Ecology, Carbon Stock and Formulation of Allometric Equation for Selected Tree and Shrub Species in Gerba Dima Forest, Southwestern Ethiopia

Abyot Dibaba

Addis Ababa University

Addis Ababa, Ethiopia

June 2018

Ecology, Carbon Stock and Formulation of Allometric Equation for Selected Tree and Shrub Species in Gerba Dima Forest, Southwestern Ethiopia

Abyot Dibaba Hundie

A Dissertation Submitted to

The Department of Plant Biology and Biodiversity Management

Presented in Fulfillment of the Requirements for the Degree of Doctor of Philosophy (Biology: Botanical Sciences)

Addis Ababa University

Addis Ababa, Ethiopia

June 2018

ADDIS ABABA UNIVERSITY
GRADUATE PROGRAMMES

This is to certify that the Dissertation prepared by Abyot Dibaba Hundie, entitled: Ecology, Carbon Stock and Formulation of Allometric Equation for Selected Tree and Shrub Species in Gerba-Dima Forest, Southwestern Ethiopia and submitted in 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.

Signed by Examining Board:

	Name		Signature	Date
1.	____________________	(Examiner)	___________	___________
2.	____________________	(Examiner)	___________	___________
3.	___________________	(Advisor)	___________	___________
4.	____________________	(Advisor)	___________	___________
5.	____________________	(Chairman)	___________	___________

____
Chair of Department or Graduate Programme Coordinator

Abstract

Ecology, Carbon Stock and Formulation of Allometric Equation for Selected Tree and Shrub Species in Gerba-Dima Forest, Southwestern Ethiopia

Abyot Dibaba Hundie, Ph.D. Dissertation
Addis Ababa University, 2018

This study was conducted in Gerba Dima Forest, South Western Ethiopia, to estimate the carbon stock, formulate allometric equations for selected tree and shrub species, determine species diversity, vegetation structure and regeneration status of woody species. A total of 90 sample plots were laid by employing stratified random sampling. Semi destructive method which involves climbing a tree was used to collect data to formulate tree allometry while destructive sampling was used to collect data for development of shrub allometric equation. A total of 180 plant species belonging to 145 genera, 69 families and comprising of 15 endemic species were recorded. Cluster analysis resulted in five different plant communities and this result was supported by the ordination result. RDA result showed altitude was the main environmental variable in determining the plant communities. Structural and regeneration status analysis of tree species revealed different population structures. The mean total carbon stock density of Gerba Dima forest was found to be 586.7 tons Carbon ha^{-1}*, out of which 243.8, 45.97, 0.03 and 292tons Carbon ha*$^{-1}$ *were stored in the above ground, below ground, litter and as soil organic carbon, respectively. Seven allometric models were developed for 5 tree and 2 shrub species. The best-fit models were selected based on their adjusted* r^2*, RMSE and AIC values. The study forest can play a significant role in biodiversity conservation as well as climate change mitigation since it harbors high species diversity, richness and can sink 2153 tons of Carbon dioxide. However, studies on the structure and regeneration of some woody species indicated that there are species that require urgent conservation measures. Sound management and monitoring, as well as maintenance of biodiversity, cultural and economic values of the forest require conservation activities that promote sustainable uses of the forest and its products.*

Keywords /phrases: Allometry, Carbon stock, Forest, Gerba Dima, Species diversity

Acknowledgments

I would like to express my deepest gratitude to Dr. Teshome Soromessa and the late Professor Ensermu Kelbessa for their inspiring guidance, advice, useful comments and effective follow up of this research work. I also extend my gratitude to Dr. Bikila Workineh for filling the gap left by the late Professor via critically reading my Ph.D. dissertation and providing suggestions for its improvement.

I thank the International Foundation for Science (IFS), for the main financial support for the accomplishment of this research. I greatfully acknowledge the following institutions: Addis Ababa University for facilitating my research work and financial support from Thematic Research Project entitled" Ecology, carbon sequestration and honey production potential of moist afromontane forest in southwestern Ethiopia: implications in climate change mitigation and food security; staff members of the National Herbarium for their material and technical support; Debre Berhan University for sponsoring my study; Oromia Forest and Wild life Enterprise, Ale, Didu and Becho District Administration offices for their cooperation in providing me necessary information about the Districts and the study site.

I would like to thank Mr. Awol Asefa for introducing me to a flame photometer and Kedjal distillation unit while conducting the soil analysis to determine Na, K and total Nitrogen in Ecophysiology laboratory of AAU. I also gratefully acknowledge Mr. Temesgen Aragaw for his assistance in using spectrophotometer while analyzing for available phosphorus in the laboratory of center for environmental science of AAU.

I am deeply indebted to my beloved wife, Genet Ademe, and my beloved daughter Fenet Abyot for their patience and strength throughout my study period. I also extend my thanks to my families and friends, whom I did not mention their name here, for their support and care.

Last but not least my special gratitude goes to the local people who had really played a significant role during field data collection. Without their devoted assistance, the field data collection in such inaccessible and harsh environment would not have been possible.

Table of Contents

LISTT OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ACRONYMS

AGB	Above Ground Biomass
BGB	Below Ground Biomass
CCA	Canonical Correspondence Analysis
CA	Correspondence Analysis
CrA	Crown Area
COP	Conference of the Parties
DBH	Diameter at Breast Height
DCA	Detrended Correspondence Analysis
DSH	Diameter at Stamp height
ETH	National Herbarium
FAO	Food and Agriculture Organizations of the United Nations
IPCC	Intergovernmental Panel on Climate Change (UN)
IUFRO	International Union of Forest Research Organizations
IUCN	International Union for Conservation of Nature and Natural Resources
IVI	Importance Value Index
NBSAP	National Biodiversity Strategy and Action plan
PCA	Principal Components Analysis
RD	Relative Density
RDA	Redundancy Analysis
RDO	Relative Dominance
RF	Relative Frequency
UNFCCC	United Nations Framework Convention on Climate Change
VIF	Variance Inflation factor
WBISPP	Woody Biomass Inventory Strategic Planning Project

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Its highly variable ecology, topography and climate make Ethiopia one of the internationally recognized centers of biodiversity (Edwards and Ensermu Kelbessa, 1999; EPA, 1997). The country has 5757 higher plant species,- of which about 10% are endemic (Hedberg *et al*., 2009; Ensermu Kelbessa and Sebsebe Demissew, 2014). Ethiopian forests and woodlands are repositories and gene banks for several domesticated and/or important wild plants and wild relatives of domesticated plants. For example, coffee (*Coffea arabica* L.) is found in the wild in the moist evergreen montane forests of the south, west, and southwest of the country. Forests are important not only for the products that can be harvested from them but also for affecting biogeochemical cycles, global climate, hydrology and biodiversity in a positive way (Loreau, *et al*., 2001; NBSAP 2005; Sharrock *et al*., 2014).

Vegetation of Ethiopia was classified into 12 types (Friis *et al*., 2010). The vegetation type at Gerba Dima is part of the moist evergreen afromontane forest which is characterized by one or more closed strata of evergreen trees that may attain a height of 30 to 40 m. This vegetation type is predominantly found in the south-western part of the Ethiopian highlands between 1500-2600 m, with an annual rainfall between 700 and 2000 mm. The characteristic emergent species that form the upper canopy include *Pouteria adolfi-friederici. Albizia gummifera, A. schimperiana, A. grandibracteata, Sapium ellipticum, Euphorbia ampliphylla, Ekebergia capensis, Ficus sur, Hallea* *rubrostipulata, Ocotea kenyensis, Olea welwitschii, Polyscias fulva and Schefflera abyssinica* are other characteristic species of this vegetation type.

Ethiopia has one of the largest forest resources in the horn of Africa and presently existing data indicate that the forest resource of the country has a good potential in mitigating climate change. The total forest carbon stock in the above ground biomass alone for Ethiopia is estimated at 2.76 billion tons CO_2e (Yitebitu Moges *et al.*, 2010).

The significance of forests in mitigating the greenhouse gas emissions was recognized by the Kyoto Protocol. According to UNFCCC (1997), Forests and soils are potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets. Sustainable forest development and forested landscape expansion is one of the fundamental approaches for reducing atmospheric carbon concentration. It is a safe, environmentally acceptable, and cost-effective way to capture and store large amounts of atmospheric carbon. The simultaneous development of tradable carbon credits offers financial incentives for considering carbon storage in forest management decisions (Siry *et al.*, 2006).

South-western Ethiopia best represents remnant natural forest but they are being destroyed at an alarming rate. In Ethiopia Reusing (1998) estimated deforestation and degradation at between 150,000-200,000 ha/year and this was associated with loss of forest structure and diversity. New investment opportunities in south-western Ethiopia are converting these remnant forests into other land uses such as tea and coffee plantation (Kumlachew Yeshitela and Tamrat Bekele, 2002). Resettlement program in early 1980's brought thousands of people from the northern part of Ethiopia, which had led to serious forest degradation. The closed high forest cover of south-western Ethiopia had declined from 38.4% in 1975 to 18.4% in 1996/97 (Reusing, 2000). Unlike in the developed countries, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. Only small efforts have been made so far to assess the biomass and soil carbon sequestration at micro-level (CCB-AR-PDD, 2009).

This study was initiated to obtain sufficient information about the carbon stock potential, the species composition, regeneration status, community types and other environmental and vegetation data of Gerba Dima forest in South Western Ethiopia that will help to design management and conservation strategies. Designing and implementing appropriate forest management and conservation strategies will help to reduce destruction of forest resources in the area, maintain sustainable balance between utilization and conservation of forests for better survival of mankind, improve the conservation of soil, water and biodiversity in the area, increase carbon-sink that helps to reduce global warming, sustainably utilize and conserve the forest and vegetation resources in the area, which might also be applied in other parts of the country.

1.2. Research Questions, Hypotheses and Objectives

1.2.1. Research questions

This study was designed to address the following research questions.

1. What is the floristic composition, the plant community types, status of vegetation structure and regeneration of woody species in the study forest?
2. Which environmental factors significantly affect the patterns of species distribution, community organization and the carbon stock of different carbon pools in the study area?
3. What is the carbon stock potential of Gerba Dima forest and which species and carbon pool sequester more carbon?
4. What is the best-fit allometric model for each species understudy?

1.2.2. Research Hypothesis

In this study 4 major hypotheses were tested

Hypothesis I: The species diversity of Gerba Dima Forest is low.

Hypothesis II: The overall population structure and regeneration status of the study forest is not healthier.

Hypothesis III. Carbon stock in different carbon pools is equal in the study forest.

Hypothesis IV. The nested allometric models are better than the complete models.

1.2.3. Research objectives

1.2.3.1. General objective

The main objective of this study is to investigate the ecology and carbon stock potential of Gerba Dima forest and to develop species-specific allometric equation for selected species in the forest.

1.2.3.2. Specific Objectives

- To examine the floristic composition, structure of the vegetation and the regeneration status of woody species in the study area.
- To classify the plant community types of the study area and relate the distribution of plant community types to some environmental parameters.
- To estimate carbon stocks in AGB, BGB, litter and dead wood biomass.
- To develop species-specific and area specific allometric equation for selected tree and shrub species.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Natural vegetation of Ethiopia

According to FAO (2006), a forest is defined as a minimum land area of 0.5 ha with tree crown cover more than 10-30% and tree height of above 2 m at maturity. Several authors and national or sub-national inventory projects have carried out assessments and documented the extent of forest resources and other land uses of Ethiopia. Among these, the following are well-known: Chaffey (1979), ENEC-CESEN (1986), LUPRD-MOA/FAO (1985), and the World Bank-funded Woody Biomass Inventory and Strategic Planning Project (WBISPP) has reviewed these various reports. The recent data on forest resources of Ethiopia reported in FAO (2010a) puts Ethiopia among countries with a forest cover of 10-30%. According to this report, Ethiopia's forest cover (FAO definition) is 12.2 million ha (11%). It further indicated that the forest cover shows a decline from 15.11million ha in 1990 to 12.2 million ha in 2010, during which 2.65% of the forest cover was deforested.

The vegetation resources of Ethiopia, including forests, woodlands and bushlands have been studied by several scholars (Logan, 1946; Hedberg, 1957; Gilbert, 1970; Chaffey, 1979; Tewoldebirhan G/Egziabher, 1986; Friis, 1992; EFAP, 1994, Tamrat Bekele, 1994). Based on the result of most of these studies, the various vegetation types of Ethiopia have been grouped into nine general categories for the purpose of developing the conservation strategy of Ethiopia. Recently a detailed vegetation map for Ethiopia has been published (Friis *et al.*, 2010). In this map, 12 vegetation types with 15 mapping units are recognized. The twelve vegetation types recognized are: 1. Desert and semi-desert scrubland; 2. Acacia-Commiphora woodland and bushland; 3. Wooded grassland of the Western Gambela region; 4. Combretum-Terminalia woodland and wooded grassland; 5. Dry evergreen Afromontane forest and grassland complex; 6. Moist evergreen Afromontane forest; 7. Transitional rain forest; 8. Ericaceous belt; 9. Afroalpine vegetation; 10. Riverine vegetation; 11. Freshwater lakes, lakeshores, marshes, swamps and floodplains vegetation, and 12. Salt-water lakes, lake shores, salt marshes and pan vegetation. From the 12 vegetation types mentioned above, moist evergreen afromontane forest, the vegetation type of the forest under study is discussed below.

2.1.1. Moist evergreen forest

This vegetation type is in most cases characterized by one or more closed strata of evergreen trees that may reach a height of 30 to 40 m. Sometimes only the lower stratum remains, owing to the elimination of the tallest trees. The Harenna Forest on the southern slopes of the Bale Mountains is the easternmost example of this forest. These forests mainly contain broad-leaved evergreen species in the multilayered canopy. The upland parts of the southern Wellega, llubabor (excluding the lowlands), and Kefa are floristic regions where the most characteristic type of this forest widely occurs.

It is found in areas between 1500 and 2500 m, with an annual rainfall between 1500 mm and more than 2000 mm, with rain all the year round. The absolute maximum of rainfall in the area is uncertain, but the estimated maximum of 2600 mm per year is thought to be reached in an area north of the town of Tepi (Friis *et al.*, 2010; Sebsebe Demsew and Inger Nordal, 2010). The large Harenna Forest on the southern side of the

Bale Mountains is floristically very very much related to the south-western Ethiopian moist afromontane forest. However, the canopy of this forest contains large specimens of *Podocarpus falcatus* near its lower limit. It would be meaningful to note if it occurs with the characteristic species mentioned above or occupy a distinct lower zone of its own. *Pouteria adolfi-friederici* is the characteristic emergent species that from the 20-30 m high canopy. Other characteristic species include *Albizia gummifera*, *A. schimperiana*, *A. grandibracteata*, *Sapium ellipticum*, *Euphorbia ampliphylla*, *Ekebergia capensis*, *Ficus sur*, *Hallea rubrostipulata*, *Ocotea kenyensis*, *Olea welwitschii*, *Polyscias fulva* and *Schefflera abyssinica*. Another very characteristic feature of this vegetation type, at least in its moister forms (but not yet observed in the Harenna Forest), is the tree fern, *Cyathea manniana* (Cyatheaceae). Woody climbers are also commonly represented by *Tiliachora troupinii* (endemic), species of Acacia, includes *A. pentagona*. Epiphytes including ferns, lycopods, orchids and Peperomia spp. are also encountered. The mountain bamboo *Arundinaria alpina* is common at higher altitudes in these forests and it occurs in areas between the 1800 and 3000 m and with annual rainfall larger than 1700 mm (Friis *et al*, 2010; Sebsebe Demsew and Inger Nordal, 2010).

2.2. The concept of carbon sequestration and carbon sink

The United Nations Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing excess C from the atmosphere and depositing it in a reservoir. It involves the transfer of atmospheric CO_2, and its secure storage in long-lived pools (UNFCCC 2007). According to IPCC, 2000, Carbon sequestration is the removal of carbon from the atmosphere by storing it in the biosphere. It is also the capture and secures storage of carbon that would otherwise be emitted to or remains in the atmosphere (FAO, 2000). It is a means to mitigate the buildup of greenhouse gases in the atmosphere released by the burning of fossil fuel and other anthropogenic activities. The term carbon sequestration is used to describe both natural and deliberate process by which carbon dioxide (CO_2) is either removed from the atmosphere or diverted from the emission sources and stored in the ocean, terrestrial environments (vegetation, soil and sediments), and geologic formation.

A carbon sink is a pool that gathers and stores carbon-containing chemical compound, it takes away CO_2 from the atmosphere through absorption. Forests, soil, oceans, plants and algae are natural sinks (Wulder *et al.*, 2008). Removal of atmospheric carbon to the other form can be the vital process to combat the global climate change. Globally, there are different reservoirs or sinks of carbon. These include: oceanic, geologic and terrestrial carbon pools/sinks. These sinks are interconnected, allowing a continual redistribution of carbon among them. Oceans and geologic formations contain the highest amounts of carbon. Carbon sequestration is the facilitated redistribution of carbon from the air to other sinks. This will reduce the rate of atmospheric CO_2 increase, thereby mitigating global warming (Sundquist *et al.*, 2008). The various carbon sinks are discussed below.

2.2.1. The oceanic carbon sink

Oceans are natural CO_2 sinks, and represent the largest active carbon sink on Earth, consuming 93% of the world‘s CO_2. Carbon dioxide moves between the atmosphere and the ocean by molecular diffusion when there is a CO_2 gas pressure (pCO_2) gradient between the atmosphere and the sea (Nieder and Benbi, 2008).

Oceans presently account for a global net uptake of about 2 G tons of carbon annually that humans put into the air (Sundquist *et al.*, 2008). Before the industrial revolution, the ocean contained about 60 times as much carbon as the atmosphere and 20 times as much carbon as the terrestrial biosphere/soil compartment.

The Earth's oceans hold 38,000 PgC, the majority of which is in the form of dissolved inorganic carbon stored at great depths where it resides for long periods of time. A much smaller amount of carbon, approximately 1,000 Pg, is located near the ocean surface. The exchange of this carbon takes place quickly with the atmosphere via both physical processes, such as CO_2 gas dissolving into the water, and biological processes, such as the growth, death and decay of plankton. Though the majority of these surface carbon cycles rapidly, some of it can also be transferred by sinking to the deep ocean pool where it can be stored for a much longer time (http://globecarboncycle.unh.edu).

The solubility of CO_2 is temperature dependent, thus the transfer of air-sea heat contributes to seasonal and regional patterns of air-sea CO_2 transfer (Watson *et al.*, 1995). Net cooling of surface waters tends to drive CO_2 uptake; net warming drives outgassing (Keeling and Peng, 1995; Watson *et al.*, 1995; Holfort *et al.*, 1998).

2.2.2. The geologic carbon sink

The planet's crust sedimentary rocks store the largest amount of carbon on Earth. These rocks are formed either by the hardening of mud (containing organic matter) into shale over geological time or by the collection of calcium carbonate particles, from the shells and skeletons of marine organisms, into limestone and other carbon-containing sedimentary rocks (Herzog, 2001; Sundiquist *et al.*, 2008).

Together all sedimentary rocks on Earth store 100,000,000 PgC (Petagrams of carbon). The Earth's crust also stored another 4,000 PgC as hydrocarbons formed over millions of years from ancient living organisms under intense temperature and pressure. These hydrocarbons are commonly known as fossil fuels (http://globecarboncycle.unh.edu).

2.2.3. Terrestrial carbon sinks

Terrestrial ecosystems are widely recognized as a major biological sequester of CO_2 (Han *et al.*, 2007). Carbon in the form of plants, animals, soils and microorganisms (bacteria and fungi) contained in terrestrial ecosystems. Among these, plants and soils are certainly the major and, when dealing with the whole world, the smaller pools are often ignored. Unlike the Earth's crust and oceans, most of the carbon in terrestrial ecosystems exists in organic forms. In this perspective, the word "organic" refers to compounds formed by living things, including leaves, wood, roots, dead plant material and the brown organic matter in soils (USNETL, 2000; Herzog, 2001; Han *et al.*, 2007).

The rapid exchange of carbon takes place between plants and atmosphere through the process of photosynthesis, in which CO_2 is absorbed and converted into new plant tissues, and respiration, where some fraction of the previously captured CO_2 is released back to the atmosphere as a product of metabolism. Among the various tissues formed by plants, woody stems such as those produced by trees have the greatest capacity to store large amounts of carbon, since wood is dense and trees can be large. Collectively, the Earth’s plants store approximately 560 PgC, with the wood in trees being the largest fraction (Herzog, 2001; Han *et al*., 2007).

The overall quantity of carbon in the world’s soils is estimated to be 1500 PgC. Most of the carbon in soils enters in the form of dead plant matter that is broken down by microorganisms during decay. Since the metabolism of these microorganisms finally breaks most of the organic matter all the way down to CO_2, the decay process also liberates carbon back to the atmosphere (Herzog, 2001; Han *et al*., 2007). The terrestrial biosphere is estimated to sequester large amounts of carbon, about 2 billion tons (2Gts) of carbon annually. Soil carbon storage is the largest terrestrial sink (Han *et al*., 2007).

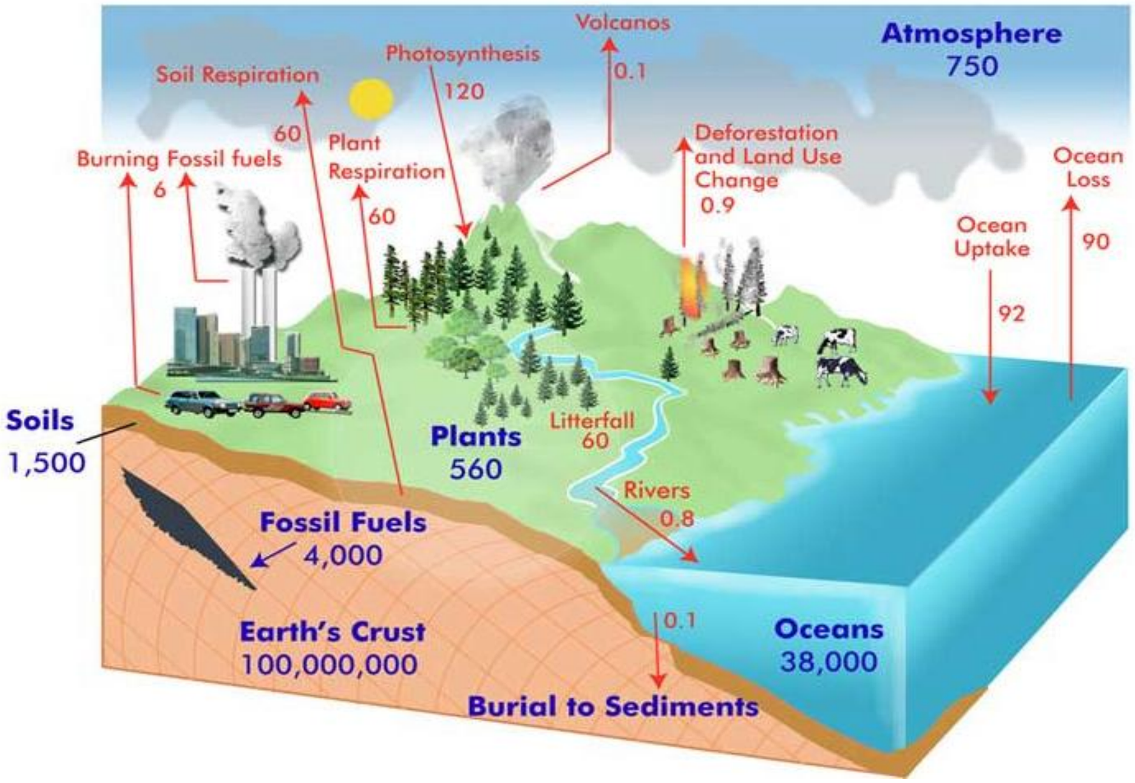


Figure 1. A simplified diagram of the global carbon cycle. Pool sizes, shown in blue, are given in peta grams (Pg) of carbon. Fluxes, shown in red, are in Pg per year.

Source: (www.globe.gov/projects/carbon).

2.2.3.1. Major terrestrial carbon sinks/pools

As IPCC pointed out, a terrestrial ecosystem consists of five carbon pools comprising biomass, namely the above-ground biomass, below-ground biomass, the dead wood, Litter and soil organic matter (IPCC, 2006). The carbon dioxide fixed by plants during photosynthesis is transferred across the different carbon pools.

2.2.3.1.1. The above ground biomass

All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage are essential parts of the above ground biomass of terrestrial ecosystem (IPCC, 2006). The above-ground biomass of a tree comprises the most important part of the carbon pool. It is the main and visible carbon pool of the terrestrial forest ecosystem (Ravindranath and Ostwald, 2008).

The above-ground biomass of the tree is mainly the largest carbon pool and it is directly affected by deforestation and forest degradation (Gibbs *et al.*, 2007). Aboveground biomass of living trees is the most dynamic forest carbon (C) pool. This C pool can be accurately measured, whereas other pools are less dynamic and more costly to quantify. The transfer of carbon between the terrestrial forest ecosystem and the atmosphere is greatly influenced by the change in the forest areas and the changes in forest biomass due to management and regrowth (Houghton, 2005).

2.2.3.1.2. The below ground biomass

The below-ground biomass constitutes all biomass of live roots while fine roots of less than 2mm diameter are often excluded since these often cannot be distinguished empirically from soil organic matter or litter. By transferring and storing carbon in the soil, the below-ground biomass which constitutes all the live roots plays a pivotal role in the carbon cycle (IPCC, 2006).

Even at moderate levels of precision, measuring root biomass is time-consuming and expensive because of the wide variability in the way that roots are distributed in the soil. The use of a conservative ratio for a shoot: root biomass as the basis for claiming carbon credit might be best to estimate root biomass for various projects. For instance, the lowest shoot: root ratio ever reported for Species X is 5:1. For developing a conservative estimate exclusive of roots measurements, an inventory could calculate root biomass as not less than 10 or 15% of above-ground biomass (MacDicken, 1997).

2.2.3.1.3. The Dead Wood

The dead-wood comprises of all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. It includes wood lying on the surface, dead roots, and stumps, bigger than or equal to 10 cm in diameter (or the diameter specified by the country (IPCC, 2006).

2.2.3.1.4. The Litter

Litter consists of all non-living biomass with a size larger than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in a litter where they cannot be distinguished from it empirically (IPCC, 2006).

Litter will still be recognizable (for example as, dead leaves, twigs, dead grasses and small branches) and some will be unidentifiable decomposed fragments of organic material (Pearson *et al*., 2005). The dead mass of litter and woody debris are not a major carbon pool as they contribute merely a small fraction to the carbon stocks of forests (Ravindranath and Ostwald, 2008).

2.2.3.1.5. The soil organic matter

The soil organic matter constitutes organic carbon in mineral soils to a specified depth preferred by the country and applied consistently through the time series. Live and dead fine roots and DOM within the soil, which are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm (IPCC, 2006).

The amount of soil organic matter depends on the above ground input received from leaf litter and on the decomposition of fine roots below ground (Rasse *et al*., 2006). Litter quality, macro and micro-faunal activity determine the recycling of the plant’s carbon in the soil system (Hairiah *et al*., 2006).

Soil organic matter is also a principal contributor to the carbon stocks of forests (Lal, 2005; Kumar *et al*., 2006), next only to the above-ground biomass (Ravindranath and

Ostwald, 2008) and soils are a main source of carbon emissions following deforestation (Page *et al.*, 2002).

Carbon fixed within plant biomass ultimately enters the soil, where it may reside for hundreds of years. Soil carbon (C) is an important part of the terrestrial carbon pool (Lal and Kimble 1997) and soils of the world are potentially viable sinks for atmospheric C and may significantly contribute to the mitigation of global climate change (Lal *et al.*, 1998; Bajracharya *et al.*, 1998). Kirschbaum (2000) estimated that world's soil contains about 1500 Gt (1Giga ton =10^{15} g) of organic carbon to a depth of 1 m and a further 900 Gt from 1-2 m.

2.3. Allometric equations

Allometric equations relate easily measured variable (e.g. tree diameter, height) to other structural and functional characteristics (Niklas, 1994), is the most common and reliable method for estimating biomass, net primary production, and biogeochemical budgets in forest ecosystems (Gower *et al.*, 1999). They have been developed to satisfy various purposes in forest ecology and management. Practically, most allometry employs diameter at breast height (DBH) as the only independent variable and develops an allometric relationship between DBH and component biomass (Gower *et al.*, 1999). Some studies proposed to include tree height (H) as the second predictor and develop DBH–H combined equation to improve the precision of biomass estimates (Ketterings *et al.*, 2001).

The allometric method estimates the whole or partial (by compartments) mass of a tree from measurable tree dimensions, including trunk diameter and height, using allometric equations (Kangas and Maltamo, 2006). Thus, dendrometric parameters of all the trees are measured and using the allometric equation the biomass of the stand is estimated by summing the biomass of individual trees. When building allometric equations of an individual tree, a sprout or a stand, different methods (destructive or not) could be considered. While destructive methods measure directly the parameters and the variables of interest by e.g. harvesting the tree to determine biomass through the actual mass of each of its compartments, for example, roots, stem, branches, and foliage (Kangas and Maltamo, 2006), indirect methods try to estimate the variable by measuring other variables that are more accessible and less time-consuming – e.g. measuring the wood volume and density (Picard *et al.*, 2012).

Generalized models have a great potential for large-scale carbon budgets derived from inventory data (Pastor *et al.*, 1984). When estimating the above ground biomass of a forest, the uses of species-specific equations are preferred because trees of different species may differ greatly in tree architecture and wood density. However, due to the great number of different tree species in humid tropical rainforests and enormous efforts needed to develop these equations. Species-specific allometric equations for the humid tropics are virtually unavailable while relatively few mixed-species equations have been developed (Ketterings, *et al.*, 2001).

2.4. The recognition of REDD And REDD+ as UNFCCC policy agenda

Under the Kyoto protocol CDM scheme, the majority of agriculture, forestry and "Reducing Emissions from Deforestation and Degradation" (REDD) projects are excluded (FAO, 2010b). The opportunity of introducing a mechanism providing incentives for reducing greenhouse gas (GHG) emissions from deforestation and forest degradation (REDD) has been the subject of very active negotiations since the 11th Conference of the Parties (CoP) to the United Nations Framework Convention on Climate Change (UNFCCC) in Montreal in December 2005. REDD is part of an action plan adopted by the Parties to the climate convention during the conference in Bali in December 2007 (CoP-13). It was anticipated that this action plan would lead to the adoption of a new international agreement on climate change at the Copenhagen conference (CoP-15, December 2009) and Reduced Emissions from Deforestation and Degradation (REDD) was high on the agenda (Calmel *et al.*, 2010).

2.4.1. Reduced Emissions From Deforestation and Forest Degradation (REDD)

The term ‘Reducing Emissions from Deforestation and Forest Degradation’ REDD was coined at the 11th Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in Montreal in December 2005. Its objective was to bring tropical deforestation back onto the UNFCCC policy agenda. It is a response to the global climate policy challenge of tropical deforestation and degradation (Vreugdenhil *et al.*, 2011).

For many developing countries without large industrial sectors, the principal source of carbon emissions is from deforestation, forest degradation and agriculture (all sources combined, such as use of agricultural inputs, methane release from livestock, etc.). In recent years, estimations for deforestation and forest degradation have been revealed to account for 20-25% greenhouse gas emissions, greater than the transportation sector.

From these new numbers it is increasingly accepted that mitigation of global warming will not be achieved without the inclusion of forests in an international regime. As a result, REDD is playing a crucial role in the post Kyoto protocol (Vreugdenhil *et al.*, 2011).

REDD provides a unique opportunity to achieve large-scale emissions reductions at comparatively low abatement costs (Phelps *et al.*, 2012). The REDD scheme allows intact forests to compete with historically more lucrative and destructive land uses by economically valuing the role forest ecosystems play in carbon capture and storage (Parker *et al.*, 2009).

In its early years, REDD was first and foremost focused on reducing emissions from deforestation and forest degradation. However, in 2007 the Bali Action Plan, formulated at the thirteenth session of the Conference of the Parties (COP-13) to the United Nations Framework Convention on Climate Change (UNFCCC), stated that all-inclusive approach to mitigating climate change should include "policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (UNFCCC,2007). A year later, this was further elaborated on as the role of conservation, sustainable management of forests and enhancement of forest carbon stocks was upgraded so as to receive the same emphasis as avoided emissions from deforestation and forest degradation (UNFCCC, 2011). Finally, in 2010, at COP-16 (19) as set out in the Cancun Agreements, REDD became REDD-plus (REDD+), to reflect the new components.

2.4.2. The Emergence of REDD+

Reducing emissions from deforestation and forest degradation (REDD+) refers to projects which achieve ERs through five main types of activities: (i) reducing emissions from deforestation; (ii) reducing emissions from forest degradation; (iii) conserving forest carbon stocks; (iv) managing forest sustainably; and (v) Enhancement of forest carbon stocks (Calmel *et al.*, 2010). Since agricultural activities are the most common driver of deforestation and forest degradation, REDD+ activities can represent a source of carbon income to agricultural producers who reduce emissions by taking actions that reduce agricultural land expansion and/or forest degradation (FAO, 2011).

Besides conserving biodiversity and sustaining vital ecosystem services, REDD+ has the potential to simultaneously contribute to climate change mitigation and poverty alleviation (UNFCCC, 2012). The Cancun COP16 made major development in realizing the potential for REDD+ financing through an international agreement for financial support for this source of mitigation. A great deal of work remains to actually operationalize this source of funding, however, and several key obstacles have to be overcome. Firstly, REDD+ actions should show effective protections for the right of indigenous peoples and local communities dependent on forest resources. Secondly, modalities for establishing reference levels and crediting procedures have yet to be agreed. A recent breakthrough on this was achieved by the World Bank BioCarbon Fund (BioCF) and the Brazilian NGO Fundação Amazonas Sustentável (FAS). The new methodology – officially approved in July 2011 by the Verified Carbon Standard (VCS) Association – allows projects in the voluntary market to calculate avoided emissions by reducing deforestation either on the edge ("frontier") of large cleared areas, like agricultural zones, or in a patchwork ("mosaic") within standing forests (FAO, 2011).

The extent of financing necessary for REDD+ shows that private sector participation will be required. The role of carbon markets in mobilizing funding, however, has not been agreed and is currently not clear (World Bank 2011). The "readiness" phase of realizing this source of mitigation, including Phase I (national strategies and capacity building) and Phase II (implementation of strategies and investment in demonstration activities), will be financed through public sources—both bilateral and multilateral (World Bank 2011).

REDD+ projects are clearly attracting interest on the voluntary markets. The demand for credits reflects growing interest among companies in social and environmental responsibility, including among those not subject to quotas and mainly for purposes of communication. The co-benefits expected from REDD+ projects, whether social and economic (job creation in agro-sylviculture, diversification of livelihoods, poverty reduction, etc.) or environmental (erosion control, protection of water resources and biodiversity, etc.), are of particular importance in this regard. However, it should be noted that only 20.8 MteqCO$_2$-e in forest carbon credits have been traded to date on these markets (Hamilton *et al.*, 2009). Credits generated by REDD+ projects specifically account for only 3.1 MteqCO2-e. These figures should alert project promoters to the fact that the voluntary markets may be unable to absorb the large credit volumes announced by many REDD+ projects (Calmel *et al.*, 2010).

2.5. Carbon sequestration potential of forest

Forest's ecosystem is one of the most important carbon sinks of the terrestrial ecosystem. Forest's vegetation takes up the carbon dioxide in the process of photosynthesis. In this natural process, it takes away the carbon dioxide from the atmosphere and stores the carbon in the plant tissues, forest litter and soils. Thus, forest ecosystem plays a very important role in the global carbon cycle by sequestering a substantial amount of carbon dioxide from the atmosphere. This process is more productive in a relatively new forest where the growths of the trees are still rapid. Globally, forests act as a natural storage for carbon, and it is estimated that about 86% of the terrestrial above-ground carbon, 40% of terrestrial below-ground biomass carbon storage and 73% of the earth's soil carbon are stored in the forests (Rodger, 1993). FAO (2010a) estimated that the world's forests store 289 Gt of carbon in their biomass alone. Presently, the net rate of C sequestration in forest ecosystems (excluding those being deforested) is 1.7 ± 0.5 Pg C yr^{-1} (Fan *et al.*, 1998).

The tropical forests are said to play a major role in the global carbon cycle, storing up to about 46% of the world's terrestrial carbon pool and about 11.55% of the world's soil carbon pool, acting as a carbon reservoir and functioning as a constant sink of atmospheric carbon (Brown and Lugo, 1982; Soepadmo, 1993). A study carried out by Lugo and Brown showed that half of the presumed "matured forests" could also sequester carbon and the rate of sequestering carbon could be further improved if anthropogenic pressures are reduced or removed from these forests (Lugo and Brown, 1992).

The major carbon pools in a tropical forest ecosystem are represented by the living biomass of trees, the understory vegetation and the deadwood, which includes the standing deadwood and the fallen deadwood like fallen stems and fallen branches, woody debris and soil organic matters represent the change in the forest areas and the changes in forest biomass owing to management and regrowth greatly determine the exchange of carbon between the terrestrial forest ecosystem and the atmosphere (Houghton, 2005).

Current estimates suggest that forestry could contribute an average 6.7 billion tons of emissions reductions yearly, with over two-thirds of this potential coming from tropical nations (Sohngen, 2009). Making full use of the forest carbon sink is appealing to both the developed and the developing world. Developed nations consider forest carbon projects as a low-cost option for mitigating climate change while for the developing world, forest carbon payments could offer a sustainable source of much-needed income (Baldwin and Richards, 2010).

As sources of GHGs, deforestation represents about 20% of anthropogenic emissions (FAO, 2006; Stern, 2006). Although deforestation is reported to represent about 20% of the global GHGs emissions, regionally the figure varies. About 70% GHGs emissions is caused by deforestation in Africa (Gibbs et al., 2007). For the entire world, carbon stocks in forest biomass reduced by an estimated 0.5 Gt annually during the period 2005 – 2010, mainly due to a reduction in the global forest area. On the other hand, the IPCC report estimated that the global forestry sector represents over 50% of the global greenhouse (IPCC, 2007). Consequently, forestry became the focus of global climate change policy and is given a key position in international climate treaties. While sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, deforestation, degradation and poor forest management reduce them.

2.5.1. Carbon sequestration potential of Ethiopian forests

Forest inventories, woody biomass assessments, agricultural surveys, land registry information and scientific research can prove useful data for acquisition of forest carbon accounting at a national level. In this context, WBISPP data is a relevant source of information for Ethiopian forest carbon accounting (Yitebitu Moges *et al.*, 2010).

WBISPP (2005) indicated that the largest store of carbon in the country is found in the woodlands (45.7%) and the shrublands (34.4%). However, these vegetation types are largely neglected in forest related discussions, including carbon negotiations despite their great potential in influencing carbon balance (Yitebitu Moges *et al.*, 2010). Ethiopia is endowed particularly with woodlands and shrublands which store more than five times higher carbon than that exists in the natural high forests, and it is strongly suggested that the country brings these resources forward in REDD negotiations (Yitebitu Moges *et al.*,2010).

The forests resources of Ethiopia store 2.76 billion tons of carbon (about 10 billion tons of CO_2) in the aboveground biomass, which will be released to the atmosphere in 50 years if the deforestation continues at the present rate of about 2% (Yitebitu Moges *et* *al.*, 2010). Brown (1997) reported a carbon density of 101 tons ha^{-1} for high forests in Ethiopia and agrees well with the estimate presented here. However, some case studies show even higher carbon density values of close 200 tons ha^{-1} than the estimates based on WBISPP for high forests in Bale Mountains (Muluken Nega *et al.*, 2015; Tibebu Yelemfrhat *et al.*, 2014). The discrepancy is due to the different methods and tools applied, regional variability in soil, topography, and forest type and the uncertainties associated with the methods used.

Table 1. Mean aboveground carbon density and total carbon stocks in major forest categories of Ethiopia

Forest category	Free bole Biomass (tons ha^{-1}) A	BEF (tons ha^{-1}) (B)	ABGC (tons ha^{-1}) A*B*0.5)	Area Million ha)	Total C stock (Million tons)
High forest	131.5	2.74	106.68	4.07	434.19
Woodland	21.0	6.9	42.75	29.55	1,263.13
Plantation	178.8	2.33	123.0	0.50	61.52
Lowland bamboo	26	6.19	47.5	1.07	50.80
Highland bamboo	83.0	3.44	84.23	0.03	2.53
Shrubland	14.9	8.20	36.0	26.40	951.54
Total C					2,763.70

* Assuming the carbon content of green wood is approximately 50% of the biomass
Source: (WBISPP, 2005).
* C is calculated based on the formula developed by Brown, 1997.
* AGB = Aboveground biomass; BEF = Biomass expansion factor

FAO (2010a) reported the carbon stocks in the forest and other wooded land of Ethiopia and the data clearly point out the difference in the carbon sock in above ground biomass (AGB), below ground biomass (BGB), litter and soil organic carbon (SOC) at a depth of 30 cm for various years but missing data for carbon stock in dead wood (DW) (Table 2). According to FAO (2010a), the amount of SOC in Ethiopian forest and other wooded land is much higher than other carbon pools and the SOC in other wooded land is greater than the SOC in the forest (Table 2). Soil is an important part of carbon cycle of the planet, has the potential to store carbon and contribute to mitigate greenhouse gases. In total, soil contains about 3 times more carbon than the atmosphere and 4.5 times more carbon than living things. Hence, a relatively small increase in the proportion of soil carbon could make a significant contribution to reducing atmospheric carbon (Walcott *et al*, 2009). According to Jones (2007), 75% of carbon in the terrestrial biosphere is in the soil and healthy grasslands may contain 100 times more carbon in the soil than on it and the data in the Ethiopian context agrees with this fact as indicated in Table 2.

Table 2. The carbon socks of various carbon pools in Ethiopian forest and other woodedland

FRA 2010 category	Carbon (Million metric tons)							
	Forest				Other wooded land			
	1990	2000	2005	2010	1990	2000	2005	2010
Carbon in Above ground biomass	227	200	186	172	172	172	172	172
Carbon in Belowground biomass	62	54	50	47	82	82	82	82
Sub total: carbon in Living biomass	289	254	236	219	254	254	254	254
Carbon in dead wood	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Carbon in litter	32	29	27	26	94	94	94	94
Sub total: Carbon in Dead wood & litter	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Soil carbon to 30 cm Depth	982	890	845	799	2902	2902	2902	2902
Total Carbon	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* n.a. = data not available.* Source: FAO (2010a)

2.6. Challenges on Ethiopian forest resources and the associated carbon stock

2.6.1. Deforestation

Deforestation and subsequent land degradation are global threats, and so are they in Ethiopia. Historical sources indicate that, on the basis of potential climatic climax, high forests might have once covered about 35-40 % of the total land area of the country. If the savanna woodlands are included, 66 % of the country used to be covered with forests and woodlands in the past (EFAP, 1994). It has been estimated that high forests covered 16 % of the land area in the early 1950s, 3.6 % in the early 1980s and only 2.7 % in 1989. In 1994, it has been estimated that such forests cover less than 2.7 % of the country (EFAP, 1994).

De Vletter (1991) estimated that 100,000-200,000 ha of forest disappears every year as a result of clearing for agriculture and pasture. EFAP (1994) and Reusing (1998) put the estimates of deforestation at 150,000-200,000.The rate of deforestation is estimated to be as high as 5% per year (EFAP, 1994; Reusing, 1998; WBISPP, 2004). With the current annual loss of high forests, estimated at 150,000-200,000 ha, it has been projected that the area covered by high forests may be reduced to scattered minor stands of heavily disturbed forests in inaccessible parts of the country within a few decades (Demel Teketay, 2001).

Whether recent or earlier, forests and other natural vegetation resources have been with no significant efforts to reverse the trend. Indeed, even the inadequate database shows the extent of annual loss at the national level, and it is very clear that Ethiopia has lost and is continuing to lose much of its vegetation cover. FAO (2005) gives a summary of the general situation for the country (Table 3).

Table 3. Changes in the forest resources of Ethiopia From 1990 to 2005

Forest					Othe land with woody biomass		
Area x 1000 ha			Annual change rate x 1000 ha		Area x 1000ha		
1990	2000	2005	1990-2000 '000 ha/yr (%)	2000-2005 '000 ha/yr (%)	1990	2000	2005
15,114	13,705	13,000	-141 (-1.0)	-141 (-1.1)	44,650	44,650	44,650

* Source: FAO (2005)

2.6.2. Causes of Deforestation

The major reasons for deforestation are clearing of forests and woodlands for cultivating crops and cutting of trees and shrubs for various purposes, notably for fuelwood, charcoal, construction material, etc. The underlying causes of deforestation are closely linked with the vicious cycle of mutually reinforcing factors, i.e. poverty, population growth, poor economic growth and the state of the environment (Demel Teketay, 2001).

Declining standard of livelihood of the farming communities and their close dependence on forests and woodlands have led to clearing / burning for subsistent farming, cutting of trees/shrubs for fuelwood and charcoal production (both for consumption and sale), construction material, over-grazing, burning associated with traditional apiculture, etc. Population growth and its pressure resulted in the concentration of the largest proportion of the population in the highlands leading to heavy load on the forests for cultivating crops, fuelwood, construction material and grazing (EFAP, 1994). Resettlement programs, migration, biofuel development initiatives and ever-present poverty are fuelling the rate of deforestation and forest degradation in Ethiopia (Mulugeta Lemenih & Tadesse Woldemariam, 2010).

Conversion of forests, woodland and shrubland into agricultural land is certainly the largest driver of deforestation in Ethiopia, causing the emission of about 40 Mt of CO_2 from deforestation in 2010. Its impact is bound to increase up to 65 Mt per year in 2030, as the development of agriculture continues to accelerate under the impulse of strong governmental support and demographic growth (EDRI, 2010).

2.6.2.1. Impact of population growth and resettlement on forest resource of Ethiopia

The population size in Ethiopia increased from 12.9 million in 1920 to 90.9 million in 2011 (CIA 2011). The current annual population growth rate is reported to be 3.2% (CIA 2011). The high population pressure has resulted in high demands for agricultural lands and this, in turn, has caused a rapid rate of deforestation in the country.

Though high population pressure and high demands for agricultural lands are considered to be the main factors for the alarming rate of deforestation in Ethiopia, it should be noted that causes of deforestation are multiple and interlinked. For example, Terefe Degefa (2001) discussed the relationship among high population growth, land tenure, political instability and war, fuel wood demands and backward agricultural systems in causing deforestation and environmental degradation. Thus, combating the challenges of deforestation needs to address these social, economic and political problems in an integrated approach.

State-sponsored resettlement programmes have been implemented by successive governments since the 1960s, including the present (Kloos, 1989; Kassa Belay, 2004; Hammond, 2008). An accurate number of people resettled by the imperial government (before 1970) are not easy to find. However, Clarke (1986) reported that up to the Revolution of 1974, 20 000 families were resettled mainly from the drought-afflicted and overpopulated north to the south.

In the mid-1970s and early-1980s, drought and famine conditions in northern and central parts of Ethiopia reached crisis levels; therefore planned resettlement (government-sponsored migration) was considered the immediate and only remedies (Dessalegn Rahimato, 1988; Kloos, 1989; Kassa Belay, 2004). The resettlement programme was started in 1976 by the then military regime. Throughout the period 1976–1979, approximately 48 000 households, mostly from the Northern provinces, were resettled in some 80 locations in the southwestern provinces, and in 1984, the resettled population reached about 200 000 (Markos Ezra, 2001). Between 1980 and 1990, a total of 343 000 households or approximately 17million individuals were resettled in the western and southwestern areas of the Country (Markos Ezra, 1997).

In some regions, resettlement is a major driver of deforestation (Mulugeta Lemenih *et al.*, 2007). Though the objective of the resettlement program is to support food insecure households get access to productive farmlands, the strategy, in most cases, is taking place through the clearing of natural vegetation, particularly forested areas. For example, between 2000 and 2004, approximately 220,000 household heads or 1.2 million people were resettled in the four National Regional States of Amhara, Oromiya, SNNP and

Tigray. These households carved out cropland and made settlement housing by clearing areas of their natural vegetation and using the woody resources unsustainably (Mulugeta Lemenih & Tadesse Woldemariam, 2010).

2.6.2.2. Impact of biomass energy in forest resources of Ethiopia

In Ethiopia, like in many developing countries, biomass fuels (fuel wood, branches, twigs, leaves, charcoal, dung etc.) are the major sources of energy supply, and the consumption pattern of energy is heavily depending on these resources. Almost all the rural and the majority of the urban population are dependent on biomass mainly for cooking, as access to modern fuel is a constraint and the price is unaffordable (Asress W/Giorgis, 2002).

Biomass energy at the national level supplies more than 99% of the total domestic energy consumption. Of the total biomass energy about 78%, 9% and 12% is derived from woody biomass, crop residue, and animal dung, respectively (WBISPP, 2004). Households use about 92% of all biomass energy, with the remaining being consumed by small-scale industry and food enterprises. The proportion of biomass fuels in total energy consumption in Ethiopia is one of the highest in the world. They make up over 90 percent of total energy consumption in the country, and about 99 percent in the rural areas; and their scarcity is one major reason of deforestation and land degradation (EFAP, 1993). One challenge Ethiopia faces in light of managing forest resources for multiple purposes including carbon is that the national energy balance is dominated by fuel wood, which is the main source of energy to both urban and rural areas. The gap between demand and supply for fuel wood is increasing with time (Yitebitu Moges *et al.*, 2010) (Table 4).

Table 4. Supply- consumption pattern of fuel wood in Ethiopia

Source	Annual wood Supply	Annual Consumption	Deficit or surplus
UNDP/World Bank,1984	8.1 million tons (13.5 million m^3)	20.34 million tons (33.9 million m^3)	Consumption is 2.5 times annual yield
ENEC/CESEN,1986	63 million tons	24 million tons (40 million m^3)	Positive balance
EFAP,1994	8.6 million tons (14.4 million m^3)	35 million tons (58.4 million m^3)	Consumption is 4 times annual yield
UNDP/World Bank, 1996	n.a	31.5 million tons (52 million m^3)	Deficit indicated
WBISPP,2005	50.1 million tons (84.9 million m^3)	53.6 million tons (89.4 million m^3)	Deficit of 3.5 million Tons
EFAP, 1994 projection for 2020			Deficit 87-121 million m^3

* n.a = data not available
*Source (Yitebitu Moges *et al.*, 2010)

2.6.2.3. Impact of fire on forest resource of Ethiopia

Ethiopian farmers have been using fire as a means of production or as a farming tool for a long time. Each year, just before the short rainy season, when farmers start preparing their land, it is familiar to see intentionally set fires. Most of the fires are attended, managed and controlled by the community members who set it. There are also fires set recklessly or accidentally, mostly in lowland savannah grass- and bushlands (Dechassa Lemessa and Matthew Perault, 2002).

In spite of inherent potential risks with fires, farmers believe it as the cheapest and most common tool used for a variety of production activities. However, there have been times when fires have broken out on a large scale and brought about serious economic, political, social and environmental shocks and devastation in Ethiopia. Historical evidence indicates that high forests of Ethiopia remain victims of war, conflict and forest fires. Yodit/Gudit (849-897 A.C.) ordered her army and the local people to set fire to forests stretching from Tigray to Gonder and Wello in suspected hiding grounds for the soldiers of Emperor Dilnaad. Similarly, Gragn Mohamed (1527-1542 A.C.) ordered his troops to clear and burn all the forests stretching from the eastern lowlands to the central highlands to make access to battlefields easier and to destroy strategic hiding grounds of the soldiers of Emperor Libne Dingil and clergies (Gebre Markos Wolde Selassie, 1998). Whatever the causes may be, fires in different parts of Ethiopia damage every year large areas of forests. Despite the country's longtime experience in using fires, there are no available statistics on the causes, risks and extent of damage caused by forest fires (Dechassa Lemessa and Matthew Perault, 2002).

Prior to the forest fires in 2000, the last major outbreak was in 1984 when the fires damaged approximately 308,200 ha of forests (George and Mutch, 2001). After almost three months of large-scale wildfires that consumed over 300,000 ha natural forests in the year 2000, Ethiopia is still not prepared and does not give adequate attention to efficiently protect its last natural forest resources (Dechassa Lemessa and Matthew Perault, 2002).

2.6.2.4. The impact of tea and coffee plantation in the forest resources of Ethiopia

The new investment opportunities being undertaken in Ethiopia, especially in southwest Ethiopia are converting the few remaining moist montane forests into other land use systems such as coffee and tea plantation (Taye Bekele *et al.,* 2002). The study on Chewaka-Utto showed that the natural forests of the area changed from 85% in 1996 to 76.3% in the year 1999 (Kumlachew Yeshitela and Tamirat Bekele, 2002) due to a clearing of the forest for tea and Eucalyptus plantation.

In recent years, over 40 investment projects were given license in forestland of Sheka zone of SNNP alone to invest in coffee and tea plantations. The biggest ones include the Gemadro Coffee Plantation, which has acquired and developing coffee on 2,295 ha and has been promised an additional 2,000 ha in Aderacha Woreda; and the East African Agribusiness, which was also granted around 3,435 ha of forestland for tea plantation (Tadesse Woldemariam and Masresha Fetene, 2007).

2.7. The concept of plant community

The plant community can be defined as the group of plant species growing together in a particular location that demonstrate a definite association or affinity with each other. The idea of association is very important and implies that certain species are found growing together in certain locations and environments more frequently than would be expected by chance. Likewise, different combinations of species will be found together in other environments more frequently than would have been expected by chance. Most environments of the world support certain associated species which can, therefore, be characterized as a plant community (Kent, 2012). According to Westhoff & van der Maarel (1978), a plant community is defined as a piece of vegetation in a uniform environment with a relatively uniform floristic composition and structure that is different from the surrounding vegetation. Grubb (1987) also defined plant communities as an assemblage of functionally similar species population found in one habitat type in an area and integrated to a degree by competition, complementarities and dependence.

The underlying reason for the existence of certain species to a particular environment could be attributed to similar requirements for existence in terms of abiotic (non-living) environmental factors such as light, temperature, water, drainage and soil nutrients. They may also share the ability to tolerate the activities of living animals and humans, such as grazing, burning, cutting or trampling, which collectively are known as biotic factors (Kent, 2012). In addition to the abiotic and biotic environmental factors, community organization may be influenced by temporal factors. This aspect may also include the dispersal mechanisms and subsequent accumulation of species in a site and the developmental stage of vegetation or succession (Jacquemyn *et al.*, 2001)

The existence and feature of the plant community have been debated by early plant ecologists and is still a matter of controversy. Two American ecologists, F. E. Clements and H.A. Gleason expressed the most extreme viewpoints, the 'organismic concept' and ‘individualistic concept' respectively.

2.7.1. Clements’ view of the plant community (The organismic’ concept of plant community)

In this view, plant communities were considered as clearly recognizable and definable entities which repeated themselves with great regularity over a given region of the Earth’s surface. Clements’ view of the plant community is known as the ‘organismic’ concept, in which the various species comprising the vegetation at a point on the Earth’s surface were compared to the organs and parts of the body of an animal or human.

Putting all the parts together made a kind of super-organism that comprised the plant community, and the organism (plant community) could not function without all its organs present (Clements, 1916, 1928 cited in Kent, 2012). In a graphical illustration, Clements's ideas are presented as an 'abstract' model of species response to a single environmental gradient as a result species growing together form an association which would have similar overlapping response curves.

2.7.2. Gleason's view of the plant community (Individualistic concept)

In this concept, species are viewed as 'individualistically' distributed along ubiquitous environmental gradients and thus cannot form bounded communities (Nicholson & McIntosh, 2002). Gleason adherers to the opinion that plant species could not form integrated communities because of their individualistic behavior and criticized the community concept of F.E. Clements (Mueller-Dombois & Ellenberg 1974). He saw all plant species distributed as a continuum.

Gleason argued that plants respond to variations in environmental factors, and those factors vary continuously in both space and time. Thus, the combination of plant species found at any given point on the Earth's surface is unique (Kent, 2012). Every species has a different distribution or tolerance range and abundance over that range. The assemblage of plants growing in an area is not only the result of environmental selection but also species migration. Any area is continuously receiving propagules of species. The success of these species would depend upon the combination of environmental factors at that site and the tolerance ranges of the invading species. Gleason argued that the range of permutations of combinations of environmental factors, together with the different tolerance ranges of the species, would always give a different combination and abundance of species. Sampling along those gradients would always produce a different mix of species composition and abundance and samples could thus never be generalized into clearly defined plant communities (Kent, 2012).

2.7.3. The 'climax pattern hypothesis'

A partial compromise to the highly contrasted views of Clements and Gleason was provided in the 'climax pattern hypothesis' (Whittaker, 1953; Whittaker and Levin, 1977). This envisaged a mosaic of different communities with repeating patterns at the regional scale, correlated with particular combinations of controlling environmental factors. Whittaker argued that in any region, broadly similar conditions in terms of environmental factors and biotic pressures will occur over considerable areas. Where these combinations repeat themselves, the vegetation is also repeated, like similar fragments within a mosaic. However, not all areas could be placed within one or other of these forest types. Often, one forest type would grade into another across an area of transition or boundary between any two forest types, so that, while perhaps 60–80% of the vegetation could be put into one definite forest type, 20–40% could not, because they were transitional between types (Kent, 2012).

2.8. Species richness and Diversity

Species richness is defined as a count of the number of plant species in a quadrat, area or community, is also often equated with diversity (Kent, 2012). According to Hamilton (2005), it is expressed as the number of species present in a given area without considering the number of individuals in each species. Species richness which is the number of species in a given locality or assemblage is the measure of biological diversity. It is used to identify biodiversity hotspots and plays an important role in conservation planning (Magurran and McGill, 2011). Measuring species richness is important for basic comparisons among sites and for addressing the saturation of local communities colonized from regional source pool (Cornnel, 1999). Maximizing species richness is often an explicit or implicit goal of conservation studies (May, 1988), and current and background rates of species extinction are calibrated against the patterns of species richness (Simberloff, 1986).

Species Diversity is measured by recording the number of species and their relative abundances (evenness or unevenness) of species within the sample or community (Kent, 2012). It is a function of the number of species present (species richness or number of species) and the evenness with which the individuals are distributed among these species (species evenness, species equitability, or abundance of each species) (Spellerberg 1991; Magurran, 2004). It is an appropriate name for ecologists who are concerned in understanding the mechanisms and effects of certain ecological phenomena, such as pollution, environmental disturbances, etc (Sanjit and Bhatt, 2005). It is also the most commonly used representation of ecological diversity ((Hamilton, 2005).

Alpha diversity refers to the number of species within the sample area or community whereas beta diversity is the difference in species diversity between samples or communities that correspond to ‘pieces’ in the landscape mosaic. Beta diversity (β-diversity) is a measure used to characterize the patterns of species diversity across heterogeneous regions and measures the change in diversity of species among set of habitats (Perlman and Adelson 1997). Beta diversity is sometimes called habitat diversity since it represents differences in species composition between very different areas or environments and the rapidity of change of those habitats (Kent, 2012). Beta diversity has gained significant value as a conservation tool by representing either species turnover in space or time, or ecological connectivity. Thus, it can help in defining regional-scale diversity and assessing changes across environmental and biogeographic gradients through characterizing the rate of species accumulation from place to place (Whittaker, 1975). Gamma diversity is a measure of the overall diversity for the different ecosystems within a region (Whittaker, 1972). It is the diversity of species in comparable habitats along geographical gradients (Kent, 2012). In short, gamma diversity is the diversity of a region or a landscape. Gamma diversity can be measured in the same units as alpha diversity. Gamma diversity of a landscape, or geographic area, is a product of the alpha diversity of its communities and the degree of beta differentiation among them (Whittaker, 1972).

An Ecological theory does not suggest guidelines as to the appropriate spatial scale for distinguishing "alpha diversity" from "gamma diversity". Indeed, these scales are arbitrary and depend upon the objectives of the study (Palmer and White 1994). In practice, we think alpha diversity to be the diversity of the individual sample unit or observation, and gamma diversity to be the diversity of all sample units combined. Beta diversity then becomes a measure of how distinct the sampling units are along gradients. A gradient with high beta diversity is considered a ‘long’ gradient because there is much change in species composition (Whittaker, 1972).

2.9. Ordination

Ordination is a multivariate technique that expresses the relationships between samples, species and environmental variables in a low-dimensional space using ordination diagrams (Gauch 1982; ter Braak 1995; McCune and Grace 2002). Ordination techniques can be classified as indirect gradient analysis (Unconstrained ordination) and direct gradient analysis (Constrained ordination) (Gauch (1982; ter Braak and Prentice 1988; Zerihun Woldu, 2016).

As the name suggests, unconstrained ordination techniques are not constrained by environmental factors and utilize only the species by sample matrix. If there is any information about the environment, it used after indirect gradient analysis, as an interpretative tool. Therefore, indirect gradient analysis technique can be considered as complementary data clustering mainly for exploratory purposes rather than in hypothesis testing (ter Braak, 1994; Zerihun Woldu, 2016). This numerical approach determines the major gradients of variation to be found in the vegetation data itself. A graphical representation of the variation in vegetation across all sites can be constructed by measuring the similarity between each site based on the species composition. Such an ordination diagram summarizes the major axes of variation in the vegetation data matrix (Austin, 2005).

Constrained ordination in contrast, utilizes external environmental data in addition to the species data and it tells us if species composition is related to measured environmental variables. The Direct analysis allows us to test the null hypothesis that species composition is unrelated to measured environmental variables (ter Braak, 1994; Austin, 2005; Zerihun Woldu, 2016). Direct gradient analysis can also be characterized as a multivariate form of regression analysis in which the species data are modeled as a function of the environment data (ter Braak, 1994).

Ordination can also classified into two types, distance-based techniques (derived from distance matrices) and eigenvalue analysis-based techniques. Eigenvalue-based ordination deal with ordination axes, calculating their eigenvalues and scores of samples and species along these axes; examples are PCA, CA, DCA, CCA, and RDA. Distance-based deal with distances between samples, measured by compositional similarity/dissimilarity measures, and projecting these distances into two or three-dimensional ordination diagrams; examples are MDS or NMDS, PCoA and PO (ter Braak and Prentice 1988; Zerihun Woldu, 2016).

The two most commonly used constrained ordination techniques are Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA). RDA is the constrained form of PCA, and is inappropriate under the unimodal model. CCA is the constrained type of CA, and thus is chosen for most ecological data sets (since unimodality is common). CCA also is appropriate under a linear model, as long as one is interested in species composition rather than absolute abundances (ter Braak and Šmilauer 1998).

PCA is recommended to analyze species data if the relations along the gradients are linear whereas RDA is used to analyze linear relationships between species and environmental variables. CA should be used for analyzing species data and unimodal relations along the gradients whereas CCA can be used to analyze unimodal relationships between species and environmental variables. PCA or RDA should be used if the beta diversity is small, or if the range of the samples covers only a small part of the gradient. A long gradient has high beta diversity, and this indicates that CA or CCA could be used (Legendre and Legendre, 1998).

2.10. Vegetation structure and pattern of Regeneration

Vegetation structure refers to the organization in space of individuals that form a vegetation type of plant association. It can be explored at the level of physiognomic, life form, floristic, biomass and stand vegetation structures which are hierarchically integrated. The life form, stratification and coverage are the vital elements which describe vegetation structure (Mueller – Dombois and Ellenberg, 1974). In the analysis of vegetation structure, the growth stages of trees as seedlings, saplings and mature trees as the distribution of size classes within a population can be one of the elements of diversity that permit or deny the likelihood of quick recovery after disturbances (Harper, 1982).

Population structure is defined as the distribution of individuals of each species in arbitrary diameter – height size classes to provide the overall regeneration profile of study species (Peters, 1996). Information on the population structure of a tree species shows the history of the preceding disturbance to that species and the environment and therefore, used to forecast the future trend of the population of that particular species (Peters, 1996). Population structure is really valuable tool for orienting management activities and perhaps most important for assessing both the potential of a given resource and the impacts of resource extraction (Peters, 1996).

The size class structure of the species shows whether regeneration is taking place or not. If regeneration were occurring continuously then the species would have a stable population distribution with inverse -J shape, which is an indicator of good regeneration (Harper, 1977; Silvertown, 1982). Such population structure (inverse-J shape) is common in natural forests where external disturbances are limited. On the other hand, bell-shaped or variable size-class distribution has been attributed to a disturbed forest where regeneration is hampered (Poorter *et al.*, 1996). Population structure (size-class distribution) gives a good indication of the impact of disturbance and the forest successional trends. Such information is vital in increasing our understanding of the conservation needs of tropical forest ecosystems (Hubbell and Foster, 1986; Condit *et al.*, 1995).

Regeneration is the process of silvigenesis by which trees and forests survive over time (Bhuyan *et al.*, 2003). The population structure along different developmental stage of a species in a forest can express its regeneration behavior (Saxena and Singh, 1984). The population structure, characterized by the presence of sufficient population of seedlings, saplings and adults, indicates successful regeneration of forest species (Saxena and Singh, 1984). Regeneration status of trees can be predicted by the age structure of their populations (Vablen *et al.*, 1979; Khan *et al.*, 1987; Tripathi *et al.*, 2007). Research in this field contributes to planning, conservation and decision making in forest resources management programmes.

The status of regeneration of species can be determined based on population size of seedlings and saplings (Shankar, 2001). Good regeneration, i.e. if particular species is present in seedling > sapling > tree; fair regeneration, i.e. if species present in seedling > sapling < tree; poor regeneration, i.e. if a species survives only in sapling stage, but not as seedling; if a species is present only in adult form it is considered as not regenerating. A species is considered as not abundant if the species has no tree representatives, but only saplings and/or seedlings (Shankar, 2001).

The environmental factors influencing the seedling features differ at spatial scales, hence, they act on at microsite – depending on the way altering the seedling survivorship probability (Castro *et al.*, 2004). The regeneration of existing tree populations in an area can be hampered by a lack of recruitment due to several causes, such as scarce production and dispersion of seeds, and high mortality of seedlings, the severity of drought, anthropogenic activities, and overgrazing by domestic and wild herbivores (Comez *et al.*, 2003). Regeneration success and stand dynamics in a forest ecosystem are strongly associated to seedling and juvenile performance (Pigott and Pigott, 1993).

Regeneration is a key ecological process and a vital component of forest ecosystem dynamics and restoration of degraded forest lands. Sustainable forest use is only possible if adequate information on the regeneration dynamics and factors affecting important canopy tree species are available. If native long-lived trees are unable to survive and regenerate in a given forest, then there is little hope to sustain the normal forest functioning in the long term (Harrington *et al.*, 1997).

CHAPTER THREE

3. Material and methods

3.1. Materials

The materials used for the data collection include tree caliper and measuring tape for measuring DBH, colored rope for making plot boundary, Global-positioning system (GPS) for locating plots, compass for measuring aspects, clinometer for measuring slope and tree height, balance for weighing soil, litter, and herb layer biomass, hand saw for collecting dead wood samles and cutting destructive samples, In addition, plastic bags for collecting harvested herbs/ litter biomass for dry weight estimation, nylon cloth for soil sampling and pressing materials for plant specimen collection and data recording sheet.

3.2. Description of the Study Area

3.2.1. Location and Topography

This study was conducted in Gerba Dima forest which is designated as Gerba Dima forest District by Oromia Forest Enterprise. This forest was also designated as part of the national forest priority area. It is found in the Illu Aba Bora zone of Oromiya regional state of Ethiopia and located between 7^0 45' to 8^0 10' North latitude and 35^0 29 ' to 35^0 50' East longitude at about 630 km away from Addis Ababa and 30 km West of the zonal capital Metu. The study forest lies in Ale, Didu and Bacho Woreda (administrative districts) of Illu Aba-Bora zone and forms part of the mountainous highlands west of the Great Rift Valley and is situated on undulating and dissected mountain ranges between1582m to 2285m a.s.l (Fig. 2). The forest is surrounded by Baro river to the south and west part of Ale district. Three other rivers, namely Bote, Hoyi and Sor also cross part of the forest in Becho district. The total area of the forest calculated from the map formed using Arc GIS (Fig. 2) is about 106,287.3 hectares.

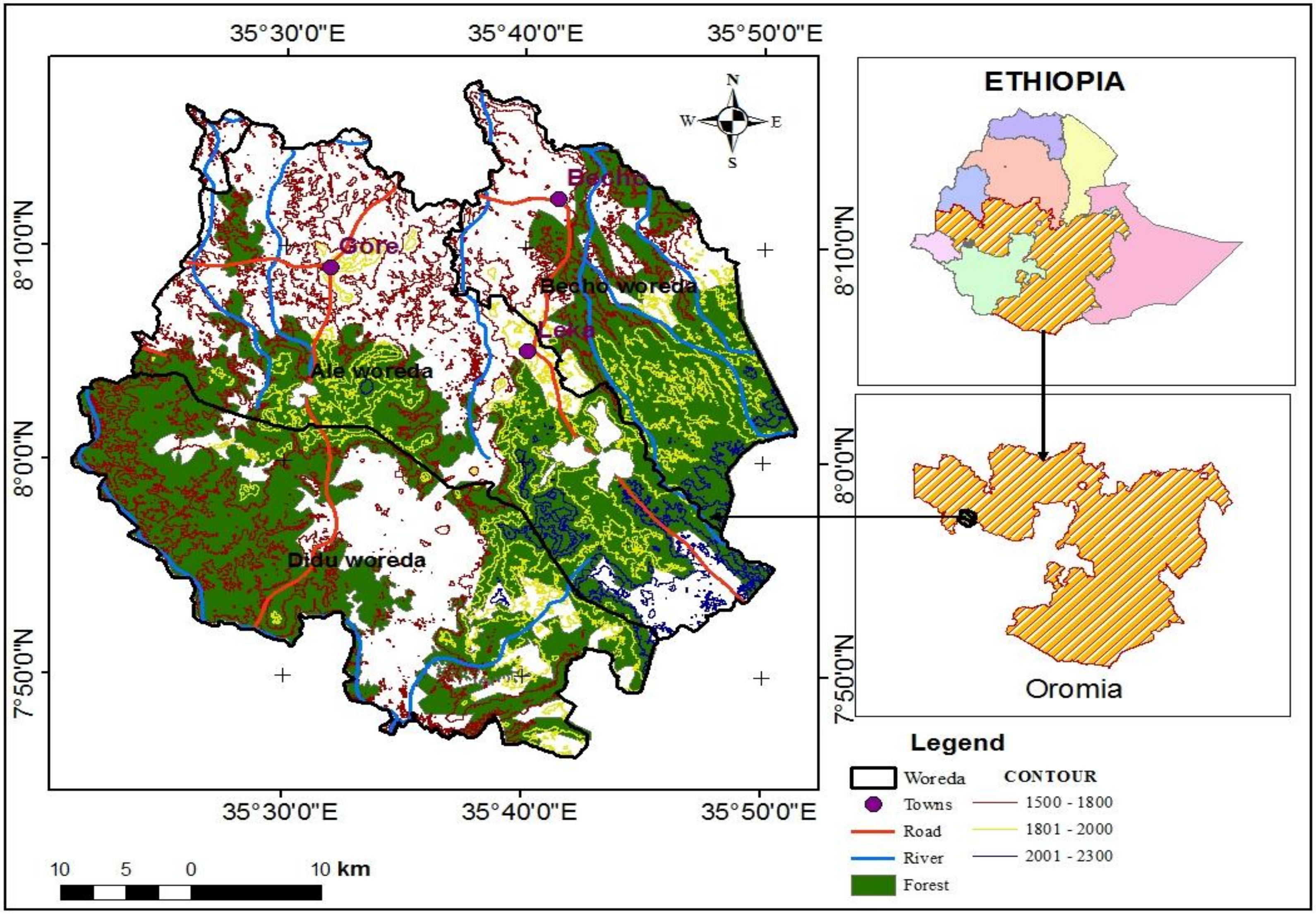


Figure 2. Map of the study area and sample sites

3.3. Geology and Soil

The Underlying basement rock in the study area consists of intensively folded and faulted Precambrian rocks, overlain by Mesozoic marine strata and Tertiary basalt types (Westphal, 1975). The tertiary volcanic rocks include rhyolites, trachytes, tuffs, ignimbrites, agglomerates, and basalts. These rocks form the substrates of most of the Afromontane forests (Friss, 1992).

Generally, the soils of the area are red or brownish ferrisols derived from the volcanic parent material. The occurrence of high rainfall has masked other soil forming factors and hence, very similar soils have developed on a variety of parent materials. Other soil groups in the area include nitosols, acrisols, vertisols, and cambisols (Tafesse Asres, 1996).

3.4. Climate

In constructing the climate diagram of Gerba Dima forest, 21 years climate data (1996-2016) of Gore station obtained from the Ethiopian Metrological Service Agency was used (NMSA, 2016). The meteorological station of Gore is used since it is the nearest station which has recorded the climate information. According to Daniel Gamachu (1977), Gore is a place receiving eight rainy months which extends from March through October with an even distribution of rainfall throughout. The rainfall data collected from Gore meteorological station indicated that the study area receives very high annual rainfall. The climate diagram shows unimodal rainfall pattern with the monthly mean maximum and mean minimum temperature of the area is 27.2 ^{0}C and 13.3 ^{0}C, respectively. The mean annual temperature is 19.2^{0}C and with slight variation from year to year (Figure 3).

The mean annual rainfall of the study area is 1854mm. The rainfall pattern shows low rainfall in December, January and February, gradually increasing to the peak period in August.

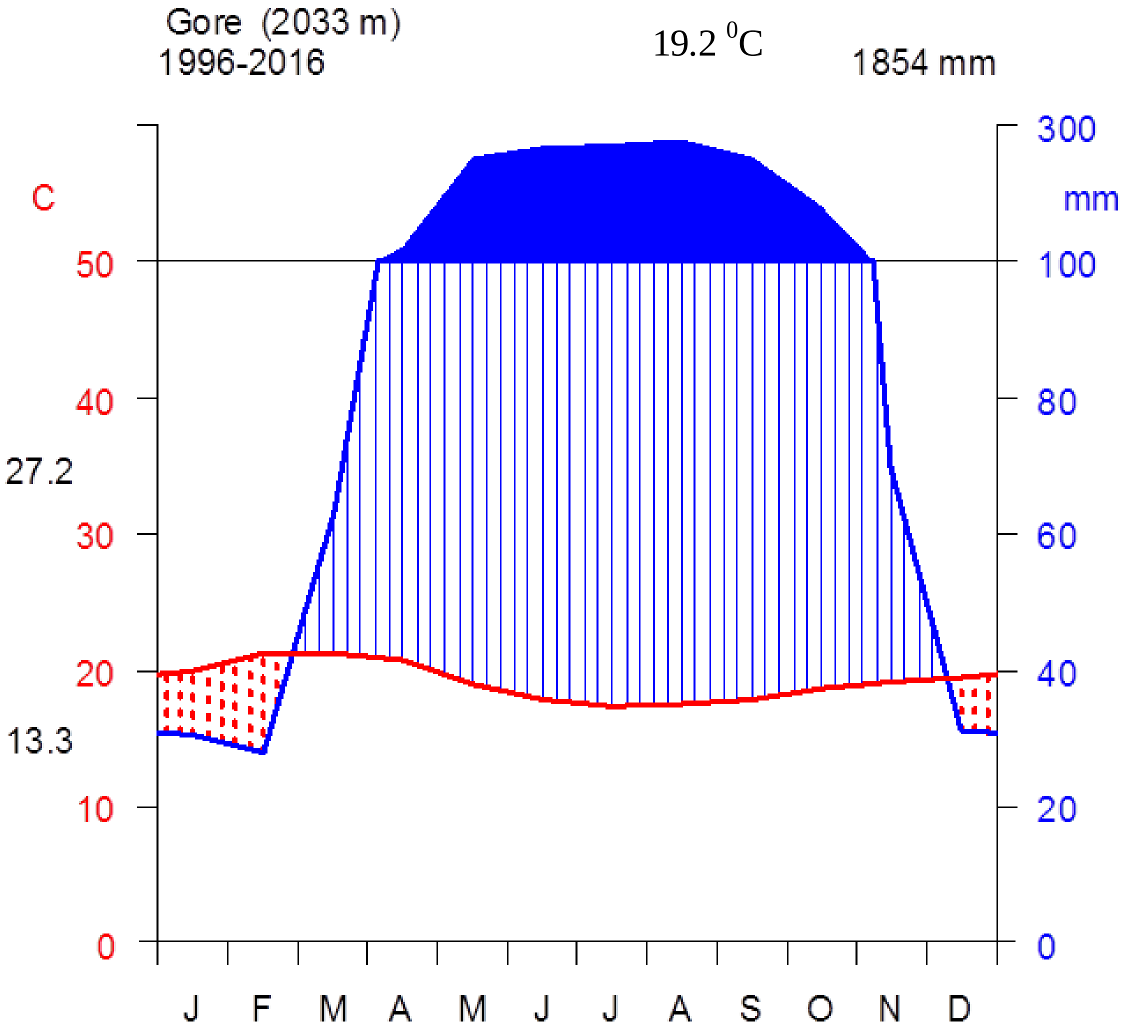


Figure 3. Climate diagram of Gore

3.5. Data collection methods

3.5.1. Vegetation data collection

Following the observation of study sites during reconnaissance survey, the study forest was stratified into three forest strata based on altitudinal variation. Strata one was found at altitudinal range of between 1500-1800m while starata two and three were located between the altitudinal range of 1801-2000m and 2001-2300m respectively (Fig. 2). In this study, a stratified random sampling design was used to collect vegetation and environmental data (Mueller-Dombois and Ellenberg 1974; Kent, 2012). Using Arc GIS, the study forest was stratified based on altitudinal gradient and three types of strata in the form of contour was established (Fig. 2). Sample plots are assigned in each contour in the form of Random points Using Arc GIS. A total of 90 sample plots having a size of 25 X 25m (625m^2) along each contour were laid. Nested plots were used to sample plants of different size and different environmental variables. All woody plant species with Diameter at breast height (DBH) $\geq$ 2.5 cm and height $\geq$ 1.5m were recorded in 25 m X 25 m plots. Within the major plots, five 3m x 3m subplots (9m^2) were set up as shown in Figure 4. These plots were used to collect two sets of vegetation data: (i) saplings and shrubs with dbh < 2.5 cm and > 1.5m height and (ii) the seedlings of all trees and number of climbers. Within each 9m^{2}subplots, two 1m^2 subplots were used to collect data on the species and abundance of herbaceous plants (Fig. 4). Finally, the percent cover of all plant species found within the sample plot were visually estimated and converted to Braun-Blanquet scale as modified by van der Maarel (1979).

Height and Diameter at Breast Height (DBH) were measured for all woody plant species with height $\geq$ 1.5m and DBH $\geq$ 2.5 cm thick. Height and DBH measurements were made using clinometer and tree caliper respectively. Regeneration pattern of study species was assessed by employing total count of seedlings (woody species of height ≤ 50 cm and dbh ≤ 2.5cm) and saplings (woody species of height > 50cm and dbh ≤ 2.5 cm) within their respective subplots indicated above. Every plant species encountered in each plot were recorded. Plant specimens were collected, pressed, dried and brought to the National Herbarium (ETH), Addis Ababa University for taxonomic identification. The specimens were determined by comparing with authenticated specimens housed at ETH and by referring to published volumes of Flora of Ethiopia and Eritrea. Nomenclature followed was that of Flora of Ethiopia and Eritrea.

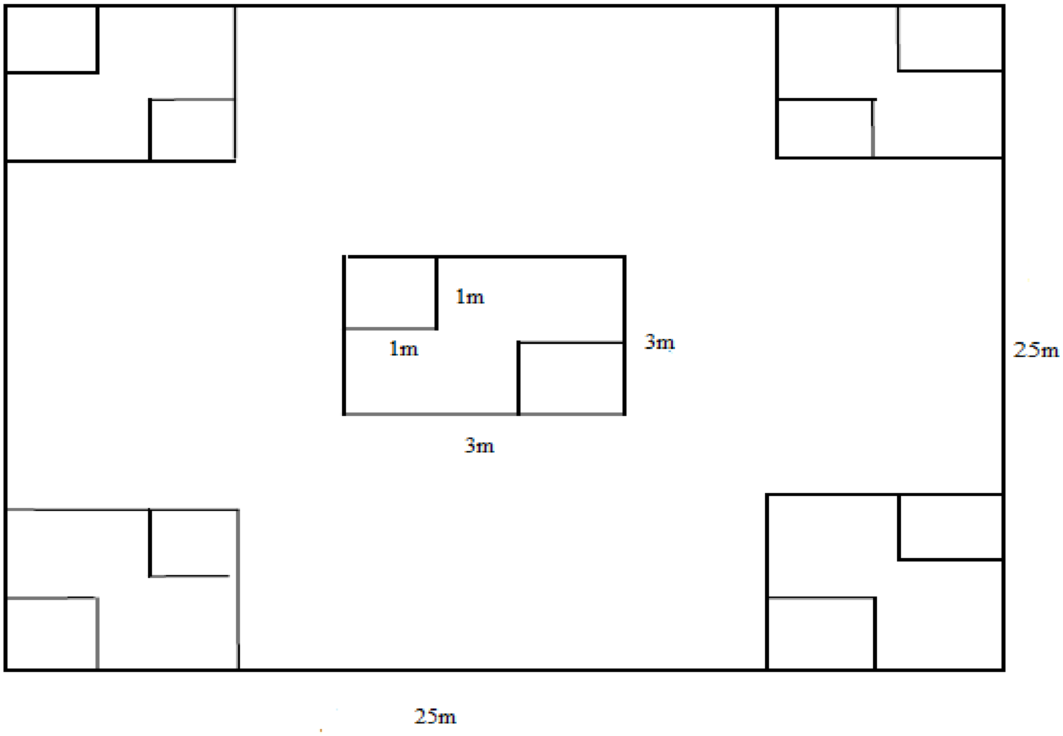


Figure 4. Lay out of the study plot

3.5.2. Environmental and soil data collection

Physiographical variables, namely altitude, geographic coordinates, slope and aspect, were recorded for each quadrat using GPS, Clinometer and Compass respectively. The values for aspect were codified based on Zerihun Woldu *et al.* (1989), where N = 0, NE = 1, E = 2, SE = 3, S = 4, SW = 3.25, W = 2.5, NW = 1.25 before analysis. For each sample plot, a disturbance was determined on the basis a five point scale following Anderson and Currier (1973). The five scales of disturbance scores were based on visible signs of tree cutting, grazing and presence of beehives. The points of scale were: 0 = (No disturbance), 1= (0-20% of the quadrat disturbed), 2= (21-40% of the quadrat disturbed), 3= (41-60% of the quadrat disturbed), 4= (61- 80% of the quadrat disturbed), 5 = (81-100% of the quadrat disturbed).

For analyzing soil variables, soil samples were collected with a soil core sampler from the top 40cm depth within 1m x 1m subplots at the four corners and middle of the quadrat. Composite soil samples from samples collected from the four corners and the middle of quadrats were brought to the soil laboratories of AAU.

The soil samples were air-dried, rolled and passed through a 2 mm sieve for laboratory analyses. These soil samples were analyzed for pH, electrical conductivity (EC), sodium, potassium, organic matter, total nitrogen, available phosphorus and texture following standard procedures outlined in Allen (1989). The pH and EC were measured using a pH meter and EC meter in the supernatant suspension of 1:2.5 soil–distilled water mixtures. Available Sodium and Potassium were determined using a flame photometer. Organic matter was determined by ignition method. The texture was determined on the basis of Bouycous Hydrometer method with the categories sand, silt, and clay (expressed as % weight) while total nitrogen was determined using Kjeldhal method. Available Phosphorus was determined by Bray-I method and the absorbance of the Bray-I extract is measured at 882 nm in a spectrophotometer.

3.5.3. Data collection methods for carbon stocks

3.5.3.1. Delineation of Project Boundaries

The first step in forest carbon measurement is a delineation of the project boundaries (Bhishma *et al.*, 2010). The spatial boundaries of the study area were clearly defined and properly recognized to facilitate accurate measuring, accounting and verification. There are many tools that are available for identifying and delineating project boundaries such as aerial photos; global positioning system (GPS); Topographic maps; land records and others. However, for this study GPS tracking were used for boundary delineation.

3.5.3.2. Stratification of the Study Area

To increase the accuracy and precision of measuring and estimating carbon, it is useful to divide the project area into sub-populations or “strata” that form relatively homogenous units. In addition, stratification also decreases the costs of monitoring because it typically diminishes the sampling efforts necessary, while maintaining the same level of confidence. A stratified sampling design also allocates a greater number of plots in strata that have greater variability. There are different important tools for defining strata. These include: ground-truthed maps from satellite imagery, aerial photographs and maps of vegetation, soils or topography (Pearson *et al.*, 2005). The three forest strata identified for ecological data collection were also used to stratify the study area for carbon stock.

3.5.3.3. Shape and Size of the Plots

The size and shape of the sample plots is a trade-off between accuracy, precision, time and cost for measurement. There are two types of plots – single plots of a fixed size or nested plots containing smaller sub-units of various shapes and sizes (Brown, 1997). However, in most cases, nested plots can be the most cost-efficient. According to Brown (1997), nested plots are a practical design for sampling and for recording discrete size classes of stems. They are well-suited to stands with a wide range of tree diameters or to stands with changing diameters and stem densities. Single plots may be preferred for systems with low variabilities, such as single species plantations.

Even though both rectangular and circular plots are applied in most of the forest carbon measurements, rectangular samples are more advantageous and recommended for the study area. This is because rectangular plots tend to include more of within-plot heterogeneity, and thus be more representative than the circular plots of the same area (Hairiah *et al.,* 2001; Brown, 1997).

In this study, nested plots were used as nested plots are practical designs for sampling and recording discrete size classes of stems. The plots used for carbon stock were superimposed on the plots used for ecological data collection. The procedures were involved setting out three nested plots with 1225 m^2 (35m x 35 m), 625m^2 (25m x 25m) and 49m^2 (7m*7m) quadrats. For trees with a diameter range of 5 cm < diameter < 20 cm, the carbon stock was measured by a plot size of 49m^2(7m*7m). For trees with a diameter range of 20 cm < diameter < 50 cm, the carbon stock was measured by a plot size of 625m^2(25m*25m). For trees > 50 cm diameter, an additional larger sample of 35 * 35 m^2 (Fig. 5) were Used (Walker *et al*., 2012). For each tree, the diameter was measured at 1.3 m above the soil surface, except where trunk irregularities at that height occur (plank woods, tapping or other wounds) and necessitate measurement at a greater height.

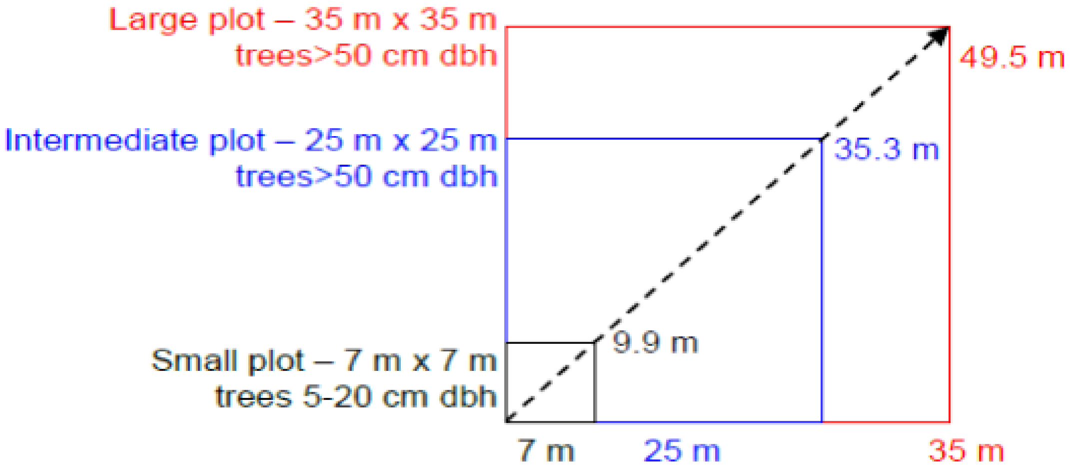


Figure 5. Nested plot design for sampling carbon pools.

3.5.4. Field Carbon Stock Measurement

The major activities of carbon measurement during the field data collection were above-ground tree biomass, leaf litter, dead wood and soil organic carbon measurements. Detailed methods are explained under the following sub-headings.

3.5.4.1. Above Ground Tree Biomass (AGTB)

The DBH (at 1.3m) and height of individual trees greater than or equal to 5cm DBH were measured in each respected nested rectangular plots using tree caliper and clinometer starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice. Each tree was recorded individually, together with its species name and ID.

According to Karky and Banskota (2007) and MacDicken (1997) trees on the border must be included if > 50% of their basal area falls within the plot and excluded if < 50% of their basal area falls outside the plot. In addition, trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included.

3.5.4.2. Leaf Litter

The leaf litter is defined as all dead organic surface material on top of the mineral soil. Dead wood with a diameter of less than 10 cm and greater than 2mm is included in the litter layer (Pearson *et al.*, 2005).

One rectangular sub plot of 1 square meter in size was established at the center of each nested plot. The leaf litter within the $1m^2$ sub plots were collected and weighed. A hundred grams of evenly mixed sub-samples were brought to the laboratory placing in a sample plastic bag to determine moisture content, from which total dry mass can then be calculated (Bhishma *et al.*, 2010).

3.5.4.3. Dead Wood

In most cases dead wood, is less abundant than live trees. Standing dead trees, fallen stems, and fallen branches with a DBH and/or diameter $\geq$ 5 cm were measured within the 625 m^2 plot, branches with diameters of 2-4 cm were measured within the 50 m^2 plots, and thinner branches were only measured within the 1 m^2 plot. The amounts of biomass found in dead wood were measured according to the types of dead wood (Bhishma*et al.*, 2010).

3.5.4.3.1. Standing Dead Wood

Within plots delineated for live trees, standing dead trees were also measured. The DBH and decomposition state of the dead tree were recorded. Decomposition classes for standing deadwood were defined practically as follows:

1. Tree with branches and twigs and resembles a live tree (except for leaves);

2. Tree with no twig, but with persistent small and large branches;

3. Tree with large branches only;

4. Bole (trunk) only, no branches.

For classes 2, 3 and 4, the height of the tree, the diameter at ground level and at the top was measured (Pearson *et al.*, 2005).

3.5.4.3.2. Downed Dead Wood

Lying dead wood is most efficiently measured using the line-intersect method. Only coarse dead wood (wood with a diameter> 10cm) is measured with this method – dead wood with a smaller diameter is measured with litter. Downed dead wood was sampled along 100m line (using the line-intersect method) involving a lay out two lines of 50m at right angles to determine biomass density (Pearson *et al.*, 2005). Diameters and density classes were recorded and subsamples were collected to determine density in each of the three density classes (sound, intermediate, and rotten).

Each piece of dead wood was assigned to one of three density classes – sound, intermediate or rotten. To determine what density class a piece of dead wood fits into, each piece was struck with a saw or machete. If the blade did not sink into the piece (that is, it bounces off), it was classified as sound. If it sank partly into the piece and there had been some wood loss, it was classified as intermediate. If the blade sank into the piece, there is more extensive wood loss and the piece is crumbly, it was classified as rotten (Pearson *et al.*, 2005).

Representative dead wood samples of the three density classes, representing the range of species present, were collected for density (dry weight per green volume) determination via water displacement method.

3.5.4.4. Non-Tree woody species

All herbaceous and other woody species with DBH < 5 cm in diameter except coffee were cut into pieces and the fresh weight collected from 1 m^2 were recorded following the same procedure with that of the litter (Pearson *et al.*, 2005).

3.5.4.5. Soil Organic Carbon (SOC)

In order to obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample (Pearson *et al.*, 2005). For convenience and cost-efficiency, it is recommended to sample to a constant depth, maintaining a constant sample volume rather than mass. A 40cm probe is an effective measurement tool.

Similarly, for the study area, the soil samples for soil carbon determination were collected at the same sampling sub-quadrats recommended for litter sampling. From the center of each plot and/or sub-plot a pit of up to 40 cm in depth was dug to best represent forest types in terms of slope, aspect, vegetation, density, and cover. A hundred grams of composite sample was collected from one plot by digging the soil with the help of standardized 100 or 300 cm^3 metal soil sampling corer. The soil samples collected from plot were brought to the laboratory placing in a sample paper bags. Then, the bulk density and amounts of soil organic matter were determined.

3.5.5. Data collection via Semi destructive method in developing species and area specific allometric equation for 5 tree species

Following the methodologies recommended in Picard *et al*., (2012), area and species-specific allometric equations were formed involving non-destructive or semi-destructive approach. A total of 150 individuals of the five dominants tree species of *Olea welwitschii*, *Pouteria adolfi-friederici*, *Elaeodendron buchananii*, *Cassipourea malosana*, and *Vepris dainellii* were selected. From each species, 30 individuals were randomly selected and sampled for measuring biomass along the three forest strata formed for ecological and carbon stock study. In order to minimize the error of sampling and to obtain the representative tree and samples, diameter distributions were taken into account during tree selection. Accordingly for the first three large tree species, the trees were classified into five DBH classes and each class having six individuals per DBH class ranging from 10-20 cm, 20.1-30 cm, 30.1-40 cm, 40.1-50 cm and greater than 50 cm. For the last two smaller tree species (*Cassipourea malosana*, and *Vepris dainellii*), the trees were also classified into five DBH classes and each class also have six individuals per DBH class ranging from 10-13 cm, 13.1-16 cm, 16.1-19 cm 19.1-22 cm and greater than

22 cm. The measurement of diameter in each section of a tree was done by experienced persons climbing on live trees using ropes. Using data obtained by climbing live trees, aboveground biomass of trunk, branches and leaves were estimated. Generally, three random small branches with less than 10cm basal diameter per individual plant were destructed and trimmed. The measurements of fresh biomass (in kg) were divided into two parts: measuring trimmed fresh biomass and measuring untrimmed fresh biomass.

3.5.5.1. Trimmed fresh biomass

The three small branches destructed per tree were trimmed in compliance with local practices (often using a machete). A tree caliper was used to determine the diameter at the base of each branch. The basal diameters were determined at the first point at which the branch became cylindrical, typically within 5 cm of the trunk then the leaves were separated from the trimmed branches. The fresh biomass of the leaves from the trimmed branches (Btrimmed fresh leaf) and the fresh biomass of the wood from the trimmed branches (Btrimmed fresh wood) were determined (by weighing separately). Three random samples of the leaves from three different trimmed branches were taken to constitute the aliquot. Its fresh weight (B aliquot fresh leaf in g) was measured. An aliquot of the wood was also taken at random from the trimmed branches, without debarking. Its fresh mass was measured (B aliquot fresh wood in g) in the field, immediately after cutting. Samples about 10 cm long were taken from twigs and 6 disks were taken from the destructed three branches. These aliquots were placed in numbered plastic bags and sent to the laboratory. The subsamples were then dried at 65^0C for 48 h or until constant weight was obtained to determine the moisture content. The fresh volume of the wood aliquot was measured in the lab, and the value was used to determine mean wood density. These data (dry biomass of trimmed component) were used to develop regressions between basal diameter and trimmed branch component weight (trimmed branches, twigs and leaves) (Vann *et al.*, 1998; Picard *et al.*, 2012).

3.5.5.2. Untrimmed fresh biomass

Untrimmed biomass is measured indirectly as non-destructive. The small untrimmed branches with less than 10cm basal diameter were processed differently from the large branches and the trunk. For the small branches, only basal diameter was measured. The biomass of these small untrimmed branches with their accompanying twigs and leaves was estimated from the relationship between their basal diameter and the regression developed from the trimmed branches (Vann *et al.*, 1998; Picard *et al.*, 2012).

The biomass of the trunk and the large branches was estimated from measurements of volumes (Vi in cm^3) and mean wood density (ῥ in g cm^{-3}). The large branches and trunk were divided virtually into sections that are then materialized by marking the tree. The volume Vi of each section i was obtained by measuring its diameter and its length. Diameter measurements were carried out in sections of about one meter in length for smaller trees and two meters in length for larger trees along the length of the trunk. For larger branches greater than 10 cm in basal diameter, diameter measurements were conducted in sections of 50 cm in length using tree caliper.

The volume (V aliquot fresh wood) of the wood aliquot taken from the trimmed compartments was measured by measuring the volume of water displaced when the sample is immersed in water using a graduated tube of suitable dimensions for the sample

(Picard *et al.*, 2012). The dry biomass of the tree was obtained by the sum of the trimmed dry biomass and the untrimmed dry biomass:

B dry = B trimmed dry + B untrimmed dry

3.5.6. Destructive sampling to formulate allometric equation for two shrub species

Thirty individuals covering the full range of sizes were harvested for each shrub species to develop new biomass regression equations. The biomass of shrub (dependent variable) depends on many independent (explanatory) variables. The identified and recorded independent variables in the field were total height (ht, height from the ground or collar region to the top of the leading shoot), Diameter at stamp height (DSH) measured at 10cm above the ground, crown height (Cr-ht, height from ground to the height of first crown origination point), crown length (Cr-L, diameter of crown at larger side), crown breadth (Cr-B, diameter of crown at smaller side) and crown depth (Cr-D, total height of tree minus the crown height).

3.6. Data analysis

3.6.1. Ecological data analysis

3.6.1.1. Species accumulation curve

To evaluate the effectiveness of the species estimators and to examine the degree of species collection (sampling), species accumulation curve was plotted in free statistical software R version 3.4.3 (R Development Core Team, 2017) using vegan package. The graph was plotted for the cumulative number of species recorded as a function of sampling effort. Species accumulation curve helps to illustrate the rate at which new species are included as the sampling effort proceed. The species accumulation curve in adequately sampled study area levels off before the total number of sampling plots is reached (Zerihun Woldu, 2016). One of its applications is to assess whether a study area has been sufficiently sampled or not and have an implication for efficient planning and sampling protocols (Colwell and Coddington, 1994; Shen *et al.*, 2003).

3.6.1.2. Cluster analysis

Prior to the analysis of the vegetation data which were originally estimated in the field in the form of a percentage of cover abundance values, were converted into Braun-Blanquet (1932) scale as codified by van der Maarel (1979).

In this study, hierarchical (agglomerative) cluster analysis was performed using the free statistical software R version 3.4.3 (R Development Core Team, 2017) using package cluster to classify the vegetation into plant community types. Similarity ratio with Ward's group linkage method was applied for cluster analysis i.e. to determine plots that can be classified into the same groups based on the species abundance data. The decision on the number of groups (clusters) was based on objective methods of obtaining an optimal number of clusters, the Multi Response Permutation Procedures (MRPP) technique (no-difference hypothesis) and the ecological interpretation of the groups conducted in R program. From the output of objective method, a sharp bend at the fifth cluster in the plot could be a good indication of the number of clusters in the data (Zerihun Woldu, 2016).

The community types identified from the cluster analysis were further refined in a synoptic table where species occurrences were summarized as synoptic cover-abundance values (van der Maarel et al., 1987). Synoptic value is the average cover abundance values of a species. Dominant species of each community type were identified based on their synoptic values and community types were named after one or more dominant species. The identified groups were tested for the hypothesis of no difference between the groups (clusters) using nonparametric Multi-Response Permutation Procedure (MRPP) in R soft ware (R Development Core Team, 2017).

Indicator species analysis was performed in R using package labdsv (R Development Core Team, 2017). In community analysis, detecting and describing the value of different species to indicate the environmental conditions is a common practice (McCunne and Grace, 2002). In this study, the new method which is proposed by Dufrene and Legendre (1997) was used. This method combines information on the concentration of species abundance in a particular group and the faithfulness of occurrence of a given species in a specific group (McCunne and Grace, 2002). It produces indicator values for each species in each group, based on these standards of perfect indicator. Indicator values are tested for statistical significance using a randomization (Monte Carlo) technique using R software (R Development Core Team, 2017). The indicator values range from zero (no indication) to 100 (perfect indication). The perfect indication means that the presence of a species points to a particular group without error, at least with the data set in hand.

3.6.1.3. Diversity analysis

Species richness, evenness, Shannon diversity and evenness, Sympson diversity and evenness and beta diversity indices were computed using the free statistical software R version 3.4.3 (R Development Core Team, 2017). Species richness is a biologically appropriate measure of alpha (α) diversity and is usually expressed as a number of species per sample unit (Whittaker 1972). The Shannon diversity (H ‘) and evenness (E’) indices are calculated as a measure to incorporate both species richness and species evenness (Magurran 1988; Kent, 2012). The Shannon diversity index (H') is calculated from the equation:

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

Where pi, is the proportion of individuals found in the ith species. The values of Shannon diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5 (Magurran 1988 Kent, 2012). The Shannon evenness index (J) was calculated from the ratio of observed diversity to maximum diversity using the equation:

$$J = \frac{H'}{Hmax} = \frac{H'}{ln \, s}$$

Where Hmax is the maximum level of diversity possible within a given population, which equals ln (number of species). J is normal between 0 and 1, and with 1 representing a situation in which all species are equally abundant (Magurran, 1988).

Simpson’s index of diversity (D) was calculated by the formula:

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

Where n = the number of individuals for each species and N = the total number of individuals of all the species.

3.6.1.4. Floristic similarity analysis between clusters

Sorensen similarity index was used to assess the degree of floristic similarity between plant communities. It is preferred because it gives weight to species that are common to the quadrats or sample plots rather than to those that only occur in either sample plots (Kent, 2012). The Sorensen similarity index is calculated from the equation:

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

Where Ss = Sorensen similarity coefficient, a = the number of species common to both sites, b = the number of species present in one of the sites to be compared and c = the number of species present on the other site. Often the Sorensen similarity coefficient is multiplied by 100 to give a percentage similarity figure. The similarity coefficient value ranges from 0 (complete dissimilarity) to 1(total similarity).

Species composition analysis was complemented by calculating the floristic dissimilarity between all pairs of clusters using beta (β) diversity. Beta diversity measures the change in the diversity of species among a set of habitats. In simpler terms, it calculates the number of species that are not the same in two different habitats. Beta diversity is, therefore, the rate of change of community along an ecological gradient. There are different ways to calculate beta diversity where all methods determine species turnover (replace one another) between different sites or along environmental gradients (Perlman and Adelson, 1997). Noticing the problem associated with the increasing number of species with increasing sample size, Whittaker (1972) suggested that beta diversity could better be calculated from pair-wise comparison of sites. In the present study, a pair-wise comparison of beta diversity between community types was computed using the formula (Whittaker, 1972),

$$\beta = \frac{b + c}{2a + b + c}$$

Where a, is the number of shared species in two sites, and b and c are the numbers of species unique to each site. A higher value of beta diversity index indicates a low level of similarity, while a lower value of beta diversity index shows a high level of similarity.

3.6.1.5. 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). There are two types of ordination techniques which are widely used in describing the pattern of plant communities along an environmental gradient. The linear response model which include (Principal component analysis - PCA or Redundancy Analysis - RDA) and Unimodal response (Deterended correspondence Analysis–DCA, Correspondence analysis–CA or Canonical Correspondence Analysis–CCA).The application of either of the methods depends on the nature of the dataset. Preliminary analysis of vegetation data using DCA can help to distinguish the appropriate methods to use for the analysis. From the output of DCA, if the value of the longest axis length is > 4 the unimodal method should be used for analysis and if it is <3 the linear model is preferably used (Ter Braak, 1995; Lepš & Šmilauer 2001). The longest axis of DCA for Gerba dima forest dataset was less than 3 (= 2.22) and thus the linear model RDA was chosen.

Before the application of RDA ordination, environmental variables which were relatively more important in explaining the species data were selected using Monte Carlo technique and function Adonis test for their significance. Computation of variance inflation factor (vif) was also conducted to eliminate those environmental variables that are collinear (variables significantly correlated with each other and add little in explaining the variability of the species data) and leave only the variables that contain unique information. Variables having vif values higher than 5 are collinear and are thus candidates for elimination (Zerihun Woldu, 2016). Both Monte Carlo test and Variance inflation factor (vif) analysis was conducted using the free statistical software R version 3.4.3 (R Development Core Team, 2017). In this analysis, 90 sample plots, 180 species and 14 environmental variables (altitude, slope, aspects, disturbance, clay, sand, silt, PH, EC, available Phosphorus, Na, K, total Nitrognen, and OM) were included.

The community types obtained were subjected to an ANOVA based on environmental variables to find out whether there are significant variations between the groups. Pearson's product-moment correlation coefficient was calculated to evaluate the relationship between the environmental variables.

3.6.1.6. Analysis of vegetation structure and regeneration status

The structure of the vegetation was described using frequency distribution of DBH, height and Importance Value Index (IVI). Tree or shrub density and basal area values were computed on a hectare basis. Importance value indices will be computed for all woody species based on their relative density (RD), relative dominance (RDO) and relative frequency (RF) to determine their dominance as recommended by Kent (2012).

IVI = Relative Density (abundance) + Relative Dominance (basal area) + Relative Frequency

Relative Density = $\frac{\text{the number of all individuals of a species}}{\text{the number of all individuals of all species}} \; X\,100$

Relative basal area = $\frac{\text{the basal area of a species}}{\text{Total basal area}} \; X\,100$

Basal area $(BA) = \frac{\pi D^2}{4}$, where π = 3.14; d = DBH (m)

Relative frequency $= \frac{\text{the number of plots where a species occur}}{\text{the total occurrence of all species in all of the plots}} X\ 100$

Relative dominance $= \frac{\text{Dominance of a species}}{\text{Dominance of all species}}$

Following (Curtis and Mcintosh, 1950), Frequency and density of woody species was calculated as follow:

Frequency (F) $= \frac{\text{No.of quadrats in which a species occurs}}{\text{Total no.of quadrats examined}} X\ 100$

$Density(D) = \frac{\text{Total no.of individuals of a species found}}{\text{Total area examined}}$

The vertical structure of the woody species occurring in the Gerba Dima Forest was analyzed using the IUFRO classification scheme (Lamprecht, 1989). This scheme categorizes a vertical structure of vegetation into upper, middle and lower storey. The population structures of some selected species were also analyzed for the interpretation of the pattern of population dynamics in the forest. The regeneration status of woody species was summarized based on the total count of seedlings and saplings of each species across all quadrats.

Information on the population structure of a tree species indicates the history of the past disturbance to that species and the environment and hence, used to forecast the future trend of the population of that particular species (Peters, 1996).

Regeneration pattern of study species was assessed by employing total count of seedlings (woody species of height ≤ 50 cm and dbh ≤ 2.5cm) and saplings (woody species of height > 50cm and dbh ≤ 2.5 cm within the main quadrats. A species is considered to have good regeneration if seedlings > sapling > adults; fair regeneration, if seedlings > or

≤ saplings ≤ adults; poor regeneration if the species survives only in the sapling stages. If a species is present only in the adult stage, it is considered as not regenerating.

3.6.2. Data analysis for carbon stock

Data analysis of various carbon pools measured in the forests were accomplished by organizing and recording on the excel data sheet. The data obtained from DBH, length, diameter, height of each species, fresh weight and dry weight of litter, dead wood and soil were analyzed using program R version 3.4.2. The height and diameter data were arranged in classes for applying an appropriate model of biomass estimation equation. The relationship between each parameter was tested by multiple regression and descriptive statistics. The linear and multilinear correlation between forest carbon stock with altitude, slope and aspect were tested independently.

3.6.2.1. Determination of Basal Area (BA)

Basal area is the horizontal (cross-sectional) area occupied by the trunk of a species or size class. Basal area calculations were made on the diameter measurements of the stem with DBH ≥ 5. There is a direct relationship between DBH and basal area (Hutchings, 1986).

The basal area was calculated, for all trees with a diameter at breast height ≥ 5 cm, by using the formula:

$$\mathbf{BA} = \frac{\pi}{4} * (\, DBH)^2) \ \mathbf{OR}\ 0.785\ \mathbf{DBH}^2$$

3.6.2.2. Estimation of Above ground Tree Biomass(AGTB)

The selection of the appropriate allometric equation is crucial in estimating aboveground tree biomass (AGTB). From the different available allometric equations to estimate the above ground biomass, the model that was developed by Chave *et al.*,(2014) is recommendable for the study site since the general criteria described by the author can agree with the study area.

$$\mathbf{AGB_{est} = \rho * d^2 * H * 0.0559}$$

Where AGBest = above ground biomass (kg), D =DBH (cm), H = height (m), and ρ = basic wood density (g cm^{-3}).

3.6.2.3. Estimation of Below Ground Biomass (BGB)

Below ground biomass estimation is much more difficult and time-consuming than estimating aboveground biomass (Geider *et al.*, 2001). According to MacDicken (1997), a standard method for estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., the root-to-shoot ratio value of 1:5 is used. Similarly, Pearson *et al.* (2005) described this method as it is more efficient and effective to apply a regression model to determine belowground biomass from knowledge of biomass aboveground. Thus, the equation developed by MacDicken (1997) to estimate below-ground biomass was used. The equation is given below:

$$\mathbf{BGB_{est} = AGB \times 0.2}$$

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

For both AGB and BGB, the biomass stock density was attained in Kg m^2 by means of dividing the sum of all individual weights (in Kg) of a sampling plot by the area of sampling plot. The value was converted to t ha^{-1} by multiplying it by 10. Since the plot areas are part of tropical region carbon content the biomass was estimated by multiplying 0.47 while multiplication factor 3.67 was used to estimate CO_2 equivalent (Pearson *et al.*, 2005).

3.6.2.4. Estimation of Carbon Stocks in the Leaf Litter Biomass

According to Pearson *et al.* (2005), estimation of the amount of biomass in the leaf litter can be calculated by:

$$\boldsymbol{LB = \frac{Wfield}{A} * \frac{Wsub\_sample(dry)}{Wsub\_sample(fresh)} * \frac{1}{10,\ 000}}$$

Where: LB = Litter (biomass of litter t ha^{-1})

W field = weight of wet field sample of litter sampled within an area of size 1 m^2 (g);

A = size of the area in which litter were collected (ha);

W sub-sample, dry = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and

W sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

3.6.2.5. Carbon stocks in litter biomass

CL = LB × % C

Where, CL is total carbon stocks in the litter in t ha^{-1}, % C is carbon fraction determined in the laboratory (Pearson *et al.*, 2005).

3.6.2.6. Estimation of Carbon Stocks in the Herbaceous Biomass

Estimation of herbaceous biomass and Carbon stock was conducted following the same procedure with that of the litter.

3.6.2.7. Estimation of Carbon Stocks in Non tree Woody Species (NTWES)

Following the method recommended in Pearson *et al.* (2005), estimation of the amount of biomass in the NTWS can be calculated by

$$\boldsymbol{NTWSB = \frac{Wfield}{A} * \frac{Wsub\_sample(dry)}{Wsub\_sample(fresh)} * \frac{1}{10,\,000}}$$

Where: NTWSB = Non tree Woody Species biomass in t ha^{-1}.

W field = weight of wet field sample of NTWS sampled within an area of size 1 m^2 (g);

A = size of the area in which NTWS were collected (ha);

W sub-sample, dry = weight of the oven-dry sub-sample of NTWS taken to the laboratory to determine moisture content (g), and

W sub-sample, fresh = weight of the fresh sub-sample of NTWS taken to the laboratory to determine moisture content (g).

The carbon content in NTWS is calculated by multiplying the biomass with the IPCC (2006) default carbon fraction of 0.47.

3.6.2.8. Estimation of Carbon Stocks in Dead Wood

3.6.2.8.1. Standing dead wood

For standing dead wood which has branches it is recommended to be measured using the allometric equation selected for estimation of above ground biomass. Whereas, if this standing dead wood has not leaves, subtracting out the biomass of leaves (about 2–3 percent of aboveground biomass for hardwood/broadleaf species and 5–6 percent for softwood/conifer species) is recommended (Pearson *et al.*, 2005).

Volume is calculated using DBH and height measurements and the estimate of the top diameter. It is then estimated as the volume of a truncated cone.

Volume (m^3) = $\frac{1}{3}\pi h(r1^2 + r2^2 + r1 \times r2)$

Where: h = the height in meters,

r1 = the radius at the base of the tree,

r2 = the radius at the top of the tree.

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

Biomass = Volume x Wood density (from samples)

As the wood must be sound to support the still-standing tree, the sound wood density from the downed dead wood measurements was used as recommended by Pearson *et al.*, (2005).

3.6.2.8.2. Downed dead wood

The wood density for each density class (sound, intermediate and rotten) was calculated from the pieces of dead wood collected. Density was calculated by the following formula:

$$\text{Density } (g/cm^3) = \frac{mass\ (g)}{volume\ (cm^3)}$$

Where: mass = the mass of the oven-dried dead wood sample, and volume = the volume of displaced water while the dead wood sample was completely immersed in a beaker of water. To get a single density value for each class, average densities were taken (Pearson *et al.*, 2005).

According to van Wagner (1968) and Pearson *et al.* (2005), the biomass of downed dead wood was estimated by the equation given below:

$$BDW = \sum_{i=0}^{n} V\ X\ s$$

Where, BDW = Biomass downed wood, V= volume and s = specific density of each density class.
The volume of downed dead wood per unit area is estimated by:

$$\mathbf{V = \pi^2 (D^2/8L)}$$

Where, V is the volume in m^3/ha; D is diameter of the dead wood tree and L is the length of the line.

The total biomass of dead wood can be obtained by adding the biomass of standing dead wood to the biomass of downed dead wood. The carbon content in dead wood is calculated by multiplying total biomass of dead wood with the IPCC (2006) default carbon fraction of 0.47.

3.6.2.9. Estimation of Soil Organic Carbon

The carbon stock density of soil organic carbon can be calculated as recommended by Pearson *et al.* (2005) from the volume and bulk density of the soil.

$$V = h \times \pi r^2$$

Where, V is volume of the soil in the core sampler augur in cm^3, h is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm (Pearson *et al.*, 2005). More over the bulk density of a soil sample can be calculated as follows:

$$\boldsymbol{BD} = \frac{\mathbf{Wav,\ dry}}{\mathbf{V}}$$

Where, BD is bulk density of the soil sample per, Wav, dry is average air dry weight of soil sample per the quadrant, V is volume of the soil sample in the core sampler auger in cm^3 (Pearson *et al.*, 2005).

$$SOC = BD * d * \% C$$

Where, SOC= soil organic carbon stock per unit area ($t\ ha^{-1}$),

BD = soil bulk density ($g\ cm^{-3}$),

D = the total depth at which the sample was taken (40 cm),

%C = Carbon concentration (%)

3.6.2.10. Total Carbon Stock Density

The carbon stock density is calculated by summing the carbon stock densities of the individual carbon pools of the stratum using the Pearson *et al.* (2005) formula. In addition, it is recommended that any individual carbon pool of the given formula can be ignored if it does not contribute significantly to the total carbon stock (Bhishma *et al.*, 2010).

Carbon stock density of a study area:

$$\boldsymbol{C_{density} = C_{AGB} + C_{BGB} + C_{Lit} + C_{DWS} + SOC}$$

Where:

$C_{density}$ = Carbon stock density for all pools [$ton\ ha^{-1}$]

C_{AGTB} = Carbon in above - ground tree biomass [t C ha^{-1}]

C_{BGB} = Carbon in below- ground biomass [t C ha^{-1}]

C_{Lit} = Carbon in dead litter [t C ha^{-1}]

C_{DWS}= Carbon in dead wood and stumps

SOC = Soil organic carbon

The total carbon stock is then converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al.*, 2007).

3.6.3. Data analysis to formulate Area and species specific allometric equation for 5 tree species

3.6.3.1. Calculating trimmed biomass

From the fresh biomass $B_{\text{fresh wood}}^{\text{aliquot}}$ of a wood aliquot and its dry biomass $B_{\text{dry wood}}^{\text{aliquot}}$, the moisture content of the wood (including bark) was calculated as follow:

$$X_{wood,i} = \frac{\text{B aliquot dry wood,i}}{\text{B aliquot fresh wood,i}}$$

Likewise, the moisture content of the leaves was calculated from the fresh biomass $B_{\text{fresh leaf,i}}^{\text{aliquot}}$ of the leaf aliquot and its dry biomass.

$$X_{leaf,i} = \frac{B_{\text{dry leaf,i}}^{\text{aliquot}}}{B_{\text{fresh leaf,i}}^{\text{aliquot}}}$$

Trimmed dry biomass can then be calculated:

$$B_{\text{trimmed dry}} = B_{\text{trimmed fresh wood}} \times X_{\text{wood}} + B_{\text{trimmed fresh leaf}} \times X_{\text{leaf}}$$

Where B trimmed fresh leaf is the fresh biomass of the leaves stripped from the trimmed branches and B trimmed fresh wood is the fresh biomass of the wood in the trimmed branches (Picard *et al.*, 2012).

3.6.3.2. Calculating untrimmed biomass

Two calculations were required to calculate the dry biomass of the untrimmed part (i.e. that still standing): one for the small branches accompanied with leaves and twigs and the other for the large branches. The untrimmed biomass is the sum of the two results:

B untrimmed dry = B untrimmed dry branch + B dry section

Each section i of the large branches was considered as a cylinder of volume (Smalian's formula):

$$Vi = \pi/8\ L_i\ (D^{2}_{1i} + D^{2}_{2i})$$

Where Vi is the volume of section i, L_i its length, and D_{1i} and D_{2i} are the diameters of the two extremities of section i. The dry biomass of the large branches is the product of mean wood density and the total volume of the large branches:

$$\text{B dry section} = \grave{\rho} \times \sum_{i} Vi$$

Where the sum corresponds to all the sections in the large branches, and where mean wood density is calculated by:

$$\grave{\rho} = \frac{B^{\text{aliquot}}_{\text{dry wood}}}{V^{\text{aliquot}}_{\text{fresh wood}}}$$

The dry biomass of small untrimmed branches, twigs and leaves was calculated from the regression model developed between the basal diameter of the trimmed branches and biomass of trimmed branches, twigs and leaves. This model is established by following the same procedure as for the development of an allometric model. Power type equations are often used:

$B_{\text{dry branch}} = a + bD^{c}$

Where a, b and c are model parameters and D branch basal diameter, but other regressions like linear regression was also tested. Using a model of this type, the dry biomass of the untrimmed branches and their components (twigs and leaves) is:

$B_{\text{untrimmed dry branch}} = \sum_{j}(a + bD_{j}^{c})$

Where the sum is all the untrimmed small branches and their components and Dj is the basal diameter of the branch j (Picard *et al.*, 2012).

3.6.3.3. Calculating the biomass of the trunk

The truncated cone volume formula was used instead of the cylinder formula, for larger trees their diameter measured at two meters interval. For each log i, the circumferences at the two extremities were measured: circumference C_{1i} is the circumference of the log taken at the bottom end and circumference C_{2i} is the circumference of the log taken at the upper end. This was conducted to calculate the volume of the fresh log using the truncated cone volume formula (or Newton's formula):

$$V_{\text{frais},i} = Li \times \frac{\pi}{3} \times (R^{2}_{1i} + R_{1i}R_{2i} + R^{2}_{2i})$$

Where L_i is the length of log $_{i,}$ and $R_{1i} = \frac{C1i}{2\pi}$; $R2i = \frac{C2i}{2\pi}$ are the radii of log$_i$ at its two extremities. The dry biomass of the trunk is the product of mean wood density and total volume of the trunk

$B_{\text{dry section}} = \acute{\rho} \times \sum_{i} Vi$, where the sum corresponds to all the sections in the trunk (Picard *et al.*, 2012).

3.6.3.4. Formulation of allometric equations for the five trees species

Based on the data collected, several equations were developed. Before establishing the allometric equation, scatter plots were used to see whether the relationship between independent and dependent variables was linear. Furthermore, several allometric relationships between independent and dependent variables were tested. The independent variables included DBH, Height, and wood density, whereas the dependent variable was the dry weight of the AGB. Because the data exhibited heteroscedasticity, a power function was an inappropriate model in this study, so the data was transformed for linear regression using logarithmic transformation. The transformation equalized the variance over the entire range of biomass values which satisfies the prerequisite of linear regression (Sokal and Rohlf, 1995; Sprugel, 1983). However, this transformation introduced a systematic bias in the calculation which was corrected using a correction factor (CF) when back transforming the calculation into biomass (Chave *et al.*, 2005).

Model comparison and selection were based on average deviation (Brand and Smith, 1985; Chave *et al.*, 2005), slope coefficient of the regression (Nelson *et al.*, 1999), Akaike Information Criterion (AIC) (Burnham and Anderson, 2002; Chave *et al.*, 2005), confidence interval (CI) of the predictions, paired t-test and Coefficients of determination (r^2)

3.6.3.4.1. Test for multicollinearity

Multicollinearity is the strong correlation between the independent variables. Some correlation between them is highly expected as all variables are ‘causing factors’ to tree biomass. However, ‘strong correlation’ causes ‘strong multicollinearity’ by which the true effect of estimated regression coefficients would be lost. As a result, we can no longer rely on standard statistical tests. If that is the case, that variable which has less explanatory power with the dependent variable should be removed from the regression model. But while doing so, there should not have strong collinearity between the remaining variable with other potential explanatory variables.

3.6.3.4.2. Detecting Multicollinearity Using Variance Inflation Factors

A variance inflation factor (VIF) quantifies how much the variance is inflated. It is a measure of how much the variance of the estimated regression coefficient bk is "inflated" by the existence of correlation among the predictor variables in the model. A VIF of 1 means that there is no correlation between the k^{th} predictor and the remaining predictor variables, and hence the variance of bk is not inflated at all. The general rule of thumb is that VIFs exceeding 4 warrant further investigations, while VIFs exceeding 10 are signs of serious multicollinearity requiring correction (Belsley *et al.*, 1980).

3.6.3.5. Formulation of allometric equation for the two shrub species

Three independent variables H, DSH and Crown Area (CrA) were used to estimate the AGB of shrub biomass. CrA was calculated by multiplying crown length and crown breadth measured in the field. Scatter plot was used to assess the relationship between dependent and independent variables. Generalized linear models of regression analysis were applied on logarithmized data to avoid problem of back transformation. Multiple regression was also used to test the influence of additional explanatory variables on the model fit and accuracy. The best fitting model was selected according to highest r^2 for equations with a single explanatory variable and adjusted r^2 for equations with two or more explanatory variables, least RMSE and AIC. F test was used to determine the significance of the regression.

CHAPTER FOUR

4. Results

4.1. Species-Accumulation Curve

Species accumulation curve was plotted for the species recorded in Gerba Dima forest. The result indicated in Fig. 6 revealed that the curve almost leveled off showing that a few or no new species would be collected if sampling effort is further continued.

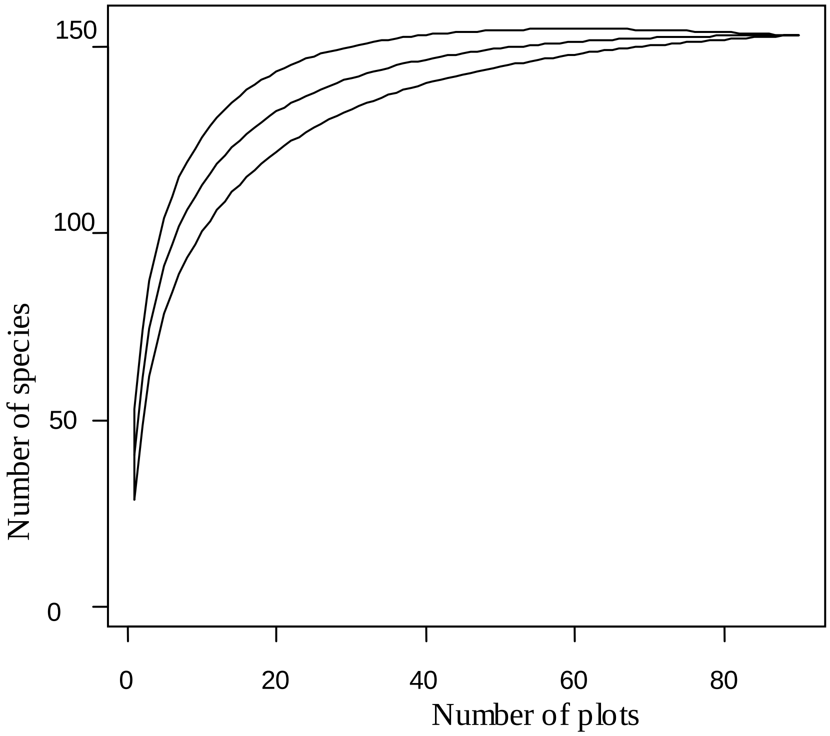


Figure 6. Species-Accumulation Curves for the vegetation of Gerba Dima forest

4.2. Floristic composition and endemic plants

A total of 180 plant species (Appendix 1) belonging to 145 genera and 69 families were recorded and identified in the sample plots in Gerba Dima forest (Table 5). Of these, 52 species (28.9%) were trees, 6 species (3.33%) were Trees/shrubs, 31 species (17.22%)

were shrubs, 76 species (42.22%) were herbs, and 15 species (8.33%) were Lianas (Fig.8).

Angiosperms were represented by 160 species while the rest 20 species were Pteridophytes. Among Angiosperms, Rubiaceae, Acanthaceae and Asteraceae were the richest family each represented by 11 genera and 11 species (6.11%), 9 genera and 11 species (6.11%), 6 genera and 11 species (6.11%), respectively of total floristic composition, followed by Fabaceae 8 genera and 9 species (5%), Euphorbiaceae 6 genera and 7 species (3.89 %). The remaining families represented less than 3% of species each. Pteridophytes were represented by 11 families, 13 genera and 20 species. Aspleniaceae, Dryopteridaceae and Pteridaceae were the richest Pteridophytes represented by 6, 3 and 2 species respectively (Table 5 and Fig.7).

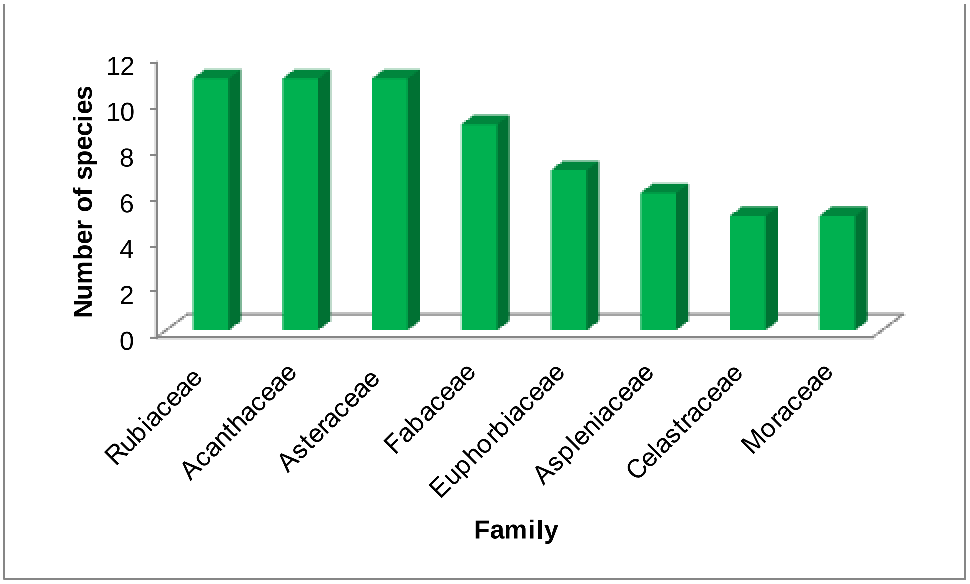


Figure 7. Dominant families with their respecive species number

The genus *Vernonia*, *Ficus*, *Asparagus*, *Dracaena* were represented by 5,4,3,3 species respectively and *Aframomu*, *Albizia*, *Asparagus*, *Cyperus*, *Euphorbia*, *Hippocratea*, *Hypoestes*, *Justicia*, *Maytenus*, *Olea*, *Peperomia*, *Polyscias*, *Pteris*, *Rubus*, *Schefflera*, *Solanaceo*, *Solanum*, *Tacazzea*, and *Zehneria* were represented by 2 species each and the rest genera contained a single species each (Appendix 1).

Table 5. Dominant families with their respecive species number

Familiies	Number of genera	Number of species	% Richness	Familiies	Number of genera	Number of species	% Richness
Acanthaceae	9	11	6.11	Marattiaceae	1	1	0.56
Adiantaceae	1	1	0.56	Melianthaceae	1	1	0.56
Alengeaceae	1	1	0.56	Melistostomaceae	1	1	0.56
Amaranthaceae	3	3	1.67	Menispermaceae	2	2	1.11
Amaryllidaceae	1	1	0.56	Moraceae	2	5	2.78
Apocynaceae	1	1	0.56	Musaceae	1	1	0.56
Aquifoliaceae	1	1	0.56	Myrsinaceae	2	2	1.11
Araceae	3	3	1.67	Myrtaceae	1	1	0.56
Araliaceae	2	4	2.22	Oleaceae	3	4	2.22
Asclepidiaceae	1	2	1.11	Orchidaceae	2	2	1.11
Asparagaceae	1	3	1.67	Piperaceae	2	3	1.67
Aspleniaceae	1	6	3.33	Pittosporaceae	1	1	0.56
Asteracea	6	11	6.11	Poaceae	2	2	1.11
Boraginaceae	2	2	1.11	Polypodiaceae	2	2	1.11
Capparidaceae	1	1	0.56	Pteridaceae	1	2	1.11
Caryophyllaceae	1	1	0.56	Ranuaculaceae	3	3	1.67
Celastraceae	3	5	2.78	Rhaminaceae	1	2	1.11
Combreataceae	1	1	0.56	Rhizophoraceae	1	1	0.56
Commelinaceae	1	1	0.56	Roseaceae	3	4	2.22
Convolvulaceae	1	1	0.56	Rubiaceae	11	11	6.11
Crassulaceae	1	1	0.56	Rutaceae	3	3	1.67
Cucurbitaceae	3	4	2.22	Sapindaceae	2	2	1.11
Cyatheaceae	1	1	0.56	Sapotaceae	1	1	0.56
Cyperaceae	2	3	1.67	Simaroubaceae	1	1	0.56
Dracenaceae	1	3	1.67	Solanaceae	1	2	1.11
Dryopteridaceae	3	3	1.67	Sterculiaceae	1	1	0.56
Euphorbiaceae	6	7	3.89	Tectariaceae	2	2	1.11
Fabaceae	8	9	5.00	Tilaceae	1	1	0.56
Flacourtiaceae	1	1	0.56	Ulmaceae	2	2	1.11

Families	Number of genera	Number of species	% Richness	Families	Number of genera	Number of species	% Richness
Hemionitidaceae	1	1	0.56	Urticaceae	4	4	2.22
Icaccinaceae	1	1	0.56	Verbenaceae	1	1	0.56
Lamiaceae	4	4	2.22	Vitaceae	1	1	0.56
Lobeliaceae	1	1	0.56	Vittariaceae	1	1	0.56
Malvaceae	2	2	1.11	Zingiberaceae	1	2	1.11
Meliaceae	4	4	2.22				

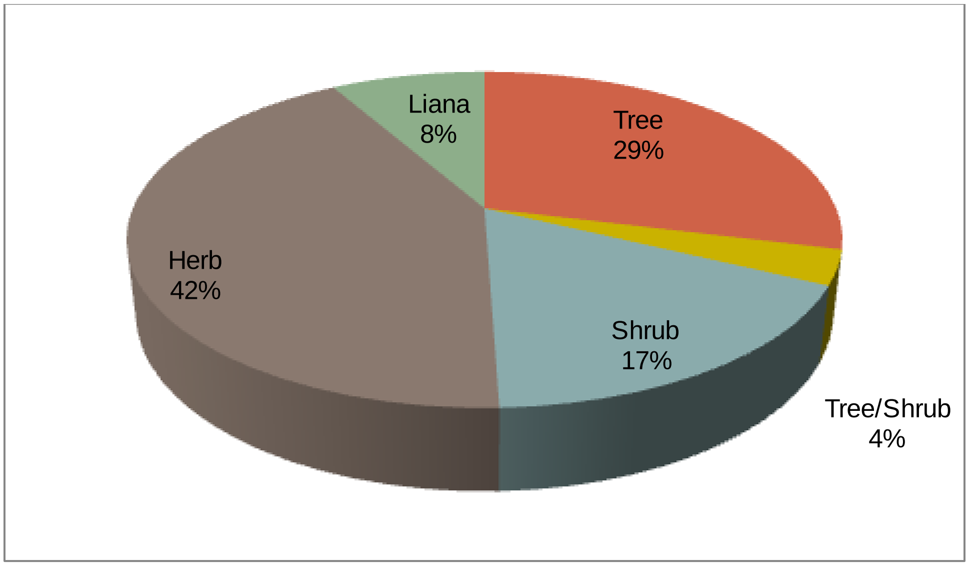


Figure 8. Proportion of plant species of Gerba Dima forest in different habits

4.3. Endemic species and their IUCN status

Based on the information available on the published Floras of Ethiopia and in Vivero *et al*. (2005) a total of 15 endemic plant species in 11 families were recorded (Table 6), comprising more than 8.33% of the recorded species. Asteraceae was the first family having three endemic species, followed by Acanthaceae and Fabaceae (two species each). The remaining eight families have a single species each in the endemic species list.

Among the total endemic species, herb, tree, shrub and liana growth forms were represented by 6,3,4,2 species respectively. Out of the 15 endemic species, *Crotalaria rosenii* and *Polyscias farinosa* have been included in the IUCN red data list of Ethiopia and Eritrea (Vivero, *et al.*, 2005) qualifying for near threatened and vulnerable category respectively.

4.4. New Records from Gerba Dima forest for Ilubabor (IL) FloristicRegion of Ethiopia

The current study recorded 37 plant species belonging to 35genera and28 families collected from Gerba Dima forest as new records for Ilubabor (IL) Floristic Region according to the distribution records in the published volumes of Flora of Ethiopia and Eritrea (Table 7). Of these, 20 species were herbs, 7 species were shrubs, 2 species were Lianas, 1 species was a tree/shrub and 7 species were trees.

Table 6. Endemic species, their habit, IUCN status and geographical distributions

Species	Family	Habit	IUCN category	Altitude (m)	Floristic region*
*Acanthopale ethio germanica**[a]	Acanthaceae	Shrub	NE	2300_2600	GD SU AR KF SD BA
Aframomum corrorima	Zingiberaceae	Herb	NE	1350_2000	KF IL WG
*Arisaema mooneyanum**[a]	Araceae	Herb	NE	2000_3450	SD BA
Bothriocline schimperi	Asteraceae	Shrub	LC	1300_2820	GD GJ SU AR WG IL KF GG SD BA
Clematis longicaudata	Ranunculaceae	Liana	LC	1350_3300	GD GJ SU WG KF IL SD
*Crotalaria rosenii**[a]	Fabaceae	Herb	NT	1350_2800	SU AR BA KF SD
Justicia bizuneshiae	Acanthaceae	Herb	NE	1200_2100	WG IL KF GG SD BA
Millettia ferruginea	Fabacae	Tree	LC	1000_2500	TU GD GJ SU WG HA IL
Polyscias farinosa	Araliaceae	Tree	VU	1600_2200	TU GD GJ SU KF
Scadoxus nutans	Amaryllidaceae	Herb	NE	1450_2300	IL KF
Solanecio gigas	Asteraceae	Shrub	LC	1750_3350	GD GJ WU SU AR SD IL KF BA HA
Tiliacora troupinii	Menispermaceae	Liana	NE	1500_2100	SU IL KF SD
*Urtica simensis**[a]	Urticaceae	Herb	LC	1500_3400	TU GD GJ SU AR BA SD
Vepris dainellii	Rutaceae	Ttree	LC	1750_2500	GJ SU WG IL KF SD BA
Vernonia rueppellii *[a]	Asteraceae	Shrub	LC	2150_3000	TU GD SU AR SD KF BA HA

* Source: Flora of Ethiopia and Eritrea Volumes (1-7) and Vivero, *et al.*, 2005; *[a] New records for IL Floristic Region

*LC, Least Concern; NE, Not evaluated; NT, Near Threatened; VU, Vulnerable.

Table 7. List of species recorded as new records for Ilubabor floristic region

No	Scientific names	Family	Habit
1	*Acanthopale ethio-germanica* Ensermu	Acanthaceae	S
2	*Adiantum poiretii* Wikstr	Adiantaceae	H
3	*Aerangis brachycarpa* (A. Rich) Th Dur.& Schinz	Orchidaceae	H
4	*Agernathum conyzoides* L.	Asteraceae	H
5	*Alangium chinense* (Lour.) Harms	Alengeaceae	T
6	*Alchemilla abyssinica* Fresen.	Roseaceae	H
7	*Allophyllus abyssinicus* (Hochst.) Radlk .	Sapindaceae	T
8	*Arisaema mooneyanum* Gilbert & Mayo	Araceae	H
9	*Asparagus africanus* Lam.	Asparagaceae	H
10	*Asplenium aethiopicum* (Burm.f.) Bech.	Aspleniaceae	H
11	*Cayratia gracilis* (Guill. & Perr.) Suesseng.	Vitaceae	H
12	*Crotalaria rosenii* (Pax) Milne-Redh. ex Polhill.	Fabaceae	H
13	*Cucumis dipsaceus* Ehrenb. ex Spach	Cucurbitaceae	H
14	*Cyperus longus* L.	Cyperaceae	H
15	*Desmodium repandum* (Vahl)DC.	Fabaceae	H
16	*Dracaena steudneri* Engl.	Dracenaceae	T
17	*Ficus ovata* Vahl	Moraceae	T
18	*Hibiscus panduriformis* Burm.f	Malviaceae	H
19	*Ipomea indica* (Burm. f) Merrill	Convolvulaceae	H
20	*Kalanchoe petitiana* A. Rich.	Crassulaceae	H
21	*Maytenus undata* (Thunb.) Blakelock	Celastraceae	T
22	*Myrsine africana* L.	Myrsinaceae	S
23	*Phyllanthus sepialis* Muell. Arg.	Euphorbiaceae	S
24	*Polyscias farinosa* (Del.) Harms	Araliaceae	T
25	*Polystachya rivae* Shweinf.	Orchidaceae	H
26	*Premna schimperi* Engl.	Verbenaceae	S
27	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae	S
28	*Rubus steudneri* Schweinf.	Roseaceae	S
29	*Sericostachys scandens* Gilg & Lopr.	Amaranthaceae	L
30	*Solanum adoense* Hochst. ex A. Rich.	Solanaceae	S
31	*Tacazzea conferta* N.E. Br.	Asclepidiaceae	L
32	*Trifolium rueppellianum* Fresen.	Fabaceae	H
33	*Trilepisium madagascariense* DC.	Moraceae	T
34	*Urtica simensis* Steudel.	Urticaceae	H
35	*Vernonia auriculifera* Hiern	Asteraceae	T/S
36	*Vernonia rueppellii* Sch. Bip. ex Walp.	Asteraceae	S
37	*Vernonia wollastonii* S. Moore	Asteraceae	H

4.5. Floristic Diversity of Gerba Dima forest

In Gerba Dima forest, at 625m^2 sample plot, species richness varied from 26 to 59 across the study plots. The Shannon diversity index also varied from 2.92 to 3.83 while evenness ranged from 0.89 to 0.95 in the study plots. The overall mean Shannon diversity index, species richness and evenness of the study area were 3.45, 41 and 0.93 respectively.

Table 8. Diversity indices for Gerba Dima forest

Diversity indices	Values
Mean Species richness per plot	41
Shannon diversity (H')	3.45
Evenness (J)	0.93

4.6. Cluster analysis

Five community types are derived from the hierarchical cluster analysis in combination with Multi-response Permutation Procedures (MRPP) of the whole data set (Fig. 9). The analysis was based on the cover abundance data of 180 vascular plant species in 90 plots. The decision on the number of groups (clusters) was based on objective methods of obtaining an optimal number of clusters in R program, the MRPP technique (no-difference hypothesis) and the ecological interpretation of the groups conducted in PC-ORD. From the output of objective method, a sharp bend at the fifth cluster in the plot could be a good indication of the number of clusters in the data (Zerihun Woldu, 2016). From the output of MRPP, the test statistic T value for the five groups was -38.26 ($P < 0.001$) and the agreement statistic A was 0.13. The test statistic T describes the separation between the groups. The more negative T value, the stronger the separation.

From the present analysis, a 5 cluster solution (plant community) was considered optimal. These clusters were designated as local plant community types and given names after two dominating woody species, usually a tree with higher synoptic value (Table 10). The cluster numbers in the dendrogram correspond to the community types. The description of the plant community types is based on the dominant species.

Community 1. *Croton macrostachyus - Bersama abyssinica* community.

This community was found in the altitudinal range of 1677-2020 m. a.s.l and slope from flat to 50%. Fourteen plots were associated to the community. *Croton macrostachyus* and *Bersama abyssinica* were the dominant species in the tree layer. *Albizia gummifera*, *Allophyllus abyssinicus*, *Olea welwitschii*, *Polyscias fulva*, *Apodytes dimidiata*, *Olea capensis*, *Ficus sur*, *Millettia ferruginea*, *Pouteria adolfi-friederici* and *Vepris dainellii* were among the common tree species. *Clausena anisata*, *Dracaena afromontana*, *Galiniera saxifraga* and *Ehretia cymosa* are among the common tree/ shrub in this community. The common shrubs included *Justicia schimperiana*, *Brillantaisia madagascariensis*, *Acanthopale ethio-germanica* and *Maytenus gracilipes*. Common species in the field layer included *Oplismenus hirtellus*, *Tectaria gemmifera*, *Justicia bizuneshiae* and *Piper capense*. The common lianas of this community were Combretum *paniculatum*, *Landolphia buchananii* and *Tiliacora troupinii*. Twenty two species are associated with this community and has 2 indicator species with significant indicator values ($P < 0.05$), namely *Prunus africana* and *Rubus apetalus* (Table 9).

Community 2. Syzygium guineense - Olea capensis community.

This community was distributed from 1699 to 2240 m a.s.l. and slope ranging from flat to 60%. It comprises of 22 plots. *Olea capensis* and *Syzygium guineense* were the dominant species in the tree layer. *Albizia gummifera*, *Apodytes dimidiata*, *Cassipourea malosana*, *Dracaena steudneri*, *Elaeodendron buchananii*, Millettia *ferruginea*, *Pouteria adolfi-friederici*, *Rothmannia urcelliformis*, *Sapium ellipticum* and *Vepris dainellii* were the common tree species. *Cantium oligocarpum*, Clausena *anisata*, *Dracaena afromontana, Galiniera saxifraga* and *Lepidotrichilia volkensii* were common tree/shrub species. *Justicia schimperiana*, *Brillantaisia madagascariensis* and *Psychotria orophila* were prominent shrubs in this community. *Combretum paniculatum*, *Landolphia buchananii*, *Tiliacora troupinii* and *Hippocratea pallens* were common lianas. The herb layer was dominated by *Oplismenus hirtellus*, *Tectaria gemmifera*, *Justicia bizuneshiae* and *Pupalia micrantha*. Twenty species are associated with this community and has one indicator species with significant indicator values ($P < 0.05$), namely *Flacourtia indica* (Table 9).

Community 3. *Dracaena afromontana- Pouteria adolfi-friederici* community.

This community was found in the altitudinal range of 1761-2000 m. a.s.l and slope from flat to 25%. Thirteen plots were associated with the community. *Ficus sur*, *Oxyanthus speciosus* and *Pouteria adolfi-friederici* were the dominant species in the tree layer. *Albizia gummifera*, *Deinbollia kilimandscharica*, *Macaranga capensis*, *Millettia ferruginea*, *Vepris dainellii*, were among the common tree species. *Dracaena afromontana* is the dominant species in the tree/shrub layer. *Galiniera saxifraga* and *Lepidotrichilia volkensii* were common tree/shrub species. *Brillantaisia* *madagascariensis*, *Acanthopale ethio-germanica*, *Maytenus* gracilipes were common species in the shrub layer. Common species in the field layer included *Tectaria gemmifera*, *Justicia bizuneshiae, and Oplismenus hirtellus*. The common lianas in this community were Hippocratea *pallens* and *Tiliacora troupinii*. Seven species are associated with this community and has two indicator species with significant indicator values (P < 0.05), namely *Elastostema monticolum* and *Pilea rivularis* (Table 9).

Community 4. *Vepris dainellii - Schefflera abyssinica* community.

The community is distributed in the altitude range of 1720–2060m a.s.l. and the slope gradient varies flat to 60%.%. It comprises of 14 plots. The dominant tree species in the community are *Vepris dainellii, Schefflera abyssinica*, *Ilex mitis* and *Deinbollia kilimandscharica*. The common tree species in this community include *Albizia gummifera*, *Ficus sur*, *Millettia ferruginea*, Oxyanthus *speciosus*, *Pouteria adolfi-friederici* and *Syzygium guineense*. *Galiniera saxifraga* and *Lepidotrichilia volkensii* were also common tree/shrub species in this community. The common shrubs in this community are *Acanthopale ethio-germanica*, *Brillantaisia madagascariensis*, *Psychotria orophila* and *Maytenus gracilipes*. The field layer is dominated by *Oplismenus hirtellus, Tectaria gemmifera*, *Piper capense* and *Pupalia micrantha*. The lianas include *Hippocratea pallens*, *Landolphia buchananii* and *Tiliacora troupinii*. Eight species are associated with this community as indicator species and four of the indicator species exhibit significant indicator values (P < 0.05), namely *Ritchiea albersii*, *Trema orientalis*, *Sapium ellipticum* and *Vernonia hochstetteri* (Table 9).

Community 5. *Albizia gummifera - Millettia ferruginea* community.

This community was found in the altitudinal range of 1728-2014 m. a.s.l and slope from flat to 50%. Twenty seven plots were associated to the community. It is dominated by the upper canopy of *Albizia gummifera* and *Millettia ferruginea*. *Allophyllus abyssinicus*, *Bersama abyssinica*, *Croton macrostachyus*, *Dracaena steudneri*, *Rothmannia urcelliformis*, *Olea capensis*, *Oxyanthus speciosus*, *Pouteria adolfi-friederici*, *Polyscias fulva*, *Syzygium guineense* and *Vepris dainellii* are common tree species in this community. The prominent species in tree/shrub layer include *Clausena anisata*, *Ehretia cymosa*, *Galiniera saxifraga* and *Lepidotrichilia volkensii*. *Acanthopale ethio-germanica*, *Brillantaisia madagascariensis* and *Maytenus gracilipes* were dominant shrubs in this community. *Combretum paniculatum*, *Hippocratea pallens*, *Landolphia buchananii* and *Tiliacora troupinii* were common lianas in this community. The herb layer of this community is dominated by *Justicia bizuneshiae*, *Oplismenus hirtellus* and *Piper capense*. Eight species are associated with this community as indicator species and four of the indicator species exhibit significant indicator values ($P < 0.05$), namely *Zehneria scabra*, *Zehneria minutiflora*, *Urera hypselodendron* and *Vernonia wollastonii* (Table 9).

Table 9. Indicator species of clusters in Gerba Dima forest with their significant P-value

Name of indicator species	Community type	Indicator value	P-value
Prunus africana	1	0.528	0.018 *
Rubus apetalus	1	0.516	0.017 *
Flacourtia indica	2	0.521	0.02 *
Pilea rivularis	3	0.498	0.016 *
Elastostema monticolum	3	0.467	0.039 *
Ritchiea albersii	4	0.861	0.001 ***
Trema orientalis	4	0.677	0.001 ***
Sapium ellipticum	4	0.636	0.002 **
Vernonia hochstetteri	4	0.538	0.014 *
Zehneria scabra	5	0.581	0.002 **
Zehneria minutiflora	5	0.552	0.005 **
Urera hypselodendron	5	0.478	0.017 *
Vernonia wollastonii	5	0.423	0.045 *

(C1= *Croton macrostachyus* - *Bersama abyssinica*, C2= *Syzygium guineense* - *Olea capensis*,C3 = *Dracaena afromontana*- *Pouteria adolfi-friederici*, C4= *Vepris dainellii*-*Schefflera abyssinica* C5 = *Albizia gummifera* - *Millettia ferruginea* community.

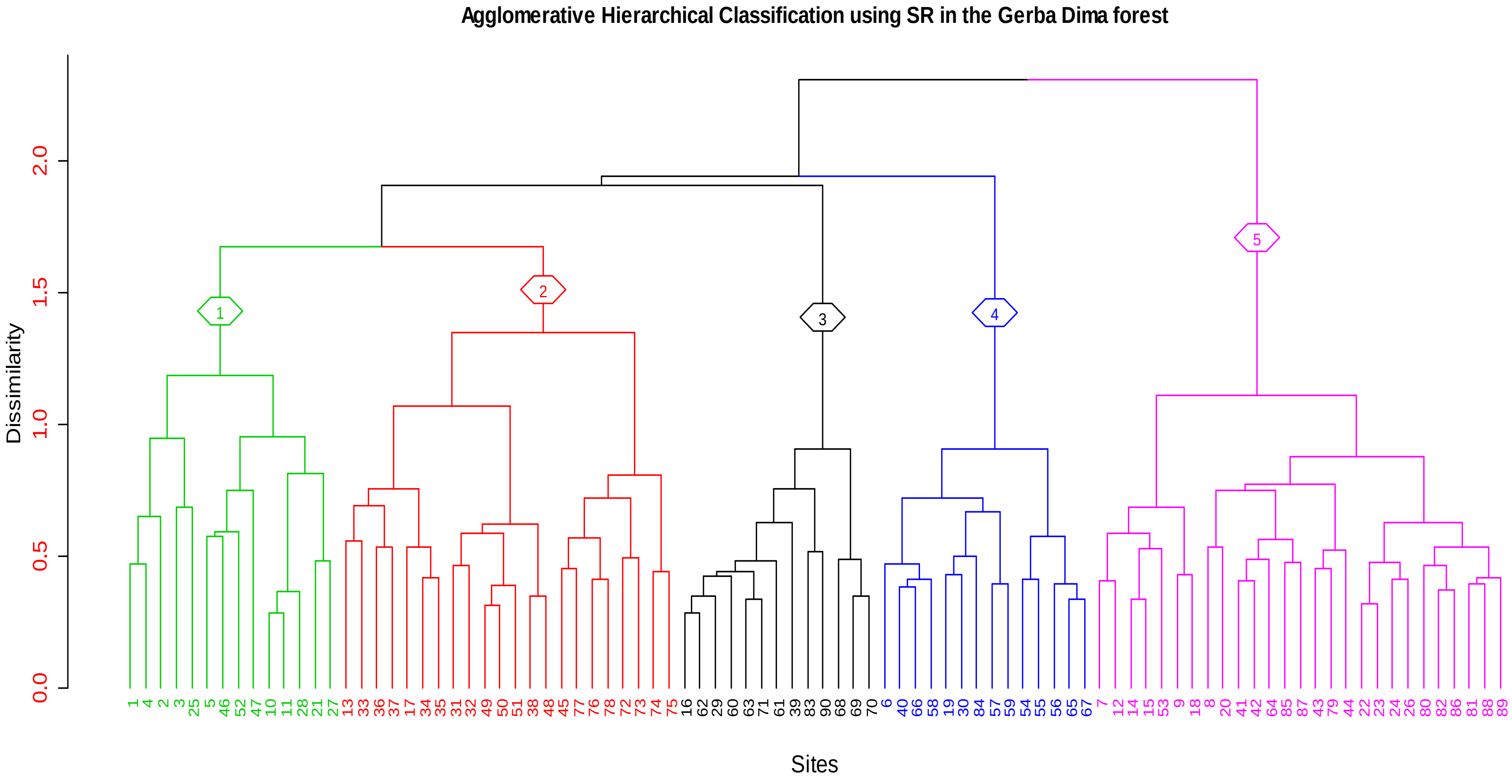


Figure 9. Dendrogram of the cluster analysis results of species abundance found in 90 plots.

The plot code and the arrangement of the plots along the dendrogram from left to right are as follows:(C1 = *Croton macrostachyus* - *Bersama abyssinica* ,C2= *Syzygium guineense* - *Olea capensis*,C3 = *Dracaena afromontana*- *Pouteria adolfi-friederici*, C4= *Vepris dainellii*- *Schefflera abyssinica* C5 = *Albizia gummifera* - *Millettia ferruginea* community.

Table 10. Synoptic cover value of plant for species reaching ≥ 1% in at least one community.

Cluster number	C1	C 2	C 3	C 4	C 5
Cluster size	14	22	13	14	27
Allophyllus abyssinicus	3.50	1.05	1.15	0.86	1.26
Bersama abyssinica	**3.71**	1.73	0.08	0.64	1.22
Croton macrostachyus	**7.50**	1.77	1.54	1.79	2.48
Cordia africana	2.79	0.55	0.00	0.00	0.63
Olea welwitschii	1.43	1.27	0.15	0.86	0.56
Ehretia cymosa	2.36	2.55	1.92	0.79	1.63
Polyscias fulva	1.64	1.36	1.85	0.93	1.33
Apodytes dimidiata	1.43	2.41	1.54	1.64	0.93
Olea capensis	3.14	**5.59**	1.54	1.93	1.04
Syzygium guineense	0.64	**5.91**	1.69	2.43	1.56
Justicia schimperiana	1.29	1.68	0.85	0.36	0.93
Canthium oligocarpum	0.29	1.05	0.62	0.50	0.52
Cassipourea malosana	0.79	1.55	1.08	0.43	0.56
Combretum paniculatum	0.86	1.14	0.54	0.43	1.04
Dracaena steudneri	1.29	3.09	0.92	1.50	1.22
Elaeodendron buchananii	0.64	1.00	0.38	0.00	0.37
Oplismenus hirtellus	2.43	4.50	3.00	2.64	2.85
Rothmannia urcelliformis	1.14	1.95	0.77	0.86	1.15
Sapium ellipticum	0.21	1.64	0.00	1.43	0.93
Tectaria gemmifera	0.93	1.36	1.23	1.29	0.81
Brillantaisia madagascariensis	1.43	2.73	3.00	2.79	2.48
Dracaena afromontana	1.00	3.05	**7.69**	0.86	0.78
Ficus sur	2.50	1.68	6.77	2.07	1.37
Galiniera saxifraga	1.00	1.05	2.31	1.43	1.56
Hallea rubrostipulata	1.07	0.00	1.31	0.00	0.00
Macaranga capensis	1.21	1.32	2.85	0.71	0.19
Oxyanthus speciosus	1.29	1.73	**7.01**	2.36	1.56
Pouteria adolfi-friederici	2.21	3.05	**7.31**	2.07	1.26
Acanthopale ethio-germanica	1.36	0.77	2.08	2.43	1.96
Deinbollia kilimandscharica	0.57	1.45	2.62	4.07	1.59
Ilex mitis	0.43	0.59	1.31	4.71	0.44
Justicia bizuneshiae	0.50	1.23	1.31	1.71	1.37
Landolphia buchananii	1.00	1.32	0.85	1.43	1.19
Piper capense	1.00	0.55	0.46	1.43	1.07
Psychotria orophila	0.93	1.36	0.85	1.36	0.85
Pupalia micrantha	0.64	1.36	0.23	1.86	0.93
Schefflera abyssinica	0.50	1.73	1.38	**7.29**	1.33
Tiliacora troupinii	1.00	1.23	1.08	1.29	1.07
Vepris dainellii	2.21	3.36	3.00	**8.43**	3.59
Albizia gummifera	3.07	2.50	2.69	2.07	**8.63**
Clausena anisata	1.79	1.86	1.31	1.43	2.11
Hippocratea pallens	0.64	1.91	1.23	1.50	1.93
Lepidotrichilia volkensii	0.57	2.59	1.23	2.43	3.30
Maytenus gracilipes	2.00	1.82	1.08	2.00	2.30
Millettia ferruginea	2.00	2.95	2.54	2.79	**7.89**

4.7. Species Richness, Evenness and Diversity of the plant community types

From computation of vegetation data in the study area Shannon-Weiner diversity and evenness indices for the 5 community types showed the output in Table 11.

Table 11. Species richness, evenness and diversity indices of plant community types

Community	Species richness	Shannon diversity index (H')	Shannon Evenness
1	138	4.40	0.89
2	144	4.27	0.86
3	107	3.99	0.85
4	104	4.05	0.87
5	140	4.19	0.85

Whrere community 1,2,3,4,5 *Croton macrostachyus - Bersama abyssinica , Syzygium guineense - Olea capensis, Dracaena afromontana- Pouteria adolfi-friederici, Vepris dainellii- Schefflera abyssinica Albizia gummifera - Millettia ferruginea* community type respectively.

The results of Shannon-Weiner diversity and evenness indices indicated more or less similar species diversity and evenness among the identified plant communities. Community 1 is relatively the most diversified one followed by community 2 and 5. Relatively highest evenness was exhibited by community 1 followed by community 4 and 2 respectively. Relatively least value of species diversity was exhibited by community 3 and least evenness index goes to community 5. The highest species richness was exhibited by community 5 followed by community 2 and 1 (Table 11).

4.8. Comparison of species composition among community types

Pair's wise comparison of Sorensen's similarity coefficient and beta diversity indices were used to compare floristic composition similarity among the five community types of Gerba Dima forest (Table 12). Sorensen's similarity coefficient indicated the highest floristic similarity was exhibited between community 1 and 4 (0.52) followed by community 1 and 2 (0.45). The least floristic similarity was exhibited between community1 and 3 (0.43) and community 2 and 3 (0.43) (Table 12). Similarity coefficients of all communities range from 0.43 to 0.52. Communities with the highest species similarity (1 & 4) shared 72.2% of the total species while those with least species similarity (1 & 3) shared 51.7% of the total species. The magnitude of beta diversity indicates the change in species composition between adjacent plant communities along the environmental gradient. Similarity coefficients and beta diversity are inversely related. Therefore, communities with the highest similarity coefficients had the least beta diversity (0.48) (Community 1 and 4) and communities with the least similarity coefficients had the highest beta diversity (0.57) (communities 1 and 3; communities 2 and 3) (Table 12).

Table 12. Pair wise comparison of Sorensen's similarity coefficient and beta diversity index in species composition between the five plant communities

Communities	**Community 1**	**Community 2**	**Community 3**	**Community 4**	**Community 5**
Community 1	1	0.45 (0.55)	0.43 (0.57)	0.52 (0.48)	0.45 (0.55)
Community 2	0.45 (0.55)	1	0.43 (0.57)	0.44 (0.56)	0.46 (0.54)
Community 3	0.43 (0.57)	0.43 (0.57)	1	0.45 (0.55)	0.44 (0.56)
Community 4	0.52 (0.48)	0.44 (0.56)	0.45 (0.55)	1	0.44 (0.56)
Community 5	0.45 (0.55)	0.46 (0.54)	0.44 (0.56	0.44 (0.56)	1

*** N.B.** Values outside the bracket indicate Sorensen's coefficient while those in bracket indicates beta diversity index.

4.9. Ordination

RDA ordination was used to show the environmental gradients and the effect of these gradients on the patterns of plant distribution in the moist afromontane vegetation of Gerba Dima. The principal aim of this particular set of analysis was to determine environmental gradients within floristic data and to assess the relative importance of environmental variables. First heterogeneity or homogeneity of vegetation data was tested using DCA and the short length (gradient) of DCA first axis is < 3 (2.22) (Table 13) which indicate the presence of lower β- Diversity (species turnover) or homogeneous vegetation data due to the linear relationship between species and environmental variables. In addition, data of environmental variables were selected using Monte Carlo technique and function Adonis test for their significance. Out of 14 variables, seven were found to be significant (Table 14) in explaining patterns of plant community distribution.

Table 13. DCA result showing the homogeneity of vegetation data

DCA axes	DCA1	DCA2	DCA3	DCA4
Eigenvalues	0.1599	0.1433	0.1044	0.09853
Decorana values	0.1813	0.1431	0.1001	0.08234
Axis lengths	2.2230	1.7254	1.6272	1.56506

Computation of variance inflation factor (vif) was also conducted to eliminate those environmental variables that are collinear (variables significantly correlated with each other and add little in explaining the variability of the species data) and leave only the variables that contain unique information. Variables having vif values higher than 5 are collinear and are thus candidates for elimination. From the seven significant environmental factors, the vif values of sand and silt were higher than 5. Sand and Silt are highly correlated with at least one of the other variable in the model. One solution to dealing with collinearity is to remove some of the violating variables from the model and thus the one with higher vif value (sand) was eliminated (Table 15). The RDA ordination was constructed only with 6 non-collinear environmental factors which significantly affect community distribution.

RDA was performed using the data of cover abundance values of plant species and a matrix of 6 non-collinear statistically significant environmental variables. The choice of when to stop interpreting new axis is largely a matter of test, the quantity, quality of the data and the ability to interpret the results. For small data, the first two or three axes will summarize most of the variations in the data whereas for larger sets of data four or five will suffice (Kent, 2012). Data of this study were relatively large, therefore, variation summarized up to axis five was considered. The result of RDA ordination showed that comparatively, the gradient of altitude and potassium was highly correlated on axis one and gradient of disturbance in axis two. The other factors are correlated with the five axes with a different value of correlation (Table 16).

Table 14. Result of function adonis test of environmental variables (significant environmental variables are indicated by asterix at their p-value).

Variables	**Df**	**Sum of Squares**	**Mean of squares**	**F Model**	**R^2**	**Pr (>F)**
Slope	1	0.2283	0.22826	1.3880	0.01373	0.127
Aspect	1	0.2553	0.25529	1.5524	0.01535	0.065 .
Disturbance	1	0.3992	0.39918	2.4273	0.02400	0.001***
Altitude	1	0.9172	0.91721	5.5774	0.05516	0.001 ***
SAND	1	0.3559	0.35590	2.1642	0.02140	0.004 **
SILT	1	0.3543	0.35431	2.1545	0.02131	0.003 **
CLAY	1	0.1655	0.16553	1.0066	0.00995	0.457
PH	1	0.2177	0.21768	1.3237	0.01309	0.160
EC	1	0.3549	0.35493	2.1583	0.02134	0.008 **
Na	1	0.1223	0.12230	0.7437	0.00735	0.803
OM	1	0.3096	0.30963	1.8828	0.01862	0.011 *
K	1	0.3115	0.31150	1.8942	0.01873	0.014 *
N	1	0.1481	0.14806	0.9004	0.00890	0.589
P	1	0.1561	0.15610	0.9492	0.00939	0.533
Residuals	75	12.3338	0.16445		0.74167	
Total	89	16.6297			1.00000	

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

Table 15. Result of variance inflation factors for significant environmental variables

Variables	Variance inflation Factor (vif)	Variance inflation Factor (vif) after removing sand
Disturbance	1.074595	1.050416
Altitude	1.676376	1.535093
Sand	6.746160	-
Silt	6.327923	1.194009
EC	1.188886	1.097707
OM	1.322118	1.364786
K	1.556081	1.430222

Table 16. Biplot score for constraining variables and their correlation with the RDA axis, eigenvalues and proportion of variance explained

Environmental variables	RDA1	RDA2	RDA3	RDA4	RDA5
Disturbance	0.089	-0.68	-0.157	0.522	0.453
Altitude	0.880	0.42	-0.054	-0.018	0.218
SILT	0.084	-0.40	-0.361	-0.323	-0.370
EC	-0.053	0.31	-0.867	0.094	-0.023
OM	-0.094	0.27	-0.208	-0.357	0.844
K	0.703	-0.27	-0.003	-0.381	-0.246
Eigenvalue	10.6445	8.0649	6.3168	5.0057	3.02318
Proportion Explained	0.3024	0.2291	0.1794	0.1422	0.08588
Cumulative Proportion	0.3024	0.5315	0.7109	0.8531	0.93902

The eigenvalue for axis one, two and three were 10.65, 8.06, and 6.32 respectively which shows a decline to the successive higher axis. Cumulative proportion variance explained by the first five RDA axis of the joint biplot was 93.9%. The proportion of variation explained by five RDA axis also shows a decline towards the successive higher axis.

Ordination of plots with non-collinear significant environmental variables using RDA is shown below (Figure 10). The RDA result tends to strengthen the cluster analysis result confirming that the two methods are complementary. Ordination of the study plots of Gerba Dima forest formed five groups or community based on the species composition. These five community types were segregated following arrows of the environmental variables. The black, turquoise, blue, green and red represent sample plots of community type 1,2,3,4 and 5 respectively. Community two mostly occur at the higher altitude while species in community one are distributed at the lower altitude and higher EC. Silt, Disturbance and potassium axes were strongly influencing the distribution of community five. Organic matter arrow has strongly influenced the distribution of species in community three and four.

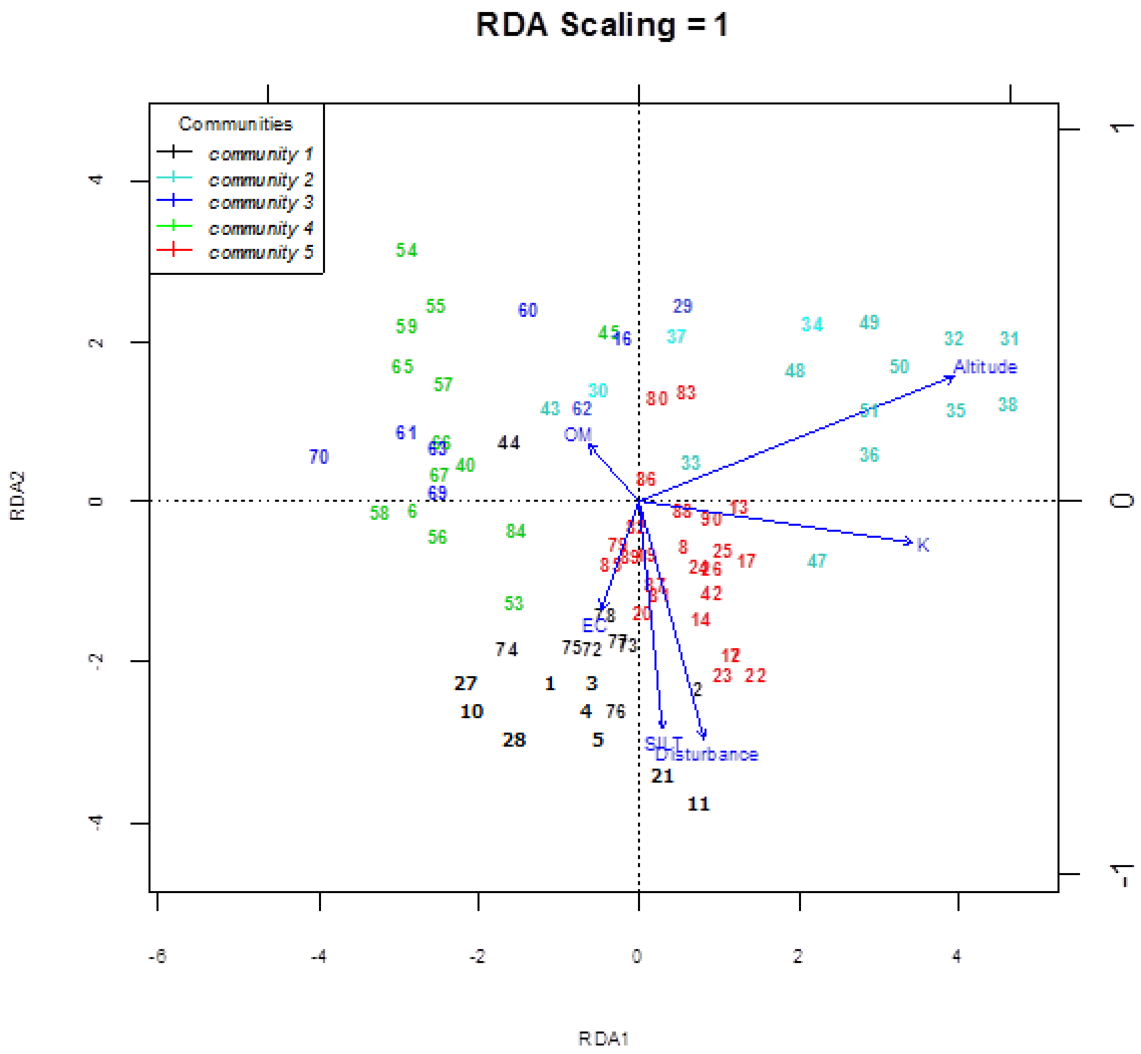


Figure 10. RDA ordination biplot of 90 quadrats and 5 environmental variables of plant communities

4.9.1. Correlation between environmental variables

Environmental variables used for RDA ordination were correlated with one another and significant correlation was tested using Pearson's product-moment correlation coefficient (Table 17). Statistically significant positive correlation was observed between Altitude and OM, Altitude and K, EC and OM. Significant negative correlation was observed between Silt and OM. High amount of organic matter at higher altitude can be attributed to low rate of decomposition due to relatively low temperature.

Table 17. Pearson's product moment correlations coefficient and P- value between environmental

	Disturbance	Altitude	SILT	EC	OM	K
Disturbance	1	-0.098	-0.126	0.029	0.075	0.021
		0.357	0.238	0.783	0.481	0.843
Altitude	-0.098	1	-0.174	0.137	0.237^{*}	0.479^{**}
	0.357		0.101	0.199	0.025	0.000
SILT	-0.126	-0.174	1	-0.092	-0.368^{**}	0.056
	0.238	0.101		0.391	0.000	0.599
EC	0.029	0.137	-0.92	1	0.287^{**}	0.032
	0.783	0.199	0.391		0.006	0.762
OM	0.075	0.237^{*}	-0.368^{**}	0.287^{**}	1	-0.117
	0.481	0.025	0.000	0.006		0.273
K	0.021	0.479^{**}	0.056	0.032	-0.117	1
	0.843	0.000	0.599	0.762	0.273	

*****. Correlation is significant at the 0.05 level and ****.** Correlation is significant at the 0.01 level. '**'= $P < 0.01$ '*' = $P < 0.05$. Cell Contents: Pearson correlation (upper cell) and P-Value (lower cell).

4.9.2. Relationship between Community types and environmental variables

An analysis of variance (ANOVA) was performed to see if there is any significant variation among the community types of Gerba Dima forest with respect to non-collinear significant environmental variables and post-hoc multiple comparison test was performed by using Tukey's HSD. This helps to determine which means amongst a set of means differ from the rest. The correct way to do the analysis is to use a one way ANOVA to evaluate whether there is any evidence that the groups mean differ, we might be interested in investigating which of the means are different. The ANOVA test indicated that the five community types differ significantly from each other with regard to EC and K (Table 18).

Table 18. ANOVA table for the mean difference of Environmental variables among five communiy types of Gerba Dima forest

Environmental variable	df	F value	P value
Altitude	85	1.9691	0.1065
Disturbance	85	2.3658	0.1065
EC	85	3.7286	0.007621 **
OM	85	1.222	0.3076
K	85	3.5936	0.009339 **

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

Tukey’s pair-wise comparison test compares the difference between each pair of means with appropriate adjustment for the multiple testing. The output is the mean difference and a 95% confidence interval of this mean difference for each possible comparison. The result of Tukey’s pair-wise comparison test indicates that community 4 and 1 differ significantly with respect to Disturbance and K while community 2 and 3 showed significant differeneces with respect to EC (Table 19).

Table 19. Pairwise comparison of clusters based on Disturbance, K and EC using Tukey HSD

Variable	Pair-wise clusters	Difference	Lower	Upper	P-adusted
Disturbance	4-1	-1.0918571	-2.1145050	-0.06920926	0.0303723*
K	4-1	-1.12785714	-2.1248793	-0.1308349547	0.0184943*
EC	3-2	1.1777692	0.2560419	2.09949661	0.0053585**

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

4.10. Vegetation structure

4.10.1. Density of woody species

The density of woody species in the study area was 1829 individuals per hectare. The species were classified into 6 density classes, A– F as follows: A ≤ 1; B = 1.01-10; C = 10.1 – 20; D = 20.1 – 35; E = 35.01 - 50; F = >50. Twenty five species exhibited density class A, 40 species density class B, 11 species density class C, 9 species density class D, 5 species density class E and 11 species exhibited density class F.The distribution of species in the six density classes is shown in (Fig. 11).

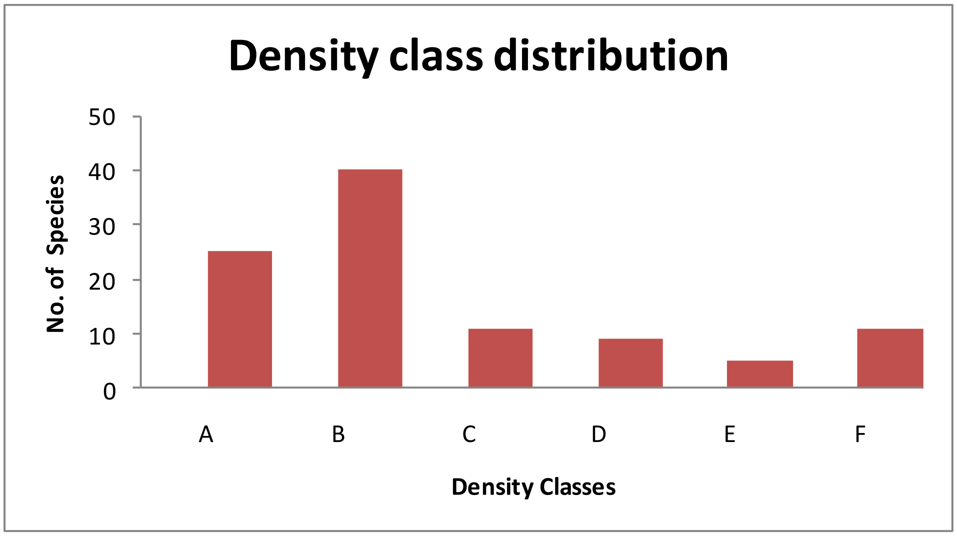


Figure 11. Density class distribution of woody species

The Density of trees and shrubs with DBH 10–20 cm was 297.77 individuals per hectare. The Density of trees and shrubs with DBH greater than 20 cm was 207.48 individuals per hectare (Table 20). Accordingly, the ratio of individuals with DBH 10–20 cm (a) to DBH > 20 cm (b) was 1.44.

Table 20. Density of trees and shrubs by DBH class

DBH (cm)	No. of individuals (ha$^{-1)}$	Percentage (%)	Ratio a to b
2.5 - 10	1090.45	68.34	1.44
10.01 - 20 (a)	297.77	18.66	
> 20 (b)	207.48	13.00	
Total	1595.7	100	

Comparison of trees and shrub densities with DBH 10-20 cm (a), DBH > 20 cm (b) and the ratio (a/b) for Gerba Dima Forest with 5 other forests in Ethiopia is given in Table 21. The ratio a/b at Gerba Dima forest was lower than at Belete, Masha, Komto and Menna Angetu but higher than Gelesha.

Table 21. Comparisons of tree and shrub densities with DBH 10-20cm(a) and tree density with DBH > 20 cm(b) from Gerba Dima forest with 5 other Moist afromontane forests in Ethiopia

Forest	Density		Ratio	Sources
	(a)	(b)	a/b	
Belete	305.07	149	2.04	Kiflay G/Hiwot & Kitessa Hundera (2014)
Gelesha	315.42	244.58	1.29	Bilew Alemu *et al.*, (2015)
Komto	330.00	215.00	1.53	Fekadu Gurmessa *et al.*, (2012)
Masha	633.00	286.00	2.21	Abreham Assefa *et al.*, (2013)
Menna Angetu	292	139	2.10	Ermias Lulekal *et al.*, (2008)
Gerba Dima	300.48	207.48	1.44	Present study

4.10.2. Frequency of Woody species

Frequency is the number of quadrats in which a given species occurred in the study area. According to their total frequency expressed as percentage, species were grouped in the following five frequency classes: A = 0 - 20%; B = 21 - 40%; C = 41 - 60 %; D = 61-80; E = 81 -100 %. In this study, 54, 17, 14, 10 and 6 species were recorded in frequency class A, B, C, D and E respectively (Fig. 12). *Vepris dainellii* was the most frequent woody species in Gerba Dima forest occurring in 97.8% of the sample plots followed by *Tiliacora troupinii* (96.7%), *Albizia gummifera* (91.1%), *Hippocratea pallens* (88.9%), *Landolphia buchananii* (88.9%) and *Millettia ferruginea* (85.6%). The least frequent woody species in the study forest each occurring only in 1.1% of the sampled plots were: *Ficus ovata*, *Cledendron myricoides*, *Alangium chinesis*, *Solanaceo manni*, *Vangueria apiculata Polyscias farinosa* and *Vernonia rueppellii* (Appendix 2).

The frequency distribution of woody species in Gerba Dima forest showed that high number of species were found in the first frequency class (lower frequency class) followed by a rapid decline towards the second frequency class and a gradual decrease towards the higher classes (higher frequency classes) (Fig.12).

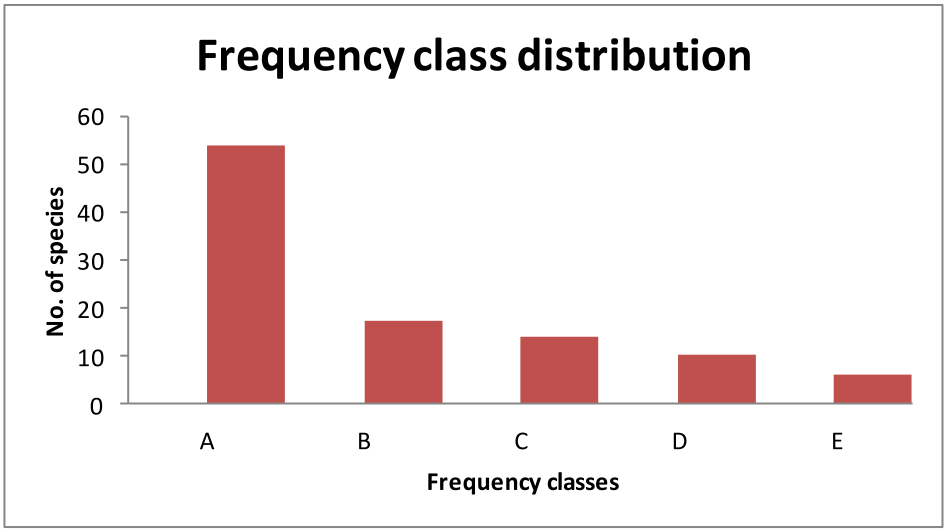


Figure 12. Frequency class distribution of woody species

4.10.3. Basal Area

Basal area is a total cross-sectional area of all stems in a stand measured at breast height and expressed as per unit of land area. The basal area of Gerba Dima forest was 65.05 m^2/ha. The highest (20.55%) and the lowest (0.001%) BA ha^{-1} was contributed by

Schefflera abyssinica and *Vernonia rueppellii* respectively (Appendix 2). About 61.4% of the total basal area was covered by six large sized tree species, i.e. *Schefflera abyssinica*, *Pouteria adolfi-friederici*, *Albizia gummifera*, *Ficus sur*, *Polyscias fulva* and *Croton macrostachyus* covered 61.4% (Table 22). *Schefflera abyssinica* possesses low density but high BA due to its maximum average DBH value. Fifty nine trees of this species contributed to a total of 13.37 m^2h^{-1} (20.55%).

Table 22. Dominant trees with their percentage basal area of Gerba Dima forest

Species name	Density/ha	Average DBH(cm)	BA(m^2)/ha	Percentage BA(%)
Schefflera abyssinica	10.49	102.8	13.37	20.55
Pouteria adolfi-friederici	55.29	24.72	10.41	16.00
Albizia gummifera	117.87	17.25	5.61	8.62
Ficus sur	26.49	31.08	4.42	6.79
Polyscias fulva	16.36	40.67	3.37	5.18
Croton macrostachyus	38.40	23.88	2.78	4.28

The basal area of Gerba Dima Forest is compared with basal areas of other six moist afromontane forests in Ethiopia (Table 23). Comparison of basal area of Gerba Dima Forest with 6 other moist afromontane forests of Ethiopia indicates that it is only greater than that of Jibat and Komto forests. However, Gerba Dima forest has less basal area than the other 4 moist afromontane forests under comparison.

Table 23. Comparison of Gerba Dima natural forest, with other 6 moist afromontane forests in Ethiopia with respect to basal area per hectare.

Forests	Basal area (m^2/ha)	Sources
Masha	142.61	Abreham Assefa *et al.*, (2013)
Belete	103.5	Kiflay G/Hiwot & Kitessa Hundera (2014)
Gelesha	98.87	Bilew Alemu *et al.*, (2015)
Menna Angetu	94.22	Ermias Lulekal *et al.*, (2008)
Gerba Dima	65.05	Present study
Jibat	60.9	Tesfaye Burju *et al.*,(2013)
Komto	50.72	Fekadu Gurmessa *et al.*, (2012)

4.10.4. Importance value index

Importance value index of woody species in the study area is shown appendix 2. The first top ten species which contributed 47.29% of the IVI in decreasing order were, *Schefflera abyssinica, Pouteria adolfi-friederici, Albizia gummifera, Vepris dainellii, Millettia ferruginea, Ficus sur, Croton macrostachyus, Syzygium guineense, Olea capensis and Dracaena afromontana* (Table. 24). About 52.71% of the IVI was contributed by the remaining 75 species (Appendix 2). Importance value index indicates structural dominance and ecological significance of tree species in the forest (Curtis and Mcintosh, 1951).

Table 24. The top ten species with the highest IVI value in Gerba Dima forest

Scientific Name	Relative frequency	Relative Density	Relative Dominance	IVI
Schefflera abyssinica	1.35	0.57	20.55	22.47
Pouteria adolfi-friederici	2.10	3.02	16.00	21.13
Albizia gummifera	3.25	6.44	8.62	18.32
Vepris dainellii	3.49	11.08	1.36	15.93
Milletia ferruginea	3.05	8.31	3.01	14.38
Ficus sur	1.90	1.45	6.79	10.14
Croton macrostachyus	2.58	2.10	4.28	8.95
Syzygium. guineense	2.02	2.62	3.47	8.12
Olea capensis	2.26	4.91	0.66	7.82
Dracaena afromontana	1.55	4.67	1.18	7.40

4.10.5. Vertical stratification

The vertical stratification of trees in Gerba Dima forest was examined following IUFRO classification scheme (Lamprecht, 1989). According to this scheme, three simplified vertical structures were distinguished in the study forest. These were upper, middle and lower storeys. The upper includes where individuals tree height exceeds 2/3 of the top height while the middle storey includes species having height between 1/3 and 2/3 of the top height and the lower storey is less than 1/3 of the top height. The tallest height in Gerba Dima forest was *Pouteria adolfi-friederici* with 45 m. Therefore, the upper storey is represented by a height > 30 m, the middle storey range between 15 - 30 m and lower storey < 15 m (Table 25).

Table 25. Density and number of woody species by storey in Gerba Dima forest

Storey	Height (m)	Density (No. of stems/ha)	Percentage (%)	Species number	Percentage (%)
Lower	2 - 15 m	1454.4	91.5	66	95.65
Middle	15 - 30 m	131.56	8.28	26	37.68
Upper	> 30 m	2.84	0.18	7	10.14

The trees and shrubs in the lower storey of the forest (2 – 15m), contributed about 91.5% of the total individuals in the forest. The most dominant trees and shrubs in the lower story (< 15 m) of the forest are *Vepris dainellii* (13.93%), *Millettia ferruginea* (10.15%), *Albizia gummifera* (6.28%), *Olea capensis* (6.17%), *Dracaena afromontana* (5.88%), *Oxyanthus speciosus* (5.21%), *Deinbollia kilimandscharica* (4.91%), *Lepidotrichilia volkensii* (3.95%), *Maytenus gracilipes* (3.65%), *Pouteria adolfi-friederici* (3.53%), *Clausena anisata* (3.30%), *Syzygium guineense* (2.74%), *Ehretia cymosa* (2.53%), *Rothmannia urcelliformis* (2.30%), *Dracaena steudneri* (2.26%), *Croton macrostachyus* (2.18%) and the remaining accounts less than 2% each.

The trees in the middle storey of the forest (15 – 30m), contributed about 8.28% of the total individuals in the forest. The tree species that occupied the middle storey in Geba Dima forest include: *Albizia gummifera* (20.14%), *Pouteria adolfi-friederici* (12.70%), *Croton macrostachyus* (9.32%), *Ilex mitis* (7.84%), *Ficus sur* (6.89%), *Syzygium guineense* (6.22%), *Schefflera abyssinica* (6.22%), *Polyscias fulva* (5.95%), *Sapium ellipticum* (3.51%), *Millettia ferruginea* (3.38%), *Macaranga capensis* (3.38%), *Olea* *welwitschii* (2.16%), *Albizia schimperiana (2.16%)* and the remaining contributed less than 2% each.

The Upper storey also contains Only 7 emergent tree species (0.18%) of the total individuals in the forest. The tree species that occupied the upper storey in Gerba Dima forest include: *Pouteria adolfi-friederici* (50%), *Olea welwitschii* (12.5%), *Elaeodendron buchananii* (12.5%), *Millettia ferruginea* (6.25%), *Trilepisium madagascariense* (6.25%), *Bersama abyssinica* (6.25%) and *Ekebergia capensis* (6.25%). There are many species, which could not attain the upper and the middle storey by their nature. All species that have a representative in the upper also appeared in the middle and lower storey.

4.10.6. Species population structure

Population structure is the distribution of individuals of each species in arbitrary diameter- height size classes to provide the overall profile of species under study (Peter, 1996). Tree species of the study area were divided into seven height and DBH classes. The distribution of individuals in different height and DBH classes is shown in figure 13 a and b. The overall height and DBH class distribution of all individuals in different size showed an inverted J- shape distribution.

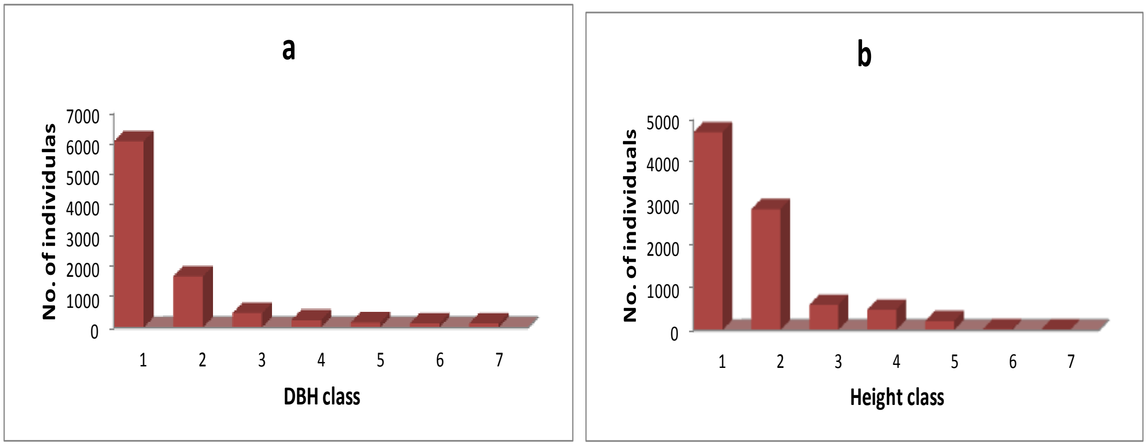


Figure 13. DBH and height class distribution of all individuals. (a) in DBH classes: (DBH classes: 1= 2.5-10 cm; 2= 10.01-20 cm; 3=20.01-30 cm; 4= >30.01-40 cm; 5= 40.01-50 cm; 6= 50.01-80 cm; 7= > 80 cm.(b) in height classes (height classes: 1= 2-5 m; 2= 5.01-10 m; 3= 10.01-15 m; 4= 15.01-20 m; 5= 20.01-25 m; 6= 25.01-30 m; 7= > 30 m).

In this study, six representative patterns of population distribution based on DBH were revealed for tree species (Fig. 14). These include:

1) Inverted J-shape, which shows a pattern where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes e.g., *Albizia gummifera*, *Cassipourea malosana*, *Dracaena afromontana*, *Ehretia cymosa*, *Macaranga capensis*, *Oxyanthus speciosus*, *Millettia ferruginea*, *Rothmannia urcelliformis* and *Vepris dainellii* among others.

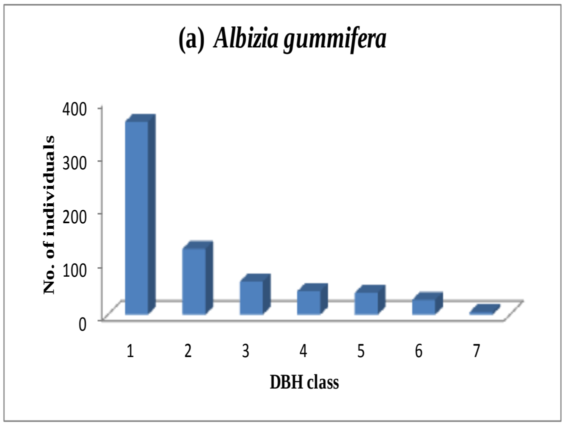
2) An increase from DBH class one to DBH class two and followed by gradual decrease towards the higher DBH classes, e.g. *Allophyllus abyssinicus*, *Croton macrostachyus* and Syzygium guineense. This pattern represents more or less a normal population structure.

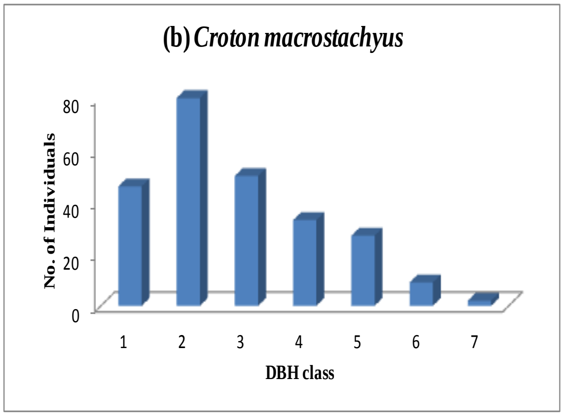
3) U-shape, which shows a type of frequency distribution in which there is a high number of lowest and highest diameter classes but a very low number in the intermediate classes, e.g., *Ficus sur*, *Pouteria adolfi-friederici*, *Olea welwitschii* and *Prunus africana*.

4) Irregular shaped, which shows a pattern where frequency is high at lower DBH classes but becomes irregular towards higher classes. The species that show such a pattern are *Albizia schimperiana*, *Polyscias fulva* and *Trilepisium madagascariense*.

5) Bell-shaped, which is a type of frequency distribution in which a number of individuals in the middle diameter classes is high and lower in lower and higher diameter classes, e.g., *Ilex mitis*?

6) J-shaped, e.g., *Sapium ellipticum*. This pattern represents abnormal population dynamics and show poor reproduction and hampered regeneration due to the fact that either most trees are not producing seeds due to age or there are losses due to predators after reproduction.





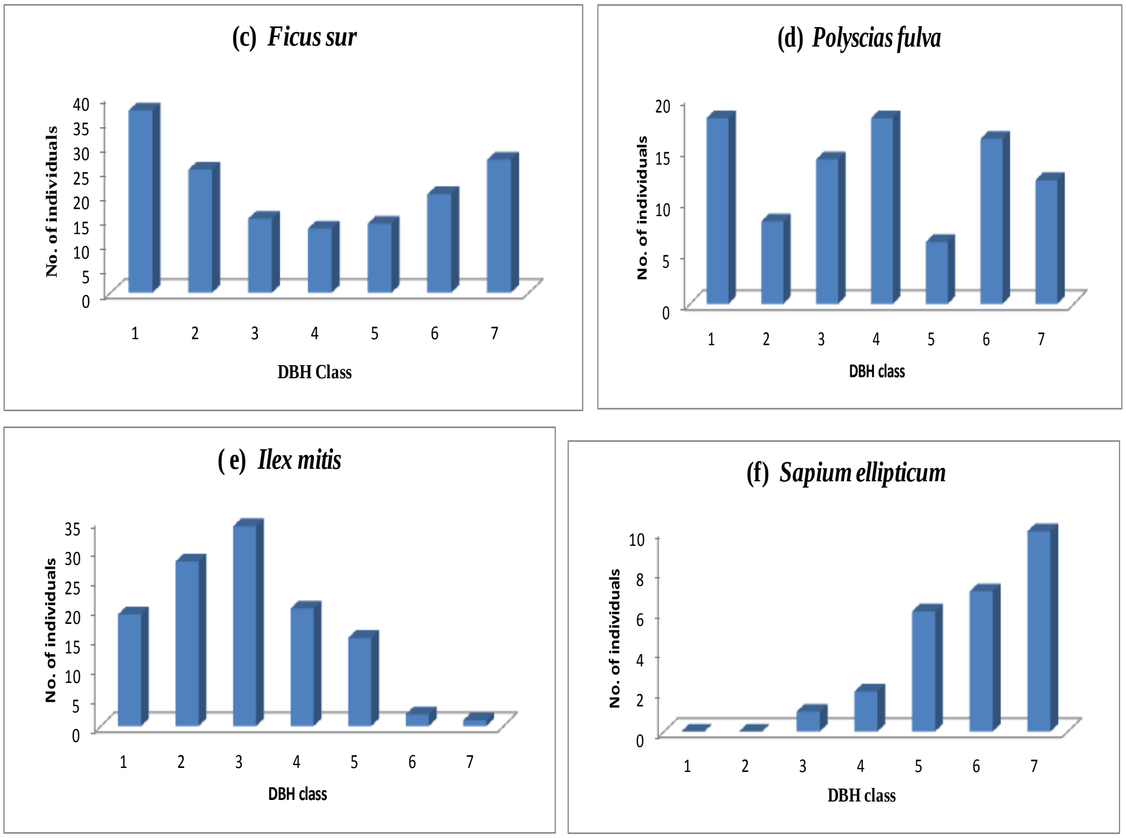


Figure 14. Pattern of frequency distribution of selected tree species over DBH classes. (DBH classes: 1= 2.5-10cm; 2= 10.01-20 cm; 3=20.01-30 cm; 4= >30.01-40 cm; 5= 40.01-50 cm; 6= 50.01-80 cm; 7= > 80 cm).

4.11. Regeneration status of Gerba Dima forest

The population structure, characterized by the presence of sufficient population of seedlings, saplings and adults, indicates successful regeneration of forest species (Saxena and Singh, 1984). Regeneration status of trees can be predicted by the age structure of their populations (Vablen *et al.*, 1979; Khan *et al.*, 1987; Tripathi *et al.*, 2007). Research in this field contributes to planning, conservation and decision making in forest resources management programmes.

In this study, the total density of seedling, sapling and tree/shrubs were 4558 ha^{-1}, 2149 ha^{-1}and 1515 ha^{-1} respectively. Out of 69 woody species, 10 species were not represented in seedling class and 9 species were not represented in sapling class (Appendix 3). Twelve species contributed 65.54 and 65.51 percent of the total seedling and sapling count respectively (Table 26). These are *Albizia gummifera*, *Vepris dainellii*, *Olea capensis*, *Oxyanthus speciosus*, *Millettia ferruginea*, *Clausena anisata*, *Maytenus gracilipes*, *Coffea arabica*, *Psychotria orophila*, *Lepidotrichilia volkensii*, *Deinbollia kilimandscharica, and Rothmannia urcelliformis.*

Table 26. List of top 12 species in the Regeneration

Name of species	**Seedling ha^{-1}**	**Percentage (%)**	**Sapling ha^{-1}**	**Percentage (%)**
Albizia gummifera	446.04	9.78	169.60	7.89
Vepris dainellii	356.62	7.82	200.00	9.31
Olea capensis	314.67	6.90	146.84	6.83
Oxyanthus speciosus	264.36	5.80	103.47	4.81
Millettia ferruginea	258.84	5.68	103.47	4.81
Clausena anisata	233.60	5.12	111.47	5.19
Maytenus gracilipes	228.27	5.01	110.04	5.12
Coffea arabica L.	214.93	4.71	96.53	4.49
Psychotria orophila	192.36	4.22	104.71	4.87
Lepidotrichilia volkensii	169.96	3.73	56.89	2.65
Deinbollia kilimandscharica	155.73	3.42	140.98	6.56
Rothmannia urcelliformis	152.71	3.35	63.82	2.97
Total		65.54		65.51

Five distribution pattern of regeneration status was observed from the 54 woody species investigated for regeneration and shown in fig. 15 below. These are:

I. Seedling > sapling> tree/shrub state. This pattern was exhibited by *Albizia gummifera*, *Bersama abyssinica*, *Canthium oligocarpum*, *Coffea arabica*, *Cassipourea malosana*, *Clausena anisata*, *Deinbollia kilimandscharica* (Fig 15a). According to Dhaulkhandi *et* *al*. (2008), such distribution pattern had good regeneration and recruitment potential. The presence of good regeneration potential shows the stability of the species to the environment. Higher seedling density values get reduced to sapling due to biotic disturbances and competition for space and nutrients.

II. Seedling > sapling < tree /shrub state. This pattern was exhibited by *Cordia africana*, *Ficus sur*, *Hallea rubrostipulata*, *Ilex mitis*, *Lepidotrichilia volkensii*, *Macaranga capensis*, *Millettia ferruginea*, *Ritchiea albersii*, *Syzygium guineense*, *Trema orientalis* and *Vernonia amygdalina*.

III. Seedling < sapling >tree/shrub, a distribution pattern which shows small density value of seedling species, a higher value of sapling followed by smaller value of seedling density. *Trilepisium madagascariense* was categorized under this distribution pattern.

IV. With no individual in seedling and sapling stages but relatively many individuals in tree/shrub stage. This pattern was recognized by *Ficus ovata*, *Ficus thonningii*, *Lobelia giberroa*, *Polyscias farinosa*, *Schefflera abyssinica*, *Trichilia dregeana*, *Urera hypselodendron*, *Vangueria apiculata* and *Vernonia rueppellii*. According to Dhaulkhandi *et al*. (2008), these plant species don't regenerate because they survive only at adult or mature tree level.

V. With smaller density values of the mature trees or shrubs but higher density value at sapling stage and complete absence of seedling species. *Chionanthus mildbraedii* was recognized under this regeneration pattern.

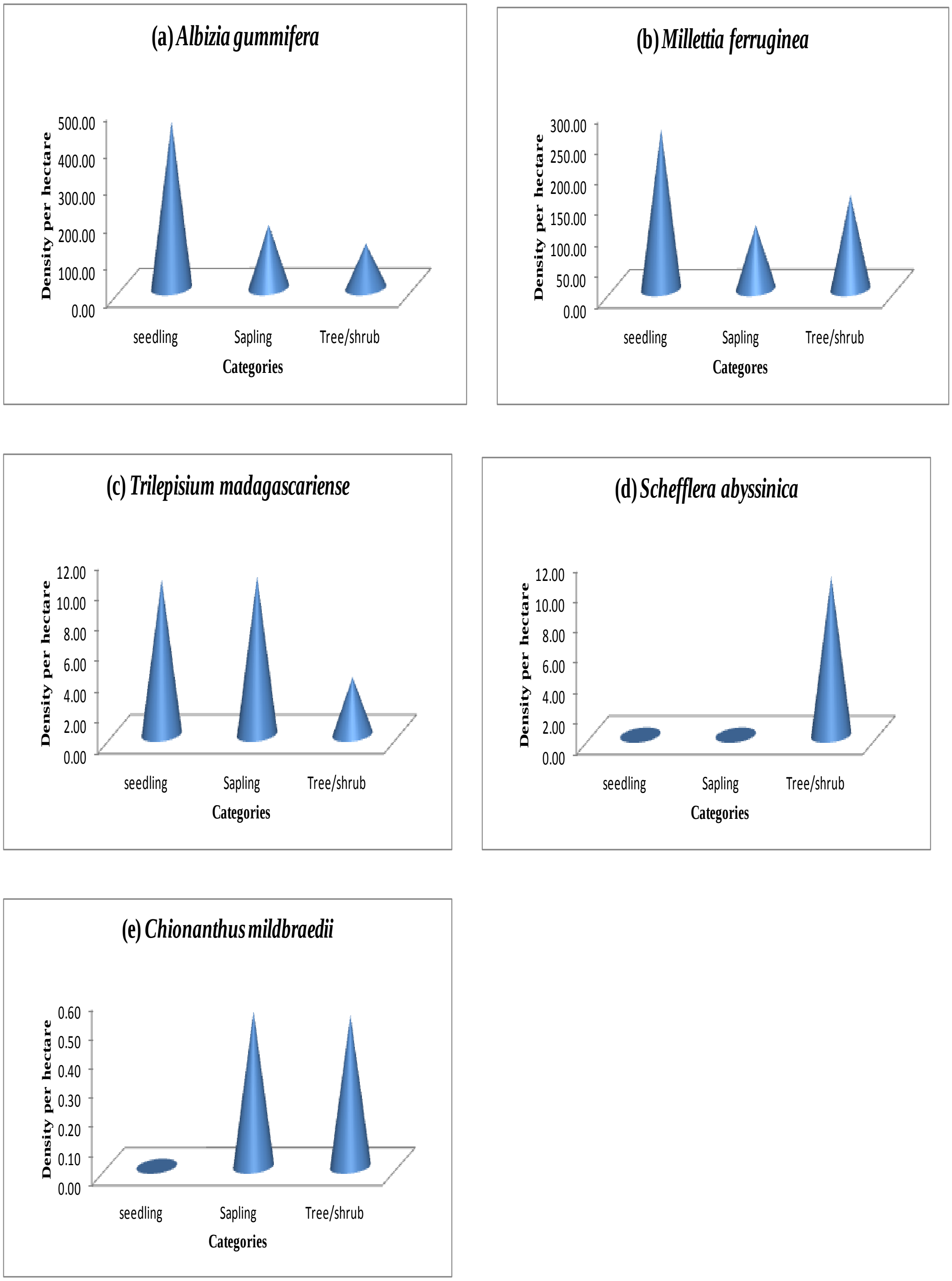


Figure 15(a-e). Seedlings, saplings and tree/shrub distribution of some selected species occurring in Gerba Dima Forest

4.12. Biomass Stock in Above Ground, Below Ground and Litter Biomass

The mean above ground biomass (AGB) and below ground biomass (BGB) were 489 ± 36.79 and 97.8 t ± 7.36 ha^{-1} respectively. The mean minimum and maximum AGB was 98.91 and 1855.85 t ha^{-1} respectively. The minimum and maximum BGB of Gerba Dima Forest was 19.78 and 371.17 t ha^{-1} respectively (Table 27 and Appendix 6). The minimum and maximum litter biomass was 0.01 and 0.79 t ha^{-1} respectively. The mean litter biomass was 0.45 t ha^{-1}.

Table 27. Mean, maximum, minimum value of above and below ground biomass, carbon stock and carbon dioxide equivalent.

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
AGB kg/m^2	12.29	10190.69	968.08	241.68
AGB ton/ha	98.91	1855.85	488.99	36.79
AGC ton/ha	57.76	872.25	243.85	17.27
CO_2 equivalent ton/ha	189.13	3201.16	847.84	63.34
BGB ton/ha	19.78	371.17	97.80	7.36
BGC ton/ha	9.30	174.45	45.97	3.46
CO_2 equivalent ton/ha	34.12	640.23	168.69	12.69
Total biomass	118.69	22270.20	586.79	44.15
Total carbon stock	69.31	1046.70	289.81	20.66
Total CO_2 equivalent ton/ha	254.38	3841.39	1063.61	75.83

4.13. Carbon Stock in the Different Carbon Pools

4.13.1. Carbon Stock in AGB

The minimum and maximum above ground carbon were 57.76 and 872.25 t ha^{-1} respectively (Appendix 6). The mean above ground carbon stock in the study site was 243.85 ±17.27 t ha^{-1} (Table 27). The first top ten species which contributed 75.41% of the total Above ground carbon stock of the forest were, in decreasing order, *Pouteria adolfi-friederici, Schefflera abyssinica*, *Albizia gummifera*, *Ficus sur, Millettia ferruginea*, *Syzygium guineense*, *Croton macrostachyus*, *Prunus africana*, *Ekebergia capensis*, *Olea welwitschii* with values of 5273.24, 2941.79, 2158.03, 1042.78, 955.61, 842.80, 830.84, 673.03, 628.25, 619.95 tons ha^{-1} respectively (Appendix 4). The least above ground carbon stock in the forest was recorded by species of *Jasminum abyssinicum*, *Solanecio gigas*, *Schefflera myriantha*, *Pterolobium stellatum*, *Solanaceo manni*, *Phyllanthus sepialis* and *Vernonia rueppellii* with values of 0.78, 0.76, 0.54, 0.45, 0.42, 0.34 and 0.17 tones ha^{-1} respectively.

The minimum and maximum carbon stock per single tree was 0.17 and 89.75 tones recorded for *Vernonia rueppellii* and *Ekebergia capensis*, respectively. Similarly, a single tree could sink a minimum carbon dioxide value of 0.61 tones and a maximum of 395.39 tones showing a trend that is the same as that of above ground biomass (Appendix 5).

4.13.2. Carbon Stock in BGB

The root biomass result, which was obtained from above ground biomass, showed a similar trend as of the carbon stock in the above ground biomass. The present result showed that the highest below ground biomass was 317.17 t ha^{-1} and lowest biomass of 19.78 t ha^{-1}. The maximum belowground carbon was 174.45 t ha^{-1} whereas the minimum below ground carbon stock was 9.30 t ha^{-1} (Appendix 6). The mean below ground carbon stock of the study site was 45.97± 3.46 t ha-1 (Table 27). This carbon pool sequestered a minimum and maximum carbon dioxide value of 34.12 t ha^{-1} and 640.23 t ha^{-1}, respectively. The mean carbon dioxide sequestration in belowground biomass was 168.69±12.69 t ha^{-1}(Table 27).

4.13.3. Carbon Stock in Litter Biomass

The laboratory analysis of litter carbon concentration per sample plot has revealed a minimum of 56.72% and a maximum of 57.97% showing little variation (Table 28 and Appendix 7). The mean litter carbon concentration in all sample plots of the study area was 57.48 ± 0.03%. The litter biomass of the sample plots showed relatively different value. The minimum value was observed with 0.013 t ha^{-1} and the maximum value was 0.787 t ha^{-1}. The maximum and minimum carbon stocks in litter biomass were 0.45 t ha^{-1} and 0.007 t ha^{-1}, respectively. Mean total carbon stock of litter of the study site was 0.026 ± 0.005 t ha^{-1} (Table 28). This carbon pool sequestered a minimum and maximum carbon dioxide value of 0.027 t ha^{-1} and 1.66 t ha^{-1}, respectively (Appendix 7). The mean carbon dioxide sequestration in litter biomass was 0.096±0.018 t ha^{-1}(Table 28).

Table 28. Litter Biomass in ton/ha, %C, Carbon stock in litter and Carbon sequestered (CO2 equivalent) in ton/ha of Gerba Dima forest

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
Weight of wet field sample of litter (g)	200	2000	594.16	43.401
Weight of fresh sub sample of litter (g)	100	500	281.58	6.030
Weight of Oven dry subsample of litter (g)	80	1050	196.12	11.035
Litter biomass ton/ha	0.0125	0.7875	0.045	0.009
% C	56.72	57.97	57.48	0.030
Carbon stock in litter	0.0072	0.4517	0.026	0.005
CO_2 equivalent of litter	0.0265	1.6577	0.096	0.018

4.13.4. Carbon Stock in Herb layer

The laboratory analysis of Herb carbon concentration per sample plot has recorded a minimum of 25.64% and a maximum of 56.34% showing a variation (Annex 8). The mean herb carbon concentration in all sample plots of the study area was 47.40 ± 0.58% (Table 29). The herbaceous biomass of the sample plots showed relatively different value. The minimum value was observed with 0.006 t ha^{-1} and the maximum value was 0.45 t ha^{-1} (Appendix 8). The maximum and minimum carbon stocks in herbaceous biomass were 0.021 t ha^{-1} and 0.002 t ha^{-1}, respectively. Mean total carbon stock of herb layer of the study site was 0.007 ± 0.0004 t ha^{-1} (Table 29). This carbon pool sequestered a minimum and maximum carbon dioxide value of 0.008 t ha^{-1} and 0.076 t ha^{-1}, respectively. The mean carbon dioxide sequestration in herbaceous biomass was 0.026±0.001 t ha^{-1} (Table 29).

Table 29. Herbaceous Biomass in ton/ha, % C, Carbon stock in Herb and Carbon sequestered (CO_2 equivalent) by Herbaceous Carbon pool in ton/ha of Gerba Dima forest

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
Weight of wet field sample of Herb (g)	100	1100	407.78	21.110
Weight of fresh sub sample of Herb (g)	100	300	241.11	8.531
Weight of Oven dry subsample of Herb (g)	45	145	86.30	2.486
Herb biomass ton/ha	0.006	0.045	0.015	0.0008
% C	25.64	56.34	47.403	0.578
Carbon stock in Herb ton/ha	0.002	0.021	0.007	0.0004
CO2 equivalent of Herb ton/ha	0.0075	0.0765	0.026	0.0013

4.13.5. Non-Tree Woody Species Carbon Stock (NTWSC)

In Gerba Dima forest the highest non-tree woody vegetation (NTWS) biomass was 0.68 t ha^{-1} and lowest biomass of 0.027 t ha^{-1}. The maximum NTWS carbon was 0.32 t ha^{-1}

whereas the minimum NTWS carbon stock was 0.013 t ha^{-1} (Table 30 and Appendix 9). The mean NTWS carbon stock of the study site was 0.12 ± 0.01 t ha^{-1} (Table 30). This carbon pool sequestered a minimum and maximum carbon dioxide value of 0.047 t ha^{-1} and 1.18 t ha^{-1}, respectively. The mean carbon dioxide sequestration in NTWS was 0.43±0.04 t ha^{-1}(Table 30).

Table 30. Non tree woody species (NTWS) Biomass in ton/ha, %C, Carbon stock in NTWS and Carbon sequestered (CO_2 equivalent) by NTWS Carbon pool in ton/ha of Gerba Dima forest

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
Weight of fresh sub sample of NTWS (g)	100	300	283.89	4.457
Weight of Oven dry subsample of NTWS (g)	68	244	158.54	5.715
NTWS biomass ton/ha	0.027	0.683	0.251	0.021
% C	0.47	0.47	0.47	0.000
Carbon stock in NTWS ton/ha	0.013	0.321	0.118	0.010
CO_2 equivalent of NTWS ton/ha	0.047	1.179	0.432	0.037

4.13.6. Carbon stock in Dead wood (CDW)

4.13.6.1. Carbon stock in Standing dead wood (CSDW)

In Gerba Dima forest the highest Standing dead wood biomass was 82.67 ha^{-1} and lowest biomass was 0.0049 t ha^{-1} (Appendix 10). The maximum SDW carbon was 38.86 t ha^{-1} whereas the minimum SDW carbon stock was 0.002 t ha^{-1} (table below). The mean SDW carbon stock of the study site was 1.83 ± 0.55 t ha^{-1} (Table 31). This carbon pool sequestered a minimum and maximum carbon dioxide value of 0.008 t ha^{-1} and 142.61 t ha^{-1}, respectively. The mean carbon dioxide sequestration in SDW was 6.73±2.00 t ha^{-1} (Table 31).

Table 31. Mean, maximum, minimum value of biomass, carbon stock and carbon dioxide equivalent for Standing Dead Wood (SDW), Ling Dead Wood(LDW) and for the overall Dead Wood (DW)

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
SDWV(m^3)	0.0006	9.9369	0.469070	0.1395233
ρ̇ (t/m^3)	0.52	0.52	0.5200	0.00000
SDWB(t)	0.0003	5.1672	0.243916	0.0725521
SDWB(t/ha)	0.0049	82.6748	3.902664	1.1608339
SDWC	0.0023	38.8571	1.834252	0.5455919
CO_2SDW	0.0084	142.6057	6.731705	2.0023224
LDWB(t/ha)	0.00	34.37	5.9736	0.73848
LDWC(t/ha)	0.00	16.15	2.8076	0.34708
CO_2LDW(t/ha)	0.00	59.28	10.3038	1.27379
DWB(t/ha)	0.3013	105.5485	9.876200	1.6199354
DWC(t/ha)	0.1416	49.6078	4.641814	0.7613696
DWCO_2(t/ha)	0.5197	182.0607	17.035457	2.7942265

4.13.6.2. Carbon stock in Lying dead wood (LDWC)

The mean wood density for sound, intermediate and rotten dead wood were 0.52 gcm^{-3},0.31 gcm^{-3} and 0.13 gcm^{-3} respectively. The mean Lying dead biomass of the study area was 5.97±0.74 ton/ha. The minimum and maximum LDWC was 0 ton/ha and 16.15 ton/ha respectively. The mean LDWC stock in the study area was 2.81±0.35t/ha. Therefore, the mean carbon sequestration of the Lying Dead Wood biomass was 10.30±1.27 ton/ha (Table 31 and Appendix 10).

4.13.6.3. The overall Dead Wood Carbon Stock (DWC)

In Gerba Dima forest the highest overall dead wood biomass was 105.55 ha^{-1} and lowest biomass was 0.30 t ha^{-1}. The maximum overall DW carbon was 49.61 t ha^{-1} whereas the minimum DW carbon stock was 0.14 t ha^{-1} (Table 31 and Appendix 10). The mean overall DW carbon stock of the study site was 4.64 ± 0.76 t ha^{-1} (Table 31). This carbon pool sequestered a minimum and maximum carbon dioxide value of 0.52 t ha^{-1} and 182.06 t ha^{-1}, respectively. The mean carbon dioxide sequestration in DW was 17.04±2.79 t ha^{-1}(Table 31).

4.13.7. Carbon Stock in Soil

The soil bulk density ranged from 0.60g cm^{-3} of minimum to 1.09 g cm^{-3} of maximum value (Table 32). On the other hand, 0.78g cm^{-3} was the average soil bulk density indicating the presence of high soil organic matter in mineral soils. The largest soil organic matter was 34.91% whereas 16.21% is the lowest value. The carbon content of soil carbon pool ranged from minimum storage of 204.32 t ha^{-1} to a maximum of 534.24 t ha^{-1} per plot of the study site. The mean soil carbon stock of the study area was 292.13 ± 5.30 t ha^{-1} (Table 32). This soil carbon pool sequestered a minimum and maximum CO_2 value of 749.87 t ha^{-1} and 1960.67 t ha^{-1}, respectively. The mean carbon dioxide sequestration in the soil carbon pool was 1072.10 ±19.46 t ha^{-1}, showing a large amount of CO_2 captured in soil (Table 32 and Appendix 11).

Table 32. Bulk Density, SOC and CO_2 equivalent of the Soil Carbon pool in Gerba Dima forest

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
Bulk density(gcm^{-3})	0.60	1.10	0.78	0.01
Depth(cm)	40	40	40.00	0.00
%OM	10.15	34.91	16.21	0.30
%C	5.89	20.25	9.40	0.18
SOC (ton ha^{-1})	204.32	534.24	292.13	5.30
CO_2 equivalent	749.87	1960.67	1072.10	19.46

4.13.8. Total Carbon Stock of Gerba Dima Forest

The total carbon stock of the study area was calculated by summing up all the carbon value of each pool for all plot samples of the study area. Accordingly, the total carbon stock values of the study forest ranged from a minimum of 325.17 in the region of plot 81 to a maximum of 1261 t ha-1 in the region of plot 50 (Fig. 16). The mean carbon stock in all carbon pool of the study site was 586.73 ± 20.81 t ha^{-1} (Appendix 6). Overall, summary of carbon stock for all carbon pools in the study site is shown in Table 33.

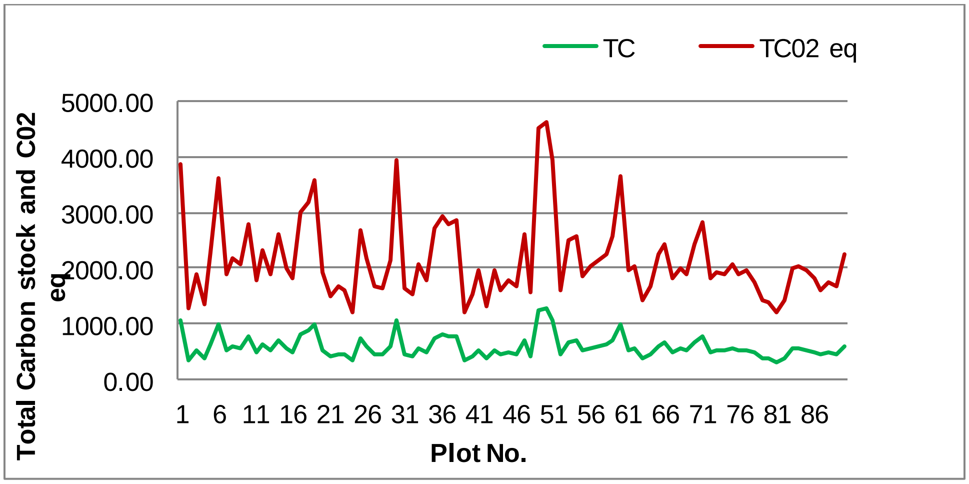


Figure 16. Total carbon stock (TC) and CO$_2$eq. of each plot.

Table 33. Summary of minimum, maximum and mean carbon stock and CO2 equivalent of different carbon pools of the study site

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Std. Error
AGC(ton/ha)	57.76	872.25	243.85	17.27
BGC (ton/ha)	9.30	174.45	45.97	3.46
Carbon stock in litter (ton/ha)	0.01	0.45	0.03	0.01
Carbon stock in Herb(ton/ha)	0.00	0.02	0.01	0.00
Carbon stock in NTWS (ton/ha)	0.01	0.32	0.12	0.01
DWC(ton/ha)	0.14	49.61	4.64	0.76
SOC(ton/ha)	204.32	534.24	292.13	5.30
Total C stock(ton/ha)	325.17	1261.11	586.73	20.81
Total CO$_2$ equivalent (ton/ha)	1193.38	4628.25	2153.30	76.39

4.14. Comparison of Carbon stock in the Different Carbon Pools

Carbon stock in a different pool of the study site shows variation. The highest percentage of carbon was stored in soil organic carbon pool (49%) followed by the above ground carbon pool (41%), below ground carbon pool (9%) and Dead wood carbon pool (1%) respectively. Compared with aforementioned carbon pool, the contribution of herbaceous, litter and non-tree woody vegetation carbon pools were insignificant (0%) (Fig .17).

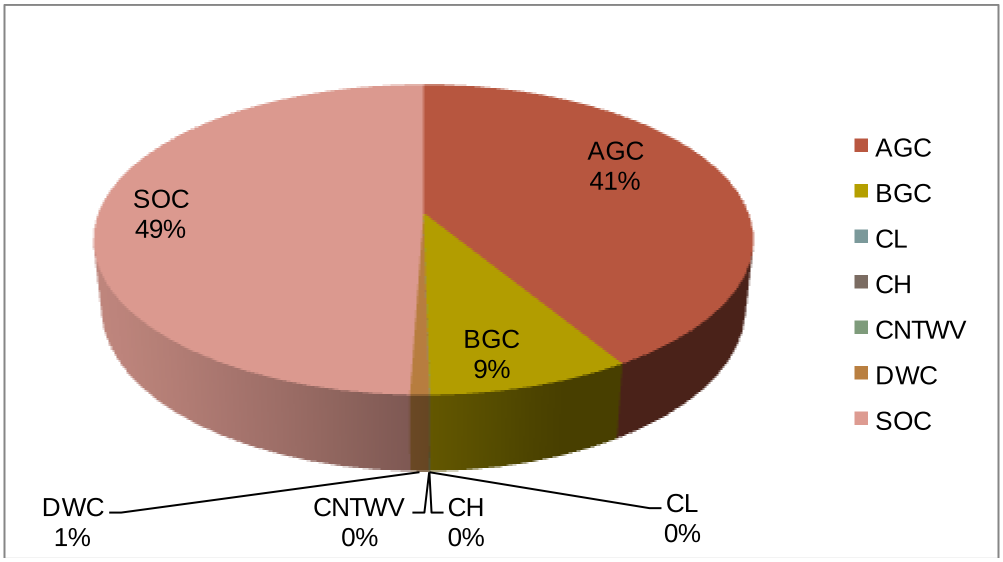


Figure 17. Proportion of various carbon pools in Gerba Dima forest

4.15. Correlation between different carbon pools

Correlation of the various carbon pools with one another was tested using Pearson's product-moment correlation coefficient (Table 34). The statistically strong positive correlation was observed between AGC and BGC, NTWSC and Carbon stock in litter, SOC and Carbon stock in Herb, SOC and NTWSC.

Table 34. Pearson’s product moment correlations coefficient and P value between Carbon pools

	AGC ton/ Ha	Carbon stock in litter ton/ha	Carbon stock in Herb ton/ha	Carbon stock in NTWS ton/ha	DWC ton/ha	SOC ton/ ha
AGC ton/ha	1					
	0.000					
Carbon stock in litter	0.032	1				
ton/ha	0.761					
Carbon stock in Herb	0.171	0.121	1			
ton/ha	0.107	0.255				
Carbon stock in NTWS	0.129	**0.249***	0.119	1		
ton/ha	0.226	0.018	0.264			
DWC ton/ha	-0.121	0.036	-0.006	-0.016	1	
	0.257	0.736	0.954	0.878		
SOC ton/ha	-0.082	0.124	**0.265***	**0.230***	-0.017	1
	0.440	0.242	0.011	0.029	0.871	

‘**’= $P < 0.01$ ‘*’ = $P < 0.05$. Cell Contents: Pearson correlation (upper cell) and P-Value (lower cell).

4.16. Relationship between carbon stocks and environmental gradients

Correlation of the various carbon pools with eight environmental variables were tested using Pearson's product-moment correlation coefficient (Table 35 and Appendix 12) Statistically strong positive correlation was observed between AGC and Diversity, BGC and Diversity, Carbon stock in litter and Clay, Carbon stock in herb and Altitude, DWC and Altitude, DWC and clay, SOC and Altitude, SOC and Sand. On the other hand strongly statistically negative correlation was shown between AGC and disturbance, BGC and Disturbance, Carbon stock in litter and Sand, NTWSC and disturbance, DWC and disturbance, SOC and clay.

4.17. Comparison of Carbon Density of Gerba Dima Forest with other Forests in Ethiopia

The Various carbon pools of Gerba Dima Forest is compared with carbon pools of other 5 forests in Ethiopia and some of the pools are also compared with default values of tropical forests and a forest in Australia. (Table 36). The result of this study revealed that Total carbon stock, AGC and BGC of Gerba Dima Forest were more or less similar to Gedo, Egdu, Deneba and SMNP forests. The AGC in Gerba Dima forest was greater than Anbesa, tropical wet, tropical moist, tropical dry and tropical montane forests. However, AGC of Gabra Dima forest was less than the forest in Gergeda and highland of Victoria in south eastern Australia. The litter carbon stock of Gerba Dima forest was more or less similar with SMNP while less than Gedo, Egdu, Danaba, Gergeda and Anbessa forests. The SOC of Gerba Dima forest was almost similar with Egdu and SMNP forests but greater than Gedo, Danaba, Gergeda and Anbessa forests.

Table 35. Pearson’s product moment correlations coefficient and P value between Carbon pools and environmental gradients

	Slope	Aspect	Disturbance	Altitude	SAND	CLAY	SILT	Diversity
AGC	0.030	-0.055	**-0.236***	0.141	-0.097	0.093	0.011	**0.207***
	0.782	0.607	0.025	0.184	0.362	0.384	0.917	0.050
BGC ton/ha	0.027	-0.049	**-0.224***	0.108	-0.035	0.028	0.015	**0.250***
	0.798	0.647	0.034	0.311	0.746	0.793	0.888	0.017
Carbon stock in litter	-0.038	-0.162	-0.189	0.120	**-0.295****	**0.224***	0.160	0.002
	0.722	0.128	0.074	0.259	0.005	0.034	0.133	0.983
Carbon stock in Herb ton/ha	0.050	-0.001	-0.191	**0.368****	-0.160	0.105	0.121	0.131
	0.642	0.989	0.071	0.000	0.133	0.323	0.255	0.218
Carbon stock in NTWS ton/ha	-0.027	0.023	**-0.239***	-0.043	-0.076	0.035	0.089	0.046
	0.797	0.827	0.023	0.690	0.479	0.742	0.404	0.665
DWC	-0.065	-0.172	-0.018	0.**290****	**-0.234***	**0.212***	0.054	0.028
	0.540	0.106	0.868	0.006	0.026	0.045	0.616	0.790
SOC	0.111	0.188	-0.014	**0.236***	**0.260***	**-0.220***	-0.092	0.015
	0.299	0.077	0.896	0.025	0.013	0.037	0.389	0.887

‘**’= $P < 0.01$ ‘*’ = $P < 0.05$. Cell Contents: Pearson correlation (upper cell) and P-Value (lower cell).

Table 36. . Comparisons of carbon stocks (t/ha) of Gerba Dima forest with other studies in Ethiopia and other part of the World.

Forest name	AGC (ton/h)	BGC (ton/h)	LC (ton/h)	DWC (ton/h)	SOC (ton/h)	Total C stock (ton/h)	References
Gerba Dima	243.85	45.96	0.026	4.64	292.13	586.73	Present study
Gedo	281	56.1	0.41	2.37	183.69	523.64	Hamere Yohannes *et al.*,(2015)
Egdu	278.08	55.62	3.47	-	277.56	614.72	Adugna Feyissa *et al.*, (2013)
Danaba	278.03	41.76	1.06	-	186.40	507.29	Muluken Nega Bazezew etal.,(2015)
SMNP	270.89	54.18	0.019	0.725	242.5	568.314	Tibebu Yelemfrhat *et al.*,(2014)
Gergeda	466.08	93.22	2.51	-	155.75	717.56	Tamene Yohannes (2016)
Anbesaa	169.02	33.80	1.15	-	149.63	353.6	Tamene Yohannes (2016)
Highlands of Victoria, Southeastern Australia	1,053					1867	Keith *et al.*,(2009)
Tropical wet	146						IPCC(2003,2006)
Tropical moist	112						IPCC(2003,2006)
Tropical dry	73						IPCC(2003,2006)
Tropical montane	71						IPCC(2003,2006)

4.18. Biomass estimation for development of allometric equation

4.18.1. Trimmed Biomass for tree species

From the trimmed fresh biomass of a wood aliquot ($B_{\text{fresh wood}}^{\text{aliquot}}$) and its dry biomass ($B_{\text{dry wood}}^{\text{aliquot}}$) calculation and from the fresh biomass of a leaf aliquot (($B_{\text{fresh leaf,i}}^{\text{aliquot}}$) and its dry biomass ($B_{\text{dry leaf ,i}}^{\text{aliquot}}$) , the moisture content of the wood and leaf as well as the trimmed dry biomass ($B_{trimmed\ dry}$) were obtained for the 5 tree species as shown in Table 38.

The average wood aliquot moisture content from oven dry biomass was calculated for *Olea welwitschii, Pouteria adolfi-friederici, Elaeodendron buchananii, Cassipourea malosana* and *Vepris dainellii* were 0.70, 0.61, 0.65, 0.64 and the average leaf aliquot moisture content of these species was 0.51, 0.53, 0.39, 0.42 and 0.37 % respectively. The mean dry wood biomass was highest for *Olea welwitschii* and *Vepris dainellii*. Similarly, the dry leaf biomass was also highest for *Olea welwitschii* and lowest for *Vepris dainellii*. The overall dry section of trimmed biomass was also highest for *Olea welwitschii* (8.36 kg) and lowest for *Vepris dainellii* (3.12 kg).

4.18.1.1. Untrimmed Biomass for small branches and its components of tree species

The dry biomass of small untrimmed branches, twigs and leaves was calculated from the regression model developed between the basal diameter of the trimmed branches and biomass of trimmed branches, twigs and leaves. From the relationship between basal area and trimmed biomass, a power model best-fit only for *Olea welwitschii* and a linear model for the other 4 species. The allometric models derived for the 5 tree species are indicated in table 37.

Using the models in table 37, the biomass of untrimmed small branches and their components were calculated and the summarized result is indicated in table 39. The highest value of untrimmed small branches and their components mean biomass was recorded for *Elaeodendron buchananii* while the lowest for *Cassipourea malosana*. The highest mean basal diameter of untrimmed small branches was recorded for *Olea welwitschii* and the lowest for *Cassipourea malosana*.

Table 37. Allometric models developed to estimate the biomass of untrimmed small branches, twigs and leaves

Species name	The allometric models for Untrimmed small branches	R^2
Olea welwitschii	$TB = 4634.3BD^{0.6308}$	0.524
Pouteria adolfi-friederici	$TB = 547.5\ BD + 15382$	0.702
Elaeodendron buchananii	$TB = 495.76\ BD + 17512$	0.67
Cassipourea malosana	$TB = 1445.3\ BD – 12430$	0.632
Vepris dainellii	$TB = 413.91\ BD + 3849.6$	0.339

4.18.1.2. Untrimmed Biomass for large branches of tree species

The untrimmed Biomass for large branches of the 5 tree species was calculated from the volume of each section of a branch obtained by Smalian's formula and average density of a tree. Summarized value of the biomass and density for all tree species is indicated in table 40. The highest value of mean biomass for large untrimmed branches was recorded for *Olea welwitschii* while the lowest for *Cassipourea malosana*. The highest wood density was recorded for *Olea welwitschii* while the lowest for *Pouteria adolfi-friederici*. Values recorded as zero indicates absence of larger untrimmed branches for trees under investigation. In case of *Cassipourea malosana*, branches cannot reach the size assumed for large branches, as this species is relatively smaller in trunk and branch diameter.

Table 38. Mean trimmed biomass of leaves, twigs and branches for tree species

Species name	Mean fresh leaf biomass (Kg)	Mean trimmed fresh wood biomass (Kg)	Mean moisture content of wood aliquot	Mean moisture content of leaf aliquot	Mean dry leaf biomass (Kg)	Mean trimmed wood dry biomass (Kg)	Mean trimmed dry biomass (Kg)
Olea welwitschii	4.95	8.34	0.70	0.51	2.52	5.84	8.36
Pouteria adolfi-friederici	6.02	7.23	0.61	0.53	3.19	4.41	7.60
Elaeodendron buchananii	5.25	8.40	0.65	0.39	2.05	5.46	7.51
Cassipourea malosana	4.77	4.40	0.64	0.43	2.05	2.82	4.87
Vepris dainellii	3.49	3.27	0.56	0.37	1.29	1.83	3.12

Table 39. Mean biomass of untrimmed small branches, twigs and leaves of trees calculated using allometric models

Species name	Untrimmed biomass for small branches (g)			Basal diameter (cm)		
	Minimum	maximum	mean	Minimum	Maximum	Mean
Olea welwitschii	7487.55	65362.06	16266.39	3.5	10	7.31
Pouteria adolfi-friederici	9014.75	74787.50	19347.75	4.1	9.8	7.25
Elaeodendron buchananii	7342.40	54787.94	20555.97	4.2	8.7	6.14
Cassipourea malosana	1921	18271	4969.45	2.1	7.3	4.16
Vepris dainellii	574.79	16757	5741.17	3.2	7.2	4.57

Table 40. The mean biomass of untrimmed large branches and mean density of tree species

Species name	Untrimmed biomass for large branches (g)			Wood density (gcm^{-3})		
	Minimum	maximum	mean	Minimum	Maximum	Mean
Olea welwitschii	0	9269228	524316	0.59	0.73	0.67
Pouteria adolfi-friederici	0	1414908	105775.45	0.35	0.63	0.45
Elaeodendron buchananii	0	425798.5	15775.74	0.54	0.66	0.60
Cassipourea malosana	0	0	0	0.33	0.72	0.58
Vepris dainellii	0	44700	5673.36	0.35	0.60	0.52

4.18.1.3. The Overall Biomass estimation for tree species

The Overall Above ground biomass for tree species was calculated by adding the biomass of trimmed small branches and their components, untrimmed small branches and their components, untrimmed large branches and the trunk. The trunk biomass was obtained from the volume of each section of a trunk obtained by truncated cone volume formula and an average density of a tree. The minimum, maximum and mean values of the response variable (Above ground biomass) and explanatory variables for each trees are presented in table 41. Among the 5 tree species, the higher mean above ground biomass was obtained for *Olea welwitschii* (2443.70kg) ranging from 170.75 to 11602.42kg and least was obtained for *Vepris dainellii* with mean biomass of 58.22 kg and ranging from 16.15 kg to 157.67 kg.

4.18.2. Biomass estimation for shrub species

The minimum, maximum and mean values of the response variable (Above ground biomass) and explanatory variables for each shrubs are presented in table 42. The higher mean above ground biomass was obtained for *Maytenus gracilipes* (4347g) ranging from 810 to 23400g and least was obtained *Psychotria orophila* with mean biomass of 2767.63g and ranging from 480g to 5805g.

4.19. Correlation between dependent and independent variables of tree species

Plotting correlation coefficient values of each independent variable with a dependent variable and between independent variables themselves are the most important step that gives us valuable clues for selecting the appropriate explanatory variables and, therefore, to develop the most promising regression model. The person's correlation analysis between above ground biomass and with biomass predictor variables (DBH, Height and wood density) are shown in table 43. The above ground biomass is strongly correlated with DBH for four studied trees species while moderately correlated for *Vepris dainellii*. Height is second important factor correlating with biomass showing strong correlation in *Olea welwitschii* and *Elaeodendron buchananii*, moderate correlation in *Pouteria adolfi-friederici* and *Cassipourea malosana* and poor correlation in *Vepris dainellii*. The biomass of all 5 tree species were poorly correlated with wood density.

Table 41. Mean above ground biomass, DBH and Height of tree species

Species name	Above ground biomass (AGB) in Kg			Wood density (WD) in gcm^{-3}			DBH in cm			Height in meter		
	Minimum	Maximum	Mean	Minimum	maximum	mean	minimum	Maximum	Mean	minimum	maximum	mean
Olea welwitschii	170.8	11602.42	2443.70±499	0.59	0.73	0.67	10	136	54.76±5.9	11	45	22.93±1.2
Pouteria adolfi-friederici	94.6	8017.05	1785.12±344	0.35	0.63	0.45	10.57	200	69.29±7.97	12	35	22.87±0.9
Elaeodendron buchananii	199.4	5076.62	1330.46±75	0.54	0.66	0.60	12.3	90	49.313±3.52	15	30	21.53±0.8
Cassipourea malosana	103.9	783.74	345.02±31	0.33	0.72	0.58	13	32	21.09±0.86	9	18	13.8±0.41
Vepris dainellii	16.15	157.67	58.22±7.77	0.35	0.60	0.52	6.7	24.6	12.07±0.73	3.5	8.5	5.72±0.24

Table 42. Mean above ground biomass, DSH, CrA and Height of shrub species

Species name	Above ground biomass (AGB) in g			DSH in cm			CrA in cm^2			Height in cm		
	Minimum	Maximum	Mean	Minimum	maximum	mean	minimum	maximum	Mean	minimum	maximum	mean
Maytenus gracilipes	810	23400	4347.65±879	3	12	4.66	18920	432000	135688	367	790	548.5±19
Psychotria orophila	480	5805	2767.63±	2.1	7.0	4.0	1500	219300	77133.67	265	680	469.30±18

Table 43. Pearson's product moment correlations coefficient and P value between the response variable (AGB) and explanatory variables(WD,DBH and H) for tree species

Name of species		WD	DBH	H
Olea welwitschii	AGB	0.203	0.828**	0.710**
		0.283	0.000	0.000
Pouteria adolfi-friederici	AGB	0.287	0.961**	0.539**
		0.124	0.000	0.002
Elaeodendron buchananii	AGB	0.130	0.770**	0.736**
		0.494	0.000	0.000
Cassipourea malosana	AGB	0.059	0.775**	0.486**
		0.758	0.000	0.007
Vepris dainellii	AGB	0.156	0.669**	0.368*
		0.409	0.000	0.045

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

*. Correlation is significant at the 0.05 level (2-tailed).

4.20. Correlation between dependent and independent variables of shrub species

The above ground biomass was moderately correlated with all three explanatory variables in both *Maytenus gracilipes* and *Psychotria orophila* (table 44)

Table 44. Pearson's product moment correlations coefficient and P value between the response variable (AGB) and explanatory variables(DSH,H and CrA) for shrub species

Name of species		DSH	H	CrA
Maytenus gracilipes	AGB	0.640**	0.570**	0.413**
		0.000	0.001	0.023
Psychotria orophila	AGB	0.696**	0.538**	0.701**
		0.000	0.002	0.000

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

*. Correlation is significant at the 0.05 level (2-tailed).

4.21. Development of biomass allometric models for tree species

Before establishing the allometric equation, scatter plots were used to see whether the relationship between independent and dependent variables was linear. Since both dependent and independent variables of all tree species exhibited heteroscedasticity while checked by plotting scatter plot in R- software, the variables were log transformed so as to equalize the variance over the entire range of variables which satisfies the prerequisite of linear regression (Sokal and Rohlf, 1995; Picard *et al.*, 2012).

To develop an allometric model for the above ground biomass of the 5 tree species, Diameter at breast height ((DBH), Height(H) and Wood density (WD) were taken as explanatory variables. Given that there are p effect variables X_1, X_2, . . . , Xp, there are $2^p - 1$ models that include all or some of these effect variables (Picard *et al.*, 2012). Thus, in this study, the 3 effect variables can result in 2^3-1 which becomes 7 candidate regression model (Table 45).

Table 45. The seven candidate regression model which serve to select the best models

Model	Allometric equations
1	$\ln(AGB) = c + \alpha \ln(DBH) + \varepsilon$
2	$\ln(AGB) = c + \beta \ln(H) + \varepsilon$
3	$\ln(AGB) = c + \chi \ln(WD) + \varepsilon$
4	$\ln(AGB) = c + \alpha \ln(DBH) + \beta \ln(H) + \varepsilon$
5	$\ln(AGB) = c + \alpha \ln(DBH) + \chi \ln(WD) + \varepsilon$
6	$\ln(AGB) = c + \beta \ln(H) + \chi \ln(WD + \varepsilon$
7	$\ln(AGB) = c + \alpha \ln(DBH) + \beta \ln(H) + \chi \ln(WD) + \varepsilon$

where: c is the intercept, and α,β and χ are the slope coefficient of the regression.

4.21.1. Model fitting for tree species

AGB of all the 5 tree species were regressed against the various form of predictors (i.e., DBH, H and WD) and more than one allometric models which show significant performance ($p < 0.05$) on their F-test and t-test was found for each species except *Olea welwitschii* (Table 49). The various significant allometric models for each species were subjected to further test to choose the best-fit model.

For Olea *welwitschii*, only one allometric model showed significant performance ($p < 0.05$) (table 49). The model indicated below is selected as a best-fit model for *Olea welwitschii.*

$lnAGB = c + \alpha lnDBH + \varepsilon$, with values of coefficient and error the model become:

$$lnAGB = 1.662 + 1.479 \times lnDBH \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$(r^2 = 0.889, \varepsilon = 0.347, \text{AIC} = 26.60, \text{RMSE} = 0.335)$

Where AGB is in kg, DBH in cm.

The ANOVA (Table 46) result shows the model selected for *Olea welwitschii* is significant.

Table 46. Analysis of Variance for best-fit model of *Olea welwitschii*

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.106	1	28.106	233.087	0.000
	Residual	3.376	28	0.121		
	Total	31.483	29			

The result of regression analysis for *Pouteria adolfi-friederici* indicated in table 49 showed that 3 allometric models are statistically significant. Among the 3 allometric equations which showed significant performance, the selection of the best-fit model was conducted based on their P-value, adjusted r^2, AIC, RMSE. The first two models are nested to model 3 and hence the complete model 3 is selected against the nested models 1 and 2 since the p-values of coefficients of the complete model are significant ($p < 0.05$).

Since the first two significant candidate models are nested to the third model and the P-values of coefficients in the 3^{rd} model are statistically significant ($p < 0.05$), the third model selected as best-fit model is indicated below.

$lnAGB = c + \alpha lnDBH + xlnWD + \varepsilon$, with values of coefficient inserted the model form is:

$lnAGB = 1.806 + 1.419 \times lnDBH + 0.628 \times lnWD$ ………………. (2)

$(r^2 = 0.951, \varepsilon = 0.2194, \mathrm{AIC} = 0.463, \mathrm{RMSE} = 0.208)$
Where AGB is in kg, DBH in cm and WD in cm^3.

The analysis of variance in table 47 below also shows that the overall allometric equation was found to be statistically significant (F=283.042, $p < 0.000$).

Table 47. Analysis of Variance for best-fit model of *Pouteria adolfi-friederici*

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.141	2	2.571	283.042	.000
	Residual	.245	27	.009		
	Total	5.386	29			

In the regression analysis of *Elaeodendron buchananii*, three regression models have shown statistically significant performance (Table 49). The model selected as best fitted model for *Elaeodendron buchananii* is indicated below.

$lnAGB = c + \alpha lnDBH + \beta lnH + \varepsilon$, with values of coefficients added the equation become:

$$lnAGB = -0.062 + 1.240 \times lnDBH + 0.754 \times lnH \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

$(r^2 = 0.882, \varepsilon = 0.251, \text{AIC} = 7.09, \text{RMSE} = 0.238)$
Where AGB is in kg, DBH in cm and H in m.

Table 48. Analysis of Variance for best-fit model of *Elaeodendron buchananii*

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.810	2	6.905	109.407	0.000
	Residual	1.704	27	0.063		
	Total	15.514	29			

The result of regression analysis for *Cassipourea malosana* has resulted in 2 statistically significant competitive models (Table.49). Among the two simple linear regression models, the first one indicated below is selected as a best-fit model.

$lnAGB = c + \alpha lnDBH + \varepsilon$, with the value of coefficient inserted the equation becomes

$$lnAGB = 0.157 + 1.84 \times lnDBH \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

$(r^2 = 0.64, \varepsilon = 0.306, \text{AIC} = 18.03, \text{RMSE} = 0.296)$
Where AGB is in kg, DBH in cm.

Results of ANOVA test in (Table 50) shows that the overall allometric equation was statistically significant (F=52.491, P < 0.000).

Table 49. Model description for the estimation of the above-ground biomass of 5 tree species in Gerba Dima forest

	N	Allometric equation	Coefficient		Standard error of the coefficient	Adjusted r^2	Residuals standard error	AIC	RMSE
			Symbol	Value					
Olea welwitschii	30	$\ln(AGB) = c + \alpha\ln(DBH) + \varepsilon$	c	1.662***	0.37479	0.889	0.347	25.60	0.335
			α	1.479 ***	0.09689				
Pouteria adolfi-friederici	30	$\ln(AGB) = c + \alpha\ln(DBH) + \varepsilon$	c	1.123***	0.26824	0.945	0.233	1.59	0.225
			α	1.462***	0.06545				
		$\ln(AGB) = c + \chi\ln(WD) + \varepsilon$	C	9.193***	0.9747	0.122	0.930	84.71	0.898
			χ	2.668 *	1.1901				
		$\ln(AGB) = c + \alpha\ln(DBH) + \chi\ln(WD) + \varepsilon$	c	1.806***	0.40937	0.951	0.2194	0.46	0.208
			α	1.419***	0.06504				
			χ	0.628 *	0.29600				
Elaeodendron buchananii	30	$\ln(AGB) = c + \alpha\ln(DBH) + \varepsilon$	c	1.337**	0.4182	0.863	0.271	10.73	0.262
			α	1.476 ***	0.1090				
		$\ln(AGB) = c + \beta\ln(H) + \varepsilon$	c	-1.308	1.329	0.5662	0.4818	45.25	0.465
			β	2.711***	0.435				
		$\ln(AGB) = c + \alpha\ln(DBH) + \beta\ln(H) + \varepsilon$	c	-0.062	0.70777	0.882	0.2512	7.09	0.238
			α	1.240 ***	0.14223				
			β	0.754*	0.31919				
Cassipourea malosana	30	$\ln(AGB) = c + \alpha\ln(DBH) + \varepsilon$	c	0.157	0.7702	0.6397	0.3061	18.03	0.296
			α	1.84 ***	0.2540				
		$\ln(AGB) = c + \beta\ln(H) + \varepsilon$	c	1.880	1.3356	0.2289	0.4557	41.91	0.440
			β	1.472 **	0.5104				
Vepris dainellii	30	$\ln(AGB) = c + \alpha\ln(DBH) + \varepsilon$	c	-0.391	0.6988	0.5686	0.4712	43.92	0.455
			α	1.725***	0.2839				
		$\ln(AGB) = c + \beta\ln(H) + \varepsilon$	c	1.7369	0.884	0.1683	0.6543	63.62	0.632
			β	1.2144*	0.510				
Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1									

Table 50. Analysis of Variance for best-fit model of *Cassipourea malosana*

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.918	1	4.918	52.491	0.000
	Residual	2.623	28	0.094		
	Total	7.541	29			

The regression analysis result for *Vepris dainellii* (Table 49) also revealed 2 simple linear statistically significant competitive models. The first model indicated below is selected as best-fit model.

$lnAGB = c + \alpha lnDBH + \varepsilon$, with the value of coefficients added the model becomes:

$$lnAGB = -0.391 \quad + 1.725 \times \text{lnDBH} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$(r^2 = 0.569, \varepsilon = 0.471, \text{AIC} = 43.92, \text{RMSE} = 0.455)$

Where AGB is in kg, DBH in cm.

The result of analysis of variance (Table 51) also shows that the overall allometric equation was statistically significant (F=2058.9, p<.000).

Table 51. Analysis of Variance for best-fit model of *Vepris dainellii*

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	4.918	1	4.918	52.491	.000
	Residual	2.623	28	.094		
	Total	7.541	29			

4.22. Development of biomass allometric models for shrub species

AGB of both shrub species was regressed against the explanatory variables of diameter at stamp height (DSH), Height (H) and Crown area(CrA) and five allometric models which show significant performance ($p < 0.05$) on their F-test and t-test was found for each species (Table 53). The various significant allometric models for each species were subjected to further test to choose the best-fit model. The result of regression analysis of *Maytenus gracilipes* (Table 53) reveals that 5 regression models were statistically significant. Model 1 is nested to model 4 and 5 while models 2 and3 are nested to models 3 and 4 respectively. Model 4 indicated below is selected as best-fit model.

$logAGB = \alpha logDSH + \beta logH + \varepsilon$, with values of coefficients inserted the model is:

$logAGB = 1.345 \times logDSH + 0.95 \times logH$ ………………………………… (6)

$(r^2 = 0.993, \varepsilon = 0.664, \text{AIC} = 64.531, \text{RMSE} = 0.642)$

Where AGB is in g, DSH in cm and H in cm.

The above multiple regression best-fit model selected to estimate the AGB of *Maytenus gracilipes* was investigated for the existence of multicollinearity between the explanatory variables and a VIFs value of 1.68 for each variable was calculated. The ANOVA result (Table 52) indicates that the overall allometric equation was statistically significant (F=2174.535, p<.000).

Table 52. Analysis of Variance for best-fit model of *Maytenus gracilipes*

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	362.062	2	181.031	2174.535	0.000
	Residual	2.331	28	0.083		
	Total	364.393	30			

Table 53. Model description for the estimation of the above-ground biomass of 2 shrub species in Gerba Dima

	N	Allometric equation	Coefficient		Standard error of the coefficient	Adjusted r^2	Residuals standard error	AIC	RMSE
			Symbol	Value					
Maytenus gracilipes	30	$\ln(AGB) = c + \alpha \ln(DSH) + \varepsilon$	C	5.286***	0.679	0.346	0.692	66.982	0.669
			α	1.806***	0.447				
		$\ln(AGB) = \beta \ln(H) + \varepsilon$	β	1.270***	0.021	0.992	0.740	70.035	0.727
		$\ln(AGB) = \chi \ln(CrA) + \varepsilon$	χ	0.683***	0.013	0.989	0.860	79.050	0.845
		$\ln(AGB) = \alpha \ln(DSH) + \beta \ln(H) + \varepsilon$	α	1.345**	0.477	0.993	0.664	64.531	0.642
			β	0.950***	0.115				
		$\ln(AGB) = \alpha \ln(DSH) + \chi \ln(CrA) + \varepsilon$	α	1.635**	0.539	0.991	0.759	72.515	0.733
			χ	0.47329***	0.070				
Psychotria orophila	30	$\ln(AGB) = c + \alpha \ln(DSH) + \varepsilon$	C	5.579***	0.337	0.597	0.400	34.065	0.386
			α	1.625***	0.245				
		$\ln(AGB) = c + \beta \ln(H) + \varepsilon$	C	6.090***	0.759	0.120	0.591	57.472	0.571
			β	0.280*	0.126				
		$\ln(AGB) = c + \chi \ln(CrA) + \varepsilon$	C	3.668**	1.003	0.352	0.507	48.271	0.490
			χ	0.375***	0.092				
		$\ln(AGB) = \alpha \ln(DSH) + \beta \ln(H) + \varepsilon$	α	2.160**	0.614	0.987	0.894	82.317	0.863
			β	0.796***	0.140				
		$\ln(AGB) = \alpha \ln(DSH) + \chi \ln(CrA) + \varepsilon$	α	0.969*	0.423	0.995	0.565	54.834	0.546
			χ	0.589***	0.053				

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

The regression analysis result for *Psychotria orophila* (Table 53) also revealed that 5 regression models were statistically significant. The first 3 models are nested to either of the last two complete models. From the last two multiple regression complete models, model 5 indicated below is the best-fit model in the estimation of the AGB of *Psychotria orophila*.

ln(AGB)= αln(DSH)+χ ln(CrA)+ ε, with the values of coefficient added the model becomes:

$$logAGB = 0.969 \times logDSH + 0.589 \times logCrA \text{ ....} \quad (7)$$

$(r^2 = 0.995, \varepsilon = 0.565, \text{AIC} = 54.834, \text{RMSE} = 0.546)$,

Where AGB is in g, DSH in cm and CrA in cm^2.

The ANOVA result in (Table 54) shows that the overall allometric equation was statistically significant (F=2831.989, P < 0.001).

Table 54. Analysis of Variance for best-fit model of *Psychotria orophila*

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	341.290	2	170.645	2831.989	0.000
	Residual	1.687	28	0.060		
	Total	342.977	30			

4.23. Evaluation of fitted models for tree and shrub species

The scatter plot of predicted and observed values showing the dispersion of the values were plotted using R program for all tree and shrub species by complementing with r^2 and RMSE statistics which add important information for model evaluation (Pineiroa *et* *al*, 2008). Among all best fitted models of tree and shrub species, highest r^2 value of (r^2 = 0.995) was obtained for *Psychotria orophila* and least was obtained for *Vepris dainellii* (r^2 = 0.569) (Fig. 18). Thus the r^2 value in the model developed indicate that a minimum of 56.9.1% and a maximum of 99.5% of the linear variation of observed values in AGB is explained by the variation of predicted values in AGB.

The highest RMSE value was obtained in *Maytenus gracilipes* (RMSE = 0.642) and the least in *Pouteria adolfi-friederici* (RMSE = 0.208). The Root Mean Square Error (RMSE) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. A smaller RMSE value indicates better model performance and hence the models developed in this study have better performance since their RMSE values are smaller.

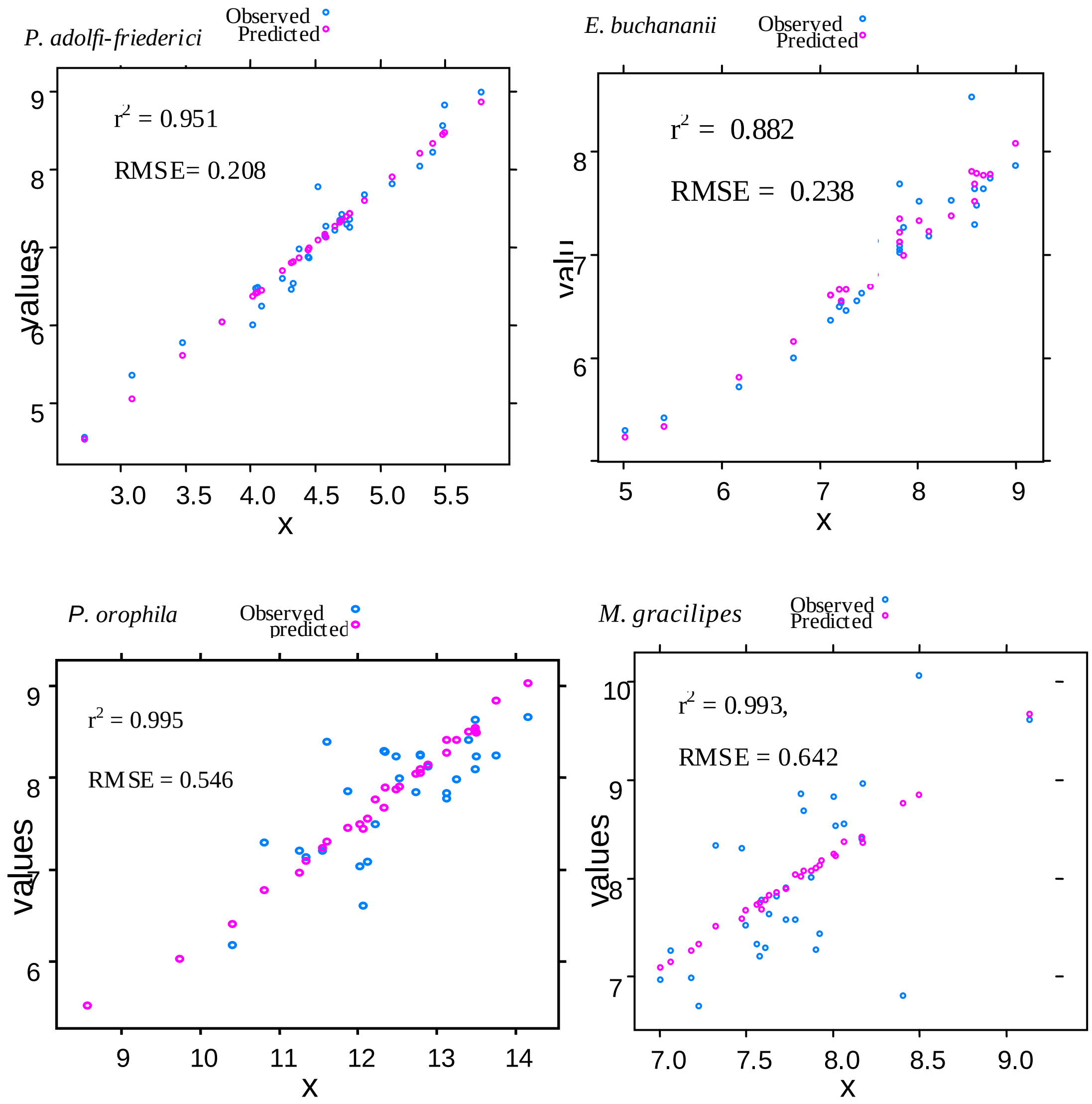


Figure 18. Scatter plot showing predicted and observed values of AGB

4.24. Model validation

The best-fit models developed for trees and shrubs have been validated by testing the regression assumptions. Model validation confirms that the model complies with underlying assumptions. All regression-type techniques are based on a series of assumptions, those of prime importance is the residuals are independent, residuals follow a normal distribution and residuals variance is constant(homoscedasticity). All the best-fit models developed for tree and shrub species fulfilled the regression assumptions as shown in sections below.

4.24.1. Testing the Independence Assumption

The Durbin-Watson statistical test was conducted for the occurrence of serial correlation between residuals which can be used to check the independence of residuals for all fitted models of tree and shrub species (Table 55). The highest value of 2.194 Durbin-Watson statistics was obtained in the model of *Maytenus gracilipes* while the least value 1.265 in the model of *Olea welwitschii.*

4.24.2. Testing the assumption of Normality and Homoscedasticity

To check that the residuals follow a normal distribution, we can plot a quantile-quantile graph and verify visually that the cluster of points forms a straight line. To check that the variance of the residuals is constant, we can plot the residuals against the fitted values and verify visually that the cluster of points does not show any particular trend (Picard *et al.*, 2012). Furthermore the scale-location plot and each points leverage plot were also constructed to check the homoscedasticity assumption and the existence of possible outliers respectively.

A quantile-quantile graph was plotted in R- software for fitted models of all species and visually verified that almost the cluster of points forms a straight line. Homoscedasticity characterized by a constant variance of the residuals was also checked by plotting the residuals against the fitted values in R software and visually verified that more or less the cluster of points does not show any particular trend (Fig 19). Figure 19 illustrates normality and homoscedasticity test for *Olea welwitschii* fitted model graphically and more or less similar pattern of graph was also obtained for the rest of the species.

Table 55. Durbin-Watson statistics for tree and shrub species

Name of species	Allometric model	Adjusted r^2	Durbin-Watson
Olea welwitschii	$\ln AGB = 1.662 + 1.479 \times \ln DBH$	0.889	1.265
Pouteria adolfi-friederici	$\ln AGB = 1.806 + 1.419 \times \ln DBH + 0.628 \times \ln WD$	0.951	1.942
Elaeodendron buchananii	$\ln AGB = -0.062 + 1.240 \times \ln DBH + 0.754 \times \ln H$	0.882	1.859
Cassipourea malosana	$\ln AGB = 0.157 + 1.84 \times \ln DBH$	0.640	1.998
Vepris dainellii	$\ln AGB = -0.391 + 1.567 \times \ln DBH$	0.569	1.926
Maytenus gracilipes	$\ln AGB = 1.345 \times \ln DSH + 0.95 \times \ln H$	0.993	2.194
Psychotria orophila	$\ln AGB = 0.969 \times \ln DSH + 0.589 \times \ln CrA$	0.995	1.750

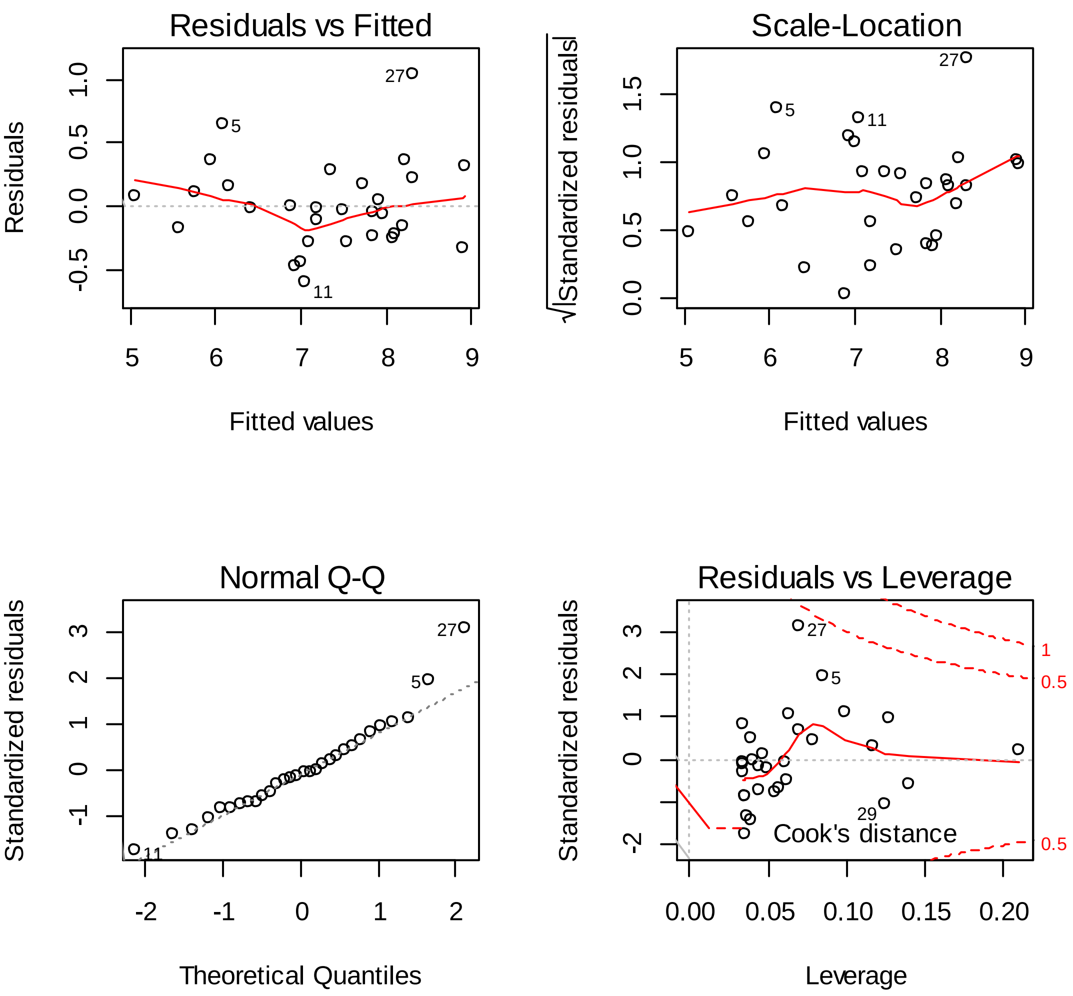


Figure 19. Residuals plotted against fitted values (upper-left), quantile–quantile plot (lower left), scale-location plot (upper - right) and plots for each point leverage (lower-right)for best fitted model of Olea welwitschii

CHAPTER FIVE

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. Floristic Composition and Diversity of Gerba Dima forest

The result of Species accumulation curve plotted for the species recorded in Gerba Dima forest showed that adequate numbers of plots were laid in the study forest. Species Accumulation Curve in adequately sampled study area levels off before the total number of sampling plots is reached. In ecological communities, the number of species increases with increasing area sampled. However, the rate of newly added species decreases with increasing sampling effort.

The result of this study revealed that Gerba Dima forest is rich in species composition as confirmed by the presence of 180 species in 145 genera and 69 families which constitute 3.1% of the flora of Ethiopia. The existence of diversified flora of Gerba Dima forest was in line with the general pattern of high species diversity in the tropical montane forests. According to Gentry (1995), tropical forests are among ecosystems that harbor high species diversity of the globe. East African montane forests of Ethiopia, Kenya, Tanzania and Uganda are among the most diverse and richest African regions with regard to flora composition and endemic plant taxa (Coetzee 1978; Tamrat Bekele 1993 and Lovett, 1998). Generally conducting a comparison of species richness of one forest with others is a very difficult task as there might be differences in forest size, data collection methodology and objectives of the studies. However, to give a general impression of the species richness of Gerba Dima Forest, the results of the present study were compared with results from other Moist Afromontane forests in Ethiopia.

The species richness of Gerba Dima forest is higher than some moist afromontane forest of Ethiopia such as Masha forest (130 species) (Abreham Assefa *et al.*, 2013), Belete forest (157 species) (Kflay Gebrehiwot and Kitessa Hundera, 2014), Gelesha forest (157 species) (Bilew Alemu *et al.*, (2015) , Agama forest (162 species) (Admasu Addi *et al.*, 2016) and more or less similar in species richness with some other moist afromontane forest of Ethiopia such as Komto forest (180 species) (Fekadu Gurmessa *et al.*, 2013) and Jibat forest (183 species) (Tesfaye Burju et al., 2013). However, the species richness of Gerba Dima forest was much lower than the values reported for few other moist afromontane forest of Ethiopia which include Bonga forest (243 species) (Ensermu Kelbessa and Teshome Soromessa, 2008), Yayu forest (220 species) (Tadesse Woldemariam *et al.*, 2008), Mana Angetu forest (212 species) (Ermias Lulekal et al., 2008) and Magada forest (197 species) (Genene Bekele and Reddy, 2015).

The difference in species richness among the compared forests could be attributed to the variations of forest sites with regard to geographical location, altitude, anthropogenic impact, rainfall and other climatic, physiographic and edaphic factors (Shmida and Wilson, 1985; Brockway, 1998). Climatic and physiographic factors have a wide range of effect on the diversity of plant species across the land escape whereas suitable environmental conditions and biotic factors influence diversity at the site level (Pausas and Austin, 2001; Tuomisto *et al.*, 2003). Species composition of forests is also influenced by regeneration success and competition among species (Chen et al., 2003).

Asteraceae, Acanthaceae, Rubiaceae, Fabaceae and Euphorbiaceae are the five dominant families which contribute more than 27% of the total species in the study forest. These dominant families were also reported as top ten species rich families in many Neotropical forests and Asia (Gentry, 1995). Except for Rubiaceae, these families are also among the top ten species rich families in the flora area (Ensermu Kelbessa and Sebsebe Demissew, 2014). The dominance of the above families together with Rubiaceae was also reported in other moist afromontane forests of southwestern Ethiopia (Ensermu Kelbessa and Teshome Soromessa, 2008; Abreham Assefa *et al.*, 2013 and Admasu Addi *et al.*, 2016). Thus, the dominance of these families in Gerba Dima forest was in agreement to their general dominance in flora area and tropical forests. The dominance of these families in the study area could be attributed to their successful colonization to the land escape owing to their efficient pollination, dispersal and germination mechanisms. For instance, many species of Asteraceae have umbrella shape structures adapted for air dispersal and increase their opportunity for their successful establishment (Hedberg, 1964).

Among the growth forms, herbs constitute more than 42% of recorded species. The prevalence of herbs could be attributed to the presence of canopy gap as a result of anthropogenic disturbance. Disturbance of forest in the form of selective cutting of trees favors the growth of herbaceous species in the forest understory. Under normal circumstances, the forest floor (herbaceous layer) of Afromontane rainforests is usually dark and poor in species composition owing to the closed canopy of the forest that prevents light from reaching the ground (Hedberg *et al.*, 2009).

The number of endemic species recorded in Gerba Dima forest 15 (8.3%) was higher than endemic species reported in other moist afromontane forests of southwestern

Ethiopia, for instance Bonga forest recorded 13 endemic species (5.35%) (Ensermu Kelbessa and Teshome Soromessa, 2008) and Yayu forest with only 3 endemic species (1.36%) (Tadesse Woldemariam *et al.*, 2008). However, the number of endemic species recorded in this study is lower than some dry Afromontane forest of Ethiopia, for example, Wofwasha forest 29 species (12%) (Demel Teketay and Tamrat Bekele, 1995); Chilimo forest 18 endemic species (8.45%) (Teshome Soromessa and Ensermu Kelbessa, 2013).

Generally, the proportion of endemic species in the Afromontane forest of Ethiopia is high ranging between 11-15% of the total plant species (Friis *et al.*, 2001). However, low endemicity is a common feature of moist Afromontane forests of southwestern Ethiopia due to the fact that moist forest of southwestern Ethiopia is much connected with the flora of adjacent countries such as southern Sudan and western Kenya which might cause in mixing up of species through different seed dispersal mechanisms (Friis *et al.*, 2001). Endemism might be the outcome of various mechanisms, but the main driving factors are the principle of geographical and ecological isolations (Kruckeberg and Rabinowitz 1985; Giménez *et al.* 2004).

Gerba Dima forest located in southwestern Ethiopia has been mapped in the floristic region of Ethiopia and Eritrea under Ilubabor floristic region. In this study, 37 species have been recorded as a new record for Ilubabor floristic region (IL). Due to lack of access, the flora of southwestern Ethiopia has been among the least explored in tropical Africa until recently (Friis *et al.*, 1982). The result of this study indicated that the vegetation of Ale, Didu and Becho districts of Ilu Ababora zone where Gerba Dima forest is located was not studied in detail and that the plant specimens were not exhaustively recorded and collected. Thus, the species data of this study might help for improving the flora books with regard to the distribution of plant species in various floristic regions.

The overall diversity analysis of Gerba Dima forest resulted in the higher mean value of Shannon diversity index (3.45) and evenness (0.93). The higher value of Shannon diversity index and evenness indicates that the study forest has high species diversity with more even distribution of the species within the study plots. The high Shannon diversity index in the study forest may be attributed to the relatively less disturbance and high evenness values. Species diversity increases when the populations have more even abundances and vice versa (Maguran, 1988). High Shannon evenness in the Gerba Dima forest indicates little dominance by any single species but the repeated coexistence of species over all plots or sites. Therefore, the implication of evenness values is that, when there is a high evenness value in a given forest, the location of conservation sites might not be of such importance compared to when the evenness value of the forest is low.

5.2. Community types in Gerba Dima forest

The output of Multi-response Permutation Procedures (MRPP) conducted in R software, resulting in T statistics having more negative value with significant P-value (T= -38.26, P< 0.001) and an agreement statistic A (0.13) confirming the distinctness of clusters. The test statistic T describes the separation between the groups. The more negative T value, the stronger the separation. The P-value associated with T is determined by numerical integration of the Pearson type III distribution. The P-value is useful for evaluating how likely an observed difference is due to chance (McCune and Grace, 2002). The agreement statistic A describes within-group homogeneity, compared to the random expectation, and falls between 0 and 1. When all items within-groups are identical A = 1 and 0 if the groups are heterogeneous. In community ecology, A values are commonly below 0.1, and an A value greater 0.3 is fairly high (McCune and Grace, 2002). From the result of this study, the null hypothesis of no difference among groups can be rejected. The five groups occupy different regions of species space, as shown by the strong chance correction within the group (A) and test statistic (T) and thus confirm the existence of 5 distinct plant community in Gerba Dima forest. The plant community can be defined as the collection of plant species growing together in a particular location that show a definite association or affinity with each other (Kent, 2012).

The idea of association is very important and implies that certain species are found growing together in certain locations and environments more frequently than would be expected by chance. Similarly, different combinations of species will be found together in other environments more frequently than would have been expected by chance. Most environments of the world support certain associated species which can, therefore, be characterised as a plant community (Kent, 2012).

In this study, the 5 communities identified were represented by the different number of indicator species exhibiting significant indicator value. Unfortunately, the indicator species with significant indicator values were not dominant species in their respective community and hence were not used in naming community types of the study forest. The major distinguishing feature of the identified plant communities in Gerba Dima forest is the difference in dominant and indicator plant species. It appears that species frequently show marked preferences for specific environmental conditions. Both the dominant and indicator species of each community are character species of the moist afromontane forest of southwestern Ethiopia (Friss, 1986; 1992).

In community 1 (*Croton macrostachyus - Bersama abyssinica* community type), *Prunus africana* and *Rubus apetalus* were indicator species for the community. *P. africana* is among the character species of moist afromontane forest in the middle canopy whereas *R. apetalus* among the associated scrambling shrubs in the afromontane forest (Friss, 1986; 1992). The dominance of *C. macrostachyus* might indicate the existence of this community under secondary stage of development following a major disturbance regime such as forest clearance for agriculture which leave few remnant tree species or intermediate disturbance regime such as selective cutting of canopy tree species for various purposes (Tamrat Bekele, 1993; Orwa *et al.*, 2009).

In Community2 (*Syzygium guineense - Olea capensis* community), *S. guineense* was the dominant species in the study site and also among the character species in the middle canopy of moist afromontane forest (Friss, 1986;1992) while *O. capensis* was the dominant species in the lower storey and *Flacourtia indica* was the indicator species with significant indicator value in this community. In community 3 *(Dracaena afromontana- Pouteria adolfi-friederici* community), P. *adolfi-friederici* is dominant species and the characteristic species of moist afromontane forest in the upper canopy whereas *D. Afromontana* was the other dominant species in this community and also among the characteristic species of moist Afromontane forest in the lower storey (Friss, 1986; 1992). *Elastostema monticolum* and *Pilea rivularis* were indicator species with significant indicator value in the herb layer of this community.

In community 4 (*Vepris dainellii - Schefflera abyssinica* community), *V. dainellii* and *S. abyssinica* were the dominant species of this community and they are also among the characteristic species in the lower and middle canopy of moist Afomontane forest respectively. *Sapium ellipticum*, *Trema orientalis* and *Ritchiea albersii* were indicator species with significant indicator value in this community and the first two are among the characteristic species in the middle layer of the moist afromontane forest while the later is in the lower storey (Friss, 1986; 1992). This community comprises of an important honey tree (*Schefflera abyssinica*) known for white honey and contributes to the income of the local communities in the area. In community 5 (*Albizia gummifera - Millettia ferruginea* community), *A. gummifera* and *M. ferruginea* are dominant species in this community and they are also among the characteristic species in the upper storey of moist Afromontane forest (Friss, 1986; 1992). Among the 4 indicator species with significant indicator value in this community, 3 of them were herbs and the other (*Urera hypselodendron*) was a liana which is also among the characteristic liana species of moist Afromontane forest (Friss, 1986; 1992). Indicator species are the most characteristic species of each group (community), found mostly in a single group of the typology, and present in the majority of the sites belonging to that group (Dufrene and Legendres, 1997).

The Shannon diversity index of communities in this study ranges from 3.98 to 4.39, indicating the existence of high diversity in the study forest. The values of the Shannon diversity index usually found to fall between 1.5 and 3.5 and only rarely exceed 4.5 (Kent, 2012). The five plant communities showed a slight variation in their species richness, diversity and evenness. Relatively community types 1, 2 and 5 were the richest with respect to species richness and diversity while community types 3 and 4 the lowest. The differences in species richness among the five communities could mainly be attributed to the dissimilarities of the communities in terms of location, altitude, human impact, rainfall, and other biotic and abiotic factors. According to Ellu and Obua (2005), different altitude and slopes influence species richness and dispersion behavior of tree species. Altitude and climatic variables like temperature and rainfall are also other determinant factors that affect species richness (Kharkwal *et al.*, 2005).

The higher species diversity in any community can be attributed to the amount of disturbance in the quadrats. Forest disturbances can affect species composition and diversity owing to their effect on the removal of some preferred species and also by changing the light environment of the understory species (Engelbrecht *et al.*, 2007). Disturbance in the form of deforestation has also been mentioned as a factor hampering natural regeneration and seedling establishment in tropical forests, and hence influences diversity and structure of plant communities (Bussmann, 2001).

The results of Shannon evenness index also indicated a slight difference in evenness among the identified plant communities. Species evenness shows the relative abundance of a species in quadrats. Low evenness value implies the dominance of the environment by few species. Based on this, communities 1 and 4 had the highest evenness value and the high evenness values observed in these communities could be attributed to the repeated coexistence of species over all plots but with little dominance by any single species in these communities.

The result of pairwise comparison of Sorensen’s similarity coefficient and beta diversity index in species composition between the five plant communities of Gerba Dima forest showed minor differences as confirmed from similarity coefficients of all communities compared ranged from 0.43 to 0.52. Communities with the highest species similarity (1 & 4) shared 72.2% of the total species while those with least species similarity (1 & 3) shared 51.7% of the total species. The magnitude of beta diversity indicates the change in species composition between adjacent plant communities along the environmental gradient. Similarity coefficients and beta diversity are inversely related. Therefore, communities with the highest similarity coefficients had the least beta diversity (0.48) (Community 1 and 4) and communities with the least similarity coefficients had the highest beta diversity (0.57) (communities 1 and 3; communities 2 and 3). The higher number of shared species between community 1 & 4 might be attributed to the narrow geographical distance between the two communities where most of the plots forming these communities may have relatively similar environmental factors (Terborgh and Andresen, 1998; Pyke *et al.*, 2001).

5.2.1. Plant community – Environmental variables relationship

Studies focusing on the relationship between plant communities and environmental variables have become increasingly important in understanding the ecology of forest communities (Smith, 1995; Olano *et al.*, 1998). Patterns of plant communities are determined by environmental factors that show variation over space and time, such as climate, topography, and soil, as well as anthropogenic disturbances (Alexander and Millington 2000; Whittaker *et al.*, 2003). The plants form a community when a plant species repeatedly appear in the similar environment. Similarly, it is the classification of plant community which temporally and spatially determines the boundaries of a plant community (Lee *et al.*, 2000). Each community has its own distribution area with a specific combination of environmental variables (Brinkmann *et al.*, 2009).

In the current study, the multivariate analyses (both Ordination and cluster analysis) were consistent in showing the patterns of floristic grouping within the studied forest and hence the two methods are complementary. In the Gerba Dima forest, the variation of plant communities was closely related to environmental factors, including Altitude, disturbance, Silt, Electrical conductivity, Organic matter, and Potassium, among which Altitude was the most important one.

From the result of RDA ordination, it has been found that most of the variation in the pattern of plant distribution was explained by RDA axis one. The position of each environmental arrow with respect to each axis indicates how closely correlated the axis is with the factor. Importance of components is in accordance with their first axis, where axis one is the most important in explaining the variation of patterns in species composition and the variation explained by higher axis decreases successively (Kent,2012). The eigenvalue for axis one was 10.65 which was higher than the eigenvalue of the second and successive higher axis. Cumulative proportion variance explained by the first five RDA axis of the joint biplot was 93.9%. From the proportion of variation explained by five RDA axes, more than 53.15% was explained by axis 1 and

2. This indicated that most of the variation in patterns of plant species distribution and plant community formation was explained by both axes. Axis one explained more than 30.24% of the variation in the patterns of plant species distribution and community formation, followed by axis two (22.91%) and the importance of higher axis in explaining the variation decreased successively.

Environmental variables highly correlated with axis one are mainly responsible for weighing axis. Axis one of the ordination diagram reflected mainly a gradient in altitude and potassium, i.e. these environmental variables were strongly correlated with axis one. Axis two reflected the gradient in disturbance. Axis three reflected a gradient of electrical conductivity. Axis four reflected the gradient in Disturbance while axis five was strongly correlated with OM. Comparatively, the gradient of altitude and potassium was highly correlated on axis one and gradient of disturbance in axis two. The other factors are correlated with the five axis with the different value of correlation.

The variable with the highest score (0.88) associated to axis one was altitude. Therefore, altitude was the most important variable in weighting axis one and to interpret or explain the axis. Similar studies conducted in other Afromontane forests of Ethiopia also confirm the importance of altitude as a major determinant of vegetation distribution along altitudinal gradients (Kumelachew Yeshitila and Tamrat Bekele, 2002; Haile Yeneger *et al.*, 2008; Tadesse Woldemariam *et al.*, 2008). Altitudinal change leads to changes in humidity, temperature, soil type, and other factors that influence the growth and development of plants which in turn determine the patterns of vegetation distribution (Austin *et al.*, 1996; Kikvidze et al 2006; Vittoz *et al.*, 2010).

Potassium followed by altitude was also the most important constraining variables in weighing axis one in the ordination. In the sandy soil, plant-soil feedback effects were most strongly correlated with potassium. Although most studies investigating abiotic plant-soil interactions have focused on nitrogen and phosphorus dynamics, in sandy soils with little clay content, potassium could be a limiting factor for plant growth (Tilman *et al.*, 1999; Kayser & Isselstein 2005). In particular, a growth of forbs can be highly dependent on potassium (Tilman *et al.*, 1999) and hence potassium at least affects the distribution of these species. In the same way, the disturbance was the most important variable in weighting axis two. Disturbance affects the distribution of plant community by hampering natural regeneration and seedling establishment in tropical forests (Bussmann, 2001). Disturbance also favors the growth of herbaceous plant species by improving the availability of light condition in the ground layer as it widens the canopy gap (Engelbrecht *et al.*, 2007) and thus affects the distribution of communities with these species.

The result of Pearson's product- moment correlation coefficient was used to show the correlation among environmental variables governing pattern of species distribution in plant communities of Gerba Dima Forest. There was a significant positive correlation between Altitude and Organic matter and the high amount of organic matter at higher altitude can be attributed to a low rate of decomposition due to relatively low temperature (Zhang 2005). The Low temperature at higher altitudes decreases the rate of mineralization of organic matter and hence leads to the accumulation of organic matter. High organic matter content in soils of higher altitude was also reported in other Afromontane forests of Ethiopia (Tamirat Bekele, 1994).

An analysis of variance (ANOVA) performed to see any significant variation among the community types of Gerba Dima forest with respect to non-collinear significant environmental variables indicated that the five community types differ significantly from each other with regard to EC and K. Similarly, result of Tukey's pair-wise comparison test indicates that community 4 and 1 differ significantly with respect to Disturbance and K while comunity 2 and 3 showed significant difference with respect to EC.

5.3. Vegetation structure of Gerba Dima Forest

Vegetation structure of Gerba Dima forest was analyzed by taking into consideration the concept of density, basal area, frequency, Important Value index and distribution of different height and DBH classes of trees. Density indicates the relative abundance of individual species in the study area. The result of this study indicate that out of 101 woody species, 65(64.4%) of the species are found in the lower density classes (A and B). Thus, most of the species (64.4%) of them were less abundant and contribute little to the total density of tree and shrub species in the study forest. The eleven most abundant species in the density class F which contributes 56.1 % of the total density include *Albizia gummifera, Deinbollia kilimandscharica, Dracaena afromontana, Hippocratea pallens, Lepidotrichilia volkensii, Maytenus gracilipes, Millettia ferruginea, Olea capensis, Oxyanthus speciosus, Pouteria adolfi-friederici* and *Vepris dainellii* (Annex.2).

Gerba Dima forest showed relatively high woody species density (1,826 individuals ha^{-1}) compared with some other Moist Afromontane forests such as Komto (952 individuals ha^{-1}) (Fekadu Gurmessa *et al.*, 2012), Jibat (702 individuals ha^{-1}) (Tesfaye Burju *et al.*, 2013), Belete (1482 individuals ha^{-1}) (Kitessa Hundera and Tsegaye Gadissa, 2008), Masha-Anderacha (1,709 individuals ha^{-1}) (Kumilachew Yeshitila and Taye Bekele, 2003). The difference in density among compared forest could be attributed to variations in topographic gradients and habitat preferences of species forming the forest, and the degree of anthropogenic disturbances (Whittaker *et al.*, 2003).

In this study, the ratio of DBH > 10cm to DBH > 20 cm (a/b ratio) indicates the predominance of small-sized individuals for some species whereas comparable distribution for others in the forest. The predominance of small-sized individuals in the forest was largely due to the high density of *Albizia gummifera, Millettia ferruginea* and *Vepris dainellii*. The ratio described as a/b is taken as the measure of size class distribution (Grubb *et al.*, 1963). The value of a/b ratio of Gerba Dima forest is comparable to the ratio obtained from Belete, Masha, Komto and Menna Angetu moist afromontane forests of Ethiopia but larger than Gelesha moist afromontane forests of Ethiopia. The proportion of small plants (DBH < 10cm) was much greater (68.34%) and this can indicate that Gerba Dima forest is in the secondary stage of development.

According to the result of this study, the basal area value of Gerba Dima Forest is very high (65.05 m^2/ha). The normal basal area value for virgin tropical forests in Africa is 23-37 m^2/ha (Lamprecht, 1989). *Schefflera abyssinica*, *Pouteria adolfi-friederici*, *Albizia gummifera*, *Ficus sur*, *Polyscias fulva* and *Croton macrostachyus* covered 61.4% of the total basal area. The basal area provides a better measure of the relative importance of the species than simple stem count (Cain and Castro, 1959). Thus, species with the largest contribution in the basal area can be considered the most important woody species in the study area. Accordingly, the above six species were the most important species in the study area. *Schefflera abyssinica* possesses low density but high BA due to its maximum average DBH value. Comparison of basal area of Gerba Dima Forest with 6 other moist afromontane forests of Ethiopia indicates that it is greater than that of Jibat and Komto forests. However, Gerba Dima forest has less basal area than the other 4 moist afromontane forests under comparison. This is due to the presence of individual tree species in Gerba Dima Forest with relatively higher DBH than Jibat and Komto forests and with lower DBH than the other 4 forests. This also indicates that the Gerba Dima Forest is found in an advanced stage of development than Jibat and Komto forests but in the lower stage of development than the rest 4 forests.

The frequency gives an approximate indication of the homogeneity and heterogeneity of a stand under consideration (Kent, 2012). In this study, 54 species (53.5%) are found in lower frequency class (A) and hence they are less frequent in the study forest. High values in higher frequency classes (D and E) and low values in lower frequency classes (A and b) indicate constant or similar species composition. On the other hand, high values in lower frequency classes and low values in higher frequency classes indicate a high degree of floristic heterogeneity (Lampriecht 1989). In this study, high values were obtained in lower frequency classes which showed the existence of a high degree of floristic heterogeneity in Gerba Dima forest. *Landolphia buchananii, Hippocratea pallens, Albizia gummifera, Millettia ferruginea, Tiliacora troupinii* and *Vepris dainellii* are the six most frequent species each occurring in more than 85% of the study plots and belong to frequency class E in Gerba Dima forest. The occurrence of most frequent species in the study forest could be attributed to usual occurrence of plant species at wide range of altitude, seed dispersal capacity, germination vigor, resistant to pests and pathogens, habitat preferences, adaptation, the degree of exploitation and availability of suitable environmental conditions for regeneration (Rey *et al.*, 2000).

In this study, *Schefflera abyssinica, Pouteria adolfi-friederici, Albizia gummifera, Vepris dainellii, Millettia ferruginea, Ficus sur, Croton macrostachyus, Syzygium guineense, Olea capensis and Dracaena afromontana* were the top ten species with the highest IVI value in decreasing order. Important Value Index (IVI) permits a comparison of species in a given forest type and depict the sociological structure of a population in its totality in the community. It often reflects the extent of dominance, occurrence and abundance of a given species in relation to other associated species in an area (Kent, 2012). It is also important to compare the ecological significance of a given species. Therefore, it is a good index for summarizing vegetation characteristics and ranking species for management and conservation practices. Important value index combines data for three parameters (Relative frequency, Relative density and Relative abundance). Curtis and Mcintosh (1951) pointed out that Important Value Index gives a more realistic figure of dominance from the structural point of view. It is useful to compare the ecological significance of species (Lampriecht, 1989). In the present study, the above ten species with higher IVI values were abundant, frequent and dominant in Gerba Dima forest.

The result of the vertical structure of Gerba Dima forest indicates that the lower storey contains the highest density of stems but the upper storey was represented by the lowest density of stems. Similarly, more species were found in the lower and middle storey but fewer species in the upper storey. Hence, the result still confirms the dominance of small-sized individuals in the forest, indicating secondary developmental stage of the forest. A similar result was reported in other moist Afromontane forests of Ethiopia (Ensermu Kelbessa and Teshome Soromessa, 2008; Fekadu Gurmessa *et al.*, 2012). The vertical structure of the forest could be influenced by the characteristics of the physical environment (Kent, 2012) and the microclimate (*Grubb et al.*, 1963; Stoutjesdijk and Barkman, 1992). The ability of species in the lower storey to grow under the canopy layer is determined by the condition of the soil, the species of vegetation, and the quantity of sunlight received by the lower vegetation layer due to the opening and closing rate of the crown (Morsdorf and Marell, 2010).

In this study, the overall height and DBH class distribution of all individuals in different size showed an inverted J- shape distribution. This general pattern demonstrates that the majority of species had the highest number of individuals at relatively low DBH and height classes with a gradual decrease towards both high DBH and height classes. This pattern is an indicator of healthy regeneration of the forest and species and shows a good reproduction and recruitment capacity (Silvertown and Doust, 1993). A significant proportion of individuals in Gerba Dima forest (i.e, > 52.61%) were found in height class 2-5 m. Only few individuals (< 0.18 %) attain heights of greater than 30 m. DBH distribution of woody species in the study forest also revealed that most of the individuals, i.e., about 87%, were in the DBH class ≤ 20 cm, and a very small proportion (i.e., 1.47%) reached DBH greater than 80 cm.

Information on the population structure of a tree species indicates the history of the past disturbance to that species and the environment and hence, used to forecast the future trend of the population of that particular species (Peters, 1996). Population structure is an extremely useful tool for orienting management activities and perhaps most important for assessing both the potential of a given resource and the impacts of resource extraction (Peters, 1996). However, the overall population structure pattern of the study forest does not show the general trends of population dynamics and recruitment processes of a given species. Thus, to understand the population dynamics of individual tree species and to obtain more realistic and specific information for conservation endeavors, analysis of population structure for individual tree species were conducted.

Investigation of population structure based on DBH classes for individual tree species in Gerba Dima forest revealed 6 different distribution patterns. The difference in the patterns of species population structure can be interpreted as an indication of variation in population dynamics and regeneration status in the forest. The first pattern which shows an inverted J-shaped distribution was represented by *Albizia gummifera*. Species in this distribution pattern had a high number of individuals in the lower DBH class and with gradual decreases towards higher DBH classes. This pattern is an indicator of stable population status or healthy regeneration of the species and shows a good reproduction and recruitment capacity (Harper, 1977; Silvertown, 1982). Dead adult plants would be easily replaced by plants in small size class and hence plant population with this distribution pattern seems to be self sustaining.

The second pattern represented by *Croton macrostachyus* showed an increase from DBH class one to DBH class two and followed by gradual decrease towards the higher DBH classes. The reason for relatively fewer individuals in DBH class one than in DBH class two may be due to selective cutting of individuals in DBH class 1. The third pattern is a

U- shaped distribution pattern represented by *Ficus sur*. A U-shaped pattern indicates selective cutting and removal of medium-sized trees most likely for house construction, bee hives or farm tools. The fourth pattern is an irregular shape with a high number of individuals at lower DBH classes but becomes irregular towards higher classes. This pattern indicates a good reproduction but discontinuous recruitment. The fifth pattern is bell-shaped and represented by *Ilex mitis*. In this distribution pattern, the number of individuals in the middle diameter classes is high and lower in lower and higher diameter classes. This pattern indicates a poor reproduction and recruitment of species, which may be associated with the overharvesting of seed bearing individuals. Selective cutting of large-sized individuals for various purposes, mainly timber for construction, could also be the reason for a decline in the number of large-sized trees. The six pattern represented by *Sapium ellipticum* represent abnormal population dynamics and show poor reproduction and hampered regeneration due to the fact that either most trees are not producing seeds due to age or there are losses due to predators after reproduction

5.4. Regeneration status of Gerba Dima forest

The status of regeneration of species can be determined based on population size of seedlings and saplings (Shankar, 2001). Good regeneration, i.e. if particular species is present in seedling > sapling > tree; fair regeneration, i.e. if species present in seedling > sapling < tree; poor regeneration, i.e. if a species survives only in sapling stage, but not as seedling; if a species is present only in adult form it is considered as not regenerating. A species is considered as not abundant if the species has no tree representatives, but only saplings and/or seedlings (Shankar, 2001). Based on the density of seedling, sapling and mature trees, 5 distribution pattern of regeneration status was observed in Gerba Dima forest.

The first distribution pattern of regeneration status showed good regeneration and recruitment potential. The presence of good regeneration potential confirms the stability of the species to the environment. Higher seedling density values get reduced to sapling due to biotic disturbances and competition for space and nutrients (Dhaulkhandi *et al.*, 2008). This regeneration status pattern also indicates the possibility of replacement of mature plants in the future and hence shows relatively better regeneration status. The second pattern of regeneration represents fair regeneration and recruitment of the species. The third distribution pattern of regeneration status which shows small density value of seedling species, higher value of sapling followed by smaller value of seedling density, exhibited poor regeneration pattern probably due to poor stocking, adverse conditions in the forest, continuous and selective cutting and human disturbance in the form of livestock grazing and trampling (Demel Teketay and Granstom, 1995). Prevention of livestock grazing and overexploitation could improve the regeneration status of woody species under this regeneration status. Species in the fourth pattern of regeneration status are not regenerating since they survive only at adult or mature tree level (Dhaulkhandi *et al.*, 2008). Thus, this situation calls for conservation and management action to sustain their life by giving them time to rejuvenate themselves from seed deposited in the soil. However, even though species like *Schefflera abyssinica*, *Ficus thonningii* and *Urera hypselodendron* exhibits this pattern of regeneration, it is difficult to conclude that these species were not regenerating. The main reason is, these are epiphytic plants which grow from their seedling germinating on other tree species and finally overwhelm the host tree to become an independent tree and hence the seedling and sapling stages are not visible on the ground (Abrham Abiyu *et al.*, 2013). The fifth regeneration status pattern represented by the low density of matured trees, high density of sapling but with a complete absence of seedlings also indicates poor regeneration capacity and requires conservation and management schemes so as to extend the life of those species.

5.5. Carbon stock in woody species of Gerba Dima Forest

The highest average carbon stock which accounts for about 66% of the total ABG carbon was stored in descending order by *Pouteria adolfi-friederici, Schefflera abyssinica, Albizia gummifera, Ficus sur, Millettia ferruginea, Syzygium guineense, and Croton macrostachyus*. These were the dominant species which exhibit higher basal area in the study forest. Thus, the plant species represented by individuals with larger DBH have a significant contribution to the carbon storage in this forest and their removal significantly alters the biomass dynamics of the forests. Bigger trees with higher diameter store the largest stocks of carbon within biomass and are often impacted by forest degradation and deforestation (Gibbs *et al.,* 2007). Similarly, the highest amount of ABG and BG carbon per single tree was stored in *Ekebergia capensis* while the least in *Vernonia rueppellii* attributed to their mean maximum and minimum DBH in the study forest

The AGC and BGC in Gerba Dima forest were higher than values reported by IPCC (2003; 2006) for tropical forests. The higher average carbon stock in above ground biomass (243.85 t ha^{-1}) in the study site could be related to the higher tree height, DBH and basal area in the forest. Tree species like *Pouteria adolfi-friederici* reached as tall as 45m and the basal area of this forest was 65.05 m^2/ha which is higher than the normal basal area value for virgin tropical forests in Africa (23-37 m^2/ha) (Lamprecht,1989). The mean litter carbon stock in Gerba Dima forest (0.026 t ha^{-1}) was lower than 2.1 tones ha^{-1} values reported for tropical forests (IPCC 2003). Since the study area is located in tropical areas, the rate of decomposition is relatively fast (Fisher and Binkly, 2000). Hence, the lowest carbon stock in litter pool could probably be due to the high rate of litter decomposition. The accumulation of litter is a function of the annual amount of litter fall, which includes all leaves, twigs and small branches, fruits, flowers, and bark, minus the annual rate of decomposition. The litter mass is also influenced by the time of last disturbance, and the type of disturbance. During the early stages of stand development, litter increases rapidly. Management such as timber harvesting, slash burning, and site preparation dramatically alters litter properties (Fisher and Binkley, 2000).

The mean carbon stock of herb layer in Gerba Dima forest was very low (0.007 t ha^{-1}) compared with the herbaceous mean carbon stock of tropical forest in Eastern Panama (0.11 tha-^{1}) (Kirby and Potvin, 2007). The decrease in the amount of carbon stock in herbaceous layer of the study forest may be attributed to the shading effect of the canopy trees which reduce light penetration and can also affect physical and chemical soil properties for the growth of herb and grasses (Engelbrecht *et al.*, 2007). The mean SOC of Gerba Dima Forest was (292.13 t ha^{-1}) larger than mean SOC of Tropical & Subtropical Moist Broadleaf Forests (57 t ha^{-1}) (Henry *et al.*, 2009). The variation of SOC between different vegetation types could be attributed to the presence of different tree species, soil nutrient availability, climate, topography, disturbance regime, the number of soil profiles considered, the soil layer that are considered and method employed to detect the amount of SOC (Houghton, 2005; Henry *et al.*,2009). The amount of organic matter and soil carbon stock is an outcome of the balance between inputs (mostly from biomass detritus) and outputs to the system (mostly decomposition and transport), which are driven by diverse parameters of natural or human origins (Schlesinger and Palmer Winkler, 2000; Amundson, 2001).

The mean carbon stock in all carbon pool of the study site was 586.73 t ha^{-1} which was higher than the average value of tropical forests. According to IPCC (2006), biome-average tropical forest carbon stock estimates of the sub-Saharan Africa tropical equatorial forest, tropical seasonal forest and tropical dry forest are 200, 152 and 72 t ha^{-1} respectively. Hence, the average total carbon stock of Gerba Dima forest was higher than the aforementioned tropical forests. The variation in carbon stock between different forest types could be attributed to imprecise measurements of tree variables, inefficiency of allometric models, the presence of bigger sized trees with a higher basal area, a higher density of woody species and anthropogenic disturbance (Lasco *et al.*, 2000)

Comparison of the different carbon pools of the study site indicates that SOC pool is the highest carbon pool followed by AGC pool. However, the contribution of herbaceous, litter and non-tree woody vegetation carbon pools were insignificant. The predominance of soil organic carbon pool in the forest ecosystem is confirmed by various scholars across the globe. Soil is the largest pool of organic carbon (C) in the biosphere, containing over 2300 Pg of carbon in the top three meters (Jobbagy and Jackson, 2000). In most ecosystems, carbon stored in soils is higher than in the aboveground biomass (White *et al.* 2000). The proportion of SOC in Gerba Dima forest (49%) was within the range commonly reported for tropical forests. In tropical forests, the proportion of carbon stored in soil carbon pool ranges between 36–60% (Don *et al.*, 2011).

The result of correlation analysis among the various carbon pools indicated a significant positive correlation between AGC and BGC, NTWSC and Carbon stock in the litter, SOC and Carbon stock in Herb, SOC and NTWSC. The positive correlation between AGC and BGC is obvious since BGC was calculated from AGB. Statistically significant positive correlation between NTWSC and SOC as well as herbaceous carbon stock and SOC can be explained with the fact that herbs and NTWS are either annuals or short-lived perennials which die and mixed with soil frequently to enrich the SOC pool.

From the result of correlation analysis between the various carbon pools of Gerba Dima forest and environmental variables, the positive significant correlation between AGC and Diversity as well as BGC and Diversity could be attributed to the fact that more diverse plant communities have a higher chance of including highly productive species that dominates the community (Tilman *et al.*, 1996; Huston, 1997; Loreau, 1998). This condition can be further explained by the complementarity and selection effects which are mechanisms of the positive effects of diversity on ecosystem functioning (Grime, 1998; Loreau & Hector, 2001). The complementarity effect increases ecosystem function through facilitation and niche partitioning because functionally diverse species assemblages would enhance resource use efficiency and nutrient retention (Loreau, 2000; Morin *et al.*, 2011). The selection effect (i.e. selection of particular species or functional traits) ensures that high species diversity increases the probability of including the most productive species which will become dominant in the community. Both complementarity and selection effects simultaneously underlie the net positive effect of biodiversity on ecosystem function including carbon stock accumulation (Tilman *et al.*, 1996; Mokany et al., 2008).

The result of this study revealed that AGC, BGC and NTWSC were negatively correlated with disturbance and such pattern of correlation clearly confirmed that forest disturbance reduced the capacity of the forests to sequester carbon. Disturbances also alter the forest productivity, may release C directly into the atmosphere and transfer large amounts of C from biomass into detritus, soils or forest products (Gardner *et al.*, 1996). With increasing disturbance frequency, a greater proportion of the forest is found in younger age classes. Young and immature stands in the landscape contain less C than mature stands (Apps and Kurz, 1993).

In Gerba Dima forest, SOC and DWC were positively correlated with altitude. The effect of elevation was complex and was probably indirect. Generally, temperature decreased and precipitation increased with increasing altitude. The changes in climate along altitudinal gradients influence the composition and productivity of vegetation and, consequently, affect the quantity and turnover of SOM (Garten *et al.*, 1999; Hontoria *et al.*, 1999; Quideau *et al.*, 2001). The decline in temperature accompanied with an increase in elevation could reduce SOC and DWC turnover rates, leading to increases in SOC and DWC levels (Leifeld *et al.* 2005). Generally, SOC is significantly higher in areas where the precipitation is greater. Higher precipitation is generally associated with higher rates of vegetation growth, and thus, with higher rates of organic carbon input and SOC accumulation.

Comparison of the carbon stock of various pool of the study forest with 5 other forests in Ethiopia, default values of tropical forest and a forest in Australia revealed that total carbon stock, AGC and BGC of Gerba Dima Forest were more or less similar to Gedo, Egdu, Deneba and SMNP forests. The AGC in Gerba Dima forest was greater than Anbesa, tropical wet, tropical moist, tropical dry and tropical montane forests. However, AGC of Gabra Dima forest was less than the forest in Gergeda and highland of Victoria in south eastern Australia. The litter carbon stock of Gerba Dima forest was more or less similar with SMNP while less than Gedo, Egdu, Danaba, Gergeda and Anbessa forests. The SOC of Gerba Dima forest was almost similar with Egdu and SMNP forests but greater than Gedo, Danaba, Gergeda and Anbessa forests. The differences in carbon stock among the compared forests could be attributed to variations in age of the trees, management of the forests, the allometric model used (Lasco *et al.*, 2000), regional variability in soil, topography, the existing species height and DBH range of trees that few large individuals can account for large proportion of the plots above and below ground carbon (Brown & Lugo, 1982).

5.6. Fitting Allometric Regression Models

Correlation between the independent and dependent variables was conducted to have a clue on best explanatory variables which might be selected to develop regression model. The above ground biomass was strongly correlated with DBH for four studied trees species while moderately correlated for *Vepris dainellii*, indicating DBH is the most influential factors affecting the biomass of the trees. Height is second important factor correlating with biomass showing a strong correlation in *Olea welwitschii* and *Elaeodendron buchananii,* moderate correlation in *Pouteria adolfi-friederici* and *Cassipourea malosana* and poor correlation in *Vepris dainellii*. The biomass of all 5 tree species was poorly correlated with wood density. Thus, if there is no multicollinearity between DBH and H, the combination of these two variables might give the best regression model in the four tree species except *Vepris dainellii*. In case of the two shrub species, all the explanatory variables were moderately correlated with response variables and thus their combination can give the best regression model in the absence of multicollinearity. Conducting correlation test between response and explanatory variables is an important step to select an appropriate explanatory variable and to develop the best-fit regression model (Maraseni *et al.*, 2005).

In the process of model fitting conducted to select the best-fit model for *Olea welwitschii,* only one allometric model showed significant performance ($p < 0.05$). The overall regression accuracy of the allometric model for *O. welwitschii* was given by a very high value of Adjusted R-squared (0.889). This shows that 88.9% of the variance of the output variable which is aboveground biomass AGB is explained by the variance of DBH input variables. The value of the adjusted R-squared value (0.889) also shows that the overall significance of the model is 88.9% significant in predicting the aboveground biomass. The rest, 11.1% of the variability of the AGB is explained by other factors. The ANOVA result also showed that this model is statistically sound ($F=233.087$, $P <0.001$).

Model fitting for *Pouteria adolfi-friederici* involves choosing the best model among the 3 statistically significant candidate models. The third complete model is selected against the first two nested models since the p-values of coefficients of the complete model are significant ($p < 0.05$). In the case of nested models, a statistical test can be used to test one of the models against the other. The null hypothesis of this test is that $\theta = 0$, i.e. the additional terms are not significant, which can also be expressed as the nested model is better than the complete model. If the p-value of this test proves to be below the significance level (typically 5 %), then the null hypothesis is rejected, i.e. the complete model is best. Conversely, if the p-value is above the significance threshold, the nested model is considered to be the best (Picard *et al.*, 2012).

Since the best-fit model selected for *P. adolfi-friederici* involves two predictor variables, the absence of multicollinearity was also checked using Variance Inflation Factors (VIF) in R-program. The VIF values obtained was 1.8 for each predictor variables and this value assures that multicollinearity is not a problem in this model. A strong correlation between independent variables causes ‘strong multicollinearity’ by which the true effect of estimated regression coefficients would be lost. The general rule of thumb is that VIFs exceeding 4 warrant further investigations, VIFs exceeding 10 are signs of serious multicollinearity requiring correction while VIFs less than 4 indicates an absence of multicollinearity problem (Belsley *et al.*, 1980).

The overall accuracy of the model is 95.11% with an overall p-value < 0.001, in this model the Adjusted R-squared (0.9511) is closer to 1, showing that 95.11% of the variability of the above ground biomass is explained by this model. The ANOVA test conducted also shows that the overall allometric equation was found to be statistically significant ($F=283.042$, $P < 0.001$).

In case of *Elaeodendron buchananii*, model fitting involves selecting the best-fit model from the three statistically significant candidate models. The complete model 3 was selected against the nested models 1 and 2 as the p-values of coefficients of the complete model were significant ($p < 0.05$). The model selected for *E. buchananii* has adjusted r^2 value of 0.882 which showed that 88.2% of the variability of the above ground biomass is explained by this model. Since the model selected have two independent variables, multicollinearity test was conducted and each predictor variables exhibit a VIFs value of 2.1 which confirms that multicollinearity cannot reduce the predictive power of the model. The ANOVA test carried out also shows that the overall allometric equation was found to be statistically significant (F=109.407, $P < 0.001$).

For *Cassipourea malosana,* among the two statistically significant simple linear regression models, the first one is selected as a best-fit model since it has relatively higher r^2, lower AIC and RMSE values. The Root Mean Square Error (RMSE) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. The RMSE values can also be used to compare the individual model performance to that of other predictive models and a smaller RMSE value indicates better model performance. The best-fit model of *C. malosana* has r^2 value of 0.664. This shows that 66.4% of the variance of the output variable (lnAGB) is explained by the variance of ln (DBH) input variables. The ANOVA test also shows that the overall allometric equation was found to be statistically significant (F=52.491, $P < 0.001$).

Two statistically significant candidate models have computed in *Vepris dainellii* and the first model is selected as the best-fit model since it has a higher value of r^2 and a lower AIC and RMSE values. The best-fit model of *Vepris dainellii* has r^2 value of 0.569

showing that 56.9% of the variance of the output variable ln (AGB) is explained by the variance of ln(DBH) input variables and the rest of the variation may be by chance. The analysis of variance (table 39) also shows that the overall allometric equation was found to be statistically significant (F=2058.9, p<.000).

For *Maytenus gracilipes* model fitting involves selecting the best-fit model among the five statistically significant candidate models. The result of regression analysis reveals that model 1 is nested to model 4 and 5 while models 2 and3 are nested to models 3 and 4 respectively. Since the coefficients in the complete models are statistically significant, the first 3 nested models are rejected. Thus, the choice for the best-fit model was conducted between model 4 and 5. Eventually, model 4 is selected as the best-fit model for the reasons attributed to its higher adjusted r^2 values and lower values of AIC and RMSE.

The multiple regression best-fit models selected to estimate the AGB of *M. gracilipes* was investigated for the existence of multicollinearity between the explanatory variables and a VIFs value of 1.68 for each variable was calculated which further confirms the quality of the model selected. The analysis of variance test also reveals that the overall allometric equation was found to be statistically significant (F=2174.535, p<.000).

For *Psychotria orophila*, among the 5 computing candidate models, the first 3 models are nested to either of the last two complete models. As the coefficients in the complete models 4 and 5 are statistically significant, they are considered as better models than the other 3 nested models. From the last two multiple regression complete models, model 5 is the best-fit model in the estimation of the AGB of *P. orophila* as it has relatively high adjusted r^2 and least AIC and RMSE. The best-fit model of *P. orophila* has adjusted r^2 value of 0.995 showing that 99.5% of the variability of the above ground biomass is explained by this model. The ANOVA test also confirms that the overall allometric equation was found to be statistically significant ($F=2831.989$, $P < 0.001$).

5.7. Model validation

The best-fit regression models developed were validated based on a series of assumptions, those of major importance is the residuals are independent, residuals follow a normal distribution and residuals variance is constant (homoscedasticity). Violation of these assumptions may result in biased parameter estimates and type I errors (Quinn & Keough 2002; Picard *et al.*, 2012).

The Independence Assumption was tested by Durbin-Watson statistics which has values ranging between 0 and 4. However, the residuals are considered not correlated (independent) if the Durbin-Watson statistic is between 1.5 and 2.5 (Field, 2009). The Durbin-Watson statistics of models for all species is less than 2.5, indicating that the residuals for all models are uncorrelated; therefore, the independence assumption is met in this study.

Regression analysis assumes that the errors, which are the residuals between the actual score and the estimated score obtained through the regression equation, are independent and there is no serial correlation (Stevens, 2009). Having no serial correlation between the residuals implies that the size of the residual for one variable has no impact on the size of the residual for another variable. Therefore, the independence assumption requires that the variables and residuals are independent and the subjects are responding independently of each other (Stevens, 2009). The independence assumption is a significant assumption that should be investigated prior to any interpretation of multiple regression analysis, as violation of this assumption could hold critical implications (Stevens, 2009). Even a slight violation of the independence assumption should be taken seriously, as it can greatly increase the risk of Type 1 error, resulting in the risk of falsely rejecting the null hypothesis several times greater than the level of error assumed for the test (Stevens, 2009).

The assumption of normality and homoscedasticity was tested by thoroughly investigating a quantile-quantile graph (Q-Q plot) and the residuals against the fitted values plot developed for all species (Fig. 19). The residual errors plotted versus their fitted values for the best-fit model of all species indicated that the residuals are randomly distributed around the horizontal line representing a residual error of zero; that is, no distinct trend in the distribution of points is observed and confirms the homoscedasticity assumption of the model. The standard Q-Q plot of all best-fit models also suggests that the residual errors are normally distributed.

The scale-location plot for all models shows the square root of the standardized residuals (sort of a square root of relative error) as a function of the fitted values. Again, there is no any obvious trend in this plot which further confirms the absence of heteroscedasticity. Finally, the plot in the lower right (Fig. 19) shows each points leverage, which is a measure of its importance in determining the regression result. Superimposed on the plot are contour lines for the Cook’s distance, which is another measure of the importance of each observation to the regression. Smaller distances mean that removing the observation has little effect on the regression results. Distances larger than 1 are suspicious and suggest the presence of a possible outlier or a poor model. In this study, all models exhibit Cook's distance of less than 1 which confirms the absence of possible outliers.

Screening for normality is an important early step when conducting multiple regressions, as residuals are normally distributed is assumed (Stevens, 2009; Tabachnick & Fidell, 2006). Non-normal distributions that are positively or negatively skewed, contain large kurtosis or have extreme outliers which can distort the obtained significance levels of the analysis, resulting in the standard errors becoming biased (Osborne & Waters, 2002).

The assumption of homoscedastic indicates that the variance of errors is equal and constant across all levels of the variables (Osborne & Waters, 2002; Stevens, 2009). Homoscedasticity is related to the assumption of normality because when the assumption of normality is met, the relationship between the variables is homoscedastic (Tabachnick & Fidell, 2006). Heteroscedasticity occurs when the variance of errors differs at different values of the independent variables (Osborne & Waters, 2002). Slight heteroscedasticity has little effect on significance tests; however, when heteroscedasticity is marked it can lead to serious distortions of findings and seriously weaken the analysis thus increasing the possibility of a Type 1 error for small sample size (Osborne & Waters, 2002).

5.8. Conclusion

Description of floristic diversity of species in Gerba Dima forest revealed the presence of high species diversity and richness. Of the species recorded in this forest, 15 (8.3%) species were endemic to Ethiopia. However, the percentage of endemic species in the study forest is lower than the proportions generally expected in Afromontane forest of Ethiopia and this is attributed to the low endemicity feature of forests in Southwestern Ethiopia. The presence of endemic plant species in the study forest shows the potential of the area for biodiversity conservation. Around 37 plant species were newly recorded in the floristic region from the study forest which indicates that the floristic region was not studied in detail and the plant specimens were not exhaustively recorded and collected so that further exhaustive botanical exploration would result in additional new records in the floristic region. In this study, 5 community types were identified and altitude was the major environmental variable in determining the community types.

Structural analysis and assessment of regeneration status of woody species in Gerba Dima forest showed that the overall ecological condition of the forest was healthier. However, structural analysis and assessment of regeneration of some species revealed that there are species which exhibit abnormal population structure and abnormal pattern of regeneration. This abnormal pattern could be attributed to poor stocking, adverse conditions in the forest, continuous and selective cutting and human disturbance in the form of livestock grazing and trampling.

The average carbon stock and the amount of carbon sequestered by this forest are also very high. Comparison of the different carbon pools of the study site indicates that SOC pool is the highest carbon pool followed by AGC pool. However, the contribution of herbaceous, litter and non-tree woody vegetation carbon pools were insignificant. The various carbon pools showed a significant correlation to different environmental variables. AGC and BGC pools were positively correlated with species diversity while disturbance negatively affects the carbon stock of these pools. The species-specific and area specific allometric models developed for dominant tree and shrub species have good quality as evaluated by testing the regression assumptions. Among the regression models developed for 5 tree species, DBH was the only predictor in the estimation of the Above ground biomass in 3 species while wood density and height are additional predictors of the AGB together with DBH in *P. adolfi-friederici* and *E. buchananii* respectively. In *M. gracilipes,* DSH and H in *P. orophila* DSH and CrA are explanatory variables for the estimation of AGB.

5.9. Recommendations

Based on the results of this study the following recommendations are forwarded to wisely use and conserve Gerba Dima forest in a sustainable manner.

- The existence of high species diversity and a number of endemic plant species in the study forest shows the potential of the area for biodiversity conservation. Thus, all Stakeholders including Oromia Forest and wildlife enterprise (OFWE) and the regional government should work to designate the forest as a biosphere reserve and being registered under UNESCO.
- An attempt should be made by OFWE, local and regional government bodies to link the Sor waterfall, an eco-tourism site found in the study forest with effective

conservation measures of the forest so as to boost the income generated from eco-tourism and sustainably conserve the natural vegetation and heritage sites.

- The occurrence of abnormal population structure and abnormal pattern of regeneration in some plant species call for conservation and management of these species. Thus, establishing nursery sites to grow threatened species in the area and re-afforestation with threatened indigenous trees should be encouraged so as to save this species from extinction at the local level.
- Prevent livestock grazing and illegal logging in the forest in order to promote the natural regeneration process of many species by designing appropriate policy and strategy.
- The participatory forest management scheme established by Farm Africa in the study area should be strengthened by linking with non wood forest product income generating activities like production of forest organic coffee, spices, poultry, modern apiculture, improved fruit and vegetables varieties to enhance livelihood diversification of the community and reduce the pressure on the natural forest through the involvement of the local community and government bodies at local level.
- Awareness creation and training on ecosystem services and wise use of the forest resource on sustainable manner should be given to the local community by relevant stakeholder.
- The REDD+ office working in the study area can use the estimated C- stocks of the study forest as a reference for the implementation of carbon credit systems project that will be conducted in the area.

- The allometric models developed for selected tree and shrub species can be used if carbon stock estimation will be conducted in the area.
- Develop allometric equations for the rest of the species and general regression model for the entire Gerba Dima forest in order to estimate the carbon stock of the forest precisely in the future.

REFERENCES

Abreham Assefa, Sebsebe Demissew and Zerihun Woldu (2013). Floristic composition, structure and regeneration status of Masha forest, south-west Ethiopia. *Afr. J. Ecol.* **52**: 151–162.

Abrham Abiyu, Georg Gratzer, Demel Teketay, Glatzel, G. and Aerts, R. (2013). Epiphytic recruitment of *Schefflera abyssinica* (A. Rich) Harms. and the role of microsites in affecting tree community structure in remnant forests in northwest ethiopia. *SINET*: *Ethiop. J. Sci.* **36**(1): 41–44.

Admassu Addi, Teshome Soromessa, Ensermu Kelebessa, Abyot Dibaba and Alemayhu Kefyalew (2016). Floristic composition and plant community types of Agama Forest, an "Afromontane Forest" in Southwest Ethiopia. *J. Ecol. Nat. Environ.* **8**(5): 55-69.

Adugna Feyissa, Teshome Soromessa, Mekuria Argaw (2013). Forest Carbon Stocks and Variations along Altitudinal Gradients in Egdu Forest: Implications of Managing Forests for Climate Change Mitigation. *J STAR* **2**: 40-46.

Alexander, R., Millington, A. (2000). *Vegetation Mapping: From Patch to Planet*. Chichester, United Kingdom: Wiley.

Allen, S.E. (1989). *Chemical analysis of ecological materials*. Blackwell, Oxford.

Amundson, R. (2001). The carbon budget in soils. *Annu. Rev. Earth Pl. Sc.* **29**: 535–562.

Anderson EW, Currier W.F. (1973). Evaluating zones of Utilization. *J. Range Manag.* **26**(2):87-91.

Apps, M. J. and Kurz, W. A. (1993). The role of Canadian forests in the global carbon balance. **In** *Carbon Balance of World's Forested Ecosystems: Towards a Global Assessment*. pp 14–28. Publ. Acad. Finland No. 3/1993 Helsinki, Finland.

Asress W/Giorgis (2002). Overview of Energy States and Trends in Ethiopia. **In**: *Energy in Ethiopia: Status, Challenges and Prospects.* Proceedings of Energy Conference 2002. Professional Associations' Joint Secretariat UNCC, Addis Ababa, 21-22 March 2002.

Austin M.P. (2005). Vegetation and environment: discontinuities and continuities **In**: *Vegetation Ecology*, pp 53-84, (van der Maarel, E, eds) , Blackwell publishing, USA.

Austin, M., Pausas, J. and Nicholls, A. (1996). Patterns of tree species richness in relation to environment in South-eastern New South Wales, *Australia. Australian Journal of Ecology* **21**:164-165.

Bajracharya, R. M., Lal, R., Kimble, J.M. (1998). Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion phases and landscape position. **In**: *Soil Processes and the Carbon Cycle*, pp 353-367, (Lal, R., Kimble, J., Follett, R. & Stewart, B.A. eds), CRC Press, Boca Raton, Florida.

Baldwin, Liz and Kenneth R. Richards (2010). "Institutional Support for an International Forest Carbon Sequestration Agreement" Discussion Paper 2010-41, Cambridge, Mass: Harvard Project on International Climate Agreements.

Belsley, D. A., Kuh, E. & Welsch, R. E. (1980). *Regression Diagnostics*: *Identifying Influential Data and Sources of Collinearity*. New York: John Wiley

Bhishma, P. S., Shiva, S. P., Ajay, P., Eak, B. R., Sanjeeb, B., Tibendra, R. B., Shambhu, C., andRijan, T. (2010). Forest Carbon Stock Measurement: Guidelines for measuring carbon stocks in community-managed forests. Funded by Norwegian Agency for Development Cooperation (NORAD). Asia Network for Sustainable Agriculture and Bio resources (ANSAB) publishing, Kathmandu, Nepal, Pp.17-43.

Bhuyan, P., Khan, M. L. and Tripathi, R. S., (2003). Tree diversity and population structure in undisturbed and human impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, *India. Biodiv. Conserv*.**12**: 1753–1773.

Bilew Alemu, Kitessa Hundera and Balcha Abera (2015). Floristic composition and structural analysis of Gelesha forest, Gambella regional State, Southwest Ethiopia. *J. Ecol. Nat. Environ.* **7**(7): 218-227.

Brand, G.J., Smith, W.B. (1985). Evaluating allometric shrub biomass equations fit to generated data. *Canadian Journal of Botany* **63**: 64–67.

Bridgewater, S., Ratter, J. A. and Ribeiro, J. F. (2004). Biogeographic patterns, β - diversity and dominance in the cerrado biome of Brazil. *Biodiversity Conserv*. **13**:2295- 2318.

Brinkmann, K., Patzelt, A., Dickhoefer, U., Schlecht, E., Buerkert, A. (2009). Vegetation patterns and diversity along an elevational and a grazing gradient in the Jabal al Akhdar mountain range of northern Oman. *Journal of Arid Environments* **73**:1035–1045.

Brockway, D.G. (1998). Forest plant diversity at local and landscape scales in the Cascade Mountains of southwestern Washington. *Forest Ecology and Management* **109**:323-341.

Brown, S. (1997). Estimating Biomass and Biomass Change of Tropical Forests: A Primer. UN FAO Forestry Paper-134, Rome.

Brown, S., & Lugo, A. E. (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* **14**: 161–187.

Burnham, K.P., Anderson, D.R., (2002). *Model selection and multimodel inference. A practical information-theoretic approach*, 2nd ed. Springer Science + Business Media, Inc., New York, 488 pp.

Bussmann, R.W. (2001). Succession and regeneration patterns of East African mountain forests. *Systematic and Geography of Plants* **71**: 957-974.

Bussmann, R.W. and Beck, E. (1995). The forests of Mt. Kenya (Kenya), a phytosociological synopsis. *Phytocoenologia* **25**: 467-560.

Cain, S.A. & Castro, G.M. de Oliveira. (1959). *Manual of vegetation analysis*. - Harper and Brothers, New York, NY, 325 pp.

Calmel, M., Martinet, A., Grondard, N., Dufour, T., Rageade, M. and Ferté-Devin, A. (2010). REDD+ at project scale: Evaluation and development guide. ONF International, Paris.

Castro, J., Zamora, R., Hoder, J.A. and Comez, J.M. (2004). Seedling establishment of a boreal tree species (*Pinus sylvestirs*) at its southern most distribution limit: consequences of being in a marginal Mediterranean limit: consequences of being in a marginal Mediterranean habituate. *Journal of ecology* **92**: 266-277.

CCB-AR-PDD (2009). (CCB-AR-PDD) Climate, community and biodiversity standards project design document form for afforestation and reforestation project activities. Humbo Ethiopia Assisted Natural Regeneration Project, Ethiopia.

Chaffey, D. R. (1979). South west Ethiopia Forest Inventory project, a Reconnaissance Inventory of Forest in South-West Ethiopia. Land Resources Development Centre, Tolworth Tower Surbition Survey, England.

Chave J, Réjou-Méchain M, Búrquez A, Chidumayo E, Colgan MS, Delitti WB, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez-Yrízar A, Mugasha WA, Muller-Landau HC, Mencuccini M, Nelson BW, Ngomanda A,Nogueira EM, Ortiz-Malavassi E, Pélissier R, Ploton P, Ryan CM, Saldarriaga JG, Vieilledent G (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology* **20**: 3177–3190.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D. & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* **145**: 87-99.

Chen, J., Song, B., Rudnicki, M., Moeur. M., Bible, K., North, M., Shaw, D.C., Franklin, J.F. and Braun, D.M. (2003). Spatial relationship of biomass and species distribution in an old-growth Pseudotsuga - Tsuga Forest. *Forest Science* **50**: 364-375.

CIA (Central Intelligence Agency) (2011). The World Fact book. https: // www .cia.gov/ library/ publications/the-worldfactbook/geos/et.html (accessed April 23, 2013).

Clarke, J. (1986). *Resettlement and rehabilitation: Ethiopia's campaign against famine*. Harney & Jones Ltd, London.

Coetzee, J.A. (1978). Phytogeographical aspects of the montane forests of the chain of mountains on the eastern side of Africa. *Erdwissenschaft Forschung* **11**: 482-494.

Colwell, R. K. and Coddington, A. J. (1994). Estimating terrestrial biodiversity through extrapolation. *Philosophical Transaction on the Royal Society Biological Science* **345**:101-118.

Comez, J.M. Garcia, D. and Zamora, R. (2003). Impact of vertebrate acron-and seedling predators on Mediterranean *Quercus pyrenaica* forest. *Forest Ecolopgy and Management* **180**: 125 – 134.

Condit, R., Hubbell, S. and Foster, R. (1995). Mortality rates of 205 neotropicaal tree and shrub species and the impact of severe drought. *Ecol. Monogr* **65**: 419-439.

Cornell, H. V. (1999). Unsaturation and regional influences on species richness in ecological communities: a review of the evidence. *Ecoscience* **6**:303-315.

Curtis, J. T., and McIntosh, R. P. (1950). The Interrelations of Certain Analytic and Synthetic Phytosociological Characters. *Ecology* **31**: 434-455.

Curtis, J. T., and McIntosh, R. P. (1951). An upland forest continuum in the prairie - forest border region of Wisconsin. *Ecology* **32**: 476-496.

Daniel Gamachu (1977). *Aspects of Climate and Water Budget in Ethiopia*. Addis Ababa University Press, Addis Ababa.

De Vletter, J. (1991). Forest genetic resources of Ethiopia. **In**: *Plant genetic resources of Ethiopia* (Engles, J. M. M. et al., eds). Cambridge University Press, UK, 83-99.

Dechassa Lemessa and Perault, M. (2002). Forest fires in Ethiopia: Reflections on socio-economic and environmental effects of the fires in 2000. **In**: *Forest fire research and wild land fire safety*: Proceedings of IV international conference on forest fire research, woodland fire safety summit. 18-23 November 2002, Luso, Coimbra, Portugal.

Demel Teketay (2001). Deforestation, Wood famine and Environmental Degradation in Ethiopia's Highlands Ecosystems: Urgent needs for Action. *Northeast African Studies* **8**(1): 53-76.

Demel Teketay and Granstrom (1995). Soil seed banks in dry Afromontane forests of Ethiopia. Journal of Vegetation science, **6**: 777-786.

Demel Teketay and Tamrat Bekele (1995). Floristic composition of Wof-Washa natural forest, Central Ethiopia: Implications for the conservation of biodiversity. *Feddes Repertorium* **106**:127–147.

Dessalegn Rahmato (1988). Settlement and resettlement in Metekel, Western Ethiopia. *Africa (Rome)* **43**: 14–43.

Dhaulkhandi, M., Dobhal, A., Bhatt, S & Kumar, M. (2008). Community structure and regeneration potential of natural forest site in Gangotri, India. *Journal of Basic & Applied Sciences* **4**: 49-52.

Don, A., Schumacher, J., Freibauer, A. (2011). Impact of tropical land-use change on soil organic carbon stocks — a meta-analysis. *Global Change Biology* **17**: 1658–1670.

Dufrêne, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Mono.* **67**: 345-366.

EDRI (2010). Preliminary assessment by the Ethiopian Development Research Institute of impacts, cost and feasibility of strategy options. Climate Resilient Green Growth initiative.

EFAP (1993). "The challenge for development, volume II," Addis Ababa: Ministry of Natural Resource Development and Environmental Protection, Transitional Government of Ethiopia.

EFAP (1994). Ethiopian forestry action program. Ministry of natural resources and environmental protection, Addis Ababa.

Eilu, G. and Obua, J. (2005). Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable forest national park, Southwestern Uganda. *Tropical Ecology* **46**: 99-111.

ENEC/CESEN (1986). Cooperation Agreement in the Energy Sector, Main Report, Addis Ababa.

Engelbrecht, B.M.J., Comita, L.S., Condit, R., Kursar, T.A., Tyree, M.T., Turner, B.L., and Hubbell, S.P. (2007). Drought sensitivity shapes species distribution patterns in tropical forests. *Nature*: **447**(3): 80-83.

Ensermu Kelbessa and Sebsebe Demissew (2014). Diversity of vascular plant taxa of the flora of Ethiopia and Eritrea. *Ethiop. J. Biol. Sci.* **13** (Supp.): 37-45.

Ensermu Kelbessa and Teshome Soromessa (2008). Interfaces of regeneration, structure, diversity and use of some plant species in Bonga forest: A reservoir for wild coffee gene pool. *SINET: Ethiopian Journal of Science* **31**(2): 121-134.

Ermias Lulekal, Ensermu Kelbessa, Tamrat Bekele & Haile Yineger (2008). Plant Species Composition and Structure of the Mana Angetu Moist Montane Forest, South-Eastern Ethiopia. *Journal of East African Natural History* **97**: 165-185.

Fan, S., Gloor, M., Mahlman, J., Pacala, S., Sarmiento, J.,Takahashi, T. & Tan, P. (1998). A large terrestrial carbon sink in North America implied by atmospheric and oceanic carbon dioxide data and models. *Science* **282**: 442–446.

FAO (2000). Carbon Sequestration Options Under the Clean Development Mechanism to Address Land Degradation. World Soil Resources Reports 92. FAO and IFAD, Rome.

FAO (2005). State of the World's Forests, Deforestation Rate in Ethiopia, FAO, Rome.

FAO (2010a). Global Forest Resources Assessment 2010 - Country Report Ethiopia. Food and Agriculture Organization (FAO), Rome, Italy.

FAO (2010b). Carbon Finance Possibilities for Agriculture, Forestry and Other Land Use Projects in a Smallholder Context, Rome, Italy.

FAO (2011). Climate Change Mitigation Finance for Smallholder Agriculture. A guide book to harvesting soil carbon sequestration benefits, Rome Italy.

FAO (2006). Global forest resource assessment 2005: Progress towards Sustainable forest management.FAO forestry Paper 147.Rome: FAO.

Fekadu Gurmessa, Teshome Soromessa and Ensermu Kelbessa (2012). Structure and Regeneration status of Komto Afromontane Moist forest, East Wollega Zone, West Ethiopia. *Journal of Forestry Research* **23** (2): 205-216.

Fekadu Gurmessa, Teshome Soromessa and Ensermu Kelbessa (2013). Floristic composition and community analysis of Komto Afromontane moist forest, East Wollega Zone, West Ethiopia. *Sci. Technol. Arts Res. J.* **2**(2): 58-69.

Field, A.P. (2009). Discovering statistics using SPSS: and sex and drugs and rock 'n' roll (3rd edition). London: Sage.

Fisher, R.F., Binkley, D. (2000). *Ecology and Management of Forest Soils*. John Willey and Sons, Inc. New York, USA.

Friis, I. (1986). The forest vegetation of Ethiopia. *Symb. Bot. Ups*. **26** (2): 31-47.

Friis, I. (1992). *Forests and forest trees of North East Tropical Africa*. Kew Bull. Add. Ser. XV.

Friis, I., Edwards, S., Ensermu Kalbessa and Sebsebe Demissew (2001). Diversity and Endemism in the Flora of Ethiopia and Eritrea - what do the published Flora volumes tell us? *Biologiske Skrifter* **54**: 173-193.

Friis, I., Sebsebe Demissew & van Breugel, P. (2010). *A new potential vegetation map of Ethiopia in 1:2,000,000*. Det Kongelige Danske Videnskabers Selskab.

Gardner, R. H., Hargrove, W. W., Turner, M. G. and Romme, W. H. (1996). Climate change, disturbance and landscape dynamics. **In** *Global Change and Terrestrial Ecosystems*, pp 149–172(Walker, B. and Steffen, W, eds). Cambridge University Press, Cambridge.

Garten, C.T., Post, W.M., Hanson, P.J., Cooper, L.W., (1999). Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains. *Biogeochemistry* **45**: 115–162.

Gauch, H. G., Jr. (1982). *Multivariate Analysis and Community Structure*. Cambridge University Press, Cambridge.

Gebre Markos Wolde Selassie (1998). The Forest Resources of Ethiopia; Past and Present. *Walia* **19**: 10-28.

Geider, J. R., Delucia, H. E., Falkowsk, G. P., Finzi, C. A., Grime, P. J., Grace, J., Kana, M. T., Roche, J. (2001). Primary productivity of planet earth: biological determinants and physical constraints in terrestrial and aquatic habitats. *Global Change biology* **7**: 849-882.

Genene Bekele and Reddy, P.R. (2015). Study of Vegetation Composition of Magada Forest, Borana Zone, Oromia, Ethiopia. *Universal Journal of Plant Science* **3**(5): 87- 96.

Gentry, A.H. (1995). Patterns of diversity and floristic composition in neotropical montane forests. **In**: *Biodiversity and Conservation of Neotropical Montane Forests,* pp 103–126 (Churchill S. P., Balslev H., Forero E. and Luteyn J. L., eds.). The New York Botanical Garden, Bronx, New York.

George, C. W. and Mutch, R.W. (2001). Ethiopia: Strengthening Forest Fire Management, FAO Project Document (TCP/ETH/0065), April, Rome.

Gibbs, H.K., Brown, S., Niles, J.O. and Foley, J.A. (2007). Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. *Environmental Research Letters* **2**: 1-13.

Giménez, E., Melendo, M. Valle, F., Gómez-Mercado, F. And Cano, E. (2004). Endemic flora biodiversity in the south of the Iberian Peninsula: altitudinal distribution, life forms and dispersal modes. *Biodiversity Conserv*. **13**: 2641-2660.

Gower, S.T., Kucharik, C.J., Norman, J.M., (1999). Direct and indirect estimation of leaf area index, F(APAR), and net primary production of terrestrial ecosystems. *Remote Sens. Environ*. **70**: 29–51.

Grime, J.P. (1998). Benefits of plant diversity to ecosystems: immediate, filter and founder effects. *Journal of Ecology* **86**: 902–910.

Grubb, J.P. (1987). Global trends in species –richness in terrestrial vegetation: A view from the northern hemisphere **In**: *Organization of communities past and present*, pp. 99-118 (Gee, J.H.R. & Giller, P.S., eds.). Scientific Publications Oxford.

Grubb, P.J., Lloyd, J.R., Pennington, J.D. and Whitmore, T.C. (1963). A comparison of montane and lowland rain forest in Ecuador. The forest structure, physiognomy, and floristics. *J. Ecol.* **51**: 567–601.

Haile Yineger, Ensermu Kelbessa, Tamrat Bekele and Ermias Lulekal (2008). Floristic Composition and Structure of the Dry Afromontane Forest at Bale Mountains National Park. *SINET: Ethiopian Journal of Science* **31**(2): 103-120.

Hairiah, K., Sitompul, S. M., Noordwijk, M. and Palm, C. (2001). Methods for sampling carbon stocks above and below ground. International Centre for Research in Agroforestry. Southeast Asian Regional Research Programme, Bogor, Indonesia, Pp. 10-15.

Hairiah,K., Sulityani, H., Suprayogo, D., Widianto,P., Pumomosididhi,P., Widodo, R.H., Van Nordwijk, M. (2006). litter layer residence time in forest and coffee agroforestry system in Sumberjaya, West Lampung. *For Ecol Manage* **2249**(1-2): 45-57.

Hamere Yohannes, Teshome Soromessa and Mekuria Argaw (2015). Carbon Stock Analysis Along Altitudinal Gradient in Gedo Forest: Implications for Forest

Management and Climate Change Mitigation. *American Journal of Environmental Protection* **4(5)**: 237-244

Hamilton, A.J. (2005). Species diversity or biodiversity? *Journal of Environmental Management* **75**: 89–92.

Hamilton, K., Sjardin, M., Shapiro, A. & Marcello, T. (2009). Fortifying the Foundation: State of the Voluntary Carbon Markets 2009. Ecosystem Marketplace & New Carbon Finance, New York, 92 p.

Hammond, L. (2008). Strategies of invisibilization: How Ethiopia's resettlement programme hides the poorest of the poor. *Journal of Refugee Studies* **21**: 517–536.

Han, X. F., Plodinec, J. M., Yi Su, David, L., Monts, L. D. and Li, Z. (2007). Terrestrial carbon pools in southeast and south-central United States. Institute for Clean Energy Technology (ICET), Mississippi State University, USA. *Climatic Change* **84**:191–202.

Harper JL (1977). *Population Biology of Plants*. Academic Press, London.p.892.

Harper. J.L. (1982). *Population biology of plants*. Academic press, London.

Harrington, G.N., Irvine, A.K., Crome F.H and Moore, L.A. (1997). Regeneration of Large-Seeded Trees in Australian Rainforest Fragments: A Study of higher-Order Interactions. **In**: *Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities*, pp 292-303 (Laurance, W.F. and Bierregaard, R.O.Jr., eds). The University of Chicago Press, Chicago & London.

Hedberg, I., Friis, I. & Persson, E. (eds) (2009). Flora of Ethiopia and Eritrea Volume 8, General part and Index to Volumes 1-7. Addis Ababa, Ethiopia and Uppsala, Sweden.

Hedberg, O. (1957). Afroalpne vascular plants, a taxonomic revision. *Symb. Bot. Upsa.* **15** (1): 1 – 411.

Hedberg, O. (1964). Features of Afroalpine plant ecology. *Acta Phytogeography Suec* **49**:1-144.

Henry, M., Valentini, R. and Bernoux, M. (2009). Soil carbon stocks in ecoregions of Africa. *Biogeosciences Discussions* **6**:797–823.

Herzog, H. J. (2001). What Future for Carbon Capture and Sequestration? American Chemical Society journal. U.S. Government Printing Offices, Washington, DC. *Feature Issue* **735**:148 A – 153 A.

Holfort, J., Johnson, K.M., Schneider, B., Siedler, G. and Wallace, D.W.R. (1998). Meridional transport of dissolved inorganic carbon in the South Atlantic Ocean. *Global Biogeochemical Cycles* **12**: 479-499.

Hontoria, C., Rodriguez-Murillo, J.C., Saa, A., (1999). Relationships between soil organic carbon and site characteristics in peninsular Spain. *Soil Science Society of America Journal* **63**: 614–621.

Houghton, R.A. (2005). Aboveground forest biomass and the global carbon balance. *Global Change Biology* **11**: 945- 958.

http://globecarboncycle.unh.edu/CarbonCycleBackground.pdf. An introduction to the global carbon cycle (accessed on: 24 March, 2015).

Hubbel, P. and Foster, B. (1986). Biology, chance, history and the structure of tropical rainforest communities. In: community ecology, pp. 314-329 (Diamond, J. and case, J. eds). Harper and Row, New York.

Huston, M.A., (1997). Hidden treatment in ecological experiment: re-evaluating the ecosystem function of biodiversity. *Oecologia* **110**: 449–460.

Hutchings, M. J. (1986). Plant population biology. **In**: Methods in Plant Ecology, pp. 377- 435 (Moore, P. D. and Chapman, S. B. eds). Black Well Scientific Publications, Oxford.

IPCC (2000). IPCC Special Report on Land Use, Land-Use Change and Forestry. A special report of the Intergovernmental Panel on Climate Change. Approved at IPCC Plenary XVI (Montreal, 1-8 May, 2000). IPCC Secretariat, c/o World Meteorological Organization, Geneva, Switzerland. At http://www.ipcc.ch/ (accessed on 10April 2015).

IPCC (2001). Climate change 2001: the scientific basis. Intergovernmental panel on climate change. Cambridge, UK: Cambridge University Press.

IPCC (2006). Guidelines for National Greenhouse Gas Inventories Prepared by the National Greenhouse GasInventories Programme, (Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K., eds.). IGES, Japan.

IPCC (2007). Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK., 7-22p

IPCC (2003). Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change, and Forestry, eds Penman J, *et al.* (Institute for Global Environmental Strategies, Kanagawa, Japan).

Jacquemyn, H., Butaye, J. and Hermy, H. (2001). Forest plant species richness in small, fragmented mixed deciduous forest patches: role of area, time and dispersal limitation. *Journal of Biogeography* **28**: 1-12.

Jobbagy, E.G., Jackson, R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* **10** (2): 423–436.

Jones, C. (2007). Australian Soil Carbon Accreditation Scheme, Presentation for "Managing The Carbon Cycle" Katanning Workshop, Carbon For Life Inc.

Kangas A. and Maltamo M. (2006). *Forest inventory: Methodology and Applications, Managing Forest Ecosystems*, Vol. 10. Springer, Dordrecht, The Netherlands.

Karky, B.S. and Banskota, K. (2007). Case study of a community-managed forest in Lamatar, Nepal.In. Banskota K, Karky B. S., and Skutsch M., Reducing Carbon Emissions through Community-managed Forests in the Himalaya Kathmandu, Nepal, 67 - 79.

Kassa Belay (2004). Resettlement of peasants in Ethiopia. *Journal of Rural Development* **27**: 223–253.

Kayser, M. & Isselstein, J. (2005). Potassium cycling and losses in grassland systems: *a review*. *Grass and Forage Science* **60**: 213–224.

Keeling, R.F., and Peng, T.H. (1995). Transport of Heat, CO_2 and O_2 by the Atlantic thermohaline circulation. *Philosophical Transactions of the Royal Society of London Series B* **348**: 133-142.

Keith, H., Brendan, G., Mackey, and David, B. Lindenmayer (2009). Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. *PNAS* **106**(28): 11635–11640.

Kent, M. (2012). *Vegetation Description and Data Analysis*: *A practical approach*. John Wiley and Sons, Chichester, 414 p.

Ketterings, Q.M., Coe, R., Van Noordwijk, M., Ambagau, Y., Palm, C.A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *For. Ecol. Manage* **146**: 199–209.

Khan, M., Rai, J. P. N. and Tripathi, R. S., (1987). Population structure of some tree species in disturbed and protected sub-tropical forests of northeast India. *Acta Ecol.* **8**: 247–255.

Kharkwal, G., Mehrotra, P., Rawat, Y. S. and Pangtey, Y. P. S. (2005). Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science* **89**: 873-878.

Kiflay G/Hiwot & Kitessa Hundera (2014). Species composition, Plant Community structure and Natural regeneration status of Belete Moist Evergreen Montane Forest, Oromia Regional state, Southwestern Ethiopia. *Momona Ethiopian Journal of Science (MEJS)* **1**: 97-101.

Kirby, K.R. and Potvin, C. (2007). Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. *Forest Ecol. Manag*. **246**: 208– 221.

Kirschbaum, M.U.F. (2000). Will changes in soil organic carbon act as a positive or negative feedback on global warming. *Biogeochemistry* **48**: 21–51.

Kitessa Hundera and Tsegaye Gadissa (2008). Vegetation composition and structure of the Belete forest, Jimma zone, southwestern Ethiopia. *Ethiopian Journal of Biological Science* **7**(1): 1-15.

Kloos, H. (1989). Settler Migration during the 1984/85 Resettlement Programme in Ethiopia. *Geo Journal* **19**: 113–127.

Krebs, C. J. (1999). *Ecological Methodology*. Second edition. Addison Welsey Educational publishers, USA. 620p.

Kruckeberg A. R. and Rabinowitz D. (1985). Biological aspects of endemism in higher plants. *Annu. Rev. Ecol. Syst*. **16**: 447-479.

Kumar, R., Pandey, S. and Pandey, A. (2006). Plant roots and carbon sequestration. Current Science **9**: 885-890.

Kumelachew Yeshitila and Taye Bekele (2003). The woody species composition and structure of Masha-Anderacha forest, southwestern Ethiopia. *Ethiopian Journal of Biological Science* **2**(1): 31 – 48.

Kumlachew Yeshitela and Tamrat Bekele (2002). Plant community analysis and ecology of Afromontane and transitional rainforest vegetation of southwestern Ethiopia. *SINET: Ethiop J Sci* **25**(2):155-175.

Lal, R. (2005). Forests soil and carbon sequestration. *Forest Ecol. Manage* **220**: 242-258.

Lal, R. and Kimble, J.M. (1997). Conservation tillage for soil carbon sequestration. *Nutr Cycl Agroecosyst* **49**: 243-253.

Lal, R., Kimble, J. M., Follett, R. F. & Cole, C. V. (1998). The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Chelsea, MI: Ann ArborPress.

Lamprecht, H. (1989). *Silviculture in the Tropics. Tropical Forest ecosystems and their tree species – possibilities and methods for their long term utilization*. TZ-Verlagsgesellschaft GmbH, Rossdort, Germany.

Lasco, R. D., Pulhin, F. B., Visco, R. G., Racelis, D. A., Guillermo, I. Q., & Sales, R. F. (2000). Carbon stocks assessment of Philippine forest ecosystems. Paper presented at the Science Policy workshop on terrestrial carbon assessment for possible carbon trading (pp. 28–29), Bogor, Indonesia.

Lee MJ, Song HK, Yee S. (2000). Study on classification of forest vegetation of songinbong and taeharyong in Ullungdo

Legendre, P. and Legendre, L. (1998). *Numerical Ecology*. 2nd ed. Elsevier, Amsterdam.

Leifeld, J., Bassin, S., Fuhrer, J. (2005). Carbon stocks in Swiss agricultural soils predicted by land-use, soil characteristics, and altitude. *Agric. Ecosyst. Environ*. **105**: 255–266.

Lepš, J. and Šmilauer, P. (2001). *Multivariate Analysis of Ecological Data using CANOCO*. Cambridge Press.

Logan, W. E. M. (1946). *An introduction of the forests of central and southern Ethiopia*. Imperial Forest Institute, University of Oxford. Inst. Paper, No. 24, 58 pp.

Loreau, M. & Hector, A. (2001). Partitioning selection and complementarity in biodiversity experiments. *Nature* **412**: 72–76.

Loreau, M. (1998). Separating sampling and other effects in biodiversity experiments. *Oikos* **82** 600–602.

Loreau, M. (2000). Biodiversity and ecosystem functioning: recent theoretical advances. *Oikos* **91**: 3–17.

Lovett, J.C. (1998). Eastern Tropical African Center of Endemism: a candidate for world heritage status? *Journal of East African Natural History* **87**: 359-366.

Lugo, A.E. and Brown, S. (1992). Tropical forests as sinks of atmospheric carbon. *Forest Ecology and Management* **54**: 239-255.

LUPRD-MOA/FAO (1985). Assistance to land use planning project. Phase I, Addis Ababa.

MacDicken, K. G. (1997). *A Guide to Monitoring Carbon Storage in Forestry and Agro-forestry Projects. In: Forest Carbon Monitoring Program*. Winrock International Institute for Agricultural Development, Arlington, Virginia.

Magurran A. E. (1988). *Ecological diversity and its measurement*. Chapman and Hall, London.

Magurran, A.E. (2004). *Measuring Biological Diversity*. Blackwell Publishing, Oxford, UK. 256pp.

Magurran, A.E. and McGill, B.J., (2011). Challenges and opportunities in the measurement and assessment of biological diversity **In**: Biological diversity, Pp. 1-7 (Magurran, A.E. and McGill, B.J. eds), Oxford university press.

Maraseni, T.N., Cockfield, G., Apan, A. and Mathers, N. (2005). Estimation of Shrub Biomass: Development and Evaluation of Allometric Models Leading to Innovative Teaching Methods. *International Journal of Business & Management Education Special Issue: Postgraduate Research in Innovative Methods of Teaching & Learning* ISSN 1832-0236.

Markos Ezra (1997). *Demographic responses to ecological degradation and food insecurity: Drought-prone areas in northern Ethiopia*. University of Groningen, The Netherlands. Amsterdam: PDOD Publications. Doctoral dissertation.

May, R.M. (1988). How many species on earth? *Science* **241**: 1441-1449.

McCune, B. and Grace, J. B. (2002). Analysis of Ecological Communities. MjM Software Design. USA.

Mokany, K., Ash, J., Roxburgh, S., (2008). Effects of spatial aggregation on competition, complementarity and resource use. *Austral Ecology* **33**(3): 261– 270.

Moreno, C. E. and Halffter, G. (2001). Spatial and temporal analysis of α, β and γ diversities of bats in a fragmented landscape. *Biodiversity Conserv*. **10**: 367–382.

Morsdorf, F., Marell, A. (2010). Discrimination of vegetation strata in a multi-layered Mediterranean forest ecosystem using height and intensity information derived from airborne laser scanning. *Remote Sens. Environ*. **114**: 1403–1415.

Mueller – Dumbois and Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology*. John Willey and Sons, New York, 547p.

Mulugeta Lemenih & Tadesse Woldemariam (2010). Review of forest, woodland and bushland resources in Ethiopia up to 2008. **In**: *Ethiopian Environment Review* No. 1. (Edwards, Sue eds.). Forum for Environment, Addis Ababa.

Mulugeta Lemenih, Sisay Feleke & Wubalem Tadesse (2007). Factors constraining the production and marketing of frankincense by local people in Metema district, North-Western Ethiopia. *Journal of Arid Environments* **71**: 393–403.

Muluken Nega Bazezew, Teshome Soromessa, Eyale Bayable (2015). Above- and Below-Ground Reserved Carbon in Danaba Community Forest of Oromia Region, Ethiopia: Implications for CO_2 Emission Balance. *American Journal of Environmental Protection* **4**(2): 75-82.

NBSAP (2005). National Biodiversity Strategy and Action Plan. Addis Ababa: Institute of Biodiversity Conservation, p. 103.

Nelson, B.W., Mesquita, R., Pereira, J.L.G., de Souza, S.G.A., Batista, G.T., Couta, L.B., (1999). Allometric regressions for improved estimate of secondary forest biomass in the Central Amazon. *Forest Ecology and Management* **117**: 149–167.

Nicholson, M. and McIntosh, R.P. (2002). Gleason and the individualistic hypothesis revisited. *Bulletin of the Ecological Society of America* **83**: 133–142.

Nieder, R. and Benbi,D.K.(2008). *Carbon and nitrogen in the terrestrial environment*. Springer + Business media B.V., New York.

Niklas, K.J., (1994). *Plant Allometry: The Scaling of Form and Process*. University of Chicago Press, Chicago, Illinois.

NMSA (2016). National Meteorological Service Agency, Ethiopia.

Olano, J.M., Loidi, J., Ander, G., Escudero, A., (1998). Relating variation in the understory of beech forests to ecological factors. *Folia Geobot*. **33**: 77–86.

Orwa C, A Mutua, Kindt R, Jamnadass R, S Anthony (2009). Agroforestry Database 4.0: a tree reference and selection guide version 4.0. (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp)

Osborne and Waters (2002). Four assumptions of multiple regression that researcher should always test. Practical Assessment, Research & Evaluation, **8**(2).

Page, S.E., Siegert, F., Rieley, J.O., Boehm Hans-Dieter, V. and Jaya (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* **420**: 61-65.

Palmer, M.W. and White, P.S. (1994). Scale dependence and the species–area relationship. *Am. Nat*. **144**: 717–740.

Parker, C., Mitchell, A., Trivedi, M., Mardas, N., and Sosis, K. (2009). The Little REDD+ Book. Global Canopy Programme, Oxford.

Pastor, J., Aber, J.D., Melillo, J.M., (1984). Biomass prediction using generalized allometric regressions for some northeast tree species. *For. Ecol. Manage* **7**: 265–274.

Pausas, J.G. and Austin, M.P. (2001). Patterns of plant species richness in relation to different environments: *An appraisal. Journal of Vegetation Science* **12**: 153-166.

Pearson, T., Walker, S. and Brown, S. (2005). *Sourcebook for land-use, land-use change and forestry projects*. Winrock International and the Bio-carbon fund of the World Bank. Arlington, USA, Pp. 57.

Pearson, T.R.H., Brown, S. L., Birdsey, R. A. (2007). Measurement guidelines for the sequestration of forest carbon. General Technical Report- NRS-18.

Perlman D. L. and Adelson G. (1997). *Biodiversity: exploring values and priorities in conservation*. Blackwell Science, Malden, Massachusetts, USA.

Peters, C.M. (1996). The Ecology and Management of Non-Timber Forest Resources. World Bank Technical Report No. 322, Washington DC, USA.

Phelps, J., Fries, D. A. and Webb, E. L. (2012). Win-win REDD+ approaches belie carbon-biodiversity trade-offs. *Biological Conservation* **154**: 53-60.

Picard N., Saint-Andre L., Henry M. (2012). Manual for building tree volume and biomass allometric equations: from field measurement to prediction. Food and Agricultural Organization of the United Nations, Rome, and Centre de cooperation Internationale en Recherche Agronomique pour le Development, Montpellier, 213 pp.

Pigott C.D. and Pigott, S. (1993). Water as a determinant of the distribution of trees at the boundary of Mediterranean zone. *Journal of ecology* **81**: 557 – 566.

Pineiroa, G, Perelmanb, S , Guerschmanb, J,P and Parueloa, M. (2008). How to evaluate models: Observed vs. predicted or predicted vs. observed? *ecological modelling* **216**: 316–322

Poorter, L., Bongers, F., van Rompaey, R.S. & de Klerk, M. (1996). Regeneration of canopy tree species at five sites in West African moist forest. *Forest Ecology and Management* **85**: 61-69.

Pyke, C.P., Condit, R., Aguilar, S. and Herna`ndez, A. (2001). Floristic composition across a climatic gradient in a neotropical lowland forest. *Journal of Vegetation Science* **12**: 533–566.

Quideau, S.A., Chadwick, Q.A., Benesi, A., Graham, R.C., Anderson, M.A. (2001). A direct link between forest vegetation type and soil organic matter composition. *Geoderma* **104**: 41–60.

Quinn, G.P. & Keough, M.J. (2002). *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge.

R Development Core Team (2017). R: A Language and Environment for Statistical Computing. URL. http://www.R-project.org/.

Rasse, D.P., Mulder, J., Moni, C., Chenu, C., (2006). Carbon turnover kinetics with depth in an Ftench loamy soil. *Soil Sci Soc Am J* **70**(6): 2097-2105.

Ravindranath, N.H. and Ostwald, M. (2008). Methods for estimating above-ground biomass. In: Carbon Inventory Methods: Handbook for greenhouse gas inventory, carbon mitigation and round wood production projects, pp113-14 (N. H. Ravindranath, and M. Ostwald eds). Springer Science + Business Media B.V.

Reusing, M. (1998). Monitoring of natural high forests in Ethiopia. Ministry of Agriculture and GTZ, Addis Ababa.

Reusing, M. (2000). Change detection of natural high forests in Ethiopia using remote Sensing and GIS techniques. International Archives of Photogrammetry and Remote Sensing. Vol. XXXIII, Part B7. Amsterdam.

Rey, P.J., Julio, M. and Alcantara, M. (2000). Recruitment dynamics of a fleshy-fruited plant (*Olea europaea*): Connecting patterns of seed dispersal to seedling establishment. *Journal of Ecology* **88**(4): 622-633.

Rodger, A.S. (1993). The carbon cycle and global forest ecosystem. *Water, Air and Soil Pollution* **70**: 295-307.

Sanjit, L. and Bhatt, D. (2005). How relevant are the concepts of species diversity and species richness? *Journal of Biosciences* **30**(5): 557-560.

Saxena, A. K. and Singh, J. S. (1984). Tree population structure of certain Himalayan forest associations and implications concerning their future composition. *Vegetation* **58**: 61–69.

Schlesinger, P. and Palmer Winkler, J. (2000). Soils and the global carbon cycle **In**: *The Carbon Cycle*, pp 93–101 (Wigley, T. M. L. and Schimel, D. S., eds). Cambridge University Press, Cambridge.

Sebsebe Demsew and Nordal, I. (2010). *Aloes and Lilies of Ethiopia and Eritrea*. Shama Books, Addis Ababa.

Shankar, U. (2001). A case of high tree diversity in a Sal (Shorea robusta) dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. *Curr. Sci.* **81**: 776–786.

Sharrock, S., Oldfield, S. and Wilson, O. (2014). A review of progress in implementation of the Global Strategy for Plant Conservation 2011-2020. Secretariat of the

Convention on Biological Diversity, Montréal, Canada and Botanic Gardens Conservation International, Richmond, UK. Technical Series No. 81, 56pp.

Shen, T. J., Chao, A., and Lin, C. F. 2003. Predicting the number of new species in further taxonomic sampling. *Ecology* **84**: 798–804.

Shmida, A. and Wilson, M.V. (1985). Biological determinants of species diversity. *Journal of Biogeography* **12**: 1-20.

Silvertown JW, Doust JL. (1993). *Introduction to Plant Population Biology*. Oxford, UK: Blackwell.

Silvertown, J.W., (1982). *Introduction to Plant Population Ecology*. Longman, London.

Simberloff, D. (1986). Are we on the verge of a mass extinction in tropical rain forests? **In**: *Dynamics of Extinction*, pp 165-180. (Elliott, D. K. eds)., John Wiley and Sons, New York.

Siry, J., Bettinger, P., Borders, B., Cieszewski, C., Clutter, M., Izlar, B., Markewitz, D. and Teskey, R. (2006). Forest Carbon Estimation Protocol for the State of Georgia, USA.

Smith, M.L., (1995). Community and edaphic analysis of upland northern hardwood communities, central Vermont, USA. *Forest Ecol. Manage*. **72**: 235–249.

Soepadmo, E. (1993). Tropical rain forests as carbon sinks. *Chemosphere* **27**: 1025-1039.

Sohngen, B. (2009). An Analysis of Forestry Carbon Sequestration as a Response to Climate Change at 11, Copenhagen Consensus on Climate.

Sokal, R.R., Rohlf, F.J., (1995). *Biometry: The Principles and Practice of Statistic in Biological Research,* 3rd ed. W.H. Freeman and Co., New York, 859 pp.

Spellerberg, I.F. (1991). *Monitoring ecological change*. Cambridge University Press. Cambridge.

Sprugel, D.G., 1983. Correcting for bias in log-transformed allometric equations. **Ecology 64** (1): 209–210

Stern, N. (2006). *The Economics of Climate Change*: The Stern Review. Cambridge University Press, Cambridge, UK.

Stevens, J.P. (2009). *Applied multivariate statistics for the social sciences,* 5th ed. New York: Routledge.

Stoutjesdijk, P.H. and Barkman, J.J. (1992). *Microclimate, vegetation and fauna*. OPULUS Press, Uppsala, 216 pp.

Sundquist, E., Robert, B., Stephen, F., Robert, G., Jennifer, H., Yousif, K., Larry, T. and Mark, W. (2008). Carbon Sequestration to Mitigate Climate Change. U.S. Geological Survey, science for a changing world, New York, USA, pp. 1-4.

Tabachnick, B. & Fidell, L. (2006). *Cleaning up your act screening data prior to analysis. Using multivariate analysis*, 5th ed. Needham Heights, MA: Allyn & Bacon.

Tadesse Woldemariam and Masresha Fetene (2007). Forests of Sheka: Ecological, social, legal and economic dimension of recent land use/ land cover changes --- Overview and Synthesis, Melca Mahiber. http://www.melcaethiopia.org/images /stories/ Publication/ Forests%20of%20Sheka.pdf (accessed: May 5, 2015).

Tadesse Woldemariam, Borsch, T., Denich, M. and Demel Teketay (2008). Floristic composition and environmental factors characterizing coffee forests in southwest Ethiopia. *Forest Ecology and Management* **255**: 2138–2150.

TadesseWoldemariam (2003). Vegetation of the Yayu forest in Southwest Ethiopia: Impacts of human use and Implications for In situ Conservation of Wild Coffea Arabica L. populations. Ecology and Development Series No. 10. Center for Development Research, University of Bonn.

Tafesse Asres (1996). Agroecological zones of Southwest Ethopia. *Matreialien Zurostafrica-Forschung* 13: 1-241.

Tamene Yohannes (2016). *Plant Diversity and Carbon Stock Analysis along Environmental Gradients: the case of Gergeda and Anbessa Forests in Western Ethiopia*. Doctoral Dissertation. Addis Ababa University.

Tamrat Bekele (1993). Vegetation ecology of remnant Afromontane forests on the central plateau of Shewa, Ethiopi. *Acta Phytogeographica, Sukecica* **79**: 1-59.

Tamrat Bekele (1994). Phytosociology and Ecology of Humid Afromontane Forest on the Central plateau of Ethiopia. *Journal of Vegetation Science* **5**: 87−98.

Taye Bekele, Getachew Berhan, Elias Taye, Matheos Ersado, and Kumlachew Yeshitla (2002). Regeneration status of moist Montane Forest of Ethiopia: Consideration for conservation, part 1: Boginda, Bonga, Masha-Anderacha and Yayu forests. *Walya* **22**: 45-60.

ter Braak, C. J. F. (1994). Canonical community ordination. Part I: Basic theory and linear methods. *Ecoscience* **1** (2): 127-140.

ter Braak, C. J. F., and Prentice, I. C. (1988). A theory of gradient analysis. *Adv. Ecol. Res.* **18**: 271-313.

ter Braak, C. J. F., and Šmilauer, P. (1998). CANOCO reference manual and User's guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power, Ithaca.

ter Braak, C.J.F. (1995). Ordination. **In**: *Data analysis in community landscape ecology*, pp. 91-173 (Jongman, R.H.G., ter Braak, C.J.F. and van Tongeren, O.F.R. eds). CambridgeUniversity Press, Cambridge, UK,

Terborgh, J. and Andresen, E. (1998). The composition of Amazonian forests: patterns at local and regional scales. *Journal of Tropical Ecology* **14**: 645–664.

Terefe Degefa (2001). *Death of the mother tree. Land tenure and environmental degradation in the Oromian Highlands, Ethiopia, 1900–1997*. PhD dissertation, Institute of Social Studies. The Hague, the Netherlands. Shaker Publishing BV, Maastricht.

Tesfaye Burju, Kitessa Hundera and Ensermu Kelbessa (2013). Floristic Composition and Structural Analysis of Jibat Humid Afromontane Forest, West Shewa Zone, Oromia National Regional State, Ethiopia. Ethiop. *J. Educ. & Sc.* **8**(2): 11-33.

Teshome Soromessa and Ensermu Kelbessa (2013). Diversity and Endemicity of Chilimo Forest, Central Ethiopia. *Bioscience Discovery* **4**(1): 01-04.

Tewoldebirhan G/Egziabher (1986). Ethiopian vegetation – past, present and future. *SINET: Ethiop. J. Sci.* **9**: 1-13.

Tibebu Yelemfrhat Simegn, Teshome Soromessa and Eyale Bayable (2014). Forest Carbon Stocks in Lowland Area of Simien Mountains National Park: Implication for Climate Change Mitigation. *Sci. Technol. Arts Res. J.* **3**(3): 29-36.

Tilman, D., Wedin, D., Knops, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature* **397**: 718–720.

Tilman, E.A., Tilman, D., Crawley, M.J. & Johnston, A.E. (1999). Biological weed control via nutrient competition: potassium limitation of dandelions. *Ecological Applications* **9**: 103–111.

Tripathi, R. S. and Khan, M. L. (2007). Regeneration dynamics of natural forests – A review. Proc. *Indian Natl. Sci. Acad*. **73**: 167–195.

Tuomisto, H., Roukolainen, K. and Yli-Halla, M. (2003). Dispersal, environment, and floristic variation of Western Amazonian Forests. *Science*: **299**: 241-244.

UNFCCC (1997). Kyoto Protocol to the United Nation Framework Convention on Climate Change. http://unfccc.int (Retrieved: 25April, 2017).

UNFCCC (2007). Report of the Conference of the Parties, on its thirteenth session held in Bali, from 3 to 15 December 2007. http://unfccc.int. (Retrieved : 22 May,2015).

UNFCCC (2012). Background (REDD). http://unfccc.int (Retrived: 16 May,2015).

UNFCCC (2011). Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010. http://unfccc.int (Retrieved: 15 May,2015).

USNETL (U.S National Energy Technology Laboratory) (2000). Carbon and Storage of Carbon in Terrestrial Ecosystems. Sequestration Program Facts. U.S department of Energy publishing, Washington, DC, Pp. 12-18.

Vablen, T. T., Ashton, D. H. and Schlsgel, F. J. (1979). Tree regeneration strategies in lowland Nothofagus dominated forest in south-central Chile. *J. Biogeogr*. 6: 329–340.

Van der Maarel, E. (1979). Transformation of cover abundance values in phytosociology and its effects on community. *Vegetation* **39**: 97-114.

van der Maarel, E., Espejel, I. and Moreno-Casasola, P. (1987). Two-step vegetation analysis based on very large data sets. *Vegetation* **68**: 139-143.

Vann, D. R., Palmiotto, P. A., Strimbeck, G. R. (1998). Allometric equations for two South American conifers: Test of a non-destructive method. *Forest Ecology and Management* **106**: 55–71

van Wagner, C. E. (1968). The line intersects method in forest fuel sampling. *Forest Science* **14**: 20-26.

Vittoz, P., Bayfield, N., Brooker, R., Elston, D.A., Duff, E.I., Theurillat, J.P., Guisan, A. (2010). Reproducibility of species lists, visual cover estimates and frequency methods for recording high-mountain vegetation. *Journal of Vegetation Science* **21**: 1035–1047.

Vivero, J.L., Ensermu Kelbessa and Sebsebe Demissew (2005). *The Red List of Endemic Trees & Shrubs of Ethiopia and Eritrea*. Fauna & Flora International, United Kingdom. Pp. 28.

Vreugdenhil, Payton, I. J., D., Vreugdenhil, A. D., Tamirat Tilahun, Sisay Nune, and Weeks, E., (2011). Establishing a "Carbon Baseline" and Mechanisms for Payments for Carbon Environmental Services Discharged by Protected Areas in Ethiopia, World Institute for Conservation and Environment, USA.

Walcott, J., Bruce, S. and Sims, J. (2009). Soil Carbon for carbon sequestration and trading: a review of issues for agriculture and forestry, Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Australian Government, Canberra.

Walker, SM, TRH Pearson, FM Casarim, N Harris, S Petrova, A Grais, E Swails, M Netzer, KM Goslee and S Brown (2012). Standard Operating Procedures for Terrestrial Carbon Measurement: Version 2012, Winrock International.

Watson, A.J Nightingale, P.D. and Cooper, D.J. (1995). Modeling atmosphere ocean CO_2 transfer. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* **348**: 125-132.

WBISPP (2004). Forest Resources of Ethiopia. Addis Ababa, Ethiopia.

WBISPP (2005). A national strategy plans for the biomass sector. Addis Ababa, Ethiopia.

Westhoff, V. & van der Maarel, E. (1978). The Braun-Blanquet approach, 2nd ed. **In**: *Classification of Plant Communities*, pp. 287–297 (R.H. Whittaker, eds). Junk, The Hague.

Westpha, E. (1975). Agricultural system in Ethiopia. Poduc, Wageningen.

White RP, Murray S, Rohweder M (2000). Pilot analysis of global ecosystems. Grassland ecosystems. World Resources Institute, Washington, DC.

Whittaker R. H. (1972). Evolution and measurement of species diversity. *Taxon* **21**: 213-251.

Whittaker, R.H. (1975). *Communities and Ecosystems*. MacMillan, London. 385pp.

Whittaker, R.J., Willis, K.J. and Field, R. (2003). Climatic–energetic explanations of diversity: a macroscopic perspective. **In**: Macroecology: concepts and consequences, pp. 107-129 (Blackburn, T.M. and Gaston, K.J. eds.). Cambridge University Press; Cambridge.

World Bank (2011). State and Trends of the Carbon Market 2011. Washington, DC, World. http://siteresources.worldbank.org/INTCARBONFINANCE/Resources/State_and_Trends_of_the_Carbon_Market_2011_low_res.pdf (Last accessed: 20May,2015).

Wulder, M.A., White, J.C., Fournier, R.A., Luther, J.E., and Magnussen, S. (2008). Spatially Explicit Large Area Biomass Estimation: Three Approaches Using Forest Inventory and Remotely Sensed Imagery in a GIS. *Sensors* **8**: 529-560.

Yitebitu Moges, Zewdu Eshetu and Sisay Nune (2010). Ethiopian Forest Resources: Current Status and Future Management Options in View of Access to Carbon Finances. http://www.norway.org.et/PageFiles/628168/EthiopiaForestResourcesCurrent Status and Future Management OptionsECRN-UNDP2010.pdf (Last accessed: 20 May, 2017).

Zerihun Woldu (2016). *Comprehensive analysis of vegetation and ecological data: Basics, concepts and methods*. Addis Ababa University Press, Addis Ababa, 408pp.

Zerihun Woldu, Feoli, E., & Lisanework Nigatu (1989). Partitioning an elevation gradient of vegetation from southeastern Ethiopia by probabilistic methods. *Vegetation* **81**: 189–198.

Zhang J-T. 2005. Succession analysis of plant communities in abandoned croplands in the Eastern Loess Plateau of China. Journal of Arid Environments **63**(2): 458–474.

APPENDICES

Appendix 1. List of species in Gerba Dima Forest

No	**Scientific names**	**Family**	**Local names ***	**Habit**
1	*Acanthopale ethio-germanica* Ensermu	Acanthaceae	Dargu	S
2	*Acanthus eminens* C.B.Clarke	Acanthaceae	Qosambe booyyee	S
3	*Achyranthes aspera* L.	Amaranthaceae	Maxxane	H
4	*Achyrospermum schimperi* (Hochst. ex Briq.) Perkins	Lamiaceae	-	H
5	*Adiantum poiretii* Wikstr	Adiantaceae		H
6	*Aerangis brachycarpa* (A. Rich) Th Dur.& Schinz	Orchidaceae	-	H
7	*Aframomum corrorima* (Braun) Jansen	Zingiberaceae	Ogiiyo	H
8	*Aframomum zambesiacum* (Baker) K. Schum.	Zingiberaceae	Ogiiyo jaldessaa	H
9	*Agernathum conyzoides* L.	Asteraceae	-	H
10	*Ajuga sp*. (=Friis et al. 1456).	Lamiaceae	Gondii	H
11	*Alangium chinense* (Lour.) Harms	Alengeaceae	Hudu fardaa/sendo	T
12	*Albizia gummifera* (J.F. Gmel.) C.A. Sm.,	Fabaceae	Ambabbessa dhaltu	T
13	*Albizia schimperiana* Oliv.	Fabaceae	Ambabbessa kormaa	T
14	*Alchemilla abyssinica* Fresen.	Roseaceae	Korbesso	H
15	*Allophyllus abyssinicus* (Hochst.) Radlk .	Sapindaceae	Se'o	T
16	*Antrophyum mannianum* Hook.	Vittariaceae	Gixoo	H
17	*Apodytes dimidiata* E. Mey. ex Arn	Icaccinaceae	Wandabiyo	T
18	*Arisaema mooneyanum* Gilbert & Mayo	Araceae	Kiicu	H
19	*Asparagus africanus* Lam.	Asparagaceae	Sariiti	H
20	*Asparagus flagellaris* (Kunth) Baker	Asparagaceae	Sariiti	H
21	*Asparagus setaceus* (Kunth) Jessop	Asparagaceae	Sariiti	H
22	*Asplenium aethiopicum* (Burm.f.) Bech.	Aspleniaceae		H
24	*Asplenium bugoiense* Hieron	Aspleniaceae	Giixoo	H
23	*Asplenium elllottii* C.H.Wright,	Aspleniaceae	Giixoo	H
25	*Asplenium erectum* Bory ex Willd.	Aspleniaceae		H

27	*Asplenium sandersonii* Hook	Aspleniaceae	Giixoo	H
26	*Asplenium warnetkei* Hieron.	Aspleniaceae	Giixoo	H
28	*Bersama abyssinica* Fresen.	Melianthaceae	Lolchisaa	T
29	*Bothriocline schimperi* Oliv. & Hiern exBenth.	Asteraceae	Ilbu	S
30	*Brillantaisia madagascariensis* T. Anders. ex Lindau	Acanthaceae	Huxii	S
31	*Brucea antidysenterica* J. F. Mill	Simaroubaceae	Qomanyo	T
32	*Canthium oligocarpum* Hiern	Rubiaceae	Mixo	S
33	*Cassipourea malosana* (Baker) Alston	Rhizophoraceae	Looko	T
34	*Cayratia gracilis* (Guill. & Perr.) Suesseng.	Vitaceae	Kalaalaa qamale	H
35	*Celtis africana* Burm.f .	Ulmaceae	Ceeyii	T
36	*Chionanthus mildbraedii* (Gilg & Schellenb.) Stearn	Oleaceae	Kara waayyu	T
37	*Cissampelos mucronata* A.Rich	Menispermaceae	-	L
38	*Clausena anisata* (Wild.) Benth.	Rutaceae	Ulmaayye	S
39	*Cledendrom myricoides* (Hochst.) Varlee,	Lamiaceae	Maraasisaa	S
40	*Clematis longicauda* Steud. ex A. Rich	Ranuaculaceae	Fiitii	L
42	*Coffea arabica* L.	Rubiaceae	Buna	T/S
41	*Coleochloa abyssinica* (Hochsl. ex A Rick) Gilly	Cyperaceae	Coqorsa mukaa	H
43	*Combretum paniculatum* Vent.	Combreataceae	Bagge	L
44	*Commelina diffusa* Burm.f.	Commelinaceae	Qorxabo	H
45	*Coniogramme africana* Heiron	Hemionitidaceae	-	H
46	*Cordia africana* Lam.	Boraginaceae	Waddessa	T
47	*Crotalaria rosenii* (Pax) Milne-Redh. ex Polhill.	Fabaceae	Ceekaa	H
48	*Croton macrostachyus* Del.	Euphorbiaceae	Makkanisa	T
49	*Cucumis dipsaceus* Ehrenb. ex Spach	Cucurbitaceae	Umbaa'oo	H
50	*Culcasia falcifolia* Engl.	Araceae	Qasso	H
51	*Cyathea manniana* Hook.	Cyatheaceae	Sesino	T
52	*Cyperus fischerianus* A. Rich.	Cyperaceae	Qunni	H
53	*Cyperus longus* L.	Cyperaceae	-	H
54	*Dalbergia lactea* Vatke	Fabaceae	Sarxe dhittaa	S
55	*Deinbollia kilimandscharica* Taub	Sapindaceae	Qaso	T
56	*Desmodium repandum* (Vahl)DC.	Fabaceae	Maxxanne	H
57	*Didymochlaena truncatula* (Sw.)J.Sm.	Dryopteridaceae	-	H

58	*Dombeya torrida* (J.F. Gmel.) P.Bamps	Sterculiaceae	Daanisaa	S
63	*Doryopteris concolor* (Langsd & Fisch.) Kuhn in von der Deck.efl	Dryopteridaceae	-	H
59	*Dracaena afromontana* Mildbr.	Dracenaceae	Sarxe	T/S
60	*Dracaena fragrans* (L.) Ker Gawl.	Dracenaceae	Sarxe	S
61	*Dracaena steudneri* Engl.	Dracenaceae	Sarxe	T
62	*Drynaria volkensii* Hieron	Polypodiaceae	Balessa	H
64	*Ehretia cymosa* Thonn.	Boraginaceae	Ulaagaa	T
65	*Ekebergia capensis* Sparrm.	Meliaceae	Sombo	T
66	*Elaeodendron buchananii* (Loes.) Loes	Celastraceae	Waaso	T
67	*Elastostema monticolum* Hook.f.	Urticaceae	-	H
68	*Ensete ventericosum* (Welw.) Cheesman	Musaceae	Eeppoo	H
69	*Erythrococca trichogyne* (Muell. Arg.) Prain	Euphorbiaceae	Caakkoo	T/S
70	*Euphorbia ampliphylla* Pax	Euphorbiaceae	Adaami	T
71	*Euphorbia schimperiana* Scheele	Euphorbiaceae	Ananno	S
72	*Ficus exasperata* Vahl	Moraceae	Baalaantaayii	T
73	*Ficus ovata* Vahl	Moraceae	Qilxu	T
74	*Ficus sur* Forssk.	Moraceae	Harbu	T
75	*Ficus thonningii* Blume.	Moraceae	Dambii	T
76	*Flacourtia indica* (Burm.f.) Merr.	Flacourtiaceae	Akuku	T
77	*Galiniera saxifraga* (Hochst.) Bridson	Rubiaceae	Simararu	T
78	*Glycine wightii* (Wight '& Am) Verde.	Fabaceae	Kalaalaa	H
79	*Gouania longispicata* Engl.	Rhaminaceae	Hidda reffaa	L
80	*Hallea rubrostipulata* (K. Schum.) J.-F. Leroy	Rubiaceae	Oobo/Bootto	T
81	*Hibiscus panduriformis* Burm.f	Malviaceae	Dabbasee	H
82	*Hippocratea africana* (Willd.) Loes.	Celastraceae	Xiyo	L
83	*Hippocratea pallens* Planch ex Oliver	Celastraceae	Qawo	L
84	*Hypoestes forskaolii* (Vahl) R. Br.	Acanthaceae	Dargu	H
85	*Hypoestes triflora* (Forssk.) Roem & Schult.	Acanthaceae	Dargu	H
86	*Ilex mitis* (L.) Radlk.	Aquifoliaceae	Qato	T
87	*Ipomea indica* (Burm. f) Merrill	Convolvulaceae	Kalaalaa	H
88	*Isoglossa somalensis* Lindau	Acanthaceae	Ilbu	H

89	*Jasminum abyssinicum* Hochst. ex DC.	Oleaceae	Ilchime	L
90	*Justicia bizuneshiae* Ensermu	Acanthaceae	-	H
91	*Justicia schimperiana* (Hochst. ex Nees) T. Anders.	Acanthaceae	Dhumugaa	S
92	*Kalanchoe petitiana* A. Rich.	Crassulaceae	Bosoqe mukaa	H
93	*Keetia gueinzii* (Sond.) Bridson	Rubiaceae	Halale	T/S
94	*Lagera crispata* (Vahl) Hepper & Wood	Asteracea	-	H
95	*Landolphia buchananii* (Hall.f.) Stapf	Apocynaceae	Geebbo	L
96	*Lepidotrichilia volkensii* (Gurke) Leory	Meliaceae	Haalalee	T
97	*Lobelia giberroa* Hemsl.	Lobeliaceae	Dingiraro	S
98	*Loxogramme abyssinica* (Baker) MG. Price	polypodiaceae	Giixo	H
99	*Macaranga capensis* (Baill.) Sim	Euphorbiaceae	Ongo	T
100	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayyi	T
101	*Marattia fraxinea* Sm.	Marattiaceae	-	H
102	*Maytenus gracilipes* (Welw.ex Oliv.) Exell	Celastraceae	Kombolcha	S
103	*Maytenus undata* (Thunb.) Blakelock	Celastraceae	Ilikke	T
104	*Megalastrum lanuginosum* (Willd. ex Kaulf) Holttum	Tectariaceae	-	H
105	*Microglossa pyriflolia* (Lam.) O. Kuntze	Asteraceae	Nobbe	H
106	*Millettia ferruginea* (Hochst.) Baker	Fabaceae	Sottallo	T
107	*Monothecium glandulosum* Hochst.	Acanthaceae	Dargu	H
108	*Myrsine africana* L.	Myrsinaceae	-	S
109	*Ocimum lamiifolium* Hochst.ex Benth.	Lamiaceae	Damakase	S
110	*Olea capensis* L.	Oleaceae	Gagamaa	T
111	*Olea welwitschii* (Knobl.) Gilg & Schellenb.	Oleaceae	Ba'aa	T
112	*Oplismenus hirtellus* (L.) P. Beauv.	Poaceae	Sutto gogorrii	H
113	*Oxyanthus speciosus* DC.	Rubiaceae	Abraango jaldessaa	T/S
114	*Pavonia schimperiana* Hochst. ex A. Rich .	Malvaceae	Gajjo	H
115	*Pentas schimperiana* (A. Rich.) Vatke	Rubiaceae	-	H
116	*Peperomia abyssinica* Miq	Piperaceae	Sarxe mukaa	H
117	*Peperomia retusa* (L.f.) A. Dietr	Piperaceae	-	H
118	*Peponium vogelii* (Hook.f.) Engl.	Cucurbitaceae	Tojjo	H
119	*Phaulopsis imbricata* (Forssk.) Sweet	Acanthaceae	Dargu	H

120	*Phoenix reclinata* Jacq.	Araceae	Mexxi	T
121	*Phyllanthus sepialis* Muell. Arg.	Euphorbiaceae	Qacamaa	S
122	*Pilea rivularis* Wedd.	Urticaceae	-	H
123	*Piper capense* L.f.	Piperaceae	Tunjo	H
124	*Pittosporum viridiflorum* Sims	Pittosporaceae	Soolee	T
125	*Polyscias farinosa* (Del.) Harms	Araliaceae	-	T
126	*Polyscias fulva* (Hiern) Harms	Araliaceae	Karaso	T
127	*Polystachya rivae* Shweinf.	Orchidaceae	Capho	H
128	*Polystichum wilsonii* H. Christ	Dryopteridaceae	-	H
129	*Pouteria adolfi-friederici* (Engl.) Baehni	Sapotaceae	Qararo	T
130	*Premna schimperi* Engl.	Verbenaceae	Urgessaa	S
131	*Prunus africana* (Hook. f.) Kalkm.	Roseaceae	Homii	T
132	*Psychotria orophila* Petit	Rubiaceae	Xumaane	S
133	*Pteris dentata* Forssk.	Pteridaceae	Giixoo	H
134	*Pteris pteridioides* (Hook.) ballard	Pteridaceae	Giixoo	H
135	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae	Harangamaa	S
136	*Pupalia micrantha* Haumam	Amaranthaceae	Maxxanne	H
137	*Ranunculus multifidus* Forssk.	Ranunculaceae	-	H
138	*Rhamnus prinoides* L'Herit.	Rhamnaceae	Gesho	S
139	*Ritchiea albersii* Gilg	Capparidaceae	Daqqo	T
140	*Rothmannia urcelliformis* (Hiern) Robyns	Rubiaceae	Diibo	T
141	*Rubus apetalus* Poir.	Roseaceae	Goraa	S
142	*Rubus steudneri* Schweinf.	Roseaceae	Goraa	S
143	*Rytigynia neglecta* (Hirn) Robyns	Rubiaceae	Mixo	S
144	*Sapium ellipticum* (Krauss) Pax	Euphorbiaceae	Bosoqa	T
145	*Scadoxus nutans* (Friis & J. Bjørnstad) Friis & Nordal	Amaryllidaceae	Qulubi jaldessaa	H
146	*Schefflera abyssinica* (Hochst. ex A. Rich.) Harms	Araliaceae	Gatamaa	T
147	*Schefflera myriantha* (Bak.) Drake	Araliaceae	Qero	L
148	*Sericostachys scandens* Gilg & Lopr.	Amaranthaceae	Suddi	L
149	*Setaria megaphylla* (Steud.) Th. Dur. & Schinz	Poaceae	Gowaa	H
150	*Solanaceo manni* (Hook.f.) C. Jeffrey	Asteraceae	Rejjii caakkaa	S
151	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	Raafu boyye	S

152	*Solanum adoense* Hochst. ex A. Rich.	Solanaceae	Hiddi- xino	S
153	*Solanum giganteum* Jacq.	Solanaceae	Tambo arbaa	S
154	*Stellaria mannii* Hook.f.	Caryophyllaceae	Moccoo	H
155	*Syzygium guineense* (Willd.) DC.	Myrtaceae	Baddessaa	T
156	*Tacazzea apiculata* Oliv.	Asclepidiaceae	Gebbo	L
157	*Tacazzea conferta* N.E. Br.	Asclepidiaceae	Gebbo qalame	L
158	*Teclea nobilis* Del.	Rutaceae	Mola'ee	T
159	*Tectaria gemmifera* (Fee) Alston.	Tectariaceae	Gixoo	H
160	*Thalictrum rhynchocarpum* Dill. & A. Rich	Ranunculaceae	Finge	H
161	*Thunbergia alata* Boj. ex Sims	Acanthaceae	-	H
162	*Tiliacora troupinii* Cufod.	Menispermaceae	Liqixi	L
163	*Trema orientalis* (L.) Bl.	Ulmaceae	Huddu farddaa	T
164	*Trichilia dregeana* Sond.	Meliaceae	Luyyaa	T
165	*Trifolium rueppellianum* Fresen.	Fabaceae	Amagixa	H **Trifoli**
166	*Trilepisium madagascariense* DC.	Moraceae	Same'eko/ceeyii	T
167	*Tristemma mauritianum* J. F. Gmel	Melistostomaceae	-	H
168	*Triumfetta brachyceras* K. Schum.	Tilaceae	Incciinii	S
169	*Turraea holstii* Gurke	Meliaceae	Ceekaa	S
170	*Urera hypselodendron* (A. Rich.) Wedd.	Urticaceae	Capho	L
171	*Urtica simensis* Steudel.	Urticaceae	Doobbii	H
172	*Vangueria apiculata* K. Schum.	Rubiaceae	-	T
173	*Vepris dainellii* (Pichi-Serm.) Kokwaro	Rutaceae	Hadhessa	T
174	*Vernonia amygdalina* Del.	Asteraceae	Eebicha	T
175	*Vernonia auriculifera* Hiern	Asteraceae	Rejjii	T/S
176	*Vernonia hochstetteri* Sch. Bip. ex Walp .	Asteraceae	Soyama masango	S
177	*Vernonia rueppellii* Sch. Bip. ex Walp.	Asteraceae	Tambo Arbaa	S
178	*Vernonia wollastonii* S. Moore	Asteraceae	-	H
179	*Zehneria minutiflora* (Cogn) C. Jeffrey	Cucurbitaceae	Kalaalaa bosonu	H
180	*Zehneria scabra* (Linn. f) Sond.	Cucurbitaceae	Kalaalaa bosonu	H

Appendix 2. Frequency, Density, Basal area and Important Value Index of Woody species of Gerba Dima Forest

Name of Species	Frequency	No. of individuals	Density (Individuals ha^{-1})	BA (m^{2}ha^{-1})	Relative frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Acanthopale ethio-germanica	61.11	55.00	9.78	0.00	2.18	0.53	0.00	2.72
Acanthus eminens	30.00	27.00	4.80	0.00	1.07	0.26	0.00	1.33
Alangium chinesis	1.11	1.00	0.18	0.01	0.04	0.01	0.01	0.06
Albizia gummifera	91.11	663.00	117.87	5.61	3.25	6.44	8.62	18.32
Albizia schimperiana	16.67	35.00	6.22	0.62	0.60	0.34	0.95	1.88
Allophyllus abyssinicus	36.67	45.00	8.00	0.38	1.31	0.44	0.58	2.33
Apodytes dimidiata	51.11	134.00	23.82	0.50	1.82	1.30	0.78	3.90
Asparagus africanus	4.44	4.00	0.71	0.00	0.16	0.04	0.00	0.20
Asparagus flagellaris	2.22	2.00	0.36	0.00	0.08	0.02	0.00	0.10
Asparagus setaceus	4.44	4.00	0.71	0.00	0.16	0.04	0.00	0.20
Bersama abyssinica	44.44	98.00	17.42	0.94	1.59	0.95	1.44	3.98
Bothriocline schimperi	2.22	2.00	0.36	0.00	0.08	0.02	0.00	0.10
Brillantaisia madagascariensis	75.56	68.00	12.09	0.00	2.70	0.66	0.00	3.36
Brucea antidysenterica	6.67	10.00	1.78	0.01	0.24	0.10	0.01	0.35
Canthium oligocarpum	25.56	46.00	8.18	0.07	0.91	0.45	0.11	1.47
Cassipourea malosana	37.78	82.00	14.58	0.12	1.35	0.80	0.18	2.33
Celtis africana	6.67	11.00	1.96	0.14	0.24	0.11	0.22	0.57
Chionanthus mildbraedii	3.33	3.00	0.53	0.00	0.12	0.03	0.00	0.15
Clausena anisata	64.44	270.00	48.00	0.15	2.30	2.62	0.24	5.16
Cledendron myricoides	1.11	5.00	0.89	0.03	0.04	0.05	0.04	0.13
Clematis longicauda	10.00	13.00	2.31	0.00	0.36	0.13	0.01	0.49
Coffea arabica	34.44	85.00	15.11	0.03	1.23	0.83	0.05	2.11
Combretum paniculatum	72.22	141.00	25.07	0.05	2.58	1.37	0.08	4.03

Name of Species	Frequency	No. of individuals	Density (Individuals ha^{-1})	BA (m^{2}ha^{-1})	Relative frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Cordia africana	15.56	37.00	6.58	0.43	0.56	0.36	0.66	1.57
Croton macrostachyus	72.22	216.00	38.40	2.78	2.58	2.10	4.28	8.95
Cyathea manniana	3.33	86.00	15.29	0.12	0.12	0.84	0.19	1.14
Dalbergia lactea	30.00	30.00	5.33	0.00	1.07	0.29	0.00	1.37
Deinbollia kilimandscharica	66.67	402.00	71.47	0.15	2.38	3.91	0.23	6.52
Dombeya torrida	11.11	13.00	2.31	0.02	0.40	0.13	0.03	0.55
Dracaena afromontana	43.33	481.00	85.51	0.77	1.55	4.67	1.18	7.40
Dracaena fragrans	21.11	16.00	2.84	0.00	0.75	0.16	0.00	0.91
Dracaena steudneri	52.22	186.00	33.07	1.75	1.86	1.81	2.68	6.36
Ehretia cymosa	54.44	208.00	36.98	0.40	1.94	2.02	0.61	4.58
Ekebergia capensis	3.33	4.00	0.71	2.11	0.12	0.04	3.24	3.40
Elaeodendron buchananii	17.78	33.00	5.87	0.34	0.63	0.32	0.52	1.48
Erythrococca trichogyne	8.89	14.00	2.49	0.01	0.32	0.14	0.01	0.46
Euphorbia ampliphylla	2.22	2.00	0.36	0.00	0.08	0.02	0.01	0.10
Ficus exasperata	2.22	2.00	0.36	0.00	0.08	0.02	0.00	0.10
Ficus ovata	1.11	1.00	0.18	0.07	0.04	0.01	0.11	0.15
Ficus sur	53.33	149.00	26.49	4.42	1.90	1.45	6.79	10.14
Ficus thonningii	2.22	4.00	0.71	0.02	0.08	0.04	0.02	0.14
Flacourtia indica	14.44	22.00	3.91	0.01	0.52	0.21	0.02	0.75
Galiniera coffeoides	15.56	32.00	5.69	0.02	0.56	0.31	0.04	0.90
Galiniera saxifraga	47.78	124.00	22.04	0.13	1.71	1.20	0.20	3.11
Gouania longispicata	24.44	51.00	9.07	0.02	0.87	0.50	0.04	1.41
Hallea rubrostipulata	5.56	26.00	4.62	0.19	0.20	0.25	0.29	0.74
Hippocratea africana	14.44	54.00	9.60	0.02	0.52	0.52	0.04	1.08
Hippocratea pallens	88.89	369.00	65.60	0.18	3.17	3.59	0.28	7.04

Name of Species	Frequency	No. of individuals	Density (Individuals ha^{-1})	BA (m^{2}ha^{-1})	Relative frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Ilex mitis	24.44	119.00	21.16	1.66	0.87	1.16	2.55	4.58
Jasminum abyssinicum	73.33	70.00	12.44	0.00	2.62	0.68	0.00	3.30
Justicia bizunesh	57.78	52.00	9.24	0.00	2.06	0.51	0.00	2.57
Justicia schimperiana	45.56	41.00	7.29	0.00	1.63	0.40	0.00	2.02
Landolphia buchananii	88.89	213.00	37.87	0.10	3.17	2.07	0.15	5.39
Lepidotrichilia volkensii	55.56	323.00	57.42	0.36	1.98	3.14	0.56	5.68
Lobelia giberroa	2.22	1.00	0.18	0.00	0.08	0.01	0.00	0.09
Macaranga capensis	26.67	103.00	18.31	0.64	0.95	1.00	0.99	2.94
Maesa lanceolata	4.44	40.00	7.11	0.05	0.16	0.39	0.08	0.62
Maytenus gracilipes	62.22	294.00	52.27	0.14	2.22	2.86	0.21	5.29
Maytenus undata	3.33	5.00	0.89	0.00	0.12	0.05	0.00	0.17
Millettia ferruginea	85.56	855.00	152.00	1.96	3.05	8.31	3.01	14.38
Myrsine africana	2.22	2.00	0.36	0.00	0.08	0.02	0.00	0.10
Olea capensis	63.33	505.00	89.78	0.43	2.26	4.91	0.66	7.82
Olea welwitschii	30.00	69.00	12.27	1.31	1.07	0.67	2.01	3.75
Oxyanthus speciosus	72.22	427.00	75.91	0.39	2.58	4.15	0.60	7.33
Phonix reclinata	6.67	22.00	3.91	0.13	0.24	0.21	0.19	0.65
Pittosporum viridiflorum	17.78	52.00	9.24	0.04	0.63	0.51	0.06	1.20
Polyscias farinosa	1.11	4.00	0.71	0.00	0.04	0.04	0.00	0.08
Polyscias fulva	33.33	92.00	16.36	3.37	1.19	0.89	5.18	7.26
Pouteria adolfi-friederici	58.89	311.00	55.29	10.41	2.10	3.02	16.00	21.13
Premna schimperi	2.22	3.00	0.53	0.00	0.08	0.03	0.00	0.11
Prunus africana	14.44	48.00	8.53	1.54	0.52	0.47	2.37	3.35
Psychotria orophila	54.44	117.00	20.80	0.05	1.94	1.14	0.08	3.16
Pterolobium stellatum	32.22	31.00	5.51	0.00	1.15	0.30	0.00	1.46

Name of Species	Frequency	No. of individuals	Density (Individuals ha^{-1})	BA (m^{2}ha^{-1})	Relative frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Rhamnus prinoides	2.22	1.00	0.18	0.00	0.08	0.01	0.00	0.09
Ritchiea albersii	10.00	26.00	4.62	0.03	0.36	0.25	0.05	0.66
Rothmannia urcelliformis	44.44	188.00	33.42	0.15	1.59	1.83	0.23	3.64
Rubus apetalus	12.22	11.00	1.96	0.00	0.44	0.11	0.00	0.54
Rubus steudneri	6.67	6.00	1.07	0.00	0.24	0.06	0.00	0.30
Rytignia neglecta	2.22	2.00	0.36	0.00	0.08	0.02	0.00	0.10
Sapium ellipticum	21.11	26.00	4.62	1.94	0.75	0.25	2.98	3.99
Schefflera abyssinica	37.78	59.00	10.49	13.37	1.35	0.57	20.55	22.47
Schefflera myriantha	3.33	3.00	0.53	0.00	0.12	0.03	0.00	0.15
Seriostachys scandus	31.11	30.00	5.33	0.01	1.11	0.29	0.02	1.42
Solanaceo manni	1.11	1.00	0.18	0.01	0.04	0.01	0.01	0.06
Solanecio gigas	5.56	12.00	2.13	0.00	0.20	0.12	0.01	0.32
Solanum giganteum	4.44	4.00	0.71	0.00	0.16	0.04	0.00	0.20
Syzygium guineense	56.67	270.00	48.00	2.26	2.02	2.62	3.47	8.12
Taccaza apiculata	4.44	7.00	1.24	0.00	0.16	0.07	0.00	0.23
Taccaza comforta	5.56	8.00	1.42	0.00	0.20	0.08	0.00	0.28
Teclea nobilis	37.78	84.00	14.93	0.07	1.35	0.82	0.11	2.28
Tiliacora troupinii	96.67	157.00	27.91	0.04	3.45	1.53	0.07	5.04
Trema orientalis	3.33	7.00	1.24	0.02	0.12	0.07	0.03	0.21
Trichilia dregeana	3.33	4.00	0.71	0.06	0.12	0.04	0.09	0.25
Trilepisium madagascariense	8.89	21.00	3.73	0.94	0.32	0.20	1.44	1.96
Urera hypselodendron	7.78	8.00	1.42	0.00	0.28	0.08	0.00	0.36
Vangueria apiculata	1.11	1.00	0.18	0.00	0.04	0.01	0.00	0.05
Vepris dainellii	97.78	1140.00	202.67	0.89	3.49	11.08	1.36	15.93
Vernonia amygdalina	2.22	23.00	4.09	0.03	0.08	0.22	0.05	0.35

Name of Species	Frequency	No. of individuals	Density (Individuals ha^{-1})	BA (m^{2}ha^{-1})	Relative frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Vernonia auriculifera	6.67	17.00	3.02	0.01	0.24	0.17	0.02	0.42
Vernonia hochstetteri	11.11	9.00	1.60	0.00	0.40	0.09	0.00	0.48
Vernonia rueppellii	1.11	1.00	0.18	0.00	0.04	0.01	0.00	0.05
Total	**2801.11**	**10291.00**	**1829.51**	**65.05**	**100.00**	**100.00**	**100.00**	**300.00**

Appendix 3. Seedling, and Tree/shrubs per hectare of woody species in Gerba Dima Forest

Species name	Seedling ha^{-1}	Sapling ha^{-1}	T/s ha^{-1}
Acanthopale ethio-germanica	0.00	0.00	0.00
Acanthus eminens	0.00	0.00	0.00
Alangium chinesis	0.71	0.36	0.18
Albizia gummifera	446.04	169.60	117.87
Albizia schimperiana	24.71	12.09	6.22
Allophyllus abyssinicus	114.67	40.18	8.00
Apodytes dimidiata	70.40	34.67	23.82
Asparagus africanus	0.00	0.00	0.00
Asparagus flagellaris	0.00	0.00	0.00
Asparagus setaceus	0.00	0.00	0.00
Bersama abyssinica	54.58	25.07	17.42
Bothriocline schimperi	0.00	0.00	0.00
Brillantaisia madagascariensis	0.00	0.00	0.00
Brucea antidysenterica	24.00	6.93	1.78
Canthium oligocarpum	32.53	15.47	8.18
Cassipourea malosana	90.84	47.47	14.58
Celtis africana	10.67	2.84	1.96
Chionanthus mildbraedii	0.00	0.53	0.53
Clausena anisata	233.60	111.47	48.00
Cledendron myricoides	2.84	0.89	0.89
Clematis longicauda	0.00	0.00	0.00
Coffea arabica L.	214.93	96.53	15.11
Combretum paniculatum	0.00	0.00	0.00
Cordia africana	12.27	5.16	6.58
Croton macrostachyus	97.42	42.31	38.40
Cyathea manniana	0.00	0.00	0.00
Dalbergia lactea	0.00	0.00	0.00
Deinbollia kilimandscharica	155.73	140.98	71.47
Dombeya torrida	12.98	7.47	2.31
Dracaena afromontana	78.40	52.44	85.51
Dracaena fragrans	0.00	0.00	0.00
Dracaena steudneri	64.00	26.13	2.84
Ehretia cymosa	60.27	29.16	36.98
Ekebergia capensis	4.98	1.42	0.71
Elaeodendron buchananii	15.29	7.11	5.87

Species name	Seedling ha^{-1}	Sapling ha^{-1}	T/s ha^{-1}
Erythrococca trichogyne	20.62	8.00	2.49
Euphorbia ampliphylla	5.51	2.31	0.36
Ficus exasperata	0.89	0.36	0.36
Ficus ovata	0.00	0.00	0.18
Ficus sur	44.09	25.78	26.49
Ficus thonningii	0.00	0.00	0.71
Flacourtia indica	35.20	15.11	3.91
Galiniera coffeoides	19.91	8.89	5.69
Galiniera saxifraga	70.04	33.96	22.04
Gouania longispicata	0.00	0.00	0.00
Hallea rubrostipulata	0.89	0.36	4.62
Hippocratea africana	0.00	0.00	0.00
Hippocratea pallens	0.00	0.00	0.00
Ilex mitis	26.31	16.18	21.16
Jasminum abyssinicum	0.00	0.00	0.00
Justicia bizunesh	0.00	0.00	0.00
Justicia schimperiana	0.00	0.00	0.00
Landolphia buchananii	0.00	0.00	0.00
Lepidotrichilia volkensii	169.96	56.89	57.42
Lobelia giberroa	0.00	0.00	0.18
Macaranga capensis	15.82	14.76	18.31
Maesa lanceolata	13.87	12.62	7.11
Maytenus gracilipes	228.27	110.04	52.27
Maytenus undata	3.20	1.24	0.89
Millettia ferruginea	258.84	103.47	152.00
Myrsine africana	0.00	0.00	0.00
Olea capensis	314.67	146.84	89.78
Olea welwitschii	31.11	17.96	12.27
Oxyanthus speciosus	264.36	103.47	75.91
Phonix reclinata	23.82	4.27	3.91
Pittosporum viridiflorum	47.11	13.33	3.91
Polyscias farinosa	0.00	0.00	0.71
Polyscias fulva	41.07	18.31	16.36
Pouteria adolfi-friederici	116.44	59.91	55.29
Premna schimperi	1.24	0.71	0.53
Prunus africana	64.18	26.31	8.53
Psychotria orophila	192.36	104.71	20.80
Pterolobium stellatum	0.00	0.00	0.00
Rhamnus prinoides	0.00	0.00	0.00

Species name	Seedling ha^{-1}	Sapling ha^{-1}	T/s ha^{-1}
Ritchiea albersii	4.80	4.27	4.62
Rothmannia urcelliformis	152.71	63.82	33.42
Rubus apetalus	0.00	0.00	0.00
Rubus steudneri	0.00	0.00	0.00
Rytignia neglecta	4.98	2.13	0.36
Sapium ellipticum	15.11	7.64	4.62
Schefflera abyssinica	0.00	0.00	10.49
Schefflera myriantha	0.00	0.00	0.00
Seriostachys scandus	0.00	0.00	0.00
Solanaceo manni	1.78	0.36	0.18
Solanecio gigas	1.07	0.36	2.13
Solanum giganteum	0.00	0.00	0.00
Syzygium guineense	98.13	44.62	48.00
Taccaza apiculata	0.00	0.00	0.00
Taccaza comforta	0.00	0.00	0.00
Teclea nobilis	70.93	27.20	14.93
Tiliacora troupinii	0.00	0.00	0.00
Trema orientalis	0.71	0.36	1.24
Trichilia dregeana	0.00	0.00	0.71
Trilepisium madagascariense	10.13	10.31	3.73
Urera hypselodendron	0.00	0.00	1.42
Vangueria apiculata	0.00	0.00	0.18
Vepris dainellii	356.62	200.00	202.67
Vernonia amygdalina	3.56	1.60	4.09
Vernonia auriculifera	7.29	4.27	3.02
Vernonia hochstetteri	0.00	0.00	0.00
Vernonia rueppellii	0.00	0.00	0.18

Appendix 4. AGB, BGB, AGC, BGC, total carbon stock and Carbon sequestered (CO_2 equivalent) per species in Gerba Dima Forest

Scientific names	Mean DBH (cm)	Number of stems	Mean AGB t/ha	Total AGB ton/ha	Total BGB	Total Biomass	Total AGC ton/ha	Total BGC t/ha	Total Carbon stock	Total CO_2 equivalent Ton//ha	Percentage (%)
Pouteria adolfi-friederici	58.72	178.00	63.03	11219.67	2243.93	13463.60	5273.24	1054.65	6327.89	23223.35	24.91
Schefflera abyssinica	123.90	73.00	85.74	6259.13	1251.83	7510.96	2941.79	588.36	3530.15	12955.64	13.90
Albizia gummifera	35.63	293	15.67	4591.55	918.31	5509.86	2158.03	431.61	2589.64	9503.96	10.19
Ficus sur	53.75	105.00	21.13	2218.69	443.74	2662.43	1042.78	208.56	1251.34	4592.40	4.93
Millettia ferruginea	17.38	193.00	10.53	2033.20	406.64	2439.84	955.61	191.12	1146.73	4208.51	4.51
Syzygium guineense	31.82	109.00	16.45	1793.20	358.64	2151.84	842.80	168.56	1011.36	3711.69	3.98
Croton macrostachyus	33.97	160	11.05	1767.75	353.55	2121.30	830.84	166.17	997.01	3659.02	3.92
Prunus africana	48.47	32.00	44.75	1431.97	286.39	1718.36	673.03	134.61	807.64	2964.02	3.18
Ekebergia capensis	147.86	7	190.96	1336.71	267.34	1604.05	628.25	125.65	753.90	2766.81	2.97
Olea welwitschii	39.69	38.00	34.71	1319.05	263.81	1582.86	619.95	123.99	743.94	2730.26	2.93
Sapium ellipticum	68.08	37.00	34.49	1275.99	255.20	1531.19	599.71	119.94	719.65	2641.12	2.83
Ilex mitis	34.24	94.00	11.23	1055.72	211.14	1266.86	496.19	99.24	595.43	2185.22	2.34
Polyscias fulva	58.31	44.00	21.57	949.06	189.81	1138.87	446.06	89.21	535.27	1964.45	2.11
Elaeodendron buchananii	35.67	22.00	42.81	941.87	188.37	1130.24	442.68	88.54	531.22	1949.56	2.09
Bersama abyssinica	25.35	40	17.19	687.7	137.54	825.24	323.22	64.64	387.86	1423.46	1.53
Vepris dainellii	7.96	181.00	3.21	581.64	116.33	697.97	273.37	54.67	328.04	1203.92	1.29
Trilepisium madagascariense	49.02	17.00	28.57	485.65	97.13	582.78	228.25	45.65	273.90	1005.21	1.08

Scientific names	Mean DBH (cm)	Number of stems	Mean AGB t/ha	Total AGB ton/ha	Total BGB	Total Biomass	Total AGC ton/ha	Total BGC t/ha	Total Carbon stock	Total CO_2 equivalent Ton//ha	Percentage (%)
Apodytes dimidiata	20.09	47	8.6	404.08	80.82	484.90	189.92	37.98	227.90	836.41	0.90
Dracena steudneri	30.84	96	4.15	397.96	79.59	477.55	187.04	37.41	224.45	823.72	0.88
Macaranga capensis	28.92	48.00	7.48	358.95	71.79	430.74	168.71	33.74	202.45	743.00	0.80
Albizia schimperiana	39.27	23	14.5	333.46	66.69	400.15	156.73	31.35	188.08	690.24	0.74
Hippocratea pallens	5.82	89.00	3.27	290.78	58.16	348.94	136.66	27.33	163.99	601.85	0.65
Ehretia cymosa	13.14	64.00	4.38	280.20	56.04	336.24	131.69	26.34	158.03	579.96	0.62
Lepidotrichilia volkensii	9.61	69.00	3.77	259.88	51.98	311.86	122.14	24.43	146.57	537.90	0.58
Cassipourea malosana	10.41	31	7.55	234.05	46.81	280.86	110	22.00	132.00	484.44	0.52
Allophyllus abyssinicus	24.93	31	7.43	230.4	46.08	276.48	108.29	21.66	129.95	476.91	0.51
Dracena afromontana	13.80	71.00	3.14	223.14	44.63	267.77	104.88	20.98	125.86	461.89	0.50
Cordia africana	33.85	26.00	8.53	221.73	44.35	266.08	104.21	20.84	125.05	458.94	0.49
Olea capensis	7.69	80.00	2.73	218.57	43.71	262.28	102.73	20.55	123.28	452.42	0.49
Oxyanthus speciosus	7.83	76.00	2.44	185.46	37.09	222.55	87.17	17.43	104.60	383.90	0.41
Rothmannia urcelliformis	8.11	41.00	3.22	132.03	26.41	158.44	62.05	12.41	74.46	273.27	0.29
Celtis africana	40.06	7	18.39	128.72	25.74	154.46	60.5	12.10	72.60	266.44	0.29
Hallea rubrostipulata	27.12	14.00	8.63	120.80	24.16	144.96	56.77	11.35	68.12	250.02	0.27
Landolphia buchananii	5.57	66.00	1.68	110.83	22.17	133.00	52.09	10.42	62.51	229.40	0.25

Scientific names	Mean DBH (cm)	Number of stems	Mean AGB t/ha	Total AGB ton/ha	Total BGB	Total Biomass	Total AGC ton/ha	Total BGC t/ha	Total Carbon stock	Total CO_2 equivalent Ton//ha	Percentage (%)
Galiniera saxifraga	9.16	34.00	2.83	96.32	19.26	115.58	45.27	9.05	54.32	199.37	0.21
Combretum paniculatum	5.50	33	2.86	94.52	18.90	113.42	44.42	8.88	53.30	195.63	0.21
Teclea nobilis	7.88	29.00	2.98	86.42	17.28	103.70	40.62	8.12	48.74	178.89	0.19
Clausena anisata	6.38	68	1.11	75.7	15.14	90.84	35.58	7.12	42.70	156.69	0.17
Maytenus gracilipes	5.80	56.00	1.33	74.47	14.89	89.36	35.00	7.00	42.00	154.14	0.17
Canthium oligocarpum	10.75	19	2.81	53.36	10.67	64.03	25.08	5.02	30.10	110.45	0.12
Tiliacora troupinii	5.45	30.00	1.67	50.19	10.04	60.23	23.59	4.72	28.31	103.89	0.11
Deinbollia kilimandscharica	5.05	78.00	0.54	42.47	8.49	50.96	19.96	3.99	23.95	87.90	0.09
Brucea antidysenterica	9.38	4	9.15	36.58	7.32	43.90	17.19	3.44	20.63	75.70	0.08
Ritchiea albersii	9.68	5.00	5.96	29.79	5.96	35.75	14.00	2.80	16.80	61.66	0.07
Gouania longispicata	6.00	12.00	2.46	29.51	5.90	35.41	13.87	2.77	16.64	61.08	0.07
Trema orientalis	13.83	4.00	7.21	28.86	5.77	34.63	13.56	2.71	16.27	59.72	0.06
Maesa lanceolata	12.70	4.00	6.30	25.19	5.04	30.23	11.84	2.37	14.21	52.14	0.06
Trichilia dregeana	32.33	3.00	6.90	20.69	4.14	24.83	9.73	1.95	11.68	42.85	0.05
Pittosporum viridiflorum	7.12	8.00	2.56	20.51	4.10	24.61	9.64	1.93	11.57	42.45	0.05
Ficus ovata	70.00	1.00	19.68	19.68	3.94	23.61	9.25	1.85	11.10	40.73	0.04
Coffea arabica	5.33	29.00	0.68	19.58	3.92	23.50	9.20	1.84	11.04	40.52	0.04
Hippocratea africana	5.61	7.00	2.76	19.34	3.87	23.21	9.09	1.82	10.91	40.03	0.04
Dombeya torrida	12.42	5	3.36	16.79	3.36	20.15	7.89	1.58	9.47	34.75	0.04

Scientific names	**Mean DBH (cm)**	**Number of stems**	**Mean AGB t/ha**	**Total AGB ton/ha**	**Total BGB**	**Total Biomass**	**Total AGC ton/ha**	**Total BGC t/ha**	**Total Carbon stock**	**Total CO_2 equivalent Ton//ha**	**Percentage (%)**
Cledendron myricoides	42.00	1.00	15.78	15.78	3.16	18.93	7.42	1.48	8.90	32.66	0.04
Vernonia amygdalina	9.60	5.00	2.86	14.32	2.86	17.18	6.73	1.35	8.08	29.64	0.03
Ficus thonningi	16.00	2.00	6.48	12.96	2.59	15.55	6.09	1.22	7.31	26.82	0.03
Seriostachys scandus	5.25	8.00	1.58	12.66	2.53	15.19	5.95	1.19	7.14	26.20	0.03
Cyathea manniana	11.50	6.00	1.98	11.90	2.38	14.28	5.60	1.12	6.72	24.66	0.03
Phonix reclinata	22.25	8.00	1.22	9.73	1.95	11.68	4.57	0.91	5.48	20.13	0.02
Psychotria orophila	6.30	8.00	1.00	8.03	1.61	9.64	3.77	0.75	4.52	16.60	0.02
Dalbergia lactea	5.00	3	2.34	7.02	1.40	8.42	3.3	0.66	3.96	14.53	0.02
Clematis longicauda	5.00	5	1.37	6.84	1.37	8.21	3.22	0.64	3.86	14.18	0.02
Flacourtia indica	5.50	4.00	0.93	3.74	0.75	4.49	1.76	0.35	2.11	7.75	0.01
Erythrococca trichogyne	6.00	3.00	1.23	3.70	0.74	4.44	1.74	0.35	2.09	7.66	0.01
Taccaza apiculata	5.50	2.00	1.74	3.48	0.70	4.18	1.64	0.33	1.97	7.22	0.01
Chionanthus mildbraedii	9.00	1.00	3.11	3.11	0.62	3.73	1.46	0.29	1.75	6.44	0.01
Ensete ventericosum	50.00	1.00	2.85	2.85	0.57	3.42	1.34	0.27	1.61	5.90	0.01
Alangium chinesis	23.00	1.00	2.38	2.38	0.48	2.86	1.12	0.22	1.34	4.94	0.01
Jasminum abyssinicum	5.00	1.00	1.65	1.65	0.33	1.99	0.78	0.16	0.93	3.42	0.00
Solanecio gigas	5.35	3.00	0.54	1.62	0.32	1.94	0.76	0.15	0.91	3.35	0.00
Schefflera myriantha	5.00	1.00	1.16	1.16	0.23	1.39	0.54	0.11	0.65	2.39	0.00

Scientific names	Mean DBH (cm)	Number of stems	Mean AGB t/ha	Total AGB ton/ha	Total BGB	Total Biomass	Total AGC ton/ha	Total BGC t/ha	Total Carbon stock	Total CO_2 equivalent Ton//ha	Percentage (%)
Pterolobium stellatum	3.80	1.00	0.97	0.97	0.19	1.16	0.45	0.09	0.55	2.00	0.00
Solanaceo manni	20.00	1.00	0.89	0.89	0.18	1.07	0.42	0.08	0.50	1.85	0.00
Phyllanthus sepialis	5.00	1.00	0.71	0.71	0.14	0.86	0.34	0.07	0.40	1.48	0.00
Vernonia rueppellii	5.00	1.00	0.35	0.35	0.07	0.42	0.17	0.03	0.20	0.73	0.00

Appendix 5. AGB, BGB, AGC, BGC and Carbon sequestered (CO_2 equivalent) per single tree of species in Gerba Dima Forest

Species Name	No of stems	Mean DBH	AGB ton ha^{-1} per single tree	BGB ton ha^{-1} per single tree	Total B ton ha^{-1} per single tree	AGC ton ha^{-1} per single tree	BGC ton ha^{-1} per single tree	Total C stock ton ha^{-1} per single tree	CO2 eqv.ton ha^{-1} per single tree
Ekebergia capensis	1.00	147.86	190.96	38.19	229.15	89.75	17.95	107.70	395.26
Schefflera abyssinica	293	123.90	85.74	17.15	102.89	40.30	8.06	48.36	177.48
Pouteria adolfi-friederici	23	58.72	63.03	12.61	75.64	29.62	5.92	35.54	130.45
Prunus Africana	31	48.47	44.75	8.95	53.70	21.03	4.21	25.24	92.62
Elaeodendron buchananii	47	35.67	42.81	8.56	51.37	20.12	4.02	24.14	88.61
Olea welwitschii	40	39.69	34.71	6.94	41.65	16.31	3.26	19.57	71.83
Sapium ellipticum	4	68.08	34.49	6.90	41.39	16.21	3.24	19.45	71.39
Trilepisium madagascariense	19	49.02	28.57	5.71	34.28	13.43	2.69	16.12	59.15
Polyscias fulva	31	58.31	21.57	4.31	25.88	10.14	2.03	12.17	44.66

Species Name	**No of stems**	**Mean DBH**	**AGB ton ha^{-1} per single tree**	**BGB ton ha^{-1} per single tree**	**Total B ton ha^{-1} per single tree**	**AGC ton ha^{-1} per single tree**	**BGC ton ha^{-1} per single tree**	**Total C stock ton ha^{-1} per single tree**	**CO2 eqv.ton ha^{-1} per single tree**
Ficus sur	7	53.75	21.13	4.23	25.36	9.93	1.99	11.92	43.73
Ficus ovata	1.00	70.00	19.68	3.94	23.61	9.25	1.85	11.10	40.73
Celtis Africana	68	40.06	18.39	3.68	22.07	8.64	1.73	10.37	38.05
Bersama abyssinica	1.00	25.35	17.19	3.44	20.63	8.08	1.62	9.70	35.58
Syzygium guineense	5	31.82	16.45	3.29	19.74	7.73	1.55	9.28	34.04
Cledendron myricoides	29.00	42.00	15.78	3.16	18.93	7.42	1.48	8.90	32.66
Albizia gummifera	33	35.63	15.67	3.13	18.80	7.37	1.47	8.84	32.46
Albizia schimperiana	26.00	39.27	14.5	2.90	17.40	6.81	1.36	8.17	29.99
Ilex mitis	160	34.24	11.23	2.25	13.48	5.28	1.06	6.34	23.25
Croton macrostachyus	6.00	33.97	11.05	2.21	13.26	5.19	1.04	6.23	22.86
Millettia ferruginea	3	17.38	10.53	2.11	12.64	4.95	0.99	5.94	21.80
Brucea antidysenterica	78.00	9.38	9.15	1.83	10.98	4.3	0.86	5.16	18.94
Hallea rubrostipulata	5	27.12	8.63	1.73	10.36	4.06	0.81	4.87	17.88
Apodytes dimidiate	71.00	20.09	8.6	1.72	10.32	4.04	0.81	4.85	17.79
Cordia Africana	96	33.85	8.53	1.71	10.24	4.01	0.80	4.81	17.66
Cassipourea malosana	64.00	10.41	7.55	1.51	9.06	3.55	0.71	4.26	15.63
Macaranga capensis	7	28.92	7.48	1.50	8.98	3.51	0.70	4.21	15.46
Allophyllus abyssinicus	22.00	24.93	7.43	1.49	8.92	3.49	0.70	4.19	15.37
Trema orientalis	1.00	13.83	7.21	1.44	8.65	3.39	0.68	4.07	14.93
Trichilia dregeana	3.00	32.33	6.90	1.38	8.28	3.24	0.65	3.89	14.27
Ficus thonningi	1.00	16.00	6.48	1.30	7.78	3.05	0.61	3.66	13.43
Maesa lanceolata	105.00	12.70	6.30	1.26	7.56	2.96	0.59	3.55	13.04
Ritchiea albersii	2.00	9.68	5.96	1.19	7.15	2.80	0.56	3.36	12.33
Ehretia cymosa	4.00	13.14	4.38	0.88	5.26	2.06	0.41	2.47	9.07

Species Name	**No of stems**	**Mean DBH**	**AGB ton ha^{-1} per single tree**	**BGB ton ha^{-1} per single tree**	**Total B ton ha^{-1} per single tree**	**AGC ton ha^{-1} per single tree**	**BGC ton ha^{-1} per single tree**	**Total C stock ton ha^{-1} per single tree**	**CO2 eqv.ton ha^{-1} per single tree**
Dracena steudneri	34.00	30.84	4.15	0.83	4.98	1.95	0.39	2.34	8.59
Lepidotrichilia volkensii	12.00	9.61	3.77	0.75	4.52	1.77	0.35	2.12	7.80
Dombeya torrid	14.00	12.42	3.36	0.67	4.03	1.58	0.32	1.90	6.96
Hippocratea pallens	7.00	5.82	3.27	0.65	3.92	1.54	0.31	1.85	6.78
Rothmannia urcelliformis	89.00	8.11	3.22	0.64	3.86	1.51	0.30	1.81	6.65
Vepris dainellii	94.00	7.96	3.21	0.64	3.85	1.51	0.30	1.81	6.65
Dracena afromontana	1.00	13.80	3.14	0.63	3.77	1.48	0.30	1.78	6.52
Chionanthus mildbraedii	66.00	9.00	3.11	0.62	3.73	1.46	0.29	1.75	6.44
Teclea nobilis	69.00	7.88	2.98	0.60	3.58	1.40	0.28	1.68	6.17
Combretum paniculatum	48.00	5.50	2.86	0.57	3.43	1.35	0.27	1.62	5.95
Vernonia amygdalina	4.00	9.60	2.86	0.57	3.43	1.35	0.27	1.62	5.95
Ensete ventericosum	56.00	50.00	2.85	0.57	3.42	1.34	0.27	1.61	5.90
Galiniera saxifrage	193.00	9.16	2.83	0.57	3.40	1.33	0.27	1.60	5.86
Canthium oligocarpum	80.00	10.75	2.81	0.56	3.37	1.32	0.26	1.58	5.81
Hippocratea Africana	38.00	5.61	2.76	0.55	3.31	1.30	0.26	1.56	5.73
Olea capensis	76.00	7.69	2.73	0.55	3.28	1.28	0.26	1.54	5.64
Pittosporum viridiflorum	8.00	7.12	2.56	0.51	3.07	1.20	0.24	1.44	5.28
Gouania longispicata	1.00	6.00	2.46	0.49	2.95	1.16	0.23	1.39	5.11
Oxyanthus speciosus	8.00	7.83	2.44	0.49	2.93	1.15	0.23	1.38	5.06
Alangium chinesis	44.00	23.00	2.38	0.48	2.86	1.12	0.22	1.34	4.94
Dalbergia lacteal	178.00	5.00	2.34	0.47	2.81	1.1	0.22	1.32	4.84
Cyathea manniana	32.00	11.50	1.98	0.40	2.38	0.93	0.19	1.12	4.10
Taccaza apiculata	8.00	5.50	1.74	0.35	2.09	0.82	0.16	0.98	3.61
Tiliacora troupinii	1.00	5.45	1.67	0.33	2.00	0.79	0.16	0.95	3.48

Species Name	No of stems	Mean DBH	AGB ton ha^{-1} per single tree	BGB ton ha^{-1} per single tree	Total B ton ha^{-1} per single tree	AGC ton ha^{-1} per single tree	BGC ton ha^{-1} per single tree	Total C stock ton ha^{-1} per single tree	CO2 eqv.ton ha^{-1} per single tree
Landolphia buchananii	5.00	5.57	1.68	0.34	2.02	0.79	0.16	0.95	3.48
Jasminum abyssinicum	41.00	5.00	1.65	0.33	1.99	0.78	0.16	0.93	3.42
Seriostachys scandus	37.00	5.25	1.58	0.32	1.90	0.74	0.15	0.89	3.26
Clematis longicauda	73.00	5.00	1.37	0.27	1.64	0.64	0.13	0.77	2.82
Maytenus gracilipes	1.00	5.80	1.33	0.27	1.60	0.63	0.13	0.76	2.77
Erythrococca trichogyne	8.00	6.00	1.23	0.25	1.48	0.58	0.12	0.70	2.55
Phonix reclinata	1.00	22.25	1.22	0.24	1.46	0.57	0.11	0.68	2.51
Schefflera myriantha	3.00	5.00	1.16	0.23	1.39	0.54	0.11	0.65	2.39
Clausena anisata	109.00	6.38	1.11	0.22	1.33	0.52	0.10	0.62	2.29
Psychotria orophila	2.00	6.30	1.00	0.20	1.20	0.47	0.09	0.56	2.07
Pterolobium stellatum	29.00	3.80	0.97	0.19	1.16	0.45	0.09	0.55	2.00
Flacourtia indica	30.00	5.50	0.93	0.19	1.12	0.44	0.09	0.53	1.94
Solanaceo manni	4.00	20.00	0.89	0.18	1.07	0.42	0.08	0.50	1.85
Phyllanthus sepialis	3.00	5.00	0.71	0.14	0.86	0.34	0.07	0.40	1.48
Coffea arabica	17.00	5.33	0.68	0.14	0.82	0.32	0.06	0.38	1.41
Deinbollia kilimandscharica	181.00	5.05	0.54	0.11	0.65	0.26	0.05	0.31	1.15
Solanecio gigas	5.00	5.35	0.54	0.11	0.65	0.25	0.05	0.30	1.10
Vernonia rueppellii	1.00	5.00	0.35	0.07	0.42	0.17	0.03	0.20	0.73

Appendix 6. AGB, BGB, AGC, BGC, Total Biomass, Total Carbon stock and Total carbon sequestered (CO_2 equivalent) in ton/ha of the two carbon pool for each study plot in Gerba Dima Forest

Plot No.	AGB ton ha^{-1}	BGB ton ha^{-1}	Total Biomass ton ha^{-1}	AGC ton ha^{-1}	BGC ton ha^{-1}	Total Carbon stock ton ha^{-1}	CO_2 equivalent ton ha^{-1}
Plot 1	1305.32	261.06	1566.38	700.11	122.70	822.81	3019.73
Plot 2	116.75	23.35	140.10	84.71	10.97	95.68	351.1538
Plot 3	430.84	86.17	517.01	236.56	40.50	277.06	1016.802
Plot 4	132.52	26.50	159.02	147.31	12.46	159.77	586.3418
Plot 5	375.95	75.19	451.13	233.99	35.34	269.33	988.4279
Plot 6	1097.93	219.59	1317.52	550.34	103.21	653.54	2398.495
Plot 7	198.90	39.78	238.68	191.49	18.70	210.18	771.3732
Plot 8	325.89	65.18	391.07	240.90	30.63	271.53	996.5246
Plot 9	499.42	99.88	599.30	266.64	46.95	313.59	1150.862
Plot 10	555.61	111.12	666.73	395.94	52.23	448.17	1644.791
Plot 11	98.91	19.78	118.69	105.80	9.30	115.09	422.3979
Plot 12	341.25	68.25	409.50	315.28	32.08	347.36	1274.804
Plot 13	252.87	50.57	303.44	176.84	23.77	200.61	736.2329
Plot 14	311.55	62.31	373.86	285.24	29.29	314.52	1154.3
Plot 15	179.94	35.99	215.93	216.71	16.91	233.62	857.3871
Plot 16	350.15	70.03	420.18	203.45	32.91	236.37	867.4745
Plot 17	899.34	179.87	1079.21	422.69	84.54	507.23	1861.523
Plot 18	803.81	160.76	964.57	377.79	75.56	453.35	1663.791
Plot 19	1055.82	211.16	1266.98	496.23	99.25	595.48	2185.412
Plot 20	374.00	74.80	448.79	175.78	35.16	210.93	774.1252
Plot 21	199.17	39.83	239.00	93.61	18.72	112.33	412.2578
Plot 22	254.73	50.95	305.67	119.72	23.94	143.67	527.2514
Plot 23	224.90	44.98	269.88	105.70	21.14	126.84	465.512
Plot 24	163.62	32.72	196.34	76.90	15.38	92.28	338.6677
Plot 25	744.78	148.96	893.74	350.05	70.01	420.06	1541.607
Plot 26	361.25	72.25	433.50	169.79	33.96	203.75	747.7521
Plot 27	189.65	37.93	227.59	89.14	17.83	106.97	392.5628
Plot 28	253.82	50.76	304.59	119.30	23.86	143.16	525.3855
Plot 29	511.64	102.33	613.97	240.47	48.09	288.56	1059.031
Plot 30	1417.11	283.42	1700.53	666.04	133.21	799.25	2933.246
Plot 31	394.95	78.99	473.94	185.63	37.13	222.75	817.5041
Plot 32	258.94	51.79	310.73	121.70	24.34	146.04	535.9747
Plot 33	365.69	73.14	438.82	171.87	34.37	206.25	756.927

Plot No.	AGB ton ha^{-1}	BGB ton ha^{-1}	Total Biomass ton ha^{-1}	AGC ton ha^{-1}	BGC ton ha^{-1}	Total Carbon stock ton ha^{-1}	CO_2 equivalent ton ha^{-1}
Plot 34	347.90	69.58	417.48	163.51	32.70	196.22	720.115
Plot 35	801.87	160.37	962.25	376.88	75.38	452.26	1659.784
Plot 36	852.34	170.47	1022.81	400.60	80.12	480.72	1764.243
Plot 37	805.71	161.14	966.85	378.68	75.74	454.42	1667.724
Plot 38	782.06	156.41	938.48	367.57	73.51	441.08	1618.78
Plot 39	122.90	24.58	147.48	57.76	11.55	69.31	254.3818
Plot 40	286.01	57.20	343.21	134.43	26.89	161.31	592.0083
Plot 41	413.91	82.78	496.69	194.54	38.91	233.44	856.7401
Plot 42	194.00	38.80	232.80	91.18	18.24	109.41	401.5516
Plot 43	446.20	89.24	535.44	209.71	41.94	251.66	923.5834
Plot 44	310.91	62.18	373.09	146.13	29.23	175.35	643.5406
Plot 45	473.95	94.79	568.74	222.76	44.55	267.31	981.0183
Plot 46	342.50	68.50	411.01	160.98	32.20	193.17	708.9434
Plot 47	778.55	155.71	934.25	365.92	73.18	439.10	1611.496
Plot 48	273.43	54.69	328.12	128.51	25.70	154.22	565.9739
Plot 49	1638.70	327.74	1966.45	770.19	154.04	924.23	3391.921
Plot 50	1855.85	371.17	2227.02	872.25	174.45	1046.70	3841.391
Plot 51	1387.86	277.57	1665.43	652.29	130.46	782.75	2872.694
Plot 52	361.04	72.21	433.25	169.69	33.94	203.63	747.3093
Plot 53	656.36	131.27	787.64	308.49	61.70	370.19	1358.594
Plot 54	749.38	149.88	899.26	352.21	70.44	422.65	1551.13
Plot 55	455.14	91.03	546.17	213.92	42.78	256.70	942.0838
Plot 56	574.83	114.97	689.79	270.17	54.03	324.20	1189.826
Plot 57	340.05	68.01	408.06	159.82	31.96	191.79	703.8554
Plot 58	526.87	105.37	632.24	247.63	49.53	297.16	1090.559
Plot 59	595.81	119.16	714.97	280.03	56.01	336.04	1233.257
Plot 60	1335.61	267.12	1602.73	627.73	125.55	753.28	2764.545
Plot 61	372.14	74.43	446.56	174.90	34.98	209.88	770.2756
Plot 62	454.51	90.90	545.41	213.62	42.72	256.34	940.7861
Plot 63	143.20	28.64	171.84	67.30	13.46	80.77	296.411
Plot 64	231.04	46.21	277.24	108.59	21.72	130.30	478.2168
Plot 65	538.22	107.64	645.86	252.96	50.59	303.55	1114.044
Plot 66	222.58	44.52	267.09	104.61	20.92	125.53	460.7069
Plot 67	468.98	93.80	562.78	220.42	44.08	264.51	970.7379
Plot 68	466.05	93.21	559.26	219.04	43.81	262.85	964.6591
Plot 69	343.96	68.79	412.76	161.66	32.33	194.00	711.9656

Plot No.	AGB ton ha^{-1}	BGB ton ha^{-1}	Total Biomass ton ha^{-1}	AGC ton ha^{-1}	BGC ton ha^{-1}	Total Carbon stock ton ha^{-1}	CO_2 equivalent ton ha^{-1}
Plot 70	692.11	138.42	830.53	325.29	65.06	390.35	1432.588
Plot 71	913.30	182.66	1095.96	429.25	85.85	515.10	1890.428
Plot 72	418.24	83.65	501.89	196.57	39.31	235.89	865.7074
Plot 73	477.76	95.55	573.31	224.55	44.91	269.45	988.8982
Plot 74	470.03	94.01	564.04	220.91	44.18	265.10	972.9096
Plot 75	481.38	96.28	577.66	226.25	45.25	271.50	996.3997
Plot 76	348.49	69.70	418.19	163.79	32.76	196.55	721.3372
Plot 77	361.37	72.27	433.65	169.85	33.97	203.81	748.0005
Plot 78	276.79	55.36	332.15	130.09	26.02	156.11	572.9199
Plot 79	170.88	34.18	205.06	80.32	16.06	96.38	353.7114
Plot 80	168.42	33.68	202.10	79.16	15.83	94.99	348.6006
Plot 81	163.90	32.78	196.68	77.03	15.41	92.44	339.2502
Plot 82	188.82	37.76	226.59	88.75	17.75	106.50	390.8423
Plot 83	412.35	82.47	494.82	193.80	38.76	232.57	853.5142
Plot 84	461.88	92.38	554.26	217.09	43.42	260.50	956.0427
Plot 85	338.62	67.72	406.35	159.15	31.83	190.98	700.9064
Plot 86	383.62	76.72	460.34	180.30	36.06	216.36	794.044
Plot 87	241.17	48.23	289.41	113.35	22.67	136.02	499.1986
Plot 88	257.78	51.56	309.34	121.16	24.23	145.39	533.5739
Plot 89	322.19	64.44	386.63	151.43	30.29	181.72	666.9022
Plot 90	462.93	92.59	555.52	217.58	43.52	261.09	958.2169

Appendix 7. Weight of Field wet sample, fresh subsample, oven dry subsample of litter in gram and litter biomass (ton/ha), %C, Carbon stock in liter (ton/ha) and Carbon sequestered (CO_2 equivalent) of litter Carbon pool in each plot of Gerba Dima Forest

plot no.	Weight of wet field sample of litter (g)	Weight of fresh sub sample of litter (g)	Weight of Oven dry subsample of litter (g)	Litter biomass (ton/ha)	% C	Carbon stock in litter (ton/ha)	CO_2 equivalent of litter(ton/ha)
1	594	300	196	0.04	0.58	0.02	0.08
2	500	200	126	0.03	0.58	0.02	0.07
3	800	200	134	0.05	0.57	0.03	0.11

plot no.	Weight of wet field sample of litter (g)	Weight of fresh sub sample of litter (g)	Weight of Oven dry subsample of litter (g)	Litter biomass (ton/ha)	% C	Carbon stock in litter (ton/ha)	CO_2 equivalent of litter(ton/ha)
4	300	250	176	0.02	0.57	0.01	0.04
5	594	300	196	0.04	0.58	0.02	0.08
6	600	200	118	0.04	0.58	0.02	0.07
7	1500	300	128	0.06	0.57	0.04	0.13
8	1500	200	1050	0.79	0.57	0.45	1.66
9	594	300	196	0.04	0.57	0.02	0.08
10	1300	200	105	0.07	0.57	0.04	0.14
11	600	200	129	0.04	0.57	0.02	0.08
12	1300	200	119	0.08	0.57	0.04	0.16
13	800	100	80	0.06	0.58	0.04	0.14
14	1550	200	102	0.08	0.58	0.05	0.17
15	1900	200	111	0.11	0.58	0.06	0.22
16	594	300	196	0.04	0.58	0.02	0.08
17	1100	300	193	0.07	0.58	0.04	0.15
18	2000	200	130	0.13	0.58	0.07	0.27
19	2000	200	105	0.11	0.57	0.06	0.22
20	1700	200	112	0.10	0.57	0.05	0.20
21	594	300	196	0.04	0.58	0.02	0.08
22	594	300	196	0.04	0.58	0.02	0.08
23	600	400	302.5	0.05	0.57	0.03	0.09
24	300	200	123	0.02	0.57	0.01	0.04
25	800	300	181	0.05	0.57	0.03	0.10
26	700	200	133	0.05	0.58	0.03	0.10
27	594	300	196	0.04	0.58	0.02	0.08
28	594	300	196	0.04	0.57	0.02	0.08
29	594	300	196	0.04	0.57	0.02	0.08
30	594	300	196	0.04	0.58	0.02	0.08
31	594	300	196	0.04	0.58	0.02	0.08
32	594	300	196	0.04	0.57	0.02	0.08
33	594	300	196	0.04	0.57	0.02	0.08
34	400	342	322.2	0.04	0.57	0.02	0.08
35	594	300	196	0.04	0.57	0.02	0.08
36	600	300	244.9	0.05	0.57	0.03	0.10
37	400	300	240	0.03	0.57	0.02	0.07
38	594	300	196	0.04	0.58	0.02	0.08
39	594	300	196	0.04	0.58	0.02	0.08

plot no.	Weight of wet field sample of litter (g)	Weight of fresh sub sample of litter (g)	Weight of Oven dry subsample of litter (g)	Litter biomass (ton/ha)	% C	Carbon stock in litter (ton/ha)	CO_2 equivalent of litter(ton/ha)
40	1000	300	168.5	0.06	0.58	0.03	0.12
41	700	400	274	0.05	0.58	0.03	0.10
42	1400	300	186	0.09	0.58	0.05	0.18
43	450	300	234	0.04	0.58	0.02	0.07
44	400	300	186	0.02	0.57	0.01	0.05
45	400	350	268	0.03	0.57	0.02	0.06
46	500	500	378	0.04	0.58	0.02	0.08
47	594	300	196	0.04	0.58	0.02	0.08
48	594	300	196	0.04	0.57	0.02	0.08
49	250	250	170	0.02	0.57	0.01	0.04
50	400	350	277	0.03	0.57	0.02	0.07
51	600	350	272.3	0.05	0.57	0.03	0.10
52	400	400	318	0.03	0.58	0.02	0.07
53	300	300	235	0.02	0.58	0.01	0.05
54	550	300	154	0.03	0.58	0.02	0.06
55	300	300	125	0.01	0.58	0.01	0.03
56	300	300	165	0.02	0.58	0.01	0.03
57	250	250	184	0.02	0.58	0.01	0.04
58	250	250	193	0.02	0.57	0.01	0.04
59	200	200	160	0.02	0.58	0.01	0.03
60	300	300	172	0.02	0.57	0.01	0.04
61	300	300	192	0.02	0.58	0.01	0.04
62	400	300	217	0.03	0.58	0.02	0.06
63	200	200	167	0.02	0.58	0.01	0.04
64	250	250	209	0.02	0.58	0.01	0.04
65	300	300	191	0.02	0.58	0.01	0.04
66	400	300	222	0.03	0.58	0.02	0.06
67	300	300	149	0.01	0.58	0.01	0.03
68	400	300	121	0.02	0.58	0.01	0.03
69	200	200	152	0.02	0.58	0.01	0.03
70	300	300	183	0.02	0.57	0.01	0.04
71	300	300	231	0.02	0.58	0.01	0.05
72	400	300	202	0.03	0.58	0.02	0.06
73	300	300	160	0.02	0.57	0.01	0.03
74	300	300	141	0.01	0.58	0.01	0.03
75	300	300	230	0.02	0.58	0.01	0.05

plot no.	Weight of wet field sample of litter (g)	Weight of fresh sub sample of litter (g)	Weight of Oven dry subsample of litter (g)	Litter biomass (ton/ha)	% C	Carbon stock in litter (ton/ha)	CO_2 equivalent of litter(ton/ha)
76	300	300	191	0.02	0.58	0.01	0.04
77	200	200	162	0.02	0.58	0.01	0.03
78	350	300	226	0.03	0.58	0.02	0.06
79	400	300	197	0.03	0.58	0.02	0.06
80	600	300	154	0.03	0.57	0.02	0.06
81	300	300	174	0.02	0.58	0.01	0.04
82	200	200	138	0.01	0.57	0.01	0.03
83	400	300	137	0.02	0.58	0.01	0.04
84	300	300	198	0.02	0.58	0.01	0.04
85	400	300	222	0.03	0.58	0.02	0.06
86	400	300	176	0.02	0.58	0.01	0.05
87	300	300	210	0.02	0.58	0.01	0.04
88	594	300	196	0.04	0.58	0.02	0.08
89	594	300	196	0.04	0.58	0.02	0.08
90	594	300	196	0.04	0.58	0.02	0.08

Appendix 8. Weight of Field wet sample, fresh subsample, oven dry subsample of Herb in gram and Herb biomass (ton/ha), %C, Carbon stock in Herb (ton/ha) and Carbon sequestered (CO_2 equivalent) of Herbaceous Carbon pool in each plot of Gerba Dima Forest

Plot No	Weight of wet field sample of Herb (g)	Weight of fresh sub sample of Herb (g)	Weight of Oven dry subsample of Herb (g)	Herb biomass ton/ha	% C	Carbon stock in Herb ton/ha	CO_2 equivalent of Herb ton/ha
1	200	100	64	0.013	0.44	0.006	0.02
2	300	150	46	0.009	0.54	0.005	0.02
3	300	150	54	0.011	0.50	0.005	0.02
4	450	100	48	0.022	0.54	0.012	0.04
5	900	200	54	0.024	0.50	0.012	0.04
6	900	100	45	0.041	0.51	0.021	0.08
7	350	200	72	0.013	0.47	0.006	0.02
8	400	200	90	0.018	0.45	0.008	0.03
9	400	100	55	0.022	0.42	0.009	0.03

Plot No	Weight of wet field sample of Herb (g)	Weight of fresh sub sample of Herb (g)	Weight of Oven dry subsample of Herb (g)	Herb biomass ton/ha	% C	Carbon stock in Herb ton/ha	CO_2 equivalent of Herb ton/ha
10	200	100	49	0.010	0.42	0.004	0.02
11	200	100	49	0.010	0.48	0.005	0.02
12	200	100	49	0.010	0.42	0.004	0.02
13	450	100	48	0.022	0.46	0.010	0.04
14	900	200	54	0.024	0.55	0.013	0.05
15	200	100	49	0.010	0.42	0.004	0.02
16	700	150	74	0.035	0.45	0.015	0.06
17	800	200	60	0.024	0.40	0.010	0.03
18	800	200	84	0.034	0.42	0.014	0.05
19	1100	200	82	0.045	0.43	0.019	0.07
20	200	100	62	0.012	0.45	0.006	0.02
21	500	300	102	0.017	0.44	0.007	0.03
22	500	300	78	0.013	0.54	0.007	0.03
23	500	300	135	0.023	0.50	0.011	0.04
24	200	100	49	0.010	0.54	0.005	0.02
25	800	300	52.3	0.014	0.50	0.007	0.03
26	400	300	90	0.012	0.51	0.006	0.02
27	200	100	49	0.010	0.47	0.005	0.02
28	800	300	52.3	0.014	0.45	0.006	0.02
29	400	300	90	0.012	0.42	0.005	0.02
30	500	300	103	0.017	0.42	0.007	0.03
31	500	300	103	0.017	0.48	0.008	0.03
32	600	300	79	0.016	0.42	0.007	0.02
33	600	300	145.3	0.029	0.46	0.013	0.05
34	500	300	132.2	0.022	0.55	0.012	0.04
35	200	200	114.5	0.011	0.42	0.005	0.02
36	800	300	89.5	0.024	0.45	0.011	0.04
37	500	300	104	0.017	0.40	0.007	0.03
38	500	300	104	0.017	0.42	0.007	0.03
39	600	300	81	0.016	0.43	0.007	0.03
40	300	300	104	0.010	0.45	0.005	0.02
41	150	150	64	0.006	0.54	0.003	0.01
42	300	300	94	0.009	0.47	0.004	0.02
43	100	100	60	0.006	0.34	0.002	0.01
44	300	300	99	0.010	0.49	0.005	0.02
45	200	200	88	0.009	0.52	0.005	0.02
46	500	300	126	0.021	0.51	0.011	0.04

Plot No	Weight of wet field sample of Herb (g)	Weight of fresh sub sample of Herb (g)	Weight of Oven dry subsample of Herb (g)	Herb biomass ton/ha	% C	Carbon stock in Herb ton/ha	CO_2 equivalent of Herb ton/ha
47	500	300	125	0.021	0.52	0.011	0.04
48	250	100	84	0.021	0.48	0.010	0.04
49	400	300	113.5	0.015	0.50	0.007	0.03
50	300	250	99	0.012	0.50	0.006	0.02
51	200	200	94	0.009	0.49	0.005	0.02
52	500	300	125	0.021	0.47	0.010	0.04
53	250	100	84	0.021	0.48	0.010	0.04
54	400	300	113.5	0.015	0.52	0.008	0.03
55	300	250	99	0.012	0.51	0.006	0.02
56	200	200	94	0.009	0.49	0.005	0.02
57	600	300	85	0.017	0.49	0.008	0.03
58	300	300	89	0.009	0.49	0.004	0.02
59	300	300	97	0.010	0.56	0.005	0.02
60	400	300	69	0.009	0.26	0.002	0.01
61	400	300	89	0.012	0.48	0.006	0.02
62	300	300	119	0.012	0.56	0.007	0.02
63	300	300	101	0.010	0.26	0.003	0.01
64	300	300	105	0.011	0.48	0.005	0.02
65	300	300	96	0.010	0.49	0.005	0.02
66	500	300	102	0.017	0.47	0.008	0.03
67	400	300	77	0.010	0.48	0.005	0.02
68	300	300	101	0.010	0.52	0.005	0.02
69	500	300	86	0.014	0.51	0.007	0.03
70	300	300	108	0.011	0.49	0.005	0.02
71	200	100	68	0.014	0.49	0.007	0.02
72	100	100	64	0.006	0.49	0.003	0.01
73	200	200	94	0.009	0.54	0.005	0.02
74	300	300	100	0.010	0.47	0.005	0.02
75	600	300	85	0.017	0.34	0.006	0.02
76	300	300	89	0.009	0.49	0.004	0.02
77	300	300	97	0.010	0.52	0.005	0.02
78	400	300	69	0.009	0.51	0.005	0.02
79	400	300	89	0.012	0.52	0.006	0.02
80	300	300	119	0.012	0.48	0.006	0.02
81	300	300	105	0.011	0.50	0.005	0.02
82	300	300	96	0.010	0.50	0.005	0.02
83	500	300	102	0.017	0.49	0.008	0.03

Plot No	Weight of wet field sample of Herb (g)	Weight of fresh sub sample of Herb (g)	Weight of Oven dry subsample of Herb (g)	Herb biomass ton/ha	% C	Carbon stock in Herb ton/ha	CO_2 equivalent of Herb ton/ha
84	400	300	77	0.010	0.47	0.005	0.02
85	300	300	101	0.010	0.48	0.005	0.02
86	400	300	94	0.013	0.52	0.006	0.02
87	300	300	87	0.009	0.51	0.004	0.02
88	400	300	106	0.014	0.49	0.007	0.03
89	500	300	86	0.014	0.49	0.007	0.03
90	300	300	108	0.011	0.49	0.005	0.02

Appendix 9. Weight of Field wet sample, fresh subsample, oven dry subsample of Non tree woody Species (NTWS) in gram and NTWS biomass (ton/ha), %C, Carbon stock in NTWS (ton/ha) and Carbon sequestered (CO_2 equivalent) of NTWS Carbon pool in each plot

Plot no	Weight of wet field sample of NTWS (g)	Weight of fresh sub sample of NTWS (g)	Weight of Oven dry subsample of NTWS (g)	NTWS biomass ton/ha	% C	Carbon stock in NTWS ton/ha	CO2 equivalent of NTWS ton/ha
1	1400	300	146.5	0.27	0.47	0.13	0.47
2	200	100	73	0.06	0.47	0.03	0.10
3	800	300	116	0.12	0.47	0.06	0.21
4	500	300	118	0.08	0.47	0.04	0.14
5	1000	300	121	0.16	0.47	0.08	0.28
6	1300	300	109	0.19	0.47	0.09	0.33
7	800	300	124	0.13	0.47	0.06	0.23
8	2100	300	244	0.68	0.47	0.32	1.18
9	1100	300	141	0.21	0.47	0.10	0.36
10	700	300	170.5	0.16	0.47	0.07	0.27
11	1000	300	217.5	0.29	0.47	0.14	0.50
12	350	300	177.5	0.08	0.47	0.04	0.14
13	800	200	169.5	0.27	0.47	0.13	0.47
14	800	300	233	0.25	0.47	0.12	0.43
15	1400	300	146.5	0.27	0.47	0.13	0.47
16	500	300	236	0.16	0.47	0.07	0.27

Plot no	**Weight of wet field sample of NTWS (g)**	**Weight of fresh sub sample of NTWS (g)**	**Weight of Oven dry subsample of NTWS (g)**	**NTWS biomass ton/ha**	**% C**	**Carbon stock in NTWS ton/ha**	**CO2 equivalent of NTWS ton/ha**
17	300	200	69	0.04	0.47	0.02	0.07
18	2000	300	199	0.53	0.47	0.25	0.92
19	1100	300	192	0.28	0.47	0.13	0.49
20	1800	300	204	0.49	0.47	0.23	0.84
21	1600	300	91	0.19	0.47	0.09	0.33
22	1500	300	153	0.31	0.47	0.14	0.53
23	1300	300	203	0.35	0.47	0.17	0.61
24	1600	300	91	0.19	0.47	0.09	0.33
25	1300	300	105	0.18	0.47	0.09	0.31
26	1400	300	195	0.36	0.47	0.17	0.63
27	850	300	82	0.09	0.47	0.04	0.16
28	1400	300	195	0.36	0.47	0.17	0.63
29	1200	300	120	0.19	0.47	0.09	0.33
30	1400	300	195	0.36	0.47	0.17	0.63
31	1200	300	187	0.30	0.47	0.14	0.52
32	1400	300	195	0.36	0.47	0.17	0.63
33	1400	300	92	0.17	0.47	0.08	0.30
34	1400	300	195	0.36	0.47	0.17	0.63
35	1300	300	109	0.19	0.47	0.09	0.33
36	2100	300	244	0.68	0.47	0.32	1.18
37	800	300	124	0.13	0.47	0.06	0.23
38	2100	300	244	0.68	0.47	0.32	1.18
39	1100	300	141	0.21	0.47	0.10	0.36
40	2100	300	244	0.68	0.47	0.32	1.18
41	700	300	170.5	0.16	0.47	0.07	0.27
42	1000	300	217.5	0.29	0.47	0.14	0.50
43	350	300	177.5	0.08	0.47	0.04	0.14
44	800	200	169.5	0.27	0.47	0.13	0.47
45	800	300	233	0.25	0.47	0.12	0.43
46	700	300	187.5	0.18	0.47	0.08	0.30
47	300	300	162.5	0.07	0.47	0.03	0.11
48	200	200	147	0.06	0.47	0.03	0.10
49	400	300	188	0.10	0.47	0.05	0.17
50	1400	300	146.5	0.27	0.47	0.13	0.47
51	500	300	236	0.16	0.47	0.07	0.27

Plot no	Weight of wet field sample of NTWS (g)	Weight of fresh sub sample of NTWS (g)	Weight of Oven dry subsample of NTWS (g)	NTWS biomass ton/ha	% C	Carbon stock in NTWS ton/ha	CO2 equivalent of NTWS ton/ha
52	300	200	69	0.04	0.47	0.02	0.07
53	2000	300	199	0.53	0.47	0.25	0.92
54	2100	300	244	0.68	0.47	0.32	1.18
55	1100	300	192	0.28	0.47	0.13	0.49
56	1800	300	204	0.49	0.47	0.23	0.84
57	2100	300	244	0.68	0.47	0.32	1.18
58	1500	300	153	0.31	0.47	0.14	0.53
59	1300	300	203	0.35	0.47	0.17	0.61
60	1600	300	91	0.19	0.47	0.09	0.33
61	1300	300	105	0.18	0.47	0.09	0.31
62	2100	300	244	0.68	0.47	0.32	1.18
63	850	300	82	0.09	0.47	0.04	0.16
64	1400	300	195	0.36	0.47	0.17	0.63
65	1200	300	120	0.19	0.47	0.09	0.33
66	2100	300	244	0.68	0.47	0.32	1.18
67	1200	300	187	0.30	0.47	0.14	0.52
68	2100	300	244	0.68	0.47	0.32	1.18
69	1400	300	92	0.17	0.47	0.08	0.30
70	2100	300	244	0.68	0.47	0.32	1.18
71	2100	300	244	0.68	0.47	0.32	1.18
72	200	200	97	0.04	0.47	0.02	0.07
73	300	250	114	0.05	0.47	0.03	0.09
74	500	300	141	0.09	0.47	0.04	0.16
75	500	300	163	0.11	0.47	0.05	0.19
76	300	300	90	0.04	0.47	0.02	0.06
77	500	300	127	0.08	0.47	0.04	0.15
78	300	200	110	0.07	0.47	0.03	0.11
79	300	200	70	0.04	0.47	0.02	0.07
80	100	100	68	0.03	0.47	0.01	0.05
81	500	300	130	0.09	0.47	0.04	0.15
82	400	300	146	0.08	0.47	0.04	0.13
83	500	300	143	0.10	0.47	0.04	0.16
84	500	300	126	0.08	0.47	0.04	0.14
85	500	200	98	0.10	0.47	0.05	0.17
86	400	300	123	0.07	0.47	0.03	0.11

Plot no	**Weight of wet field sample of NTWS (g)**	**Weight of fresh sub sample of NTWS (g)**	**Weight of Oven dry subsample of NTWS (g)**	**NTWS biomass ton/ha**	**% C**	**Carbon stock in NTWS ton/ha**	**CO2 equivalent of NTWS ton/ha**
87	300	300	133	0.05	0.47	0.03	0.09
88	300	300	130	0.05	0.47	0.02	0.09
89	500	300	126	0.08	0.47	0.04	0.14
90	200	200	86	0.03	0.47	0.02	0.06

Appendix 10. Mean, maximum, minimum value of biomass, carbon stock and carbon dioxide equivalent for Standing Dead Wood(SDW), Ling Dead Wood(LDW) and for the overall Dead Wood (DW)

Plot No.	SDWB (t/ha)	SDWC (t/ha)	C0$_2$SDW (t/ha)	LDWB(t/ ha)	LDWC (t/ha)	C0$_2$LDW (t/ha)	DWB (t/ha)	DWC (t/ha)	DWC0$_2$ (t/ha)
plot No.1	0.51	0.24	0.87	8.50	3.99	14.66	9.01	4.23	15.54
plot No.2	11.06	5.20	19.07	20.57	9.67	35.47	31.62	14.86	54.55
plot No.3	0.47	0.22	0.82	1.44	0.68	2.48	1.91	0.90	3.30
plot No.4	1.13	0.53	1.95	0.87	0.41	1.50	2.00	0.94	3.45
plot No.5	3.20	1.50	5.52	4.02	1.89	6.94	7.22	3.39	12.46
plot No.6	2.09	0.98	3.61	4.05	1.90	6.99	6.15	2.89	10.60
plot No.7	3.59	1.69	6.20	0.87	0.41	1.50	4.47	2.10	7.70
plot No.8	4.96	2.33	8.56	8.07	3.79	13.91	13.03	6.12	22.47
plot No.9	0.37	0.17	0.64	2.23	1.05	3.85	2.60	1.22	4.49
plot No.10	22.78	10.71	39.30	4.36	2.05	7.52	27.14	12.76	46.82
plot No.11	3.53	1.66	6.09	5.15	2.42	8.88	8.68	4.08	14.97
plot No.12	2.21	1.04	3.81	6.84	3.21	11.79	9.05	4.25	15.60
plot No.13	3.21	1.51	5.54	17.23	8.10	29.72	20.44	9.61	35.26
plot No.14	0.14	0.07	0.25	7.85	3.69	13.54	7.99	3.76	13.79
plot No.15	0.59	0.27	1.01	2.38	1.12	4.10	2.96	1.39	5.11
plot No.16	0.00	0.00	0.01	6.06	2.85	10.46	6.07	2.85	10.47
plot No.17	0.01	0.00	0.01	2.48	1.16	4.27	2.48	1.17	4.28
plot No.18	1.78	0.84	3.07	3.86	1.81	6.66	5.64	2.65	9.73
plot No.19	1.27	0.60	2.20	0.35	0.16	0.60	1.62	0.76	2.80
plot No.20	0.82	0.39	1.41	1.03	0.48	1.78	1.85	0.87	3.19
plot No.21	14.11	6.63	24.34	13.09	6.15	22.58	27.20	12.79	46.92
plot No.22	58.11	27.31	100.23	22.47	10.56	38.75	80.58	37.87	138.99
plot No.23	2.42	1.14	4.18	34.37	16.15	59.28	36.79	17.29	63.46

Plot No.	SDWB (t/ha)	SDWC (t/ha)	C0$_2$SDW (t/ha)	LDWB(t/ha)	LDWC (t/ha)	C0$_2$LDW (t/ha)	DWB (t/ha)	DWC (t/ha)	DWC0$_2$ (t/ha)
plot No.24	3.46	1.62	5.96	3.44	1.62	5.93	6.89	3.24	11.89
plot No.25	19.20	9.02	33.11	19.01	8.93	32.79	38.20	17.96	65.90
plot No.26	0.30	0.14	0.51	24.54	11.53	42.33	24.84	11.67	42.85
plot No.27	82.67	38.86	142.61	22.87	10.75	39.45	105.55	49.61	182.06
plot No.28	1.27	0.60	2.19	28.30	13.30	48.81	29.57	13.90	51.01
plot No.29	0.80	0.38	1.38	6.03	2.84	10.41	6.83	3.21	11.79
plot No.30	1.73	0.81	2.99	14.12	6.64	24.36	15.86	7.45	27.35
plot No.31	4.08	1.92	7.04	20.27	9.53	34.96	24.35	11.45	42.01
plot No.32	0.99	0.47	1.71	16.31	7.67	28.13	17.30	8.13	29.84
plot No.33	14.68	6.90	25.33	5.12	2.41	8.84	19.81	9.31	34.17
plot No.34	0.52	0.25	0.90	3.41	1.60	5.88	3.93	1.85	6.78
plot No.35	0.88	0.41	1.51	3.44	1.62	5.94	4.32	2.03	7.45
plot No.36	2.61	1.23	4.50	0.59	0.28	1.01	3.20	1.50	5.52
plot No.37	7.31	3.43	12.60	18.66	8.77	32.19	25.97	12.21	44.79
plot No.38	1.04	0.49	1.79	1.06	0.50	1.83	2.10	0.99	3.62
plot No.39	1.19	0.56	2.06	0.00	0.00	0.00	1.19	0.56	2.06
plot No.40	4.97	2.34	8.57	1.67	0.78	2.87	6.64	3.12	11.45
plot No.41	0.06	0.03	0.10	1.05	0.49	1.81	1.11	0.52	1.91
plot No.42	0.20	0.10	0.35	3.72	1.75	6.42	3.93	1.85	6.77
plot No.43	0.40	0.19	0.68	1.23	0.58	2.12	1.62	0.76	2.80
plot No.44	3.15	1.48	5.44	6.46	3.04	11.15	9.61	4.52	16.58
plot No.45	0.43	0.20	0.75	0.30	0.14	0.51	0.73	0.34	1.26
plot No.46	0.46	0.22	0.80	4.53	2.13	7.82	5.00	2.35	8.62
plot No.47	1.75	0.82	3.03	2.63	1.23	4.53	4.38	2.06	7.55
plot No.48	1.10	0.52	1.90	0.00	0.00	0.00	1.10	0.52	1.90
plot No.49	1.26	0.59	2.17	2.29	1.07	3.94	3.54	1.66	6.11

Plot No.	SDWB (t/ha)	SDWC (t/ha)	$C0_2$SDW (t/ha)	LDWB(t/ ha)	LDWC (t/ha)	$C0_2$LDW (t/ha)	DWB (t/ha)	DWC (t/ha)	DWC0_2 (t/ha)
plot No.50	0.17	0.08	0.29	2.79	1.31	4.82	2.96	1.39	5.11
plot No.51	6.19	2.91	10.68	7.35	3.45	12.67	13.54	6.36	23.36
plot No.52	0.91	0.43	1.56	0.46	0.22	0.80	1.37	0.64	2.36
plot No.53	8.49	3.99	14.65	7.35	3.45	12.67	15.84	7.45	27.33
plot No.54	0.17	0.08	0.29	3.26	1.53	5.63	3.43	1.61	5.92
plot No.55	9.66	4.54	16.66	4.58	2.15	7.91	14.24	6.69	24.57
plot No.56	2.45	1.15	4.23	2.79	1.31	4.82	5.24	2.46	9.04
plot No.57	1.11	0.52	1.92	6.07	2.85	10.47	7.18	3.38	12.39
plot No.58	0.51	0.24	0.87	2.00	0.94	3.45	2.51	1.18	4.32
plot No.59	1.63	0.77	2.82	3.98	1.87	6.86	5.61	2.64	9.68
plot No.60	0.17	0.08	0.30	0.13	0.06	0.22	0.30	0.14	0.52
plot No.61	1.19	0.56	2.06	13.47	6.33	23.23	14.66	6.89	25.29
plot No.62	0.41	0.19	0.71	3.13	1.47	5.40	3.54	1.66	6.11
plot No.63	0.25	0.12	0.44	3.53	1.66	6.08	3.78	1.78	6.52
plot No.64	0.03	0.02	0.06	1.02	0.48	1.76	1.05	0.50	1.82
plot No.65	0.03	0.02	0.06	1.02	0.48	1.76	1.05	0.50	1.82
plot No.66	0.12	0.05	0.20	0.56	0.26	0.97	0.68	0.32	1.17
plot No.67	0.09	0.04	0.15	0.82	0.39	1.42	0.91	0.43	1.56
plot No.68	4.46	2.10	7.69	1.14	0.54	1.97	5.60	2.63	9.66
plot No.69	0.73	0.34	1.26	8.41	3.95	14.50	9.14	4.30	15.77
plot No.70	1.59	0.75	2.75	1.14	0.53	1.96	2.73	1.28	4.71
plot No.71	0.34	0.16	0.59	11.11	5.22	19.16	11.45	5.38	19.75
plot No.72	0.75	0.35	1.30	4.50	2.11	7.76	5.25	2.47	9.06
plot No.73	0.90	0.42	1.55	0.91	0.43	1.57	1.81	0.85	3.12
plot No.74	0.34	0.16	0.58	7.09	3.33	12.24	7.43	3.49	12.82
plot No.75	0.78	0.37	1.34	1.55	0.73	2.68	2.33	1.09	4.02

Plot No.	SDWB (t/ha)	SDWC (t/ha)	C0$_2$SDW (t/ha)	LDWB(t/ ha)	LDWC (t/ha)	C0$_2$LDW (t/ha)	DWB (t/ha)	DWC (t/ha)	DWC0$_2$ (t/ha)
plot No.76	0.57	0.27	0.98	2.06	0.97	3.55	2.62	1.23	4.53
plot No.77	0.80	0.37	1.38	4.93	2.32	8.51	5.73	2.69	9.88
plot No.78	0.82	0.39	1.42	2.51	1.18	4.33	3.34	1.57	5.76
plot No.79	0.94	0.44	1.62	5.12	2.41	8.83	6.05	2.85	10.44
plot No.80	0.07	0.03	0.11	2.22	1.04	3.83	2.29	1.07	3.94
plot No.81	0.57	0.27	0.97	0.46	0.22	0.80	1.03	0.48	1.77
plot No.82	0.11	0.05	0.19	5.33	2.51	9.20	5.44	2.56	9.39
plot No.83	0.05	0.02	0.09	7.40	3.48	12.76	7.45	3.50	12.85
plot No.84	0.77	0.36	1.33	2.61	1.23	4.50	3.38	1.59	5.83
plot No.85	0.02	0.01	0.04	0.74	0.35	1.27	0.76	0.36	1.31
plot No.86	7.00	3.29	12.08	3.10	1.46	5.35	10.10	4.75	17.43
plot No.87	0.72	0.34	1.24	3.26	1.53	5.62	3.98	1.87	6.86
plot No.88	0.31	0.15	0.54	1.51	0.71	2.60	1.82	0.85	3.14
plot No.89	0.05	0.02	0.08	1.66	0.78	2.87	1.71	0.80	2.95
plot No.90	0.05	0.02	0.09	5.36	2.52	9.25	5.42	2.55	9.34

Appendix 11. Bulk Density, SOM, SOC and CO2 equivalent for each study plot in Gerba Dima Forest

Plot no	Bulk density	Depth (cm)	%OM	%C	SOC (ton ha^{-1})	CO_2 equivalent (ton ha^{-1})
1	0.88	40.00	11.06	6.41	224.60	824.27
2	0.89	40.00	11.48	6.66	235.95	865.93
3	0.79	40.00	13.21	7.66	240.65	883.19
4	0.87	40.00	10.15	5.89	204.32	749.87
5	0.88	40.00	17.18	9.96	351.56	1290.22
6	0.90	40.00	15.76	9.14	329.96	1210.95
7	0.84	40.00	15.56	9.03	304.33	1116.90
8	0.94	40.00	14.64	8.49	318.10	1167.43
9	0.76	40.00	13.82	8.01	244.70	898.04
10	0.83	40.00	15.45	8.96	298.87	1096.84
11	0.79	40.00	19.73	11.45	361.74	1327.59
12	0.79	40.00	15.48	8.98	283.83	1041.66
13	0.79	40.00	16.36	9.49	300.40	1102.46
14	0.84	40.00	20.00	11.60	390.41	1432.80
15	0.79	40.00	16.74	9.71	306.82	1126.04
16	0.84	40.00	13.21	7.66	258.27	947.85
17	0.78	40.00	16.94	9.82	305.95	1122.83
18	0.82	40.00	21.77	12.63	413.61	1517.94
19	0.86	40.00	18.95	10.99	378.11	1387.65
20	0.79	40.00	17.06	9.89	312.10	1145.41
21	0.78	40.00	15.50	8.99	280.42	1029.14
22	0.76	40.00	15.74	9.13	277.67	1019.05
23	0.73	40.00	17.18	9.96	289.82	1063.65
24	0.73	40.00	13.98	8.11	236.48	867.89
25	0.71	40.00	17.59	10.20	288.15	1057.52
26	1.07	40.00	15.08	8.75	375.90	1379.54
27	0.70	40.00	18.66	10.82	303.50	1113.86
28	0.78	40.00	15.64	9.07	283.90	1041.92
29	0.74	40.00	16.76	9.72	288.98	1060.56
30	0.77	40.00	14.81	8.59	264.02	968.95
31	0.71	40.00	12.97	7.52	212.41	779.53
32	0.84	40.00	13.34	7.74	259.38	951.93
33	0.96	40.00	15.71	9.11	348.87	1280.34
34	0.69	40.00	17.90	10.38	288.51	1058.82

Plot no	Bulk density	Depth (cm)	%OM	%C	SOC (ton ha^{-1})	CO_2 equivalent (ton ha^{-1})
35	0.65	40.00	19.02	11.03	287.58	1055.41
36	0.79	40.00	17.16	9.96	315.47	1157.76
37	0.65	40.00	19.45	11.28	294.05	1079.16
38	0.75	40.00	19.66	11.40	340.61	1250.04
39	0.77	40.00	14.38	8.34	257.73	945.87
40	0.69	40.00	15.87	9.21	253.99	932.15
41	0.78	40.00	16.44	9.53	297.43	1091.58
42	0.70	40.00	15.47	8.97	251.08	921.47
43	0.83	40.00	14.52	8.42	279.03	1024.05
44	0.65	40.00	17.01	9.87	258.37	948.22
45	0.76	40.00	12.37	7.18	219.48	805.50
46	0.75	40.00	14.86	8.62	257.49	944.98
47	0.76	40.00	15.19	8.81	268.19	984.24
48	0.83	40.00	13.96	8.10	268.76	986.34
49	0.84	40.00	15.35	8.90	300.76	1103.80
50	0.60	40.00	15.32	8.89	212.86	781.20
51	0.85	40.00	14.58	8.45	286.20	1050.35
52	0.78	40.00	13.05	7.57	235.22	863.27
53	0.79	40.00	16.55	9.60	304.64	1118.03
54	0.76	40.00	15.61	9.05	274.56	1007.64
55	0.83	40.00	12.65	7.34	242.72	890.79
56	0.63	40.00	15.51	9.00	228.18	837.42
57	1.10	40.00	15.41	8.94	391.92	1438.36
58	0.90	40.00	15.16	8.79	316.94	1163.18
59	0.91	40.00	17.20	9.98	362.42	1330.09
60	0.67	40.00	15.25	8.85	237.37	871.15
61	0.78	40.00	17.60	10.21	320.15	1174.96
62	0.78	40.00	16.52	9.58	299.56	1099.39
63	0.76	40.00	17.50	10.15	307.92	1130.07
64	0.69	40.00	20.26	11.75	326.39	1197.87
65	0.75	40.00	17.64	10.23	308.25	1131.29
66	0.66	40.00	34.91	20.25	534.24	1960.67
67	0.75	40.00	13.17	7.64	229.48	842.19
68	0.70	40.00	17.10	9.92	275.80	1012.17
69	0.78	40.00	17.29	10.03	312.07	1145.31
70	0.69	40.00	16.58	9.62	265.39	973.98
71	0.68	40.00	15.81	9.17	249.48	915.61

Plot no	**Bulk density**	**Depth (cm)**	**%OM**	**%C**	**SOC (ton ha^{-1})**	**CO_2 equivalent (ton ha^{-1})**
72	0.71	40.00	15.78	9.15	258.55	948.89
73	0.78	40.00	14.08	8.17	256.03	939.62
74	0.86	40.00	12.21	7.08	245.02	899.23
75	0.80	40.00	15.61	9.05	289.50	1062.45
76	0.82	40.00	16.87	9.78	319.76	1173.50
77	0.82	40.00	17.18	9.96	328.22	1204.56
78	0.74	40.00	18.21	10.56	313.69	1151.25
79	0.73	40.00	17.03	9.88	289.55	1062.64
80	0.72	40.00	16.89	9.80	283.38	1039.99
81	0.67	40.00	14.89	8.64	232.19	852.15
82	0.69	40.00	17.44	10.11	278.28	1021.29
83	0.79	40.00	16.70	9.68	305.62	1121.62
84	0.77	40.00	16.10	9.34	288.40	1058.43
85	0.77	40.00	19.10	11.08	340.52	1249.72
86	0.70	40.00	17.10	9.92	277.08	1016.88
87	0.83	40.00	15.70	9.10	302.09	1108.68
88	0.82	40.00	17.19	9.97	328.28	1204.80
89	0.73	40.00	16.09	9.33	273.68	1004.41
90	0.85	40.00	17.69	10.26	347.45	1275.13

Appendix 12. Pearson's product moment correlations coefficient and P-value between Carbon pools and Environmental variables

	AGC	**BGC ton/ha**	**Carbon stock in litter**	**Carbon stock in Herb ton/ha**	**Carbon stock in NTWS ton/ha**	**DWC**	**SOC**	**Slope**	**Aspect**	**Disturbance**	**Altitude**	**SAND**	**CLAY**	**SILT**	**Diversity**
AGC	1.00	**0.98****	0.03	0.17	0.13	-0.12	-0.08	0.03	-0.06	**-0.24***	0.14	-0.10	0.09	0.01	0.21*
		0.00	0.76	0.11	0.23	0.26	0.44	0.78	0.61	0.03	0.18	0.36	0.38	0.92	0.05
BGC ton/ha	**0.98****	1.00	-0.04	0.15	0.14	-0.12	-0.09	0.03	-0.05	**-0.22***	0.11	-0.04	0.03	0.02	**0.25***
	0.00		0.72	0.16	0.18	0.25	0.38	0.80	0.65	0.03	0.31	0.75	0.79	0.89	0.02
Carbon stock in litter	0.03	-0.04	1.00	0.12	**0.25***	0.04	0.12	-0.04	-0.16	-0.19	0.12	**-0.30****	**0.22***	0.16	0.00
	0.76	0.72		0.26	0.02	0.74	0.24	0.72	0.13	0.07	0.26	0.01	0.03	0.13	0.93
Carbon stock in Herb ton/ha	0.17	0.15	0.12	1.00	0.12	-0.01	0.265*	0.05	0.00	-0.19	**0.37****	-0.16	0.11	0.12	0.13
	0.11	0.16	0.26		0.26	0.95	0.01	0.64	0.99	0.07	0.00	0.13	0.32	0.26	0.22
Carbon stock in NTWS ton/ha	0.13	0.14	**0.25***	0.12	1.00	-0.02	**0.23***	-0.03	0.02	**-0.24***	-0.04	-0.08	0.04	0.09	0.05
	0.23	0.18	0.02	0.26		0.88	0.03	0.80	0.83	0.02	0.69	0.48	0.74	0.40	0.67
DWC	-0.12	-0.12	0.04	-0.01	-0.02	1.00	-0.02	-0.07	-0.17	-0.02	**0.29****	**-0.23***	**0.21***	0.05	0.03
	0.26	0.25	0.74	0.95	0.88		0.87	0.54	0.11	0.87	0.01	0.03	0.05	0.62	0.79
SOC	-0.08	-0.09	0.12	**0.27***	**0.23***	-0.02	1.00	0.11	0.19	-0.01	**0.24***	**0.26***	**-0.22***	-0.09	0.02
	0.44	0.38	0.24	0.01	0.03	0.87		0.30	0.08	0.90	0.03	0.01	0.04	0.39	0.89
Slope	0.03	0.03	-0.04	0.05	-0.03	-0.07	0.11	1.00	0.13	**0.29****	0.15	-0.01	0.04	-0.07	-0.03
	0.78	0.80	0.72	0.64	0.80	0.54	0.30		0.22	0.01	0.17	0.93	0.70	0.52	0.77
Aspect	-0.06	-0.05	-0.16	0.00	0.02	-0.17	0.19	0.13	1.00	0.19	-0.04	0.20	-0.14	-0.14	0.04
	0.61	0.65	0.13	0.99	0.83	0.11	0.08	0.22		0.07	0.73	0.06	0.20	0.18	0.72
Disturbance	**-0.24***	**-0.22***	-0.19	-0.19	**-0.24***	-0.02	-0.01	**0.29****	0.19	1.00	-0.10	0.20	-0.13	-0.16	-0.11

	0.03	0.03	0.07	0.07	0.02	0.87	0.90	0.01	0.07		0.36	0.06	0.24	0.13	0.30
Altitude	0.14	0.11	0.12	**0.37****	-0.04	**0.29****	**0.24***	0.15	-0.04	-0.10	1.00	0.02	-0.17	**0.35****	0.14
	0.18	0.31	0.26	0.00	0.69	0.01	0.03	0.17	0.73	0.36		0.89	0.10	0.00	0.18
SAND	-0.10	-0.04	**-0.30****	-0.16	-0.08	**-0.23***	**0.26***	-0.01	0.20	0.20	0.02	1.00	**-0.90****	**-0.25***	-0.09
	0.36	0.75	0.01	0.13	0.48	0.03	0.01	0.93	0.06	0.06	0.89		0.00	0.02	0.40
CLAY	0.09	0.03	**0.22***	0.11	0.04	**0.21***	**-0.22***	0.04	-0.14	-0.13	-0.17	**-0.90****	1.00	**-0.21***	-0.04
	0.38	0.79	0.03	0.32	0.74	0.05	0.04	0.70	0.20	0.24	0.10	0.00		0.05	0.69
SILT	0.01	0.02	0.16	0.12	0.09	0.05	-0.09	-0.07	-0.14	-0.16	**0.35****	-0.25*	**-0.21***	1.00	**0.29****
	0.92	0.89	0.13	0.26	0.40	0.62	0.39	0.52	0.18	0.13	0.00	0.02	0.05		0.01
Diversity	**0.21***	**0.25***	0.00	0.13	0.05	0.03	0.02	-0.03	0.04	-0.11	0.14	-0.09	-0.04	**0.29****	1.00
	0.05	0.02	0.98	0.22	0.67	0.79	0.89	0.77	0.72	0.30	0.18	0.40	0.69	0.01	

‘**’= $P < 0.01$ ‘*’ = $P < 0.05$. Cell Contents: Pearson correlation (upper cell) and P-Value (lower cell).

Appendix 13. Photograph illustrating the forest overview

Apendix 14. Photos illustrating data collection of different carbon pools

Appendix 15. Photos illustrating measurement for volume of a trunk and trimmed biomass

Appendix 16. Photos illustrating density measuremnet by water displacement and Oven drying leaf, wood, liiter and herb samples biomass

.

Appendix 17. Photos illustrating laboratory analysis of soil texture, Na and K

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: ___________________________ Signature: _______________ Date: _____________

This work has been done under my supervision.

Name: ___________________________ Signature: __________________ Date: ___________

___________________________ Signature: __________________ Date: ___________