market is one of the important mechanisms through which developing countries including Ethiopia would be benefited from developed nations for sustaining carbon sink capacity by their forests (Lovera, 2009). Ethiopia has started earning carbon credits through clean development mechanisms (CDM) from the rejuvenation of previously denuded land (WBI, 2010). The country has also the potential to receive support through Reduced Emission from Deforestation and Degradation (REDD+) initiatives. The country has submitted Nationally Appropriate Mitigation Actions (NAMAs) in the forestry section following the Copenhagen accord. Among the NAMAs submitted to the United Nations Framework Convention on Climate Change is sustainable management of natural forest, deciduous forestland, and national parks to reduce GHG emissions from deforestation

and forest degradation (UNFCCC, 2011). Thus, the sustainable biodiversity management in Ethiopia and Carbon market system should be integrated with REDD+ and CDM of the Kyoto Protocol accord. Furthermore, the financial incentives that are planned to be available under the REDD+ mechanism should be comparable and be better than the incentives obtained from other land use options.

The LULC dynamics result of the study area showed continuous agricultural expansion and settlement area coupled with other anthropogenic pressures at the expense of natural forest and grassland. Thus, this current information could help to induce sustainable management strategies and regulative interventions of Wof-Washa Forest and its watershed. In addition, the contribution of soil seed bank flora for the regeneration of above-ground vegetation is very low. Most of the large tree species including *Juniperus procera*, *Ilex mitis*, *Prunus africana* and others showed abnormal and poor regeneration status. Thus, to create options for more native tree species that regenerate naturally, have a balanced proportion of seedling, sapling and mature trees, and sustainability of the most important species of the forest, conservation, and protection of selected sites that keep a natural ecological condition is a vital approach.

5.2 CONCLUSION

Wof-Washa Forest is characterized by high species richness, high vegetation biomass and land use change which had experiences of extensive anthropogenic disturbance due to livestock grazing, timber and non-timber products, agricultural expansion and traditional apiary to support the livelihood of local communities surrounding the forest. Results revealed that Wof-Washa Forest comprises of high plant species composition including endemic taxa compared to similar forests in central Ethiopia. Thus, it is one of the most important forest areas for biodiversity conservation. The presence of more endemic plant species and new

records for this Flora area showed the potential of the area. The five plant community types identified were highly influenced by altitudinal gradients than other environmental factors. Diversity analysis result indicates the presence of species turnover along altitudinal gradients. This variation in species diversity among study plots and community types are due to habitat heterogeneity, history of disturbance level and scope overlap in community types.

Overall pattern of species population structure suggests two major categories, species able to regenerate in the forest understory while other species had difficulties to regenerate and reproduce. Poor regeneration and recruitment status of some species jeopardize biological dynamics in the forest aggravated by external influences mainly grazing and human-induced threats. Some tree species showed abnormal population structure and hampered regeneration. *Prunus africana* and *Schefflera abyssinica* are present to date but might become locally extinct because of no regeneration observed.

Analysis of results for IVI showed that few species such as *Juniperus procera*, *Erica arborea*, *Podocarpus falcatus* and *Maesa lanceolata* had significant proportion in Wof-Washa Forest. Some species are both very rare and locally threatened like *Prunus africana*, *Ficus sur*, and *Grewia ferruginea*. However, a large number of seedlings and saplings of some tree and shrub species (*Podocarpus falcatus*, *Maytenus arbutifolia*, and *Hypericum revolutum*) were found in Wof-Washa Forest indicating their regeneration potentials.

The low species similarity between soil seed flora and above ground vegetation indicated that the removal of mature individuals restricts the regeneration of primary tree species from seeds and most woody species have another alternative means of regeneration than using soil seed bank. In general, the contribution of soil seed bank in woody species diversity and recovery through regeneration is very low. Thus, future survival and existence of the woody species rely on the sustainable management and conservation of the remnant forest and plant species.

The analysis of total carbon stock of Wof-Washa Forest in the five major carbon pools showed different carbon storage capacity along altitude and aspects which might be due to the difference in size of woody species, wood density (g/cm^3), height and DBH values of each species, the extent of disturbance and forest management practice. Topography is the principal controlling factor in determining growth, spatial distribution and vegetation patterns in the forest. This, in turn, determines the biomass and carbon stock storage potentials of Wof-Washa Forest. Even though most of the area of Wof-Washa Forest is East and South East facing, South West and North facing aspects of Wof-Washa Forest contribute high carbon stock. This is due to the difference in solar radiation and higher land surface temperature that promote less evapotranspiration than east facing parts of Wof-Washa Forest. In addition, inaccessibility of the North, West and Southwest part of Wof-Washa Forest has their own contribution to the existence of large-sized and intact forest microhabitat. The above and below ground carbon pools showed decreasing trends of carbon store with increasing altitude while the soil organic carbon exhibited the reversed patterns. The total amount of carbon stock indicates that Wof-Washa Forest is an important carbon reservoir to play a significant role in carbon financing that foster sustainable forest management practice, and restoration of the watershed.

However, the progressive agricultural land and settlement expansion and human-induced pressure observed at the expense of natural forest and grassland could be a potential pressing threat for carbon stock and sustainability of the forest. About 3,273 ha of agricultural land expansion, observed population growth with their demands and activities, deliberate and natural forest fire indicated the lost carbon stock over the last 30 years in and around Wof-Washa Forest. Agricultural land expansion has been increasing in the past and recent periods due to human population increment and their corresponding demands and requirements. One

can forecast the trajectory of biodiversity and carbon stock loss based on the impacts imposed by the major driving forces for the LULC change.

Generally, the results of this study clearly showed that LULC change due to human intervention has significantly affected Wof-Washa Forest biodiversity and carbon stock potential. Thus, the findings of this study can provide information for researchers, conservationists, policymakers, and other stakeholders for the conservation and management of this remnant forest and to develop appropriate and applicable land use plan, implementation strategies, and management options.

5.3 RECOMMENDATIONS

Wof - Washa forest harbors diverse flora and fauna, including most significant species (*Juniperus procera* and *Podocarpus falcatus*), endemic and other rare species such as *Prunus africana* and *Serinus ankoberensis*. The forest plays a significant role as a storehouse of carbon and carbon sequestration due to large, old and abundant tree species like *Juniperus procera* and *Podocarpus falcatus*. Despite its ecological and economic importance, severe land uses land cover change surrounding the forest coupled with human-induced pressures threatening the species diversity and sustainability of the forest. Therefore, based on the findings of this research work, the following recommendations are forwarded to strengthen the current conservation efforts and minimize the threats of Wof-washa Forest.

- The species diversity in the upper altitude (>2800 m.a.s.l), northern, central and northeastern part of the forest is in decline except the Ericaceous belt, indicating the need for urgent rehabilitation using environmentally friendly tree species and regeneration of the remnant woody species as well as giving special attention to the intact forest part in the southeast part and implementation of these measures would assist in halting the decline of the species.

- The contribution of soil seed bank to the regeneration of woody species is low and could not capable of restoring all species of the existing aboveground vegetation. Thus, current and future regeneration of remnant woody species of the forest and rehabilitation of the fragmented areas relays on participatory and integrated forest management and conservation;
- The amount of carbon stored in the forest is the basis for a beneficial carbon credit system through CDM and REDD+, which in turn brought long-term continuity of carbon storage and biodiversity. Thus, raising awareness to all the concerned stakeholders on how to protect further farmland expansion and conservation priority as among the indispensable alternatives to protect the forest from further fragmentation and species loss;
- Storing cattle in the barns within the forest throughout the year is common phenomena in Wof-Washa Forest, and hence, participating the local people in planning, design, and implementation of forest management and biodiversity conservation activities and provide training related to grazing in harmony with the sustainability of biodiversity should be done by the local and regional government, Amhara Forest Enterprise, research institutes and other stakeholders.
- The traditional beekeeping activities have threats of fire, thus these activities require knowledge-based modification and utilization of technology-assisted beehives and other materials to protect the forest from fire and to increase income source diversification to support the livelihood of the communities which will in turn reduce the burden of deforestation.
- Finally, some but significant species of the forest including *Prunus africana*, *Ilex mitis*, and *Schefflera abyssinica* showed abnormal population structure, poor regeneration

status and found to be locally threatened. To prevent local extinction of these and other rare species and to sustain the whole biodiversity of the forest, the current conservation effort should be strengthened and intensified by establishing a nursery for seedling production and plantation of indigenous species to the most affected areas of the forest.

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Appendices

Appendix 1. List of plant species found in Wof-Washa Forest

An abbreviation of habits is indicated as T (Tree), H (Herb), S (shrub), L(Liana), Ha(habit), Am(Amharic) and T(Tigrigna).

No	Scientific Name	Family	Local name:	Habit
1	<i>Abutilon longicuspe</i> Hochst.ex. A.Rich.	Malvaceae	Nechilo	S
2	<i>Acacia abyssinica</i> Hochst. ex Benth.	Fabaceae	Bazira Garar	H

No	Scientific Name	Family	Local name:	Habit
3	<i>Acacia negrii</i> Pic.Serm.	Fabaceae	Grar	T
4	<i>Achyranthes aspera</i> L.	Amaranthaceae	Telenji	H
5	<i>Achyropermum schimperi</i> (Hochst. ex Briq.) Perkins	Lamiaceae		H
6	<i>Adiantum poiretii</i> Wikstr.	Adiantaceae	Etse Anbesa	H
7	<i>Aeonium leucoblepharum</i> A.Rich.	Asteraceae		H
8	<i>Agarista salicifolia</i> (Comm.ex Lam.) Hook.f. ex.Oliv.	Ericaceae		S
9	<i>Agrocharis melanantha</i> Hochst.	Apiaceae		H
10	<i>Agrostis quinquesta</i> (Hochst. ex Steud.) Hochst.	Poaceae		H
11	<i>Ajuga integrifolia</i> Buch. -Ham.ex D.Don	Lamiaceae	Armagusa	H
12	<i>Albuca abyssinica</i> Jacq.	Hyacinthaceae	Shgurtizbi(T)	H
13	<i>Alchemila abyssinica</i> Fresen.	Rosaceae	Yemidr koso	H
14	<i>Alchemila pedata</i> A.Rich.	Rosaceae	Yemidr kosso	H
15	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	Embus	T
16	<i>Aloe ankoberensis</i> Gilbert and Sebsebe	Aloaceae	Merarie	S
17	<i>Aloe debrana</i> Christian	Aloceae	Merarie	S
18	<i>Aloe pulcherrima</i> Gilbert and Sebsebe	Aloaceae	Sete eret	S
19	<i>Amaranthus hybridus</i> L.	Amaranthaceae	Aluma	H
20	<i>Anagallis arvensis</i> L.	Primulaceae	Yemrikmedihanit	H
21	<i>Andropogon abyssinicus</i> Fresen.	Poaceae	Gaja sar	H
22	<i>Anthemis tigreensis</i> J. Gay ex A. Rich.	Asteraceae	Mihiba(T)	H
23	<i>Anthospermum herbaceum</i> L.f.	Rubiaceae		H
24	<i>Anthriscus sylvestris</i> (L.) Hoffm.	Apiaceae		H
25	<i>Arabis alpina</i> L.	Brassicaceae		H
26	<i>Arabis thaliana</i> L.	Brassicaceae		H
27	<i>Argemone mexicana</i> L.	Papaveraceae	Dandaro	H
28	<i>Argyrobium ramosissimum</i> Bak.	Fabaceae	*	H
29	<i>Arisaema addis-ababense</i> Chiov.	Araceae	Yeregnochtila	H
30	<i>Arisaema enneaphyllum</i> Hochst.ex A. Rich.	Araceae	Amoc	H
31	<i>Artemisia abyssinica</i> Sch.Bip. ex A.Rich.	Asteraceae	Chikugn	H
32	<i>Artemisia afra</i> Jacq.ex Willd.	Asteraceae	Chikugn	H
33	<i>Arundinaria alpina</i> K. Schum.	Poaceae	Kerkeha	S
34	<i>Arundo donax</i> L.	Poaceae	Shembeko/Meka	H
35	<i>Asparagus africanus</i> Lam.	Asparagaceae	Yesetkest	S
36	<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	Aspleniaceae	Fern	H
37	<i>Asplenium monanthes</i> L.	Aspleniaceae	Fern	H
38	<i>Asplenium protensum</i> Schrad.	Aspleniaceae	Fern	H
39	<i>Asplenium theciferum</i> (Humb.Bonpl.andKunth)Mett.	Aspleniaceae	Fern	H
40	<i>Astragalus atropilosus</i> (Hochst.)	Fabaceae	Tetem agazien(T)	H

No	Scientific Name	Family	Local name:	Habit
	<i>Bungesubsp. atropilosus</i>			
41	<i>Barbarea intermedia</i> Boreau.	Brassicaceae		H
42	<i>Bartsia longiflora</i> Hochst.ex Benth.	Scrophulariaceae		S
43	<i>Berberis holstii</i> Engl.	Berberidaceae	Zinkila/ Yeset Af	S
44	<i>Bersama abyssinica</i> Fresen.	Melianthaceae	Azamir	T
45	<i>Bidens biternata</i> (Lour.) Merr.andSherff.	Asteraceae	Adey Abeba	H
46	<i>Bidens macroptera</i> (Sch.Bip. ex Chiov.) Mesfin	Asteraceae	Adey Abeba	H
47	<i>Bidens pilosa</i> L.	Asteraceae	Yeseyitan merfie	H
48	<i>Bidens prestinaria</i> (Sch.Bip.) Cufod.	Asteraceae	Meskel Abeba	H
49	<i>Brassica carinata</i> A.Br.	Brassicaceae	Gomen zer	H
50	<i>Bromus leptocladus</i> Nees	Poaceae		H
51	<i>Bromus pectinatus</i> Thunb.	Poaceae	Serti arem	H
52	<i>Buddleja polystachya</i> Fresen.	Loganiaceae	Anfar	T
53	<i>Bulbostylis coleotricha</i> (Hochst.ex A. Rich.) C.B. Clarke	Cyperaceae		H
54	<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae	Digita	S
55	<i>Campanula edulis</i> Forssk.	Campanulaceae		H
56	<i>Capsella bursa-pastoris</i> (L.) Medic.	Brassicaceae	*	H
57	<i>Cardamine africana</i> L.	Brassicaceae		H
58	<i>Cardamine trichocarpa</i> A.Rich.	Brassicaceae	*	H
59	<i>Carduus nyassanus</i> (S. Moore) R. E. Fr.	Asteraceae	Kosheshila	H
60	<i>Carduus schimperi</i> Sch. Bip.	Asteraceae	Kosheshila	H
61	<i>Carex bequaertii</i> De Wild.	Cyperaceae		H
62	<i>Carex chlorosaccus</i> C.B. Clarke	Cyperaceae		H
63	<i>Carex conferta</i> Hochst. ex A.Rich.	Cyperaceae		H
64	<i>Carex johnstonii</i> Bock.	Cyperaceae		H
65	<i>Carissa spinarum</i> L.	Apocynaceae	Agam	S
66	<i>Carum piovanii</i> Chiov.	Apiaceae		H
67	<i>Cassipourea malosana</i> (Baker) Alston	Rhizophoraceae	Buna kitel	T
68	<i>Casuarina cunninghamiana</i> Miq.	Casuarinaceae	Arzelibanos	T
69	<i>Celtis africana</i> Burm.f.	Ulmaceae	Kawoot	T
70	<i>Cerastium ocandrum</i> A.Rich.	Caryophyllaceae		H
71	<i>Cerastium afromontanum</i> T.C.E. Fr. and Weimarck	Caryophyllaceae		H
72	<i>Cheilanthes farinosa</i> (Forssk.) Kaulf.	Sinopteridaceae		H
73	<i>Chenopodium ambrosioides</i> L.	Chenopodiaceae	Abir	H
74	<i>Chenopodium murale</i> L.	Chenopodiaceae	Amedmado	H
75	<i>Chloris gayana</i> Kunth	Poaceae		H
76	<i>Cineraria abyssinica</i> Sch.Bip. ex A. Rich.	Asteraceae	Etse merfie	H
77	<i>Cineraria deltoidia</i> Sond.	Asteraceae	*	H
78	<i>Cirsium vulgare</i> (Savi.)Ten.	Asteraceae		H

No	Scientific Name	Family	Local name:	Habit
79	<i>Cissus quadrangularis</i> L.	Vitaceae	Yezihon anjet	S
80	<i>Clematis hirsuta</i> Perr. and Guill.	Ranunculaceae	Azo Hareg	Li
81	<i>Clematis simensis</i> Fresen.	Ranunculaceae	Azo hareg	Li
82	<i>Clerodendrum myricoides</i> (Hochst.) Vatke	Lamiaceae	Misirch	S
83	<i>Clutia abyssinica</i> Jaub.and Spach.	Euphorbiaceae	Fiyele fej	S
84	<i>Colutea abyssinica</i> Kunth and Bouche	Fabaceae	Duaduatie	S
85	<i>Commelina africana</i> L.	Commelinaceae	wof ankur	H
86	<i>Commelina diffusa</i> Burm.f.	Commelinaceae	wof ankur	H
87	<i>Conium maculatum</i> L.	Apiaceae		H
88	<i>Conostomium quadrangulare</i> (Rendle) Cufod.	Rubiaceae		H
89	<i>Conyza bonariensis</i> (L.) Cronq.	Asteraceae		H
90	<i>Conyza hypoleuca</i> A. Rich.	Asteraceae		H
91	<i>Cordia africana</i> Lam.	Boraginaceae	Wanza	T
92	<i>Cotula abyssinica</i> Sch.Bip. ex A. Rich.	Asteraceae	Chiger arem	H
93	<i>Crassocephalum macropappum</i> (Sch.Bip. ex A.Rich) S.Moore	Asteraceae	Liti marefia	H
94	<i>Crassula alsinoides</i> (Hook.f.) Engl.	Crassulaceae	*	H
95	<i>Crepis rueppellii</i> Sch.Bip.	Asteraceae	Yefyel Woet	H
96	<i>Crepis carbonaria</i> Sch.Bip.	Asteraceae	Yefiyel wotet	H
97	<i>Crinum abyssinicum</i> Hochst. ex A.Rich.	Amaryllidaceae	Yejib shinkurt	H
98	<i>Crotalaria incana</i> subsp. <i>purpurascens</i> (Lam.)Milne-Redh.	Fabaceae	Etse hiwot	S
99	<i>Crotalaria laburnifolia</i> L. sub sp. <i>laburnifolia</i>	Fabaceae	Ye ayt misir	H
100	<i>Crotalaria rosenii</i> (Pax) Milne-Redh. ex Polhill	Fabaceae	*	S
101	<i>Croton macrostachyus</i> Del.	Euphorbiaceae	Bisana	T
102	<i>Cupressus lusitanica</i> Mill.	Cupressaceae	Yeferenj tid	T
103	<i>Cuscuta kilimanjari</i> Oliv.	Cuscutaceae		H
104	<i>Cyanotis barbata</i> D.Don	Commelinaceae	Birko	H
105	<i>Cyathula cylindrica</i> Moq.	Amaranthaceae	Yedem abnet	H
106	<i>Cyathula uncinulata</i> (Schrad.) Schinz	Amaranthaceae	Yemognfikir	H
107	<i>Cynanchum abyssinicum</i> Decne.	Asclepiadaceae		H
108	<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	serdo sar	H
109	<i>Cynoglossum amplifolium</i> Hochst ex A.DC	Boraginaceae	Chegotot	H
110	<i>Cynoglossum coeruleum</i> Hochst. ex A.DC subsp. <i>geometricum</i> (Bak.andWright)Edwards	Boraginaceae	Chegotot	H
111	<i>Cyperus conglomeratus</i> Rottb.	Cyperaceae	Sibsbu	H
112	<i>Cyperus costatus</i> Mattf.andKuk.	Cyperaceae		H

No	Scientific Name	Family	Local name:	Habit
113	<i>Cyperus densicaespitosus</i> Mattf. and Kuk.	Cyperaceae		H
114	<i>Cyperus elegantulus</i> Steud.	Cyperaceae		H
115	<i>Cyperus fischerianus</i> A.Rich.	Cyperaceae	Engicha	H
116	<i>Cyperus longus</i> L.	Cyperaceae	Engicha	H
117	<i>Cyperus pinguis</i> (C. B. Clarke) Mattf. and Kuk.	Cyperaceae	Engicha	H
118	<i>Cyperus rigidifolius</i> Steud.	Cyperaceae	Engicha	H
119	<i>Cyperus rotundus</i> L.	Cyperaceae	Engicha	H
120	<i>Datura stramonium</i> L.	Solanaceae	Atsefaris	H
121	<i>Debregeasia saeneb</i> (Forssk.) Hepper and Wood	Urticaceae	Shunshuna/Ashosho	S
122	<i>Delphinium wellbyi</i> Hemsl.	Ranunculaceae	Gedel adimik	H
123	<i>Desmodium repandum</i> (Vahl) DC.	Fabaceae		H
124	<i>Diaphanthe schimperiana</i> (A. Rich.) Summerh.	Orchidaceae		H
125	<i>Dichondra repens</i> J.R. and G. Forst.	Convolvulaceae	*	H
126	<i>Dicrocephala chrysanthemifolia</i> (Bl.) DC.	Asteraceae	Lit	H
127	<i>Digitaria abyssinica</i> (Hochst. ex A. Rich.) Stapf	Poaceae	Wariyat	H
128	<i>Diospyros abyssica</i> (Hiern) F. White	Ebenaceae	Selechegn	T
129	<i>Dipsacus pinnatifidus</i> Steud. ex A. Rich.	Dipsacaceae	Kelem	H
130	<i>Discopodium penninervium</i> Hochst.	Solanaceae	Ameraro	S
131	<i>Dodonea angustifolia</i> L.F.	Sapindaceae	Kitkita	S
132	<i>Dombeya torrida</i> (J.F. Gmel.) P. Bamps	Sterculiaceae	Wolikifa	S
133	<i>Dovyalis abyssinica</i> (A. Rich.) Warb.	Flacourtiaceae	Koshim	S
134	<i>Dracaena steudneri</i> Engl.	Dracaenaceae	Etse Patos	S
135	<i>Dregea schimperii</i> (Decne.) Bullock	Asclepiadaceae	Shankuk(T)	Li
136	<i>Droguetia iners</i> (Forssk.) Schweinf.	Urticaceae		H
137	<i>Dryopteris lewalleana</i> Pic. Serm.	Dryopteridaceae		H
138	<i>Dyschoriste multicaulis</i> (A. Rich.) O. Kuntze	Acanthaceae		H
139	<i>Echinops ellenbeckii</i> O. Hoffm.	Asteraceae	Kosheshila	H
140	<i>Echinops longisetus</i> A. Rich.	Asteraceae	Kosheshila	H
141	<i>Echinops macrochaetus</i> Fresen.	Asteraceae	Kosheshila	H
142	<i>Ehrharta erecta</i> Lam.	Poaceae		H
143	<i>Ekebergia capensis</i> Sparrm.	Meliaceae	Lol	T
144	<i>Eleusine floccifolia</i> (Forssk.) Spreng.	Poaceae	Akirma	H
145	<i>Embelia schimperii</i> Vatke	Myricaceae	Enkoko	Li
146	<i>Epilobium hirsutum</i> L.	Onagraceae	yelam chew	H
147	<i>Eragrostis cilianensis</i> (All.) Vign. ex Janchen	Poaceae		H
148	<i>Eragrostis schweinfurthii</i> Chiov.	Poaceae		H

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149	<i>Erica arborea</i> L.	Ericaceae	Asta	T
150	<i>Erodium cicutarium</i> (L.) Aiton	Geraniaceae		H
151	<i>Erodium moschatum</i> (L.) Aiton	Geraniaceae		H
152	<i>Erucastrum arabicum</i> Fisch. and Mey.	Brassicaceae	Yewof zer	H
153	<i>Erythrina brucei</i> Schweinf.	Fabaceae	Korch/Ergofit	T
154	<i>Eucalyptus camaldulensis</i> Dehnh.	Myrtaceae	Key Bahir zaf	T
155	<i>Eucalyptus globulus</i> Labill.	Myrtaceae	Nech bahirzaf	T
156	<i>Euphorbia abyssinica</i> Gmel	Euphorbiaceae	Kulkual	T
157	<i>Euphorbia ampliphylla</i> Pax	Euphorbiaceae	Kulkual	T
158	<i>Euphorbia dumalis</i> S.Carter	Euphorbiaceae	Anterfa	S
159	<i>Euphorbia schimperiana</i> Scheele	Euphorbiaceae	Anterfa	S
160	<i>Festuca abyssinica</i> Hochst. ex A.Rich.	Poaceae	Guasa sar	H
161	<i>Festuca macrophylla</i> Hochst.ex A. Rich.	Poaceae	Guasa sar	H
162	<i>Ficus sur</i> Forssk.	Moraceae	Shola	T
163	<i>Foeniculum vulgare</i> Miller.	Apiaceae	Ensilal	H
164	<i>Galiniera saxifraga</i> (Hochst.) Bridson	Rubiaceae	Yetota kolet	T
165	<i>Galinsoga quadriradiata</i> Ruiz and Pavon	Asteraceae	Deha nekay/Yeshewa arem	H
166	<i>Galium simense</i> Fresen.	Rubiaceae	Ashect	H
167	<i>Galium thunbergianum</i> Eckl.and Zeyh.	Rubiaceae		H
168	<i>Geranium arabicum</i> Forssk.	Geraniaceae		H
169	<i>Geranium dissectum</i> L.	Geraniaceae	*	H
170	<i>Gerbera piloselloedes</i> (L.) Cass.	Asteraceae	Yamora kibie	H
171	<i>Girardinia bullosa</i> (Steudel) Wedd .	Urticaceae		H
172	<i>Gladiolus abyssinicus</i> (Brongn. ex Lemaire)Goldblattandde Vos	Iridaceae	Enzerzey	H
173	<i>Gnaphallium rubriflorum</i> Hilliard	Asteraceae		S
174	<i>Gomphocarpus purpurascens</i> A.Rich.	Asclepiadaceae	Tifirna	S
175	<i>Grewia ferruginea</i> Hochst. ex A.Rich.	Tiliaceae	Lenkuata	T
176	<i>Guizotia scabra</i> (Vis.) Chiov.	Asteraceae	Mechi	H
177	<i>Guizotia schimperii</i> Sch.Bip. ex Walp.	Asteraceae	Mechi	H
178	<i>Gunnera perpensa</i> L.	Haloragaceae	Kuarf	H
179	<i>Hagenia abyssinica</i> (Bruce)J.F.Gmel.	Rosaceae	Kosso	T
180	<i>Halleria lucida</i> L.	Scrophulariaceae	Masinkero	T
181	<i>Haplocarpha rueppelli</i> (Sch.Bip.)Beauv.	Asteraceae	Getin	H
182	<i>Haplocarpha schimperii</i> (Sch.Bip.) Beauv.	Asteraceae	Getin	H
183	<i>Haplosciadium abyssinicum</i> Hochst.	Apiaceae		H
184	<i>Harpachne scchimperii</i> Hochst.ex A.Rich.	Poaceae	Cheguara saeri(Tya)	H
185	<i>Hebenstretia angolensis</i> Rofle	Scrophulariaceae	Galelo	H
186	<i>Helichrysum citrispinum</i> Del.	Asteraceae	Setgarda	S

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187	<i>Helichrysum formosissimum</i> Sch.Bip. ex A.Rich.	Asteraceae	Nechilo	H
188	<i>Helichrysum nudifolium</i> (L.) Less.	Asteraceae		H
189	<i>Helichrysum splendidum</i> (Thunb.) Less.	Asteraceae	Nechilo	H
190	<i>Helichrysum stenopterum</i> DC.	Asteraceae		H
191	<i>Helichrysum schimpri</i> Sch. Bip. ex Arich.) Moeser	Asteraceae	Nechilo	S
192	<i>Helictotrichon elongatum</i> (Hochst. ex A. Rich.) C.E. Hubb.	Poaceae		H
193	<i>Heracleum abyssinicum</i> (Boiss.)Norman	Apiaceae		H
194	<i>Hesperantha petitiana</i> (A. Rich.) Baker	Iridaceae		H
195	<i>Heteromorpha arborescens</i> (Spreng.) Cham.and Schltdl.	Apiaceae	Yejib mirkuz	S
196	<i>Hibiscus diversifolius</i> A.Rich.	Malvaceae	Hibiscus	H
197	<i>Hibiscus micranths</i> L.f.	Malvaceae		S
198	<i>Hyparrhenia hirta</i> (L.) Stapf	Poaceae	Sembeliet	H
199	<i>Hypericum peplidifolium</i> A.Rich.	Hypericaceae	Tawadi	H
200	<i>Hypericum quartinianum</i> A.Rich.	Hypericaceae	Amja	S
201	<i>Hypericum revolutum</i> Vahl	Hypericaceae	Amja	T
202	<i>Hypoestes forskalii</i> (Vahl) R.Br.	Acanthaceae	Tay Beder	H
203	<i>Hypoestes triflora</i> (Forssk.)RoemandShult.	Acanthaceae	Tikur telenj	H
204	<i>Ilex mitis</i> (L.) Radlk.	Aquifoliaceae	Misir gemfo	T
205	<i>Impatiens hochstetteri</i> Warb.	Balsaminaceae	Girishit	H
206	<i>Impatiens rothii</i> Hook. f.	Balsaminaceae	Ensosila	H
207	<i>Impatiens tinctoria</i> A.Rich.subsp. <i>abyssinica</i> (Hook. F.) GreyWilson	Balsaminaceae		H
208	<i>Indigofera arrecta</i> Hochst. ex A.Rich.	Fabaceae	Digndig	S
209	<i>Indigofera rothii</i> Bak.	Fabaceae	khoshi (Or);	S
210	<i>Inula confertiflora</i> A.Rich.	Asteraceae	Weinagift	S
211	<i>Ipomoea tenuirostris</i> Choisy subsp. <i>tenuirostris</i> Choisy	Convolvulaceae	Ye ayt hareg	H
212	<i>Isodon ramosissimus</i> (Hook.f.)Codd	Lamiaceae		H
213	<i>Isoglossa somalensis</i> Lindau	Acanthaceae		H
214	<i>Jasminum abyssinicum</i> Hochst.ex DC.	Oleaceae	Abita hareg	Li
215	<i>Jasminum grandiflorum</i> L.	Oleaceae	Tenbelel	Li
216	<i>Juniperus procera</i> Hochst. ex Endl.	Cupressaceae	Tid	T
217	<i>Justicia schimperiana</i> (Hochst. ex Nees) T.Anders.	Acanthaceae	Sensel/Simiza	S
218	<i>Kalanchoe densiflora</i> Rolfe	Crassulaceae	Endahula	H
219	<i>Kalanchoe marmorata</i> Bak.	Crassulaceae	Yekola Endahula	H
220	<i>Kalanchoe petitiana</i> A. Rich.	Crassulaceae	Yekola Endahula	H
221	<i>Kniphofia foliosa</i> Hochst.	Asphodelaceae	Ashenda	H

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222	<i>Kniphofia insignis</i> Rendle	Asphodelaceae	Yejib shinkurt	H
223	<i>Kniphofia isoetifolia</i> Steud. ex Hochst.	Asphodelaceae	Yejib shinkurt	H
224	<i>Kosteletzkya begoniifolia</i> (Ulbr.) Ulbr	Malvaceae	Nacha	S
225	<i>Lactuca inermis</i> Forssk.	Asteraceae		H
226	<i>laggera crispate</i> (Vahl) Hepper and Wood	Asteraceae		H
227	<i>Laggera tomentosa</i> (Sch.Bip. ex A. Rich.)Oliv.andHiern	Asteraceae	Alashumie	S
228	<i>Launaea rueppellii</i> (Sch.Bip. Ex Oliv. and Hiern)L.Boulos	Asteraceae		H
229	<i>Leonotis ocymifolia</i> (Burm. F.) Iwarsson	Lamiaceae	Ras-kimmir	S
230	<i>Leucas martinicensis</i> (Jacq.)R.Br.	Lamiaceae	Yeferes zeng	H
231	<i>Linum trigynum</i> L.	Linaceae	*	H
232	<i>Lippia adoensis</i> Hochst.ex Walp.	Verbenaceae	Kessie	S
233	<i>Lithospermum afromontanum</i> Weim.	Boraginaceae		H
234	<i>Lobelia goberroa</i> Hemsl.	Lobeliaceae	Etse komen	S
235	<i>Lobelia rhynchopetalum</i> Hemsl.	Lobeliaceae	Jibra	S
236	<i>Lolium temulentum</i> L.	Poaceae	Enkirdad	H
237	<i>Lotus corniculatus</i> L.	Fabaceae	*	S
238	<i>Lotus discolor</i> E.May.	Fabaceae		S
239	<i>Maesa lanceolata</i> Forssk.	Myrsinaceae	Kelewa	T
240	<i>Malva verticillata</i> L.	Malvaceae	*	H
241	<i>Maytenus arbutifolia</i> (A. Rich.) Wilczek	Celastraceae	Atat	T
242	<i>Maytenus gracilipes</i> (Welw. Ex Oliv.)Exell	Celastraceae	Atat	T
243	<i>Maytenus obscura</i> (A. Rich.) Cuf.	Celastraceae	Kumbel	T
244	<i>Maytenus undata</i> (Thunb.) Blakelock	Celastraceae	Geram atat	T
245	<i>Medicago polymorpha</i> L.	Fabaceae	Maget	H
246	<i>Merendera schimperiana</i> Hochst.	Colchicaceae	Abagumie(T)	H
247	<i>Mikaniopsis clematoides</i> (Sch.Bip. ex A. Rich.) Milne-Redh.	Asteraceae	Kuakuatie hareg	Li
248	<i>Mimulopsis solmsii</i> Schweinf.	Acanthaceae		H
249	<i>Misopates orontium</i> (L.) Rafin.	Scrophulariaceae		H
250	<i>Momordica foetida</i> Schumach.	Cucurbitaceae	Mar kura	H
251	<i>Monopsis stellarioides</i> (Presl) Urb.subsp <i>schimperiana</i> (Presl) Urb	Lobeliaceae		H
252	<i>Myrica salicifolia</i> A.Rich.	Myricaceae	Shinet	T
253	<i>Myrsine africana</i> L.	Myrsinaceae	Kechemo	S
254	<i>Nephrophyllum abyssinicum</i> Hochst. ex A.Rich.	Convolvulaceae		H
255	<i>Nuxia congesta</i> R. Br. ex Fresen.	Loganiaceae	Atkuar	T
256	<i>Oenanthe palustris</i> (Chiov.) Norman	Apiaceae	Etse siol/Dodot	H
257	<i>Olea capensis</i> L. subsp. <i>macrocarpa</i>	Oleaceae	Damot	T

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	(C.A. Wright.)Verdc.		weira/Gegema	
258	<i>Olea europaea</i> L.subsp. <i>cuspidata</i> (Wall.ex G. Don.) Cif.	Oleaceae	Weira	T
259	<i>Olinia rochetiana</i> A. Juss.	Oliniaceae	Tifie	T
260	<i>Oplismenus hirtellus</i> (L.) P.Beauv.	Poaceae	Kok sar	H
261	<i>Opuntia ficus-indica</i> (L.) Miller	Cactaceae	Beles	S
262	<i>Orobanche minor</i> Smit.	Orobanchaceae	Sat Yegib ras	H
263	<i>Osyris quadripartita</i> Decn.	Santalaceae	Keret	S
264	<i>Otostegia fruticosa</i> (Forssk.) Schweinf. ex Penzig subsp. <i>fruticosa</i>	Lamiaceae	Geram Tunijit	S
265	<i>Oxalis corniculata</i> L.	Oxalidaceae		H
266	<i>Pavetta abyssinica</i> Fresen.	Rubiaceae	Kamaduwa	S
267	<i>Pavonia urens</i> Cav.	Malvaceae	Koskuasie	S
268	<i>Pelargonium glechomoides</i> Hochst.	Geraniaceae	yebeg gomen	H
269	<i>Pennisetum sphacelatum</i> (Nees) Th. Dur. and Schinz	Poaceae	Sindedo/Geta	H
270	<i>Pennisetum thunbergii</i> Kunth	Poaceae	Tucha sar/Guba	H
271	<i>Pentas schimperiana</i> (A. Rich.) Vatke	Rubiaceae	Woinagift	S
272	<i>Peperomia abyssinica</i> Miq.	Piperaceae		H
273	<i>Periploca linearifolia</i> Quart. -Dill.and A.Rich.	Asclepiadaceae	Moider	Li
274	<i>Periscaria setosula</i> (A.Rich.)K.L.Wilson	Polygonaceae		H
275	<i>Peucedanum pettitiana</i> A.Rich.	Apiaceae		H
276	<i>Phagnalon abyssinicum</i> Sch. Bip. ex A.Rich.	Asteraceae	Nib Asil	H
277	<i>Phalaris paradoxa</i> L.	Poaceae	Asendabo	H
278	<i>Phytolacca dodecandra</i> L 'Herit.	Phytolaccaceae	Endod	Li
279	<i>Pimpinella hywodii</i> Abebe	Apiaceae		H
280	<i>Pinus patula</i> Schiede ex Schltdl. and Cham.	Pinaceae	Patula	T
281	<i>Pittosporum viridiflorum</i> Sims	Pittosporaceae	Weil	T
282	<i>Plantago lanceolata</i> L.	Plantaginaceae	Gorteb	H
283	<i>Plantago major</i> L.	Plantaginaceae		H
284	<i>Plantago palmata</i> Hook.f.	Plantaginaceae	Gorteb	H
285	<i>Plectocephalus varians</i> (A.Rich.)C. Jeffrey ex Cufod.	Asteraceae	Etse yohannis	H
286	<i>Plectranthus lanuginosus</i> (Hochst. ex Benth.) Agnew	Lamiaceae	Agashur	H
287	<i>Plectranthus punctatus</i> (L.f.)L Her	Lamiaceae	Dembo	H
288	<i>Pleopeltis macrocarpa</i> (Willd.)Kaulf	Polypodiaceae		H
289	<i>Poa annua</i> L.	Poaceae		H
290	<i>Poa leptoclada</i> (Hochst. ex A.Rich.)	Poaceae	Dega sar	H
291	<i>Poa schimperiana</i> (Hochst. ex A.Rich.)	Poaceae	Serti arem	H

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292	<i>Podocarpus falcatus</i> (Thunb.) R.B ex Mirb.	Podocarpaceae	Zigba	T
293	<i>Polygala steudneri</i> Chod.	Polygalaceae	Etse libona	H
294	<i>Polygonum aviclarum</i> L.	Polygonaceae	Anifafa(Tya)	H
295	<i>Polygonum nepalensis</i> (Meisn.)Miyabe	Polygonaceae	Ye enbosa siga	H
296	<i>Polyscias fulva</i> (Hiern) Harms	Araliaceae	Yezinjero wenber	T
297	<i>Premna schimperii</i> Engl.	Lamiaceae	Chocho	S
298	<i>Prunus africana</i> (Hook.f.) Kalkm.	Rosaceae	Tikur enchet	T
299	<i>Pseudognaphalium luteo-album</i> (L.)Hilliard andBurtt	Asteraceae		H
300	<i>Psyrax schimperiana</i> (A. Rich.) Bridson	Rubiaceae	Seged/Shiro	T
301	<i>Pteridum aquilinum</i> (L.) Kuhn subsp. <i>capense</i> (Thunb.) C.Chr.	Pteridaceae		H
302	<i>Pteris cretica</i> L.	Pteridaceae		H
303	<i>Pterocephalus frutescens</i> Hochst. ex A.Rich.	Dipsacaceae		H
304	<i>Pterolobium stellatum</i> (Forssk.) Brenan	Fabaceae	Kentefa	Li
305	<i>Ranunculus multifidus</i> Forssk.	Ranunculaceae	Etse siol	H
306	<i>Ranunculus oreophytus</i> Del.	Ranunculaceae		H
307	<i>Ranunculus simensis</i> Fresen.	Ranunculaceae	Ger hareg	H
308	<i>Rhabdotosperma scrophulariifolia</i> (Hochst. ex A.Rich.)Hartl	Scrophulariaceae		H
309	<i>Rhamnus prinoides</i> L'Herit.	Rhamnaceae	Gesho	S
310	<i>Rhoicissus tridentata</i> (L.f.) Wild and Drummond	Vitaceae	Abba-weldu	Li
311	<i>Rhus glutinosa</i> A. Rich. <i>sub sp. glutinosa</i> Gilbert.	Anacardiaceae	Tilem	T
312	<i>Rhus retinorrhoea</i> Oliv.	Anacardiaceae	Talo/tilem	T
313	<i>Rhus vulgaris</i> Meikle	Anacardiaceae	Kimo	T
314	<i>Rhus natalensis</i> Krauss	Anacardiaceae	Busi	T
315	<i>Ricinus communis</i> L.	Euphorbiaceae	Gulo/chakima	S
316	<i>Rosa abyssinica</i> Lindley	Rosaceae	Kega	S
317	<i>Rubia cordifolia</i> L.	Rubiaceae	Enchibir	H
318	<i>Rubus apetalus</i> Poir.	Rosaceae	Yedega Enjory	Li
319	<i>Rubus volkensii</i> Engl.	Rosaceae	Enjori	Li
320	<i>Rumex abyssinicus</i> Jacq.	Polygonaceae	Mekimeko	H
321	<i>Rumex nepalensis</i> Spreng.	Polygonaceae	Yewosha tulit	H
322	<i>Rumex nervosus</i> Vahl	Polygonaceae	Embacho	S
323	<i>Salix mucronata</i> Thunb.	Salicaceae	Akeya/wonz adimk	T
324	<i>Salvia merjamie</i> Forssk.	Lamiaceae	Tololat	H
325	<i>Salvia nilotica</i> Jacq.	Lamiaceae	Ehul geb	H
326	<i>Sanicula elata</i> Buch. -Ham.ex D.Don	Apiaceae	*	H
327	<i>Satureja paradoxa</i> (Vatke) Engl. ex	Lamiaceae		H

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	Seybold			
328	<i>Satureja pseudosimensis</i> Brenan	Lamiaceae		H
329	<i>Satureja punctata</i> (Benth.) Briq. subsp. <i>Punctata</i>	Lamiaceae	ye enbosa chenger	H
330	<i>Satyrium aethiopicum</i> Smmurh.	Orchidaceae		H
331	<i>Scabiosa columbaria</i> L.	Dipsacaceae	Yetija zago	H
332	<i>Schefflera abyssinica</i> (Hochst. ex A. Rich.) Harms	Araliaceae	Gitem, Kokora	T
333	<i>Schoenoplectus corymbosus</i> (Roem.andSchult.)Rayn.var <i>brachyceras</i> (A.Rich.)Lye	Cyperaceae	Ketema	H
334	<i>Sedum glomerifolium</i> M.Gilbert	Crassulaceae		H
335	<i>Senecio fresenii</i> Sch.Bip. ex Oliv. and Hiern	Asteraceae		H
336	<i>Senecio myriocephallus</i> Sch.Bip. ex A.Rich.	Asteraceae	*	S
337	<i>Senecio ochrocarpus</i> Oliv. and Hiern	Asteraceae	kebkebo	H
338	<i>Senna multiglandulosa</i> (Jacq.) Irwin and Barneby	Fabaceae		S
339	<i>Senna occidentalis</i> (L.) Link	Fabaceae	leleba mar	S
340	<i>Sida tenuicarpa</i> Vollesen	Malvaceae	Chifrig	S
341	<i>Silene burchellii</i> DC.	Cryophyllaceae		H
342	<i>Sisymbrium erysimoides</i> Desf.	Brassicaceae	Sinko	H
343	<i>Smilax aspera</i> L.	Smilacaceae	Ashikla	Li
344	<i>Snowdenia polystachya</i> (Fresen.) Pilg.	Poaceae	Muja	H
345	<i>Solanecio gigas</i> (Vatke) C. Jeffery	Asteraceae	Shikoko gomen	S
346	<i>Solanum anguivi</i> Lam.	Solanaceae	zirch Embuay	S
347	<i>Solanum benderianum</i> Schimper ex Dammer	Solanaceae	Awati hareg	Li
348	<i>Solanum marginatum</i> L.f.	Solanaceae	Geber Embuay	S
349	<i>Solanum villosum</i> Mill.	Solanaceae		H
350	<i>Sonchus bipontini</i> Asch.	Asteraceae		H
351	<i>Sonchus oleraceus</i> L.	Asteraceae	Ye Ahiya choma	H
352	<i>Sparmannia ricinocarpa</i> (Eckl.andZeyh.) O.Ktze.	Tiliaceae	Wolkifa	S
353	<i>Spergula arvensis</i> L.	Caryophyllaceae	Seyitan sar	H
354	<i>Spilanthes costata</i> Benth.	Asteraceae	Yemidir berbere	H
355	<i>Sporobolus festivus</i> Hochst. ex A. Rich.	Poaceae		H
356	<i>Sporobolus africanus</i> (Poir.) Robyns and Tournay	Poaceae	Murrie	H
357	<i>Stachys aculeolata</i> Hook.f.	Lamiaceae		H
358	<i>Stephania abyssinica</i> (Dillon and A. Rich.) Walp.	Menispermaceae	Engochit	H

No	Scientific Name	Family	Local name:	Habit
359	<i>Swertia abyssinica</i> Hochst.	Gentianaceae	*	H
360	<i>Tacazzea conferta</i> N.E. Br.	Asclepiadaceae	Kuando hareg	Li
361	<i>Tagetes minuta</i> L.	Asteraceae	Gimie/yeahiya shito	H
362	<i>Teclea nobilis</i> Del.	Rutaceae	Atesa	T
363	<i>Tephrosia interrupta</i> Hochst. and Steud. ex Engl.	Fabaceae	Yejib ater	S
364	<i>Thalictrum rhyhocarpum</i> Dill. and A. Rich.	Ranunculaceae	Sire bizu	H
365	<i>Thymus schimperi</i> Ronnigersubsp. <i>schimperi</i>	Lamiaceae	Tosign	H
366	<i>Toddalia asiatica</i> (L.) lam.	Rutaceae		Li
367	<i>Torilis arvensis</i> (Hudson) Link	Apiaceae	Chegotogot	H
368	<i>Trifolium acaule</i> Steud. ex A. Rich.	Fabaceae	Maget	S
369	<i>Trifolium calocephalum</i> Fresen.	Fabaceae		H
370	<i>Trifolium campestre</i> Schreb.	Fabaceae	Wodima	H
371	<i>Trifolium repens</i> L.	Fabaceae		H
372	<i>Trifolium rueppellianum</i> Fresen.	Fabaceae	Wodima	H
373	<i>Trifolium simense</i> Fresen.	Fabaceae	*	H
374	<i>Turraea holstii</i> Gurke	Meliaceae	Atesaa	S
375	<i>Umbilicus botryoides</i> A. Rich.	Crassulaceae		H
376	<i>Urera hypselodendron</i> (A. Rich.) Weed.	Urticaceae	Lanikuso	Li
377	<i>Ursinia nana</i> DC.	Asteraceae		H
378	<i>Urtica simensis</i> Steudel	Urticaceae	Sama	H
379	<i>Verbascum sinaiticum</i> Benth.	Scrophulariaceae	Yahiyajoro	H
380	<i>Vermifruix abyssinica</i> (A. Rich.) Gillett	Fabaceae		H
381	<i>Vernonia adoensis</i> Sch. Bip. ex Walp.	Asteraceae	Feres zeng	S
382	<i>Vernonia amygdalina</i> Del.	Asteraceae	Girawa	T
383	<i>Vernonia auriculifera</i> Hiern	Asteraceae	Gujjo	S
384	<i>Vernonia hochstetteri</i> Sch. Bip. ex Walp.	Asteraceae	Grawa	S
385	<i>Vernonia leopoldi</i> (Sch. Bip. ex Walp.) Vatke	Asteraceae	Girawa	S
386	<i>Vernonia rueppellii</i> Sch. Bip. ex Walp.	Asteraceae	Grawa	S
387	<i>Veronica abyssinica</i> Fresen.	Scrophulariaceae		H
388	<i>Vicia hirsuta</i> (L.) S.F. Gray	Fabaceae		H
389	<i>Vigna membranacea</i> A. Rich. sub sp. <i>membranacea</i>	Fabaceae		H
390	<i>Viola abyssinica</i> Oliv.	violaceae		H
391	<i>Vulpia bromoides</i> (L.) S.F. Gray	Poaceae	Gofer sar	H
392	<i>Xanthium spinosum</i> L.	Asteraceae	Yeset milas	H
393	<i>Xanthium strumarium</i> L.	Asteraceae	Yeset milas	H
394	<i>Zehneria scabra</i> (Linn. f.) Sond.	Cucurbitaceae	Etse-sabek	H

Appendix 2. List of endemic taxa in Wof-Washa Forest

Habits are indicated as T (Tree), H (Herb), S (shrub), and L (liana) and Vernacular or Local name: Amharic (Am), Tigrigna (T).

No	Scientific Name	Family	Local name(Am)	Habit
1	<i>Acacia negrii</i>	Fabaceae	Grar	T
2	<i>Aloe ankoberensis</i>	Aloaceae	Merarie	S
3	<i>Aloe debrana</i>	Aloaceae	Merarie	S
4	<i>Aloe pulcherrim</i>	Aloaceae	Sete eret	S
5	<i>Arisaema addis-ababense</i>	Araceae	Yeregnoch tila	H
6	<i>Astragalus atropilosus</i> subsp. <i>atropilosus</i>	Fabaceae	Tetem agazien(T)	H
7	<i>Bidens macroptera</i>	Asteraceae	Adey Abeba	H
8	<i>Carum piovanii</i>	Apiaceae		H
9	<i>Crassocephalum macropappum</i>	Asteraceae	Liti marefia	H
10	<i>Crotalaria rosenii</i>	Fabaceae	*	S
11	<i>Echinops ellenbeckii</i>	Asteraceae	Kosheshila	H
12	<i>Echinops longisetus</i>	Asteraceae	Kosheshila	H
13	<i>Erythrina brucei</i>	Fabaceae	Korch/Ergofit	T
14	<i>Euphorbia dumalis</i>	Euphorbiaceae	Anterfa	S
15	<i>Gomphocarpus purpurascens</i>	Asclepiadaceae	Tifirna	S
16	<i>Impatiens rothii</i>	Balsaminaceae	Ensofila	H
17	<i>Impatiens tinctoria</i> subsp. <i>abyssinica</i>	Balsaminaceae		H
18	<i>Indigofera rothii</i>	Fabaceae	khoshi (Or);	S
19	<i>Inula confertiflora</i>	Asteraceae	Weinagift	S
20	<i>Kalanchoe petittiana</i> Var <i>petittiana</i>	Crassulaceae	Yekola Endahula	H
21	<i>Kniphofia foliosa</i>	Asphodelaceae	Ashenda	H
22	<i>Kniphofia insignis</i>	Asphodelaceae	Yejob shinkurt	H
23	<i>Kniphofia isoetifolia</i>	Asphodelaceae	Yejob shinkurt	H
24	<i>Laggera tomentosa</i>	Asteraceae	Alashumie	S
25	<i>Launaea rueppellii</i>	Asteraceae		H
26	<i>Lippia adoensis</i>	Verbenaceae	Kessie	S
27	<i>Lobelia rhynchopetalum</i>	Lobeliaceae	Jibra	S
28	<i>Mikaniopsis clematoides</i>	Asteraceae	Kuakuatie hareg	Li
29	<i>Nephrophyllum abyssinicum</i>	Convolvulaceae		H
30	<i>Peucedanum petittiana</i>	Apiaceae		H
31	<i>Phagnalon abyssinicum</i>	Asteraceae	Nib Asil	H
32	<i>Pimpinella hywodii</i>	Apiaceae		H
33	<i>Plectocephalus varians</i>	Asteraceae	Etse yohannis	H
34	<i>Ranunculus simensis</i>	Ranunculaceae	Ger hareg	H
35	<i>Rhus glutinosa</i> subsp. <i>glutinosa</i>	Anacardiaceae	Tilem	T
36	<i>Satureja paradoxa</i>	Lamiaceae		H
37	<i>Satyrium aethiopicum</i>	Orchidaceae		H
38	<i>Sedum glomerifolium</i>	Crassulaceae		H
39	<i>Senecio fresenii</i>	Asteraceae		H
40	<i>Senecio myriocephallus</i>	Asteraceae	*	S
41	<i>Senecio ochrocarpus</i>	Asteraceae	Kebkebo	H
42	<i>Solanecio gigas</i>	Asteraceae	Shikoko gomen	S
43	<i>Thymus schimperi</i> subsp. <i>schimperi</i>	Lamiaceae	Tosign	H
44	<i>Trifolium calocephalum</i>	Fabaceae	Maget	H
45	<i>Vernonia leopoldi</i>	Asteraceae	Grawa	S
46	<i>Vernonia rueppellii</i>	Asteraceae	Grawa	S

Appendix 3. New plant taxa recorded for Shewa (SU) floristic region in Wof-Washa Forest

No	Scientific Name	Family	Habit
1	<i>Conostomium quadrangulare</i>	Rubiaceae	H
2	<i>Cynoglossum coeruleum</i>	Boraginaceae	H
3	<i>Cyperus conglomeratus</i>	Cyperaceae	H
4	<i>Cyperus densicaespitosus</i>	Cyperaceae	H
5	<i>Dryopteris lewalleana</i>	Dryopteridaceae	H
6	<i>Erodium cicutarium</i>	Geraniaceae	H
7	<i>Geranium dissectum</i>	Geraniaceae	H
8	<i>Isodon ramosissimus</i>	Lamiaceae	H
9	<i>Kosteletzkya begoniifolia.</i>	Malvaceae	S
10	<i>Lotus corniculatus</i>	Fabaceae	S
11	<i>Misopates orontium</i>	Scrophulariaceae	H
12	<i>Sedum glomerifolium</i>	Crassulaceae	H
13	<i>Trifolium repens</i>	Fabaceae	H

Appendix 4. Families, genera and species distribution of plants collected in Wof-Washa Forest

Family	Genera	Species	Family	Genera	Species
Asteraceae	35	62	Rutaceae	2	2
Poaceae	22	30	Sapindaceae	2	2
Fabaceae	18	29	Tiliaceae	2	2
Lamiaceae	12	17	Vitaceae	2	2
Cyperaceae	4	15	Adiantaceae	1	1
Apiaceae	13	13	Amaryllidaceae	1	1
Brassicaceae	7	9	Apocynaceae	1	1
Rubiaceae	8	9	Aquifoliaceae	1	1
Euphorbiaceae	4	7	Asparagaceae	1	1
Malvaceae	6	7	Berberidaceae	1	1
Ranunculaceae	4	7	Cactaceae	1	1
Rosaceae	5	7	Campanulaceae	1	1
Scrophulariaceae	7	7	Casuarinaceae	1	1
Acanthaceae	5	6	Colchicaceae	1	1
Crassulaceae	4	6	Cuscutaceae	1	1
Polygonaceae	3	6	Dracaenaceae	1	1
Solanaceae	3	6	Dryopteridaceae	1	1
Asclepiadaceae	5	5	Ebenaceae	1	1
Geraniaceae	3	5	Flacourtiaceae	1	1
Urticaceae	5	5	Gentianaceae	1	1
Amaranthaceae	3	4	Haloragaceae	1	1
Aspleniaceae	1	4	Hyacinthaceae	1	1
Boraginaceae	3	4	Linaceae	1	1

Family	Genera	Species	Family	Genera	Species
Caryophyllaceae	3	4	Melanthaceae	1	1
Celastraceae	1	4	Menispermaceae	1	1
Oleaceae	2	4	Moraceae	1	1
Aloeaceae	1	3	Oliniaceae	1	1
Anacardiaceae	1	3	Onagraceae	1	1
Asphodelaceae	1	3	Orobanchaceae	1	1
Balsaminaceae	1	3	Oxalidaceae	1	1
Commelinaceae	2	3	Papaveraceae	1	1
Convolvulaceae	3	3	Phytolaccaceae	1	1
Dipsacaceae	3	3	Pinaceae	1	1
Hypericaceae	1	3	Piperaceae	1	1
Lobeliaceae	2	3	Pittosporaceae	1	1
Plantaginaceae	1	3	Podocarpaceae	1	1
Araceae	1	2	Polygalaceae	1	1
Araliaceae	2	2	Polypodiaceae	1	1
Chenopodiaceae	1	2	Primulaceae	1	1
Cucurbitaceae	2	2	Rhamnaceae	1	1
Cupressaceae	2	2	Rhizophoraceae	1	1
Ericaceae	2	2	Salicaceae	1	1
Iridaceae	2	2	Santalaceae	1	1
Loganiaceae	2	2	Sinopteridaceae	1	1
Meliaceae	2	2	Smilacaceae	1	1
Myricaceae	2	2	Sterculiaceae	1	1
Myrsinaceae	2	2	Ulmaceae	1	1
Myrtaceae	1	2	Verbenaceae	1	1
Orchidaceae	2	2	Violaceae	1	1
Pteridaceae	2	2			

Appendix 5. The most common eleven tree species density over DBH classes

Species	DBH classes							Total
	<10	10.01-20	20.01-30	30.01-40	40.01-50	50.01-60	>60 cm	
<i>Juniperus procera</i>	87	96	85	44	56	19	78	465
<i>Erica arborea</i>	429	197	25	12	4	1	0	668
<i>Podocarpus falcatus</i>	186	106	37	13	11	5	12	370
<i>Hagenia abyssinica</i>	32	35	18	13	14	7	11	130
<i>Hypericum revolutum</i>	67	95	26	15	10	8	7	228
<i>Maesa lanceolata</i>	61	92	62	23	12	4	1	255
<i>Olea europaea</i> subsp. <i>cuspidata</i>	23	32	19	8	16	2	10	110
<i>Galiniera saxifraga</i>	64	44	24	12	7	0	2	153

<i>Ilex mitis</i>	11	23	18	14	20	2	5	93
<i>Pittosporum viridiflorum</i>	53	61	45	19	18	12	7	215
<i>Olinia rochetiana</i>	51	22	10	2	2	1	0	88

Appendix 6. Density of trees, shrubs and Lianas with DBH > 2 cm, 10 cm and 20 cm

<i>Species</i>	DBH > 2 cm		DBH > 10 cm		DBH > 20 cm	
	Indi./ha	%	Indi./ha	%	Indi./ha	%
<i>Erica arborea</i> L.	175.8	16.8	55.3	9.7	9.7	3.2
<i>Juniperus procera</i>	122.4	11.7	97.4	17.1	74.2	24.5
<i>Podocarpus falcatus</i>	97.1	9.3	30.8	5.4	18.9	6.2
<i>Maesa lanceolata</i>	67.1	6.4	49.2	8.6	25.5	8.4
<i>Hypericum revolutum</i>	58.9	5.6	38.2	6.7	13.2	4.3
<i>Pittosporum viridiflorum</i>	56.6	5.4	41.6	7.3	25.8	8.5
<i>Maytenus arbutifolia</i>	48.7	4.7	19.5	3.4	6.1	2
<i>Galiniera saxifraga</i>	40.3	3.8	22.9	4	11.8	3.9
<i>Hagenia abyssinica</i>	35	3.3	25.5	4.5	15	4.9
<i>Allophylus abyssinicus</i>	32.9	3.1	21.3	3.7	12.1	4
<i>Olea europaea</i> subsp. <i>cuspidata</i>	28.9	2.8	22.1	3.9	14.5	4.8
<i>Osyris quadripartita</i>	26.1	2.5	10	1.8	3.4	1.1
<i>Ilex mitis</i>	24.5	2.3	21.3	3.7	15.5	5.1
<i>Bersama abyssinica</i>	23.9	2.3	12.9	2.3	6.8	2.3
<i>Olinia rochetiana</i>	23.2	2.2	9.5	1.7	3.4	1.1
<i>Discopodium penninervium</i>	15	1.4	5	0.9	0.8	0.3
<i>Polyscias fulva</i>	13.9	1.3	12.1	2.1	8.7	2.9
<i>Ekebergia capensis</i>	13.4	1.3	8.2	1.4	4.7	1.6
<i>Dovyalis abyssinica</i>	12.9	1.2	5	0.9	1.1	0.3
<i>Halleria lucida</i>	11.1	1.1	5.8	1	0.8	0.3
<i>Nuxia congesta</i>	10.5	1	7.4	1.3	3.9	1.3
<i>Myrsine africana</i>	10.3	1	0.3	0	0	0

<i>Species</i>	DBH > 2 cm		DBH > 10 cm		DBH > 20 cm	
	Indi./ha	%	Indi./ha	%	Indi./ha	%
<i>Psydrax schimperiana</i>	10	1	2.6	0.5	0.8	0.3
<i>Ficus sur</i>	8.9	0.9	7.9	1.4	6.3	2.1
<i>Rhus natalensis</i>	7.9	0.8	6.1	1.1	4.5	1.5
<i>Clematis simensis</i>	6.8	0.7	0	0	0	0
<i>Rosa abyssinica</i>	6.8	0.7	1.6	0.3	0.5	0.2
<i>Vernonia auriculifera</i>	5.8	0.6	1.8	0.3	0	0
<i>Croton macrostachyus</i>	5.5	0.5	3.9	0.7	2.4	0.8
<i>Euphorbia ampliphylla</i>	5.3	0.5	5	0.9	3.9	1.3
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	4.5	0.4	0.8	0.1	0	0
<i>Dombeya torrida</i>	3.2	0.3	2.6	0.5	1.6	0.5
<i>Inula confertiflora</i>	2.9	0.3	0	0	0	0
<i>Prunus africana</i>	2.4	0.2	0.8	0.1	0.3	0.1
<i>Rhus retinorrhoea</i>	2.4	0.2	1.8	0.3	0.5	0.2
<i>Dodonea angustifolia</i>	2.1	0.2	0.5	0.1	0.3	0.1
<i>Myrica salicifolia</i>	2.1	0.2	0.8	0.1	0.5	0.2
<i>Schefflera abyssinica</i>	2.1	0.2	2.1	0.4	1.3	0.4
<i>Turraea holstii</i>	2.1	0.2	1.1	0.2	0.3	0.1
<i>Celtis africana</i>	1.8	0.2	0.5	0.1	0	0
<i>Lobelia rhynchopetalum</i>	1.6	0.2	1.6	0.3	0.5	0.2
<i>Cupressus lusitanica</i>	1.3	0.1	1.1	0.2	0.5	0.2
<i>Erythrina brucei</i>	1.3	0.1	1.3	0.2	1.1	0.3
<i>Helichrysum citrispinum</i>	1.3	0.1	0.3	0	0	0
<i>Hypericum quartinianum</i>	1.3	0.1	0.3	0	0	0
<i>Teclea nobilis</i>	1.3	0.1	1.1	0.2	0.5	0.2
<i>Premna schimperi</i>	1.1	0.1	0.3	0	0	0
<i>Rhus vulgaris</i>	1.1	0.1	0.8	0.1	0.3	0.1
<i>Dracaena steudneri</i>	0.8	0.1	0.5	0.1	0.3	0.1
<i>Embelia schimperi</i>	0.8	0.1	0	0	0	0
<i>Rubus volkensii</i>	0.8	0.1	0	0	0	0
<i>Buddleja polystachya</i>	0.5	0.1	0.3	0	0.3	0.1
<i>Euphorbia abyssinica</i>	0.5	0.1	0.5	0.1	0.5	0.2
<i>Solanum benderianum</i>	0.5	0.1	0	0	0	0
<i>Urera hypselodendron</i>	0.5	0.1	0	0	0	0
<i>Lobelia goberroa</i>	0.3	0	0.3	0	0.3	0.1
<i>Maytenus obscura</i>	0.3	0	0.3	0	0	0
<i>Toddalia asiatica</i>	0.3	0	0	0	0	0
Total	1046.6	100	569.5	100	303.4	100

Appendix 7. Importance Value Index (IVI) values, rank and priority classes of woody species of Wof - Washa forest, where P = priority and R = rank

Species	Basal Area	RBA	Dens	RD	Ferq %	RF	IVI	Rank	Priority
<i>Juniperus procera</i>	38.96	25.4	122.4	11.7	78.9	6.4	43.5	1	1
<i>Erica arborea</i>	7.06	4.6	175.8	16.8	42.1	3.4	24.8	2	1
<i>Podocarpus falcatus</i>	15.41	10.1	97.1	9.3	35.8	2.9	22.2	3	1
<i>Pittosporum viridiflorum</i>	11.1	7.2	56.6	5.4	52.6	4.2	16.9	4	1
<i>Maesa lanceolata</i>	9.47	6.2	67.1	6.4	43.1	3.5	16.1	5	1
<i>Hypericum revolutum</i>	5.81	3.8	58.9	5.6	42.1	3.4	12.8	6	1
<i>Hagenia abyssinica</i>	7.3	4.8	36.1	3.4	29.5	2.4	10.6	7	1
<i>Maytenus arbutifolia</i>	2.89	1.9	48.7	4.7	63.2	5.1	11.6	8	1
<i>Ilex mitis</i>	9.6	6.3	24.5	2.3	28.4	2.3	10.9	9	1
<i>Olea europaea subsp.cuspidata</i>	6.01	3.9	28.9	2.8	33.7	2.7	9.4	10	1
<i>Galiniera saxifraga</i>	4.58	3.0	40.3	3.9	33.7	2.7	9.6	11	1
<i>Allophylus abyssinicus</i>	4.7	3.1	32.9	3.1	32.6	2.6	8.8	12	2
<i>Osyris quadripartita</i>	2.27	1.5	26.1	2.5	37.9	3.1	7.0	13	2
<i>Myrsine africana</i>	0.09	0.1	10.1	1.0	69.5	5.6	6.6	14	2
<i>Bersama abyssinica</i>	3.02	2.0	23.9	2.3	36.8	3.0	7.2	15	2
<i>Rosa abyssinica</i>	0.21	0.1	6.8	0.6	63.2	5.1	5.9	16	2
<i>Inula confertiflora</i>	0.02	0.0	2.4	0.2	59.0	4.8	5.0	17	2
<i>Polyscias fulva</i>	4.72	3.1	13.9	1.3	16.9	1.4	5.8	18	2
<i>Olinia rochetiana</i>	1.58	1.0	23.2	2.2	25.3	2.0	5.3	19	2
<i>Discopodium penninervium</i>	0.5	0.3	15.0	1.4	39.0	3.1	4.9	20	2
<i>Clematis simensis</i>	0.06	0.0	6.8	0.6	51.0	4.1	4.8	21	2
<i>Ekebergia capensis</i>	1.93	1.3	13.4	1.3	23.2	1.9	4.4	22	2
<i>Rhus natalensis</i>	3.12	2.0	8.4	0.8	16.0	1.3	4.1	23	2
<i>Ficus sur</i>	3.6	2.3	8.9	0.9	10.5	0.9	4.0	24	2
<i>Dovyalis abyssinica</i>	0.63	0.4	12.9	1.2	30.5	2.5	4.1	25	2
<i>Nuxia congesta</i>	1.44	0.9	10.4	1.0	17.9	1.4	3.4	26	2
<i>Halleria lucida</i>	0.54	0.4	11.1	1.1	17.9	1.4	2.9	27	2
<i>Psydrax schimperiana</i>	0.36	0.2	10.0	1.0	19.0	1.5	2.7	28	2
<i>Rubus volkensii</i>	0.01	0.0	0.8	0.1	28.4	2.3	2.4	29	2
<i>Lobelia giberroa</i>	0.04	0.0	0.3	0.0	4.2	0.3	0.4	30	3
<i>Euphorbia ampliphylla</i>	1.61	1.1	5.3	0.5	9.5	0.8	2.3	31	3
<i>Embelia schimperi</i>	0.01	0.0	0.8	0.1	20.0	1.6	1.7	32	3
<i>Croton macrostachyus</i>	0.57	0.4	5.5	0.5	5.3	0.4	1.3	33	3
<i>Vernonia auriculifara</i>	0.18	0.1	5.8	0.6	8.4	0.7	1.4	34	3
<i>Dombeya torrida</i>	0.6	0.4	3.2	0.3	7.4	0.6	1.3	35	3
<i>Urera hypselodendron</i>	0	0.0	0.5	0.0	14.7	1.2	1.2	36	3
<i>Olea capensis subsp.</i>	0.09	0.1	4.5	0.4	8.4	0.7	1.2	37	3

<i>macrocarpa</i>									
<i>Solanum benderianum</i>	0.01	0.0	0.5	0.0	11.0	0.9	0.9	38	3
<i>Myrica salicifolia</i>	0.17	0.1	2.1	0.2	6.3	0.5	0.8	39	3
<i>Turraea holstii</i>	0.1	0.1	2.1	0.2	3.2	0.3	0.5	40	3
<i>Rhus retinorha</i>	0.32	0.2	2.4	0.2	4.2	0.3	0.8	41	3
<i>Schefflera abyssinica</i>	0.45	0.3	2.1	0.2	3.0	0.2	0.7	42	3
<i>Dodonea angustifolia</i>	0.07	0.0	2.1	0.2	6.3	0.5	0.8	43	3
<i>Lobelia rhynchopetalum</i>	0.22	0.1	1.8	0.2	4.2	0.3	0.7	44	3
<i>Prunus africana</i>	0.19	0.1	2.4	0.2	4.2	0.3	0.7	45	3
<i>Erythrina brucei</i>	0.64	0.4	1.3	0.1	1.1	0.1	0.6	46	3
<i>Celtis africana</i>	0.03	0.0	1.8	0.2	5.0	0.4	0.6	47	3
<i>Helichrysum citrispinum</i>	0.03	0.0	1.3	0.1	3.2	0.3	0.4	48	3
<i>Premna schimperi</i>	0.02	0.0	1.1	0.1	5.3	0.4	0.5	49	3
<i>Cuppressus lucitanica</i>	0.19	0.1	1.3	0.1	3.2	0.3	0.5	50	3
<i>Teclea nobilis</i>	0.3	0.2	1.1	0.1	2.1	0.2	0.5	51	3
<i>Hypericum quartinianum</i>	0.04	0.0	0.5	0.0	4.2	0.3	0.4	52	3
<i>Toddalia asiatica</i>	0	0.0	0.3	0.0	3.2	0.3	0.3	53	3
<i>Euphorbia abyssinica</i>	0.25	0.2	0.5	0.0	8.4	0.7	0.9	54	3
<i>Rhus vulgaris</i>	0.09	0.1	1.1	0.1	1.1	0.1	0.2	55	3
<i>Buddleja polystachya</i>	0.05	0.0	0.5	0.0	2.1	0.2	0.3	56	3
<i>Dracaena steudneri</i>	0.06	0.0	0.8	0.1	1.0	0.1	0.2	57	3
<i>Maytenus obscura</i>	0.01	0.0	0.2	0.0	1.0	0.1	0.1	58	3
	153.33	100.0	1046.6	100.0	1238.5	100.0	300.0		

Appendix 8. List of plant species identified from soil seed bank of Wof-Washa Forest

Species name	Soil seed bank layers(cm)				Seedling density no/area(m ²)	Habit	Family
	0-3	3.0-6	6.0-9	Total			
<i>Crasula alsinoides</i>	495	445	427	1367	63.94	H	Crassulaceae
<i>Nephrophyllum abyssinicum</i>	322	175	112	609	28.48	H	Convolvulaceae
<i>Oxalis corniculata</i>	177	84	97	358	16.74	H	Oxalidaceae
<i>Eragrostis schweinfurthii</i>	132	96	78	306	14.31	H	Poaceae
<i>Callitriche oreophila</i>	213	47	14	274	12.82	H	Callitrichaceae
<i>Agrocharis melanantha</i>	189	34	21	244	11.41	H	Apiaceae
<i>Dichondra repens</i>	144	75	10	229	10.71	H	Convolvulaceae
<i>Eragrostis racemosa</i>	117	41	54	212	9.92	H	Poaceae
<i>Spilanthes costata</i>	151	34	8	193	9.03	H	Asteraceae
<i>Trifolium repense</i>	74	48	53	175	8.19	H	Crassulaceae
<i>Cyperus costatus</i>	86	33	27	146	6.83	H	Cyperaceae
<i>Cotula abyssinica</i>	57	19	35	111	5.19	H	Asteraceae

<i>Galinsoga quadriradiata</i>	73	30	5	108	5.05	H	Asteraceae
<i>Silene burchellii</i>	87	15	0	102	4.77	H	Caryophyllaceae
<i>Uebelina abyssinica</i>	67	23	9	99	4.63	H	Caryophyllaceae
<i>Centella asiatica</i>	48	19	0	67	3.13	H	Apiaceae
<i>Alchemila pedata</i>	45	10	4	59	2.76	H	Rosaceae
<i>Plantago major</i>	31	18	3	52	2.43	H	Plantaginaceae
<i>Cyperus pinguis</i>	34	12	4	50	2.34	H	Cyperaceae
<i>Ajuga integrifolia</i>	15	23	8	46	2.15	H	Lamiaceae
<i>Stellaria media</i>	15	23	5	43	2.01	H	Caryophyllaceae
<i>Achyranthus aspera</i>	17	9	13	39	1.82	H	Amaranthaceae
<i>Umbelicus botroides</i>	7	29	3	39	1.82	H	Crassulaceae
<i>Rumex nepalense</i>	21	13	2	36	1.68	H	Polygonaceae
<i>Geranium arabicum</i>	9	22	3	34	1.59	H	Geraniaceae
<i>Chloris gayana</i>	19	7	7	33	1.54	H	Poaceae
<i>Geranium aculeolatum</i>	23	5	2	30	1.40	H	Geraniaceae
<i>Arabis alpina</i> L.	16	9	4	29	1.36	H	Brassicaceae
<i>Poa leptoclada</i>	23	3	0	26	1.22	H	Poaceae
<i>Polygonum nepalensis</i>	16	7	0	23	1.08	H	Polygonaceae
<i>Maesa lanceolata</i>	18	0	3	21	0.98	T	Myrsinaceae
<i>Amaranthus silvestris</i>	13	6	2	21	0.98	H	Amaranthaceae
<i>Basella alba</i> L.	12	5	2	19	0.89	H	Basellaceae
<i>Festuca macrophylla</i>	18	1	0	19	0.89	H	Poaceae
<i>Sonchus bipontini</i> Asch.	6	3	9	18	0.84	H	Asteraceae
<i>Cardamine trichocarpa</i>	0	4	13	17	0.80	H	Brassicaceae
<i>Cyanotis barbata</i>	16	0	0	16	0.75	H	Commelinaceae
<i>Desmodium repandum</i>	11	4	1	16	0.75	H	Fabaceae
<i>Plectranthus lanuginosus</i>	0	3	12	15	0.70	H	Lamiaceae
<i>Hypericum peplidifolium</i>	10	0	4	14	0.65	H	Hypericaceae
<i>Arabis thaliana</i>	2	2	9	13	0.61	H	Brassicaceae
<i>Periscaria setosula</i>	9	3	1	13	0.61	H	Polygonaceae
<i>Datura stramonium</i>	0	8	4	12	0.56	H	Solanaceae
<i>Sanicula elata</i>	8	3	1	12	0.56	H	Apiaceae
<i>Sparmannia ricinocarpa</i>	8	3	1	12	0.56	H	Tiliaceae
<i>Ehrharta erecta</i>	6	4	1	11	0.51	H	Poaceae
<i>Oplismenus hirtellus</i>	10	1	0	11	0.51	H	Poaceae
<i>Solanm incanum</i>	3	4	4	11	0.51	H	Solanaceae
<i>Chenopodium murale</i>	8	1	1	10	0.47	H	Chenopodiaceae
<i>Commelina diffusa</i>	9	0	0	9	0.42	H	Commelinaceae
<i>Crepis rueppellii</i>	0	9	0	9	0.42	H	Asteraceae
<i>Plantago lanceolata</i>	1	3	5	9	0.42	H	Plantaginaceae
<i>Solanum bundrianum</i>	4	0	5	9	0.42	L	Solanaceae

<i>Torilis arvensis</i>	5	3	1	9	0.42	H	Apiaceae
<i>Vernonia amygdalina</i>	4	1	3	8	0.37	T	Asteraceae
<i>Zehneria scabra</i>	3	3	2	8	0.37	H	Cucurbitaceae
<i>Erodium moschatum</i>	4	0	3	7	0.33	H	Geraniaceae
<i>Eucalyptus camaldulensis</i>	1	0	5	6	0.28	T	Myrtaceae
<i>Conyza bonariensis</i>	1	0	5	6	0.28	H	Asteraceae
<i>Barbarea intermedia</i>	3	2	0	5	0.23	H	Brassicaceae
<i>Commelina Africana</i>	5	0	0	5	0.23	H	Commelinaceae
<i>Gunnera perpensa</i>	4	1	0	5	0.23	H	Haloragaceae
<i>Juniperus procera</i>	1	3	0	4	0.19	T	Cupressaceae
<i>Calpurnia aurea</i>	3	0	1	4	0.19	S	Fabaceae
<i>Galium simensis</i>	4	0	0	4	0.19	H	Rubiaceae
<i>Ficus sur</i>	3	0	0	3	0.14	T	Moraceae
<i>Plectranthus punctatus</i>	1	1	1	3	0.14	H	Lamiaceae
<i>Smilax aspera</i>	1	2	0	3	0.14	L	Smilacaceae
<i>Eucalyptus globulus</i>	2	0	0	2	0.09	T	Myrtaceae
<i>Hypericum revolutum</i>	2	0	0	2	0.09	T	Hypericaceae
<i>Clutia abyssinica</i>	1	1	0	2	0.09	S	Euphorbiaceae
<i>Saxifraga hederifolia</i>	2	0	0	2	0.09	H	Saxifragaceae
<i>Urera hypselodendron</i>	1	1	0	2	0.09	L	Urticaceae
<i>Olea europaea</i> L. subsp. <i>cuspidata</i>	1	0	0	1	0.05	T	Oleaceae
<i>Rumex abyssinicus</i>	0	1	0	1	0.05	H	Polygonaceae
<i>Erucastrum arabicum</i>	1	0	0	1	0.05	H	Brassicaceae
Total	2948	1494	1107	5549	259.54		

Appendix 9. Jaccard's (JSC), Sørensen's (SS) similarity coefficient and β -diversity of soil seed species composition among community types

Community types	Exclusive to first community type	Exclusive to second community type	Common to both community types	Jaccard's (JSC)	Sørensen's (SS)	β -diversity
I, II	42	1	35	0.449	0.619	0.381
I, III	47	0	39	0.453	0.624	0.376
I, IV	34	0	42	0.553	0.712	0.288
I, V	35	0	24	0.407	0.578	0.422
II, III	18	13	18	0.367	0.537	0.463
II, IV	10	19	26	0.473	0.642	0.358
II, V	26	11	10	0.213	0.351	0.649
III, IV	9	23	19	0.373	0.543	0.457
III, V	18	12	11	0.268	0.423	0.577
IV, V	29	7	16	0.308	0.471	0.529

Appendix 10. Environmental data of Wof-Washa Forest, P = Phosphorus, TN = Total Nitrogen D = Disturbance

Plot	Altitude	Slope	Aspect	D	Sand	Silt	Clay	pH	Carbon	CEC	Ex.acid	TN	P
1	3392	2	30	2	58	22	20	5.5	3.928	26.45	2.539	0.189	1.016
2	3332	2	30	2	70	14	16	5.44	5.317	31.146	1.289	0.238	5.671
3	3289	2	30	2	66	10	24	6.52	15.694	45.76	2.288	0.133	11.302
4	3221	20	30	2	66	16	18	6.48	17.476	60.89	2.281	0.427	46.849
5	3211	16	30	2	48	12	40	5.72	12.006	36.649	2.188	0.371	4.705
6	3178	2	30	2	68	16	16	6.56	16.464	57.866	1.871	0.245	35.758
7	3118	2	30	3	60	16	24	6.24	4.54	21.798	1.257	0.553	3.164
8	3017	2	30	1	50	26	24	6.76	4.661	22.058	2.583	0.42	2.325
9	2914	16	30	2	58	10	32	6.71	13.962	41.22	1.374	0.133	7.03
10	2836	25	30	2	38	36	26	5.74	1.962	23.994	1.692	0.161	1.036
11	3321	28	30	1	44	26	30	6	2.614	24.288	1.268	0.597	1.796
12	3290	28	30	1	50	26	24	6.04	21.344	38.509	0.875	0.308	4.289
13	3161	25	30	1	40	28	32	6.03	3.289	25.512	1.276	0.126	0.574
14	3140	25	30	2	50	20	30	6.66	9.097	37.026	0.392	0.469	7.036
15	3090	20	30	2	40	30	30	6.17	2.938	27.43	0.38	0.441	1.055
16	3046	20	30	2	44	32	24	6.15	6.699	33.508	1.114	0.252	5.424
17	3004	16	30	3	62	14	24	6.2	8.304	32.483	0.383	0.385	3.536
18	2971	20	30	3	38	30	32	5.84	7.435	25.823	0.759	0.558	0.991
19	2919	20	30	3	50	12	38	5.5	10.666	27.664	0.383	0.413	1.127
20	2825	25	30	3	38	30	32	5.85	11.446	21.945	0	0.469	4.348
21	3376	28	20	0	50	18	32	5.52	12.808	37.514	1.164	0.735	3.922
22	3256	28	20	1	52	20	28	6.01	12.569	44.226	0.393	0.679	4.392
23	3185	28	20	1	50	20	30	6.41	7.841	27.456	0.38	0.252	2.661
24	3143	28	20	2	50	18	32	5.83	16.044	47.589	0.394	0.378	6.715
25	3096	20	20	2	58	12	30	5.63	23.177	57.091	0.817	0.084	15.369
26	3048	25	20	2	44	22	34	5.4	7.834	23.738	0.759	0.581	1.203
27	3031	12	20	3	50	14	36	5.3	4.772	31.595	1.157	0.532	7.883
28	2970	12	20	3	36	24	40	5.26	4.5	24.769	0	0.763	0.843
29	2894	16	20	3	50	24	26	5.27	9.379	32.788	0.387	0.483	2.366
30	2867	16	20	3	58	20	22	5.72	15.12	45.612	0.782	0.728	2.628

Plot	Altitude	Slope	Aspect	D	Sand	Silt	Clay	pH	Carbon	CEC	Ex.acid	TN	P
31	2803	20	20	2	40	34	26	7	10.894	31.156	0.384	0.273	3.264
32	2887	16	0	2	50	26	24	6.61	4.845	25.578	0.376	0.336	10.359
33	2892	12	0	1	50	30	20	6.11	10.331	21.945	0.756	0.401	1.428
34	2888	12	0	1	48	18	34	5.8	10.626	29.362	0.381	0.441	1.674
35	3104	18	25	2	50	18	32	6.63	25.044	38.612	0.837	0.357	9.566
36	3223	24	25	2	66	20	14	6.31	6.988	19.394	0.379	0.396	20.469
37	3339	27	25	3	38	36	26	6.14	4.037	10.35	0.745	0.336	6.563
38	3498	24	25	3	42	16	42	5.6	5.085	11.577	0.376	0.302	1.565
39	3271	28	10	3	56	18	26	5.75	16.942	26.716	1.173	0.317	1.673
40	3234	24	10	3	54	20	26	5.8	13.539	17.463	1.894	0.351	1.473
41	3102	24	10	2	50	22	28	5.7	19.463	51.347	1.197	0.314	4.412
42	3035	24	10	2	64	14	22	5.75	17.027	32.124	1.164	0.301	5.971
43	2954	24	10	0	50	28	22	6.7	15.302	42.598	0.807	0.252	22.085
44	2886	28	10	1	62	10	28	6.34	15.483	29.722	1.545	0.588	2.876
45	2763	25	10	1	58	14	28	6.1	20.69	26.101	1.528	0.35	14.477
46	2674	25	10	2	56	12	32	5.78	12.507	26.832	1.923	0.413	9.105
47	2583	2	10	2	58	12	30	6	13.474	26.362	0.765	0.399	23.918
48	2529	25	10	2	58	12	30	5.45	10.374	16.173	1.149	0.418	2.703
49	2667	25	20	3	54	20	26	5.74	18.954	27.864	1.167	0.422	4.904
50	2596	20	20	3	58	18	24	5.44	10.511	25.441	1.164	0.387	3.989
51	2615	20	10	3	64	16	20	5.38	3.068	16.469	1.133	0.49	2.749
52	2570	8	0	2	48	20	32	6	4.13	29.758	1.906	0.41	10.991
53	2494	8	0	2	62	16	22	6.1	4.105	36.342	1.995	0.224	28.435
54	2480	16	0	1	82	14	4	6.02	5.202	26.888	1.152	0.182	3.328
55	2380	25	0	2	50	24	26	6.12	4.134	20.14	1.527	0.182	2.397
56	2406	20	0	1	46	24	30	5.95	8.299	23.089	1.149	0.28	5.086
57	2338	12	0	0	50	12	38	5.45	10.413	22.535	1.154	0.308	3.653
58	2348	4	40	1	48	18	34	5.42	6.183	19.977	1.142	0.224	4.927
59	2424	8	40	1	60	18	22	5.8	3.474	15.51	0.755	0.231	1.405
60	2474	20	40	3	60	16	24	5.96	3.033	11.2	0.747	0.28	8.212
61	2483	16	40	2	50	14	36	5.7	7.914	26.807	1.154	0.329	4.38

Plot	Altitude	Slope	Aspect	D	Sand	Silt	Clay	pH	Carbon	CEC	Ex.acid	TN	P
62	2437	20	40	3	48	16	36	5.58	7.713	26.297	1.154	0.182	2.372
63	2423	20	40	2	48	16	36	6.02	6.195	20.862	0.762	0.245	14.948
64	2449	16	40	2	58	18	24	5.78	17.347	39.698	0.445	0.294	7.316
65	2481	16	40	1	38	38	24	5.8	3.057	15.362	0.836	0.211	1.129
66	2450	2	40	1	26	42	32	5.44	3.074	14.819	1.261	0.156	3.826
67	2470	2	40	2	46	32	22	6.8	17.363	33.39	1.336	0.116	11.576
68	2425	2	40	1	28	42	30	5.9	4.115	7.174	1.266	0.255	1.583
69	2498	4	40	1	46	30	24	5.57	5.124	10.195	1.262	0.371	1.724
70	2784	16	40	3	62	20	18	5.52	9.337	22.025	1.277	0.231	2.191
71	2790	8	40	2	68	16	16	6.02	27.167	57.47	1.858	0.331	31.707
72	2796	8	40	2	50	14	36	5.94	5.148	19.642	2.111	0.211	1.964
73	2807	8	40	3	30	38	32	5.7	4.029	10.64	0.826	0.118	7.622
74	2815	8	40	3	70	22	8	6.04	12.695	38.084	0.434	0.226	4.362
75	2786	8	40	1	64	16	20	5.7	12.39	27.11	1.27	0.217	1.99
76	2750	16	30	2	48	18	34	5.91	3.345	15.98	1.123	0.312	32.267
77	2744	12	30	3	58	16	26	5.23	4.56	21.15	1.131	0.416	2.591
78	2764	12	30	2	28	42	30	6.11	19.45	34.57	1.211	0.22	3.223
79	2720	16	20	1	58	30	12	5.54	10.58	48.55	1.011	0.19	2.557
80	2720	16	20	1	62	18	20	6.24	7.55	51.957	1.009	0.11	27.421
81	2706	12	20	1	56	30	14	5.55	22.75	37.513	1.547	0.232	19.531
82	2641	20	25	3	45	30	25	5.95	15.71	42.11	1.33	0.331	31.313
83	2650	20	35	3	28	42	30	5.33	9.125	41.97	1.274	0.215	17.719
84	2619	15	30	2	58	22	20	5.76	25.534	36.756	1.55	0.115	12.905
85	2641	16	30	1	50	14	36	6.2	4.594	35.55	1.712	0.111	10.55
86	2604	20	30	2	20	40	40	5.81	5.591	35.79	2.01	0.411	13.095
87	2612	20	30	3	46	28	26	5.77	7.937	19.95	2.227	0.29	16.165
88	3167	4	25	2	81	14	5	5.94	13.518	22.59	1.935	0.19	8.671
89	3152	8	0	2	40	34	26	6.15	10.55	27.098	1.793	0.218	9.059
90	3131	12	0	1	68	14	18	6.44	11.123	42.55	1.327	0.171	14.909
91	3144	12	40	3	50	20	30	5.51	10.72	50.59	1.535	0.14	12.05
92	3116	12	40	2	65	20	15	5.95	11.432	17.33	1.435	0.44	16.79

Plot	Altitude	Slope	Aspect	D	Sand	Silt	Clay	pH	Carbon	CEC	Ex.acid	TN	P
93	3111	20	0	3	54	26	20	5.7	12.579	23.546	1.11	0.312	4.95
94	3096	20	20	3	50	28	22	5.72	16.513	27.891	1.21	0.141	3.595
95	3083	25	0	3	61	10	28	5.82	18.591	42.159	1.719	0.234	1.095

Appendix 11. Plotwise mean carbon stock values at the five pools in Wof-Washa Forest(t/ha)

Plot No	Mean AGC	Mean BGC	Mean SOC	Mean LC	Mean DC
1	4.24	0.85	40.07	0.17	10.88
2	5.40	1.08	59.02	0.04	9.30
3	9.89	1.98	157.72	0.08	21.59
4	20.19	4.04	186.12	0.03	23.92
5	49.39	9.88	100.85	0.28	39.92
6	25.55	5.11	180.28	0.05	30.37
7	15.14	3.03	44.95	0.08	26.96
8	48.97	9.79	44.75	0.06	51.85
9	35.41	7.08	127.75	0.09	6.57
10	69.49	13.90	17.66	0.08	21.80
11	9.07	1.81	23.53	0.05	14.64
12	7.44	1.49	158.88	0.08	32.67
13	9.61	1.92	28.61	0.05	35.17
14	24.18	4.84	83.24	0.03	21.36
15	81.51	16.30	26.00	0.07	11.28
16	33.83	6.77	63.31	0.05	22.62
17	101.23	20.25	82.21	0.04	45.38
18	52.09	10.42	63.57	0.02	12.28
19	132.47	26.49	91.19	0.02	12.11
20	65.54	13.11	97.86	0.03	4.05
21	64.79	12.96	115.27	0.04	24.95
22	69.32	13.86	116.89	0.04	18.39
23	35.29	7.06	71.75	0.06	27.02
24	70.63	14.13	144.40	0.01	21.46
25	81.24	16.25	187.65	0.02	2.13
26	51.36	10.27	68.16	0.01	15.21
27	119.83	23.97	41.52	0.01	6.36
28	131.08	26.22	36.45	0.15	44.50

29	76.06	15.21	88.63	0.04	35.75
30	134.49	26.90	151.96	0.03	64.40
31	99.60	19.92	99.68	0.05	16.04
32	284.87	56.97	46.51	0.04	17.61
33	357.80	71.56	103.83	0.04	1.11
34	482.11	96.42	92.45	0.12	3.26
35	207.00	41.40	189.40	0.03	23.59
36	234.97	46.99	78.62	0.03	52.54
37	87.35	17.47	36.33	0.04	0.52
38	40.05	8.01	41.19	0.08	9.10
39	163.30	32.66	162.64	0.03	11.99
40	47.59	9.52	129.97	0.15	39.43
41	53.52	10.70	181.01	0.02	13.25
42	154.43	30.89	173.68	0.04	14.88
43	183.89	36.78	149.19	0.02	7.33
44	68.69	13.74	148.64	0.03	72.08
45	97.82	19.56	195.52	0.03	2.36
46	90.54	18.11	123.82	0.15	2.54
47	514.37	102.87	125.31	0.04	3.53
48	259.41	51.88	96.48	0.06	28.15
49	79.19	15.84	181.96	0.02	2.98
50	349.69	69.94	102.48	0.39	5.43
51	52.68	10.54	31.75	0.15	2.04
52	247.53	49.51	36.55	0.19	0.77
53	158.74	31.75	41.87	0.07	9.51
54	105.78	21.16	44.48	0.27	24.72
55	219.98	44.00	39.07	0.03	14.78
56	195.95	39.19	74.69	0.22	0.17
57	169.70	33.94	89.03	0.11	7.58
58	216.43	43.29	53.79	0.15	23.78
59	105.45	21.09	34.91	0.12	17.06

60	77.16	15.43	30.03	0.18	4.84
61	65.99	13.20	68.85	0.13	4.60
62	317.40	63.48	67.10	0.16	6.91
63	109.39	21.88	53.90	0.04	1.82
64	127.41	25.48	169.13	0.04	0.92
65	119.89	23.98	28.43	0.02	0.31
66	104.37	20.87	25.36	0.26	13.28
67	115.70	23.14	166.68	0.09	7.97
68	103.05	20.61	34.57	0.02	13.19
69	187.73	37.55	42.27	0.05	4.14
70	136.43	27.29	98.04	0.06	21.36
71	104.27	20.85	187.98	0.04	6.53
72	42.65	8.53	44.79	0.04	3.68
73	131.04	26.21	33.84	0.05	4.22
74	160.40	32.08	159.96	0.04	17.32
75	174.95	34.99	128.24	0.13	44.85
76	132.88	26.58	29.10	0.05	3.69
77	170.78	34.16	43.78	0.16	1.35
78	86.72	17.34	163.38	0.08	4.10
79	112.43	22.49	120.61	0.06	9.17
80	133.39	26.68	78.14	0.06	5.00
81	345.96	69.19	193.92	0.03	2.60
82	153.86	30.77	146.10	0.03	2.61
83	234.85	46.97	76.65	0.03	0.46
84	140.47	28.09	184.82	0.01	0.92
85	245.88	49.18	39.97	0.04	2.53
86	224.17	44.83	42.77	0.02	1.40
87	263.62	52.72	73.81	0.04	0.00
88	70.98	14.20	188.58	0.02	7.71
89	115.11	23.02	96.53	0.04	10.10
90	113.36	22.67	120.13	0.08	2.25

91	261.13	52.23	98.09	0.05	5.60
92	1076.02	215.20	126.90	0.07	14.33
93	225.70	45.14	126.42	0.07	9.57
94	196.58	39.32	161.00	0.05	12.23
95	287.34	57.47	178.47	0.04	1.42
Total mean	143.50	28.70	97.19	0.07	14.70

Declaration

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

Name: Abiyou Tilahun Ayalew Date: _____ Signature: _____

This work has been done under my supervision.

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