
# THE ECOLOGY, CARBON STOCK, BEE FORAGE DIVERSITY IN A MOIST AFROMONTANE FOREST OF GESHA AND SAYILEM DISTRICTS IN KAFFA ZONE, SOUTH WEST ETHIOPIA

**BY**

Admassu Addi Merti

**Addis Ababa University**

**Addis Ababa, Ethiopia**

**April 2018**


# ECOLOGY, CARBON STOCK POTENTIAL BEE FORAGEDIVERSITY AND HONEY CHARACTERISTICS IN MOIST AFROMONTANE FOREST OF GESHA AND SAYILEMDISTRICTS IN KAFFA ZONE, SOUTH WEST ETHIOPIA

Admassu Addi Merti

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 (Plant Biology and Biodiversity Management)

Addis Ababa University
Addis Ababa, Ethiopia
April 2018

# ADDIS ABABA UNIVERSITY

## GRADUATE PROGRAM

Declaration

This is to certify that the Dissertation prepared by Admassu Addi Merti, entitled: *Ecology, carbon stock, bee forage diversity and honey characteristics of the moist afromontane forest in Gesha and Sayilem districts of Kaffa Zone, Southwest Ethiopia* and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy (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) | _____ | _____ |

ABSTRACT

Ecology, carbon stock, Bee forage diversity and honey characteristics of the Moist Afromontane Forest in Gesha and Sayilem districts in Kaffa Zone, Southwest Ethiopia

**Admassu Addi Merti, PhD dissertation**

**Addis Ababa University, 2018**

*The study was conducted at Gesha and Sayilem districts of the Kaffa Zone, with the objective of documenting the floristic compositions, determining the carbon stock and bee forage diversityof the area.Stratified random sampling technique was followed to establish plot sizes of 25 X 25m. A total of 90 plots were used to collect vegetation and carbon data.The plant community classification was performed using R-software packages.Species diversity and evenness were evaluated using the Shannon diversity and evenness indices respectively.The study revealed that the study area composed of 300 species that belong to 239 genera in 96 families. Asteraceae was the most abundant family followed by Fabaceae, Acanthaceae, Poaceae, Rubiaceae and Euphorbiaceae. Five plant community types were identified and these were Ilex mitis-Syzygium guineense,Pouteria adolfi-friederici-Schefflera abyssinica, Millettia ferruginea-Sapium ellipticum, Arundinaria alpina and Schefflera volkensii-Masea-lanceolata community types.Among the community types,Pouteria adolfi-friedericii–Syzygium guineense community was the most diverse and whereas Arundinaria alpina community was the least diverse community. CCA of vegetaion data indicated that altitude, disturbance,slope, phosphorus and EC were the environmental factors that significantly influence of the plant communities.The structures of woody plant species of the forest showed five general population patterns (inverted J-shape, Gauss type, U-shaped, J-shape and irregular patterns and unknown pattern). The mean total carbon stock density of Gesha-Sayilem forest was found to be 362.04tons of carbon per hectareout ofwhich168.05,32.8, 1.27, 23.8 and 136.8 ton $ha^{-1}$ were stored in the above ground,below ground,litter, deadwood and in soil organic carbon respectively. The analysis of allometric equation for different woody species indicated that the developed model comprising of DBH and wood density are the reliable model for estimating the above ground biomass for the study species.The assessment of bee forage based on field observation, pollen analysis and key informant interview indicatedthat 79 bee forages were identified of which Schefflera abyssinica,Croton macrostchyus and Vernonia amaygdalina are the the major source of monofloral honey in the area.The high dependency of local communities on the forest resources are affecting the plant biodivresrity and honey production. Thus conservation of the forest through introduction of sustainable forest management interventions including $REDD^{+}$) seems an appropriate action.*

**Key words:** Allometry Biomass, Gesha forest, plant diversity, plant community, pollen, Sayilem forest

# Dedication

This dissertation is dedicated to the People of Kaffa who maintained the rich biodiversity of the forest for generations, despite the growing demand of forest resources for utilization and to improvee their socioeconomic condition and the late Professor Ensermu Kelbessa, a member of the Department of Plant Biology and Biodiversity Management of Addis Ababa University who passed away after a short illness. I always remember him with love and appreciation for his scientific contributions in the area of plant taxonomy and biodiversity conservation.

.

## Acknowledgments

I would like to thank the late Professor Ensermu Kelbessa for his kind supervision and accepting me for the PhD program and assisting with plant specimen identification and confirmation. I would like to express my deepest appreciation and thanks to my supervisors Prof Sebsebe Demissew and Dr Teshome Soromessa for their deserved guidance, follow up, providing of valuable comments and proof reading of the thesis.My special thanks go to Prof. Zemede Asfaw for his continuous and unlimited assistance in commenting on the structure of the thesis and editing the thesis. I would also like to acknowledge my Department,Plant Biology and Biodiversity Management, Particularly Dr. Bikila Warkineh, Dr. Tamirat Bekele, Prof. Zerihun Woldu, Dr Ermias Leulkal, Dr. Tigist Wondimu, Melaku Mondafrash, Shewanesh Lemma, Woge Abebe and W/ro Yirgalem H/Selassie, for their continuous moral support, sharing their valuable knowledge and facilitation of the program for field data collection.I would like to thank Mr. Samson Workeye and Mesfin Sahile for their unlimited support on the basic concepts, methods and applications of GIS.

I would like to thank my institute, Oromia Agricultural Research Institute (OARI), and Biovision Ethiopia for some financial assistance. I am particularly indebted to Mr. Kibebew Wakijra, the former Director of Holeta Bee Research and Mr. Taye Negera, the Director of Holeta Bee Research, who have provided me with all the support as a friend. Mr Gemechis Legesse, Tura Berke, Dr Abera Belay, Dr Debissa Lamessa and Dr Tesfaye Bekele are highly acknowledged for their kind help throughout my study. I also thank the Ethiopian Nutrition and Public Health Research Institute for nutritional analysis of the pollen samples and Ethiopian Agricultural Research Institute for the soil analysis. My special thanks also go to the Kaffa peoplea and the administrative staffs in the study area

at the various levels (Kebele, District, Zone and Region) are also highly acknowledged for providing all necessary support during the data collection. Last, but not least, I am indebted to my beloved family, my wife W/ro Abaynesh Nigussie and my children Ezana Admassu, Abreham Admassu, Mana Admassu and Samuel Admassu for their continuous love support and encouragement.

# Table of Contents

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ACRONYMS

| | |
|---|---|
| AGB | Above Ground Biomass |
| AGC | Above Ground Carbon |
| AIC | Akaike Information Criterion |
| BGB | Below Ground Biomass |
| BGC | Below Ground Carbon |
| CBD | Convention on Biological Diversity |
| CCA | Canonical Correspondence Analysis |
| DBH | Diameter at Breast Height |
| DCA | Detrended Correspondence Analysis |
| DEM | Digital Elevation Model |
| EFAP | Ethiopian Forestry Action Program |
| EIAR | Ethiopian Institute of Agricultural Research |
| ENMSA | Ethiopian National Meteorological Service Agency |
| FAO | Food and Agriculture Organization of the United Nations |
| FEE | Flora of Ethiopia and Eritrea |
| IBC | Central Statistical Agency of Ethiopia |
| IBCR | Institute of Biodiversity Conservation and Research |
| IPCC | Intergovernmental Panel on Climate Change |
| IUCN | International Union for the Conservation of Nature and Natural Resources |
| IVI | Important Value Index |
| LB | Litter Biomass |
| NABU | Nature and Biodiversity Conservation Union |
| NTFP | Non-Timber Forest Product |
| PCA | Principal Component Analysis |
| PFM | Participatory Forest Management |
| RD | Relative Density |
| RDA | Redundancy Analysis |
| RDO | Relative Dominance |
| REDD | Reduced Emission from Deforestation and Degradation |
| RF | Relative Frequency |
| S.R. | Similarity Ratio |
| SOC | Soil Organic Carbon |
| SOP | Standard Operating Procedures for Terrestrial Carbon Measurement |
| UNCED | United Nations Conference on Environment and Development |
| UNESCO | United Nations Educational Scientific and Cultural Organizations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WBISPP | Woody Biomass Inventory and Strategic Planning Project |
| WCMC | World Conservation Monitoring Center |
| WD | Wood density |

# CHAPTER ONE

## 1. Introduction

### 1.1Background

Nature provides various services and goods to humankind.Most of these benefits are derived from the biodiversity existing on earth. Among these benefits that biodiversity provides are pure water air, soil formation and the provision of foods, medicinal drugs, maintaining of $CO_2$ balance and other services. Biodiversity is defined as the variety of life on earth at genetic, organism and ecological levels and also cultural diversity (Jeffries, 2005). According to this definition, biodiversity is described at three levels, which include genetic diversity, species diversity and ecosystem diversity (UNCED, 1992). However, the unsustainable exploitation of natural resources by humans has caused habitat destruction and is leading to loss of biodiversity. The current decline in biodiversity is mainly the result of anthropogenic activity and it raises serious challenges to human development. Thus, conservation of biological diversity is a major concern for human society for survival and continuity of future generations.

Biodiversity is not uniform throughout the globe and increases towards the equator (Bartlett, 1998). Ethiopia is one of the tropical countries which have high biological diversity. It is rated among the top 25 countries in the world known for their high biodiversity (WCMC, 1994). The high biodiversity found in Ethiopia is attributed to its wide ranges of altitude, its great geographical diversity with high and rugged mountains, flat-topped plateaus and deep gorges and rolling plains (Ensermu Kelbessa and Sebsebe

Demissew, 2014).This diversity of physiographic features is unique in Africa and is responsible for the presence of a wide range of habitats suitable for the evolution and survival of various plant and animal species (Zerihun Woldu, 1999).

Ethiopia is the fifth major country in tropical Africa in terms of the diversity of flora (Ensermu Kelbessa and Sebsebe Demissew, 2014). In the Horn of Africa region, Ethiopia is regarded as a major center of diversity and endemism for several plant species (Hedberg *et al*.,2009). The flora of Ethiopia is diverse and is estimated to constitute about 6000 species of higher plants with 647 (10.74%) endemic taxa (Ensermu Kelbessa and Sebsebe Demissew, 2014). Endemism is relatively high in the Afro alpine vegetation, in the dry montane forest and grassland complex of the plateau (EWNHS, 1996).

These studies were carried out in different parts of Ethiopia and provided a general description of vegetation types and their associated flora. The most recent contribution of Ethiopian vegetation by (Friis *et al*., 2011) distinguished twelve major vegetation types. From these vegetation types, the Moist Afromontane Forest of southwest Ethiopia comprises the forest found in the southern parts of the Bale Mountains (the Harena forest) and the high forests of Wollega, Illubabor and Kaffa floristic regions. Various authors have attempted to describe the southwest forests based on floristic description and community analysis including (Friis *etal*., 1982); Lisanework Negatu,1987); Kumlachew Yeshitela and Tamrat Bekele,2002; Tadesse Woldemariam, 2003; Abayneh Derero *et al.,* 2003; Feyera Senebeta, 2006; Ensermu Kelbessa and Teshome Soromessa,2008).

The Ethiopian forests have a high biodiversity and hence they are significantly contributing to the national economy and the climatic regulation of the country. In this

regard, the forests in southwest Ethiopia have a critical role in maintaining ecosystem services and provision of habitat for a wide range of flora and fauna. Furthermore, they play a great role for hydrological balance and are a source of major rivers and basins of nation wide importance, e.g, the Omo-Ghibe and Lake Turkana Basin accounts for about 42% of the water in the Nile (NTFP, 2006).

Forests play a significant role in keeping the balance of carbon in the atmosphere by sequestrating carbon through photosynthesis and converting it into biomass and releasing it back into the atmosphere during respiration and decomposition of plant materials (Karousakis, 2009).The forest biodiversity sequesters more carbon and stores it in plant tissues and soil than any terrestrial ecosystem. It stores > 80% of all terrestrial above ground carbon and > 70% all carbon stored in the form of soil organic carbon (Perschel*et al*., 2007; Sundquist *et al.,* 2008).

Ethiopian forests have a potential to sink about 2720 million tons of carbon, which is almost 83% of the country's mean annual carbon emission (Yitebitu Moges *et al*., 2010).The forests of southwest Ethiopia contain an enormous amount of biomass above and below ground and can absorb substantial tons of $CO_2$ per year.The highland and lowland forests and woodlands in southwest Ethiopia sequester about 300 million tons of carbon dioxide per year, a major greenhouse gas (Sutcliffe, 2009). Hence, they are important carbon reservoirs for global climate regulation.

The Ethiopian forests also provide livelihood options for millions of people, through the production of non-timber products.These products include spices, forest coffee and honey. The moist Afromontane forests of Southwest Ethiopia have a high potential for honey production, due to the presence of very diverse bee flora (Fichtl and Admassu

Addi, 1994; Awararis Getachew *et al*.,2012).The current annual honey production of Ethiopia is estimated to about 54,000 metrics tons of honey and 5000 tons of beeswax making Ethiopia the first honey-producing country in Africa and 9$^{th}$ in the world (Admassu Addi *et al*., 2014). Of this production, 1318 tons (7.1%) comes from the southwest forests (Riechmann, 2007).

The moist Afro-montane forest of the southwest is also home to the genetic origin wild *Coffea arabica* where it has been domesticated and disseminated to the world (Schmitt, 2006). Southwest forests are also home to a large diversity of endemic birds of which Kaffa forest accounts for 61% of the total bird families in Ethiopia (Riechmann, 2007; Sisay Nune, 2008). However, during the last two decades, the natural forest cover of the southwest forests has shrunk dramatically and this has resulted in the degradation of habitat quality and biodiversity.Therefore, it is vital to understand the pattern of distribution of the ecologically and economically important plant species of high conservation priority found in the forest (Debissa Lamessa and Yayehyirad Teka, 2017). Generating data on aboveground and below ground carbon stock of the study forest with sufficient accuracy is of paramount importance to support the international effort of combating climate change and to benefit the local communities from the REDD+ project. These can improve the livelihoods of the local community whose socioeconomic conditions of the local community whose livelihoods to a greater extent depend on forest resources.

**1.2 Statement of the problem**

Even though the natural forests of Ethiopia make a significant contribution to the ecological wellbeing and economy of the country, most of the natural vegetation is today

highly degraded in terms of quality (species reduction) and quantity (shrinkage in volume) (Demel Teketay,2001). Historical sources indicate that 35% of the country's area was once covered by natural high forest (EFAP,1994). However today, the forest cover in Ethiopia is estimated at about 2.5% (Badege Bishaw, 2001). The recent national forest cover estimate of Ethiopia has grown from 3.65% (WBISPP, 2004) to 11% based on the adopted forest definition by the REDD+ Secretariat (MEFCC, 2015).The consequence of deforestation is affecting the climate of Ethiopia and contributing to global warming since the substantial amount of carbon initially stored in the forest ecosystem is now emitted as $CO_2$ to the atmosphere. The main causes for the shrinkage of the forest resource in Ethiopia in general and the southwest Ethiopian forests in particular, are anthropogenic pressures like clearing and burning of natural forest for crop cultivation, expansion of coffee and tea plantations, settlements, gathering of fuelwood and construction material (Feyera Senbeta, 2006;Sisay Nune, 2008).These consequences reduce the ecosystem services like carbon stocks, soil biota, the hydrological cycle, soil water storage and disrupt cycling of carbon (Lal, 2012). Thus owing to the above conditions and other related influences, the country has been facing climate change as evidenced by the increase in average temperature, a change in rainfall patterns, heavy flooding and recurrent drought. These situations not only affect Ethiopia but also the whole nations, particularly, the Sub-Saharan Africa, where countries are already exposed to climate variability (BERSMP, 2010). Ethiopia, is one of the countries in Sub-Saharan Africa, that is facing a problem of drought and floods. However the government is making an effort to minimize the effect of climate change protecting the existing forest resources and planting trees on disturbed forest land and degraded mountains.

To date, there is a lack of detailed studies on the ecology and carbon stock potential of the southwestern Ethiopian forests.The studies conducted by Friis *et al*., (1982); Kumelachew Yeshitila *et al*., (2002); Abayneh Derero, *et al*., (2003) and Feyera Senbeta, 2006 focused on plant diversity and community classification of Bonga forest. Ayele Kebede, 2011) reported that 11 forest patches were designated for core zones and most of these forest patches are found in remote and inaccessible areas of the different districts of Kaffa Zone. Gesha and Sayilem districts are potential forest areas designated as part of the Bonga National Forest Priority area (NFPA). This forest (Gesha- Sayilem) in the their respective districts are found in inaccessible areas and so far, no study has been conducted on vegetation ecology, carbon stock potential and honeybee forage species diversity. In addition the country is lacking periodic inventory data of carbon stocks for national carbon inventoryfor the purpose of REDD+ initiatives.

The current rate defeoration for coffee planation also affecting honey production.Celaring of potential bee forages such as *Croton macrostachyus* and *Schefflera abyssinica* for the preparation of land for coffee planting. This situation is threatening honey production and affecting the livelihood of the communities who depend on forest beekeeping.

Hence this study was designed to assess species composition, species diversity and plant community types which are associated to with environmental factors and also to determine the carbon sequestering potential of the forest. Thus, from this point of view, the following research questions were developed.

## 1.3 Research questions, hypotheses and objectives

### 1.3.1 Research questions

- What are the major plant communities existing in the forest and the environmental factors affecting plant diversity and richness?
- What is the estimated carbon stock potential of the forests in Gesha and Sayilem districts and how does it vary according to environmental factors?
- What are the major bee forage species and the major monofloral honey produced

### 1.3.2 Research hypotheses

- The plant diversity is not significantly vary among the plant communities
- Altitude and level of disturbance are not the major influencing environmental factors in determining plant communities and carbon stock in the area.
- Plant diversity has no correlation with carbon stock in the area.
- Carbon stock of the study forest is low in above ground carbon and than soil corganic carbon.
- All plant species are visted by honeybees and one type of honey is produced from the study area.

### 1.3.3 Research objectives

#### 1.3.3.1 General objective

This research aims at investigating the floristic composition, plant co diversity and estimating the carbon stock potential of the forest and to identify the major bee forages contributing to honey production in the Afromontane rain forest of Gesha and Sayilem districts.

### 1.3.3.2 Specific objectives

- To determinethe floristic composition, structure, plant species diversity and plant communities existing in the forest;
- To estimate carbon stock potential and environmental factors affecting the carbon stock;
- To develop species specific allometric equation for the dominant plant species in the area;
- To identify the bee floral resources and to determine proximate composition of pollen, honey and to document honey production practice ofthe area.

**CHAPTER TWO**

# 2. Review of Literature

## 2.1 Floristic diversity and vegetation types

Ethiopia is an important regional center for biological diversity due to its wide range of altitudinal and topographical variation that have resulted in the presence of diverse habitats, which serve as refugia for existence of different plant species. This geographical and ecological diversity contributes to the high rate of endemism of plant species and diversity of vegetation resources (Demel Teketay *et al.,* 2004).The vegetation of the Ethiopia is very diverse and it varies from semi-desert to Afro-alpinevegetation (Friis *et al.*,2010). Furthermore, the Ethiopian Flora harbors about 6000 higher plant species with about 10% endemism (Vivero *et al.,* 2005; Ensermu Kelbessa and Sebesbe Dimssew, 2014). According to Demel Teketay *et al.(*,2000) and Azene Bekele ( 2005), the estimate of woody plant species in the Flora of Ethiopia and Eritrea is about 1100 with about 300 of these being tree species.

### 2.1.1Vegetation history and Forest Resources of Ethiopia

The vegetation in Ethiopia comprises forests, woodlands and bushlands and thickets. The first study of the Ethiopian forests was undertaken by Logan an American forester who studied the forests in southern Ethiopia between 1940 and 1945 (Logan, 1946). Following this study (Pichi-Sermolli, 1957) identified 24 vegetation units based on physiognomy of vegetaion and his work was the most detail one covered vast areas of Djibouti, Eritrea and Somalia and significantly contributed to the classification of Ethiopian vegetation. Following the work of Pichi-Sermolli, Von Breitenbach (1963) published forest trees of Ethiopia and he mapped the forest vegetation building upon the

same system of that of Pichi-Sermolli. Von Breitenbach used seven vegetation categories for mapping which he further classified into 82 units mainly based on the classification of plant association by Westhoff and (Vandermarrel,1978). Chaffey, a British forester from Land the Resource Development Centre of the British Ministry of Overseas development did much to provide a better knowledge on the useful trees of Ethiopia and published a glossary of vernacular names (Chaffey, 1979).The studies by Friis for the last three decades have also contributed towards the inclusive classification and mapping of the forest vegetation of Ethiopia.Vegetation studies have been undertaken by Ethiopian scientist including Abayneh Derero *et al.*, (2003) on Bonga forest, Lissanework Nigatu, (1987) on Harnnea forest, Tamrat Bekele,(1994) on vegetation of the central Plateau of Shewa.In addition Sebsebe Demissew *et al*., (1996, 1998); Zerihun Woldu, (1999); Friis and Sebsebe Demissew,(2001); Sebsebe Demissew *et al.*, (2004) and Sebsebe Demissew, (2009) made considerable contributions in describing the natural vegetation of Ethiopia. Recntly (Friis *et al.*, 2011) have prepared an Atlas of the Ethiopian vegetation and described the vegetaion classify and it into twelve vegetation types (Fig.1).

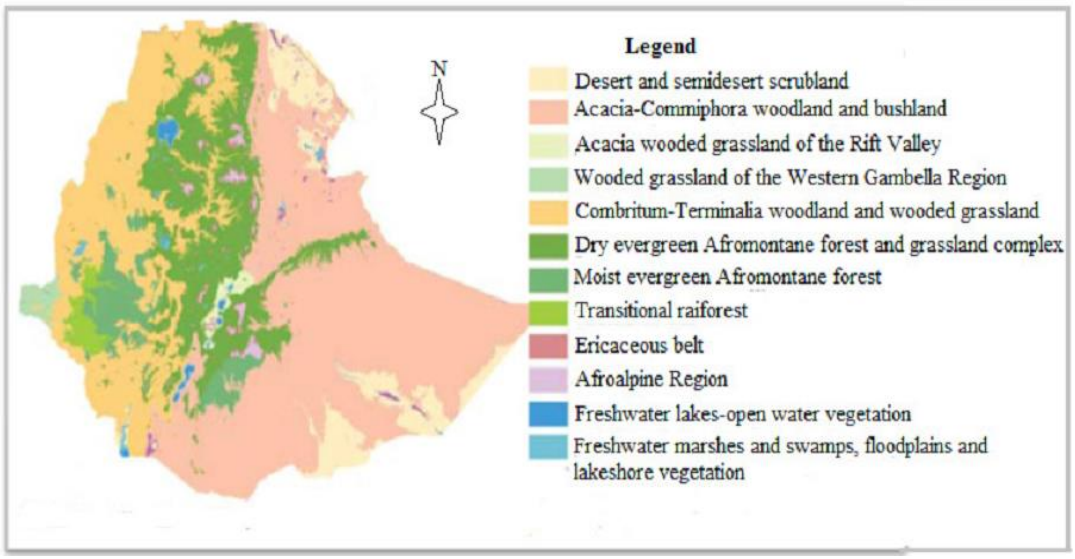



Figure 1. Potential vegetation map of Ethiopia**:** Source Friis *et al*. (2011)

### 2.1.2 The vegetation of southwest Ethiopia

The study of the forests of southwest Ethiopia was started at the beginning of the 18 century by two foreign travelers,my names infull O. Neumann and F, Bieber, who documented the existence of rainforests in Southwest Ethiopia in 1906 (Friis, 1992). Later on, some Italian foresters, (Giordano, cited in Friis *et al.,* 1982) also visited the forests of southwest Ethiopia and produced the bulk of papers around the1930s and early 1940s.The construction of the road from Mizan to Jimma in 1964 facilitated botanical collection and the exploitation of forest in southwest Ethiopia (Friis *et al.,* 1982). There were 25 botanical collectors from Europe and America and their collection are available in the National Herbarium of Addis Ababa University and in major European Herbarium (Friis, 1982). On top of this,several authors like Chaffey, 1979, (Friis, 1992); Lisanework Nigatu,(1987) ; Zerihun Woldu *et al.,* (1991); Kumlachew Yeshitila *et al.,(*2002);Tadesse Woldemariam,(2003); Feyera Senebeta (2006); Tesfaye Awas, (2007) and Ensermu Kelbessa and Teshome Soromessa,(2008) have studied the forest vegetation of southwest Ethiopia.

The classification of forest vegetation in Ethiopia by Friis, 1992 identified seven vegetation types of which four are found in southwest Ethiopia. They include Dry peripheral semideciduous Guineo-Congolian forest, Transitional rainforest, Afromontane rainforest and Riverine forests). The Guineo-congolian forest has been recently included in Transitional Forest types (Friis *et al.,* 2011). Of the twelve types described by (Friis *et al.,* 2011) three are found in southwest Ethiopia and include the Transitional rain forest, Moist Afromontane rainforest and Riverine forests.

#### 2.1.2.1 Transitional rainforest (TRF)

The transitional rainforest is found in the edges of the southwestern highlands between peripheral the Guineo-Congolian and Afromonatne rain forest. According to Friis, (1992 ) this forest is found between altitude of 500 and 1500m.The mean annual temperatures ranges from 20-25$^{o}$c and the mean annual rainfall is about 2000 mm.The characteristic species of this forest are *Manilkara butugi, Pouteria altissima,Pouteria alnifolia, Antiaris toxicaria* and *Celtis philippensis,Trilepisium madagascariense* and *Triehilia dregeana.*

#### 2.1.2.2 Moist Afromontane Forest (MAF)

This forest occurs in the southwestern highlands of Kaffa, Welega and Illuababor and Harenna forest is part of the Bale Mountains located in south the eastern highlands of Ethiopia. According to Friis, (1992) these forests are predominately composed of broad leaved evergreen species with multi layered canopies. *Podocarpus falcatus* is a characteristic species in the eastern and northern most parts of these forest but it become in frequent in southwest forest in Kaffa.The dominant species in this forest includes *Albizia grandibracteata,Polyscia fulva, Schefflera abyssinica, Sapium ellipticum, Macranga capesnsis, Celtis africana, Croton macrostachyus, Lepidotricum volkensii, Hallea ruberosteplatha, Ilex mitis* and *Vepris danielli.*

#### 2.1.2.3 Riverine forest

The riverine forest in southwest Ethiopia is also found along the Baro Rivers in Gambella. The common species found in this forest includes: *Baphia abyssinica, Celtis toka, Lecaniodiscus faxinus, Lepisanthus senegalensis,Trichilia retusta* and *Zixiphus pubsences.*

The shrubs include *Grewia trichocarpa*.The climbers, *Acridocarpus ugandensis, Cissus petiolata* and *Tilicora funifera.*

### 2.1.3 Threats to the forest of Ethiopia

Ethiopia is facing rapid deforestation and degradation of its land resource due to expansion of agricultural land, coupled with the geometric increase in population and high dependence on biomass energy (Reusing, 1998). Estimates of the rate of deforestation range from 140 000–200 000 ha per year and at present only about 12.3 million ha of forest cover remains (FAO, 2010). As a result,the forest resources of the country have declined rapidly and had reached 3.6% by 1980 and 2.6% by 1987 (IUCN, 1990) and 2.3% (Sisay Nune, 2007).The intensity of deforestation ranges varied from region to regions.The northern part of the country has experienced continual deforestation over the past thousands of years, while deforestation in the southern and southwest is a relatively recent occurrence (Nyssen *etal*., 2004; Dessie,2007).

The southwest montane forests are among the most affected ecosystems in Ethiopia. Reusing (1998) reported that the closed high forests of southwest Ethiopia dropped from a 40% cover between 1971 and 1975 to only ca. 18% by 1997, which is a loss of ca. 60% of the forest cover.In the 1900s almost all the southwestern highlands were covered by moist evergreen montane forest of which about 7.8% or 235,400 ha of the forest was deforested between 1971 and 1997. The main causes for the decline of forest cover in the area is due to clearing forest for coffee and tea plantations and subsistence farming and unplanned movements of immigrant's looking for daily jobs or fertile lands (Ensermu Kelbessa and Teshome Soromessa, 2008).These factors made a significant contribution for the loss of forest cover and this affecting the livelihood of the local communities. In understanding the ecological and economic benefits' of the forest resources of the country, the government is committed to designing different strategies to conserve the remaining forest resources. As a result of deforestation or forest conversion, the south west region is

facing the climate change effects which include rainfall varability and extended drought period. On top of this celaring of potential bee forages such as *Croton macrostachyus* and *Schefflera abyssinica* for the preparation of land for coffee planting is compounding the problem further.This situation is threatening honey production and affecting the livelihood of the communities who depend on forest beekeeping. Knowing the impact of deforestation on climate change and honey production, the government designed different strategies to conserve the remaining forest resources in southwest Ethiopia in general and the study area in particular. Participatory Forest Management( PFM) is considered as one of the solutions to solve the problem of open access to forest resources and promote sustainable forest management.The local communities under the PFM program benefits from non-timber products (honey and spice). Along with this effort the German-based biodiversity conservation institutions called NABU (Nature and Biodiversity conservation Union) has been working in the Kaffa Zone and supported the establishment of UNESCO Kaffa Coffee Biosphere to conserve 200,000 ha of Kaffa's moist forest and as the result it was able to inhibit an emission of two million tons of $CO_2$ ( NABU, 2012) and the local communities may benefit from Carbon trade when $REDD^+$ program is implemented in the area.

### 2.2 Plant communities and community theories

As described by (Goldsmith *et, al*., 1986), vegetation, is as an assemblage of the diversity of plant species growing together in a particular location and characterized either by its component species or by the combination of structural and functional characters that determine the appearance or physiognomy of vegetation. In nature, plant species are always part of an assemblage or community of species populations living together in the same area.The fundamental unit of plant sociology is the plant association, which is a

vegetation community of definite floristic composition (Kent and Coker 1992). Based on this concept the plant communities are defined as the collection of plant populations growing together in particular habitat that show definite association or affinity with each other (Kent and Coker,1992) or as a combination of species that are dependent on their environment and influence one another and modify their own environment (Mueller-Dombois and Ellenberg, 1974). It is dominated by one or more prominent species in a given time and space.The distribution of the plant communities is influenced by different environmental factors such as climate, soil, topographic conditions and biotic factors such as competitive ability of species (Walter, 1985).

### 2.2.1 Plant community theories

There has been a long debate in the past by different vegetation ecologists regarding the concept of plant community.Plant ecologists have been divided in their views as to whether vegetation consists of a series of distinct communities or whether vegetation is a continuum. Clements' (1936) has also been described as as a defined plant community as discrete and definable entities, with clear boundaries (Ricklefts,1997). It is also known as "supra-organisms that have its own life and structure as well as its own temporal and spatial limits (Chapman and Reiss, 1992). On the other hand, according to Gelason, plant communities change gradually along complex environmental gradients so that no distinct associations of species can be identified. It is also argued that all plant species distributed as continuum and respond individually to variation to environmental factors and those factors vary continuously in space and time（Robert, 1987).

### 2.2.2 The discrete and continuum community concept

The discrete community concept envisages that the distribution of species or plant communities along certain environmental gradients would replace one another and species with wider distribution ranges are avoided and each community is separated from the other based on indicator or dominant species (Shipley and Keddy, 1987), Barbour *et al*., (1988) and Kent and Coker (1992). Thus, for discrete communities to exist they must show discontinuities over the continuous environmental template (Roberts,1987). Discontinuities in communities could occur if few potential dominant species control the environment and avoid others by competitive segregation and subsequent modification of the environment (Brown and Lomolino, 1998).The alternative continuum model posess that plant community's change gradually along the complex environmental gradient rather than by forming distinct, clearly separated zones of plant association and hence recognition of distinct community association is not possible Collins *et al*., (1993). The distribution of each species along the environmental gradient is based on its own genetic, physiological and life-cycle characteristics and its way of responding to both physical environment and interactions with other species (Whittaker, 1975).Thus the species distribution and richness are based on the limit of tolerance of the species to various environmental factors.

### 2.2.3 Species diversity, evenness and richness

#### 2.2.3.1 Species diversity

Floristic description of a vegetation community involves the analysis of species diversity which is the fundamental unit of biological organization (Magurran, 2004).The word biodiversity is commonly associated with 'diversity (Hamilton, 2005; Leps, 2005). Species diversity is described on the basis of two concepts, the total number of species in

the community (species richness) and the relative abundance of species (evenness) within the community.Thus, the description of plant communities comprises the analysis of species diversity, richness and evenness indices. Diversity and equitability of species in a given vegetation community is used to interpret the relative variation among and within the community and helps to explain the underlying reasons for such differences (Kent and Coker, 1992).

Whittaker (1975) has distinguished three different kinds of species diversity, alpha (α), beta (β) and gamma (γ) diversity. Alpha (α diversity) refers to the number of species within a sample area or community. Beta diversity (β diversity) measures the change in the diversity of species among the set of habitats or it calculates the number of species that are not in the same habitats and measures the species turnover rates (Zerihun woldu,2017). Beta diversity is also called habitat diversity because it represents differences the species composition between very different areas or environments. Gamma diversity (γ diversity) describes regional differences in species composition and it depends on the alpha and beta diversity (Kent and Coker, 1992). A great number of diversity indices have been developed, each of which expresses the diversity of a sample or quadrat by a single number. Of the various indices used in vegetation ecology, the Simpson index (D) and the Shannon index (H) are the most common ones. Shannon-Wiener index of species diversity was applied to quantify species diversity and richness. It is one of the most widely used methods for measuring the diversity of species and richness (Kent and Coker, 1992). Simpson (1949) developed an index based on the probability that any two individuals taken at random from an infinitely large community will belong to the same species. It is sometimes named as a dominance index because it gives more weight to common species. Shannon-Wiener measures the species diversity

because it accounts for both species richness and evenness and not largely affected by sample size (Kent and Coker, 1992). Evenness or equitability is used to quantify the unique representation of a given species against a hypothetical community in which all species are equally common. The value of evenness index falls between 0 and 1.The higher the value of evenness index, the more even the species within the given area of distribution (Kent and Coker, 1 992).

#### 2.2.3.2 Species richness

The term species richness is expressed as a number of species in the community (Krebs, 1999). Species richness can be numerical or be related to species density in an area (Simpson, 1949). Determining and documenting species richness of the forest is important, not only for basic comparisons among sites, but also for addressing the concentration of local communities being colonized from existing regional pool. Maximizing species richness is often the major goal of conservation studies and current rates of species extinctions are calibrated against the patterns of species richness (abundance).The analysis of community diversity and richness have been widely applied as the indicator ecological condition and also indicates the human effect on ecosystems (Leitner and Turner, 2001).

### 2.3 Multivariate data analysis

Multivariate analysis of vegetation data has major role in describing plant communities and associated environmental factors (Kent & Ballard, 1988). Owing to its high relevance for vegetation classification; it has received considerable interest in different disciplines such as land-use change and for nature conservation. Among the multivariate techniques cluster analysis and ordination are the two main and basic techniques in vegetation science (Mueller-Dombois and Ellenberg, 1974; Whittaker, 1975).

### 2.3.1 Cluster analysis

Cluster analysis is a useful tool for identifying groups using the ecological data and it has been used for several years in community ecology (McCune and Grace, 2002). It encompasses a number of different classification algorithms, which seek to organize a given data set into homogeneous subgroups, or clusters in such way that similar objects are grouped in the same cluster and dissimilar objects are grouped in different clusters based on their level of similarity. Moreover, cluster analysis is used to group sites versus species based on similarity in species composition and abundance to generate a classification of vegetation communities (Kent and Coker, 1992; Mc Cune and Medford, 1999 and McCune and Grace, 2002). Cluster analysis can be hierarchical or non-hierarchical. Hierarchical clustering is a clustering method when the classes themselves are classified into groups, the processes being repeated at different levels to form a tree.There are two types of hierarchical clustering methods:Agglomerative and divisive. Agglomerative clustering performed by first finding the clusters of the most similar items and progressively adding less similar items until all items have been included into a single large cluster. On the other hand, divisive methods start with the total population of individuals and progressively divide them into smaller groups. Division ceases either when each group is represented by a single individual, or when some form of predetermined stopping rule is applied to halt division (Kent and Coker, 1992).The basic tool for hierarchical clustering is a measure of the dissimilarity or proximity of one item relative to another. There are several dissimilarity and distances indices used in ecological data analysis. Dissimilarity indices such as similarity ratio are bounded between 0 and 1 while distance measure such as Euclidean distance can be of any size.

The main outcome of a hierarchical cluster analysis is a dendrogram, which can be cut at arbitrary heights to give a fixed number of clusters.

### 2.3.2 Ordination

The word ordination is defined as the ordering or arrangement of samples (species) in relation to one or more environmental gradients (Whittaker, 1967). It is a multivariate technique that depicts the relationships between samples species and environmental variables in reduced dimensional ordination space (ter Braak, 1995; McCune and Grace, 2002). Ordination can be viewed as Constrained Ordination (Direct Gradient Analysis) and Unconstrained Ordination (Indirect Gradient Analysis). Constrained ordinations are directly influenced by a set of explanatory variables and the resulting axes are constrained by environmental factors since the matrix with environmental factors directly enter the ordination algorithm while unconstrained ordination techniques are not constrained by environmental factors. In unconstrained ordinations, searches for pre made any variable that best explains the species composition. The unconstrained ordination axes therefore, correspond to the directions of the greatest variability. Constrained analysis has been the most popular ordination methods in community ecology (ter Braak, 1986) and these methods are capable of testing the hypotheses about the influence of environmental factors on species composition. Generally, ordination is of two types: eigenvalue-based and distance-based. 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.

PCA and RDA analyze linear responses along the gradient,and CA and CCA look at unimodal responses along the gradient. he use of PCA, RDA, Ca or CCA therefore depends on whether the relationship between species data environmental data is linear or

whether the gradient is short or long or the relationship between species data and environmental data is unimodal or not.

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.

### 2.4 Vegetation structure

Vegetation structure is one of the crucial components of vegetation ecology and it has a significant role in maintaining the reproductive cycle of plants through recruitment of seedlings. It depicts the horizontal and vertical and temporal arrangement of vegetation (Barkman, 1979).The vertical and horizontal distributions of tree sizes determine the distribution of micro-climatic conditions, the availability of resources and the formation of habitat niches.Thus,information about vegetation structure contributes to improved understanding of the history, functions and future development potential of a particular forest ecosystem (Spies 1997 ; Franklin *et al*. 2002).

Tropical forests reveal variation in the pattern of regeneration both through the difference in their species structure and the environmental factors in which they grow (GetachewTesfaye, 2012). Regeneration of tree species is commonly employed or assessed by the distribution of the size classes measured as Diameter at Breast Height (DBH). The size class distribution indicates whether the regeneration is taking place or not. If the regeneration were taking place constantly then the species would have a stable population distribution with an inverse J-shape is an indication of good or healthy regeneration potential (Harper, 1977; Silvertown, 1982).On the other hand, a bell-shaped or variable size class distribution, is an indication of forest disturbance and the hampered

regeneration (Poorter *et al*., 1996).Thus,the population structure of the different trees in the forest gives an indication of the impact of disturbance and the forest successional trends (Hu bbell and Foster, 1986). Such information is critically important for the understanding of the conservation of the forest ecosystem.

Forest trees regenerate from one or more pathways such as seed rain, dispersed seeds, soil seed banks and coppices (Demel Teketay,1996). Seedling densities in the forest under stories are dynamic and may vary among species, in gap and shade environments (Bazzaz,1991). The seedling density also varies due to mortality which could include abiotic factors such as light, drought and biotic factors that encompasses herbivory, dissection and competition (Augspurger, 1984).The tree seedling and sapling ecology can provide information for forest development through improvement in seed recruitment and growth of the desired species with out affecting the forest (Swaine, 1996). Thus, regeneration study has the significant effect on the management, conservation and restoration of degraded natural forests.

**2.5 Climate change**

The green house gas concentration in the atmosphere is responsible for warming the earth's surface by absorbing the out-going infra-red radiation. The major greenhouses gases responsible for the climate change are Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrousoxide ($N_2O$), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride ($SF_6$), and Fluorinated gases (IPCC, 2001). Among the above, $CO_2$ is the most abundant greenhouse gas that contributes to the greenhouse effect in the natural ecosystem which causes global warming and contributes to climate change (Stern 2008).The main causes of global climate change include burning of coal, natural gas,

industry and deforestation (IPCC 2007).The energy supply from the burning of coal, natural gas and oil are the largest sources of global greenhouse gas emissions which contribute 26% followed by industry (19%) while the forestry contribution to global emission is 17%. In addition to this, the agriculture and transport sector contribute to (14%) and 13% respectively. About 11% of greenhouse gas emission comes from industrial wastes and other wastes. These would lead to the atmospheric concentration of $CO_2$, from the pre-industrial concentration of about 280 ppm, since 1750 to 393ppm in 2010 and increasing at the rate of about 2.2 ppm per year (IPCC, 2007).

### 2.5.1 The role of forests in climate change

Forests play an important role in the global carbon balance. As both carbon sources and sinks, they have the potential to form an important component to combat global climate change.The world's forests store more than 650 billion tons of carbon, of which 44% in the above-ground biomass, 11% in dead wood and litter, and 45% is in the soil (FAO, 2010). The tropical forests are supposed 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 *et al.*,1982).

### 2.5.2 Carbon sequestration of the forest

The United Nation Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing carbon from the atmosphere and depositing it in a reservoir which includes vegetation, soils and ocean (UNFCCC, 2007). The transfer of carbon between the atmosphere and terrestrial ecosystems is contributes to the concentration of carbon dioxide in the atmosphere which is the major cause for

global warming (Houghton, 2007; IPCC, 2007). In the Carbon cycle, huge amount of carbon entered the plant from the atmosphere during photosynthesis and are stored in the form of fixed cellulose and lignin in the forest vegetation.The carbon dioxide captured by plants during photosynthesis is transferred across the different carbon pools . When a plants die it becomes humified into soil organic carbon and released back to the atmosphere when there is disturbance.Thus, the earth's carbon reservoirs naturally act as both sources, adding carbon to the atmosphere, and sinks, removing carbon from the atmosphere (Lal, 2006).

### 2.5.3 Forest carbon pools

Carbon pools are the important components of the ecosystem that can either store or release carbon. Different authors have categorized forest carbon into different pools. According to IPCC (2006) carbon pools have been grouped into five main categories: Above ground biomass, below ground biomass dead organic matter in wood, litter and soil. In a tropical forest ecosystem, the living biomass of trees, the understory vegetation and the deadwood and soil organic matters constitute the main carbon pools (IPCC, 2003) (Figure2). According to (Djomo *et al*., 2010) Moist Tropical forests in Africa had more than three times as much carbon in AGB as compared with soils.The above-ground biomass is the main carbon pool and it is affected by land use change (Gibbs *et al.*, 2007). Hence, estimating the forest carbon stocks is important for assessing the magnitude of carbon exchange between the forest ecosystem and the atmosphere.

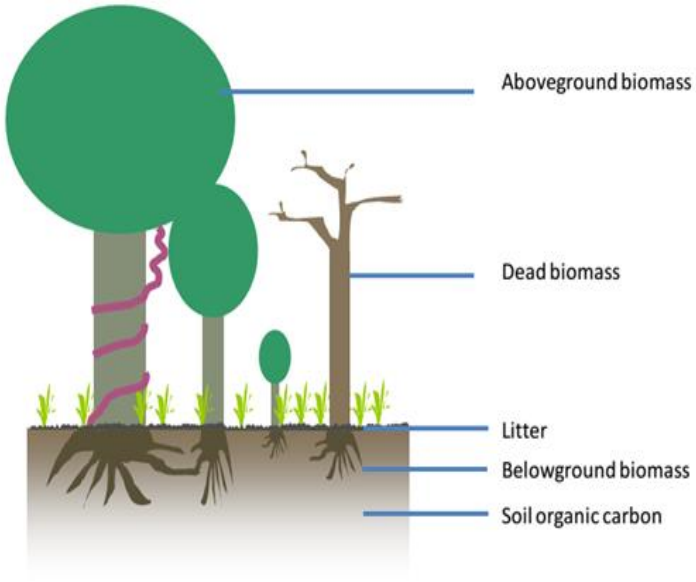



**Figure 2. Different Carbon pools as defined by the IPCC** (Source: IPCC, 2003)

### 2.5.4 Estimating the above-ground biomass (AGB)

The estimation of the above-ground biomass in aforest ecosystem is essential for describing the productivity and sustainability of the forest for carbon potential that can be released in the form of $CO_2$ when the forest is deforested or burned. It may also help to identify the status of carbon stocks and to predict the future change in forest carbon stock. Above Ground Biomass of the tree can be estimated through field measurement and remote sensing. For the field measurement of carbon stock either destructive or non destructive methods can be used. The destructive method involves harvesting of all the trees from the known area and measuring the fresh weight of the different components of the tree. These include trunk, branches and leaves which can be dried in the oven for obtaining the dry weight of the tree (Devi Yadava, 2009). This method is applied to the small-sized tree classes but it is time consuming and labor intensive. The second method of aboveground biomass estimation is the non-destructive method. This method estimates the biomass of a tree without felling and it is applicable for endangered and rare

species.The determination of biomass by the nondestructive method is usually done by climbing the tree to measure the various parts of the trees.The measured parts of tree components can be converted to appropriate allometric equations on dry weight basis.The selection of an appropriate allometric equation is crucial to increase the precision of the carbon stock estimation.There are different generalized allometric equations developed for different forest types (Henry,2011) which are presented in (Table1).

The allometric equation developed for different forests are based on establishing the relationship between the various dendrometric variables of the tree such as the diameter at breast height (DBH), commercial bole height, total height and crown diameter of the tree species (Brown *et al.*,1989 and Buski *et al*,2009). The most widely known equation for tropical rain forest, are (Brown *et al*.,1989; Chave *et al*.,2001, 2005& 2014) who are developed allometric regression equation as function of DBH, total height and wood density.However, the generalized models do not accurately represent biomass in the in all forests of the particular area.

**Table 1. Allometric equations developed by different authors for the estimation of above ground biomass as a function of DBH**

| Climatic zone | Equation | References |
|---|---|---|
| Dry (< 900 mm rainfall) | Exp (-1.996+2.32*log (X) | Brown, 1997 |
| Dry (900–1500) mm rainfall) | Biomass = 0.2035 x 2.31DBH | Brown unpublished |
| Dry (< 1500 mm rainfall) | *Y= 34.4703 - 8.0671 DBH +0.6589 DBH* | Brown *et al.(1989*) |
| Dry transition to moist (rainfall>900mm) | Y= exp (-1.996+2.32xln(DBH) | FAO,1997 |
| Moist (rainfall 1500 to 4000 mm) | Y= exp (-2.134 +2.530 x ln (DBH) | FAO, 2004 |
| Moist (rainfall 1500 to 4000 mm) | Y= exp (-3.1141 + 0.9719 x ln [(DBH2) H] | Brown *et al.(*1989) |
| Wet (> 4000mm rainfall) | Biomass = 21.297– 6.953 x dbh+ 0.740 x $dbh^2$ | Brown, 1997 |

**Source: (Henry, 2010)**

### 2.5.5 Carbon in below ground biomass (BGB)

The BGB carbon pool comprises the biomass contained within live roots of trees and below stump height. Fine roots of less than 2 mm diameter cannot be considered as below ground biomass because it cannot be distinguished from soil organic matter (IPCC, 2006). For below ground biomass estimation (Cairns *et al.,* 1997) reviewed more than 160 studies encompassing a wide range of ecological regions (tropical, temperate, and boreal forests). Based on these studies the mean R/S ranges 0.18 to 0.30% with mean value of 0.26%.

### 2.5.6 Carbon in litter and soil

Litter is defined as dead surface plant that includes dead leaves, twigs, dead grasses, small branches. MacDicken (1997) indicated that the litter carbon pool consists of all non-living biomass with greater than the limit for soil organic matter and quadrat are usually used to assess the litter biomass per unit area.

Soil organic carbon is defined as the amount of carbon per unit area (Lal, 2008). The soil organic carbon (SOC) pool is estimated from soil samples taken in the sample plots with the help of metallic cylinder. In order to attain an accurate measurement of organic carbon stocks in the soil, three variables must be measured:soil depth to which carbon is accounted, soil bulk density calculated from the oven-dry weight of soil from a known volume of sampled material and concentrations of organic carbon. Thus, in most forestry related studies soil carbon assessment is recommended a depth of 0-30 cm horizon (MacDicken, 1997).

### 2.5.7 Non-woody vegetation (NWV)

The non- woody vegetationcan be sampled directly in small subplots within nested plot. A square plot, usually having an area of about 1mx1m, can be used for sampling of undergrowth. All live herbaceous flora from the forest is removed from the subplots within main plots and weighed. A well-mixed subsample is then collected and placed in a plastic bag.The subsample is used to determine oven-dry-to-wet mass ratios, the amounts of biomass per unit area are given by sampling frame area ($cm^2$) x10000 which converts the units into metric t/ha and finally multiplying by 0.5 gives the amount of carbon (Pearson, 2005).

### 2.5.8 Measurement of Carbon in Dead Wood

This carbon pools consists of all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10cm. The dead wood carbon pools can contain 10-20% of that of the AGB pool in mature forest (Delaney *et al*., 1998). An efficient method for sampling of laying dead wood is the line intercept method which measures the debris which crosses transect line (Palace *et al*., 2007).In this measurement of deadwood at least 100 m length of line per plot must be used (Harmon and Sexton,

1996). The diameters of all pieces of wood that intersect the line are measured and the density recorded.

### 2.5.9 Environmental factors affecting forest carbon stock

Carbon sequestration potential of plants depends on a number of environmental factors which include topography micro climate,nutrient availability and land management. Among the topographic variables elevation is one of the influencing factors for carbon sequestration potential of the forest. As described by (Sheikh *et al*.,2009), elevation is one of the most important environmental gradients that affect biomass of the trees. Andreas *et al.*(2015) indicated that the total biomass of the the a tree on Mount Kilimanjaro varies at different elevation ranges. Altitude also influences the soil organic carbon by controlling soil water balance, soil erosion and this further affects the quantity of the whole carbon stock of the forest (Tamene Yohannes, 2016). Like the altitude, slope and aspect, are also known to influence the amount of carbon stock. According to Bayat (2007) slope and aspect have significant effect on the biomass of forest. Different studies have shown that, a higher slope class showed a low total carbon stock as compared to the low slope class, since increase in slope will increase runoff and soil erosion (Adugna Feyissa *et al*., 2013; Hamere Yohannes *et al*., 2015).

### 2.5.10 Carbon stock and biodiversity

Biodiversity can be assessed in terms of the number of different types of biological resources present in particular ecosystems. These biological resources can range in size and complexity from individual genotypes, to species, to higher taxonomic levels s within their environment (Michael & Gregg, 2003). Species composition of the forest can influence the long-term balance of carbon gains and losses in ecosystems through different components of the carbon cycle, including the extent, turnover and endurance of

carbon stocks in soils and vegetation (Díaz *et al*.2009; Maestre *et al*.,2012). Studies have shown that, tree plantations with two or more species may achieve higher levels of productivity than single-species plantations (Forrester *etal.*, 2006). Furthermore (Hicks *et al.*, 2014) indicated that, increased species richness has been shown to increase carbon sequestration of forest, due to the presence of highly productive species with high biomass accumulation. Healthy ecosystem can maintain the decomposer which break down dead plant material to release nutrients essential for the growth of new plant tissue which again contribute for higher biomass and carbon stock in natural ecosystem.

### 2.5.11 Carbon sequestration potential of Ethiopian forest

Ethiopia is one of the tropical countries with a forest cover which can sequester a significant amount of carbon to mitigate climate change.The total forest cover of Ethiopia is estimated to be around 13 billion ha or covering 11.4% of the total area of the country due to change of forest definition (FAO, 2010). According to this definition, land having at least 0.5 ha covered by trees and bamboo, attaining a height of at least 2m and a canopy cover of at least 20% (MEFCC, 2015). The reason for the change in forest definition is to capture Ethiopia's dense woodlands that have a wider distribution through the country. Following the new forest definition, Ethiopian forests contain about 2720 million metric tons of carbon or 2.8 billion tons of carbon (Yitebitu Moges *et al.*, 2010).

The major store of carbon in the country is found in the woodlands (45.7%) and the shrublands (34.4%) and relatively lesser amount is found in the high forests, (15.7%), plantations (2.2%) and in the lowland and highland bamboos (1.92%). According to estimated AGB using remote sensing, data, the Ethiopia's biomass stocks are largely concentrated in the montane forests of the south and southwest of the country, in the

south-central Oromia,Western Oromia,Kaffa-Sheka zones in Southen Nations and Nationalities of People region and the lower AGB stocks are found in Gambella, Benishangul Gumuz, Amhara, and Tigray, Afar and Somali regions (FAO, 2010).

The mitigation potential of Ethiopian forests is currently affected by deforestation and forest degradation. The major drivers of the deforestation and degradation process are: land-use change, promotion of large-scale commercial and foreign investment, collection of fuelwood and timber, human settlement in forest areas and road construction that affects the carbon sequestration of Ethiopian forest. To minimize the deforestation and carbon emission levels, the government made efforts to increase the afforestation on degraded lands and also promote community based forest management through the implementation of the REDD+ projects. Bale Mountains Eco-region REDD+ Project and Humbo Natural Regeneration Project are the worth to mentioning and had been implemented in the country. The Bale Eco region REDD+ project is the largest REDD+ pilot project in the country and is funded by Norway through the World Bank and located in Oromia regional state.Similarly,the Humbo Ethiopia Assisted Natural Regeneration Project was established in 2005. The World Vision initiated the afforestation project over 2700 ha of highly degraded lands in Wolayita Zone in SNNPR. The project was identified and validated as an afforestation project under the Clean Development Mechanism (CDM) in 2009.

There are some fragmented studies on carbon stock estimates of the Ethiopian forests. Brown (1997) reported that carbon density of high forests of Ethiopia was estimated to be 101 tons, $ha^{-1.}$ Tsegaye Tadesse,( 2010) also indicated that higher carbon density values for high forests in Bale Mountains were close to 200 tons $ha^{-1}$. Adugna Feyissa *et*

*al.,* (2013) studied the mean values of carbon stock as high as 614.72 C $ha^{-1}$ in Egdu forest which is found in the central highlands of Ethiopia.Similarly Belay Melese *et al*., (2014) found that the mean carbon density of the Arba Minch Ground Water Forest was 583.27 C $ha^{-1}$ while Tamene Yohannes, (2016) also found 717C ton $ha^{-1}$ for Gergeda forest in western Ethiopia. Nesru Hassen, (2015) estimated the carbon stock of Gera Moist Evergreen Afromontane forest, in Oromia regional state and found, the mean total carbon density to be 440.71t $ha^{-1}$. Tullu Tolla (2011) estimated the mean total carbon stock of selected church forests in Addis to be 291.79 t $ha^{-1}$.

**2.6 Beekeeping potential of the area**

Beekeeping is considered as one of the oldest professions of humankind in Ethiopia. The country is considered as a potential beekeeping giant, having wide ecological zones ranging from deserts to rainforests and Afro alpine habitats.The country encompasses about 10 million bee colonies and it has the highest honeybee density in Africa (Hartmann, 2004). The country is the largest honey producer in Africa and the tenth in the world ( Amssalu *et al.,* 2004). Annually 53,000 metric tons of honey is produced in Ethiopia, 24% of the Africa production, representing a value of about 620 million Birr (CSA, 2015). The country is also the fourth largest beeswax producer after China,Mexico and Turkey and the estimated production of beeswax is 5000 tones (CSA, 2017).

The Moist Afromonatane Forests of Southwest Ethiopia have potential for organic honey production that would serves as major source of household income. In Kaffa zone where there is an intact natural forest, a dense honeybee population and huge water resources,

honey production is an important source of income for smallholder farmers in area as a result, large volume of honey is produced annually. In most parts of the study area honey production is the second important agricultural activity next to Ensete (*Ensete ventricosum)* and average of 20-30 beehives are owned by households (Nuru Adigaba and Desalegn Begna, 2001). Although the yields vary with the rainfall,in the area in good years, one hive can produce about 10-15 kg/hive from traditional beehives and 30-52kg /hive from improved beehives (Awararis Getachew, 2012). The honey is used both as a source of food and medicine for local communities and as well, as a source of revenue.

The unpublished honey production data from the Ministry of Agriculture Office of Kaffa Zone, the honey and beeswax production data for the past five years indicates that the average annual production of honey in Gesha-Sayilem forest is 1450.95 and 893.45 tons respectively which accounts for 2.2% of Ethiopian honey production (Table2). Bees wax is also one of the important bee products in the area and the annual beeswax production for Gesha and Sayilem districts are 115.95 and 66.52 tons respectively.

**Table 2.Annual honey production between 2004 and 2008**

| Year | Gesha | | Sayilem | |
|---|---|---|---|---|
| | Honey (tons) | Bees wax(tons) | Honey(tons) | Bees wax(tons) |
| 2004 | 1207.85 | 96 | 858.07 | 53.4 |
| 2005 | 1385.4 | 110.8 | 868.28 | 59.27s |
| 2006 | 1462.5 | 116.9 | 876.45 | 66.02s |
| 2007 | 1513 | 121.2 | 931.5 | 94.s4 |
| 2008 | 1686 | 134.88 | 895.95 | 79.65 |

**Source:** Livestock department of Kaffa Zone (Unpublished archived document)

### 2.6.1 Beekeeping and forest management in study area

Apiculture and forest management practice are deep rooted in Ethiopian rural life. Several studies have shown that forest management and beekeeping have had a long history of interdependence in the world because beekeeping dovetails naturally with agro-forestry for the functioning of the ecosystem, biodiversity conservation, honey production and crop pollination (Dereje Woltedji, 2004). Beekeepers in Gesha-Sayilem forest have a better understanding of the value of forest for honey production. For instance, the traditional beekeepers in the area have long established traditional forest management practices, which locally called "KOBO". KOBO is a block of forest land bounded and demarcated by big trees and or physical features like river and small streams and exclusively used for the purpose of traditional beekeeping (Dereje Tadesse *et al.*, 2008). In the "KOBO" system nobody is allowed to cut a single stick or hang hives in the forest which does not belong to them. In this system the forests are inherited from one generation to another over the centuries and it has a great conservation value for forests (Hartmann, 2004). From the forest resource management perspective forest beekeeping is the most important activity, that connects the farmers' economies with the preservation of the forest trees. For the last two decades timber extraction and expansion of coffee and tea plantations in the communal forests, in south west Ethiopia by foreign investors has resulted in severe destruction of the honey beeflora (Hartmann, 2002). Apiculture provides not only honey and beeswax but also contribute in the pollination of wild and cultivated crops. In Kaffa zone, forest coffee is the major crop pollinated by honeybees and contributes for maintaince of Coffee gene pool. Ulrika *et al.,* (2014) a survey of coffee pollinators under different shade-tree structures and found that the native

honeybee (*Apis mellifera*) the dominant visitor of coffee flowers and hence contributing in the pollination of coffee plants.

### 2.6.2 Honey

Honey is a natural sweet substance produced by honeybees from the nectar of flowers which they combine with other substances of their own and store in the honey comb (White, 1980). Honey is composed of a mixture of carbohydrate ( fructose and glucose) and also other minor substance like organic acid, amiono acids, proteins, vitamins and lipds (Gomes*et al.*, 2010). Honey is the one of the important nutritious food and has been consumed by humans since ancient times.

In Ethiopia, the use of honey as food and medicine has been part of the cultural medicine practice.The honey production system is dominated by traditional beekeeping as the result the production per hive also limited. According to (CSA, 2017) 53,000 tons of honey is produced per annum in Ethiopia and the country ranks first as a honey producer in Africa and ninth in the world. However the honey production is more traditional and the honey produced from this production system is poor in quality. Several authors have reported that the quality of honey is affected by moisture content due to harvesting of honey before it is ready, un suitable honey containers and blending of honey with table sugar (Gemchis Legesse, 2015). Thus studying the quality of honey from the forest will require attract the involvement of honey traders and processors.

### 2.6.3 Melissopalynological analysis of honey

Melissopalynology is the branch of palynology which deals with the study of the botanical and geographical origin of honey by analyzing honey sediments such as pollen, spores and other fungal spores contained in honey samples. Pollen grains of each plant

species, besides having its own genetic code of inheritance, have special structural patterns, which enable the differentiation of pollen grains of one species from another. In this regard pollen grains are essential tools in the analysis of honey and are used to indicate floral nectar sources utilized by honeybees to produce honey. Moreover the relative frequency of polle in honey is used to verify and label a honey sample with its botanical sources.This information has important commercial value because honey requires certain types of verification and it must be correctly labeled based on botanical origin before marketed.

### 2.6.4 Pollen

Honeybees depend on flowering plants for food in the form of nectar and pollen. Nectar and pollen are the primary attractants for honeybees in plants. During the anthesis of the flowers, there is extensive movement of honeybees between flowers of the same plant species to collect pollen and nectar.This in turn favors the successful cross-pollination of the plants (Faeger & Van der Pijl, 1979; Free,1970).

Pollen is commonly used as a source of food by honeybees for brood rearing. Several investigations have been carried out on the chemical composition and nutritive value of pollen. Pollen offers honeybees with their natural source of protein, which is required for larval development and also satisfies the dietary requirements for lipids, vitamins and minerals (Herbert, 1992). The protein content of pollen is an indication of pollen quality and fresh pollen is 100% effective in the development of the hypophrangeal glands of worker honeybees that secrete the royal jelly for the feeding of young larvae of honeybees (Pernal and Currie, 2001). The pollen load collection activities of honeybees from different plant species have been studied by Free (1970) who found that the

accessibility, amount and nutritious value of pollen varies among the plant species. The pollen load is a good indicator of the surrounding flowering plant species that are providing pollen for the honeybees. The pollen loads also reflect the availability of the dominant food resource for the honeybees as well as for the different pollinators in the ecosystem. In recent years there has been an ever-increasing interest in the use of bee collected pollen as part of the human diet. At present time pollen is used in two ways: as a "health food" as well as for the treatment of certain diseases. Pollen has been added to diets for domestic animals and laboratory insects resulting in improvements of health, growth and food conversion rates (Crane, 1990). Bee collected pollen is also used as pollen supplement or pollen substitutes for honeybees during dry periods with limited natural pollen sources. The composition of pollen loads can vary according to the region or season, indicating patterns and variations of the local flora.

# CHAPTER THREE

## 3. Materials and Methods

### 3.1Materials

The materials used for data collection includes measuring tape for measuring DBH, nylon rope for making quadrat, GPS (Global position system), spring balance for weighing herb, litter and branches and leaves for biomass determination. Moreover, plastic bags for collecting fresh samples of herb, litter, branches and leaves for oven drying. Plant pressing materials, compass, clinometer, core sampler, scissors, calipper and data recording notebook also used during the data collection. Laboratory equipments such as microscope, centrifuge, test tubes and pH meter were used for the laboratory analysis of honey and pollen samples.

### 3.2 Description of the Study Area

This study was conducted in the two districts of Gesha and Sayilem in Kaffa Zone of Southern Nations Nationalities Peoples Regional State (Fig.3).Gesha district is geographically located between, $7^0$ 35.36 N latitude and $35^o$, 4527 E longitude while Sayilem is located between, $7^0$ 49 57N latitudes and $35^0$49.32 E longitude. The southern part of Gesha district is bordered by Bita district in the west by the Sheka Zone, in the North by Illuababor Zone of Oromia Region and in the east by Gewata district. The total area coverage of the Gesha and Sayilem districts are 705.20 and 856.60 square kilometers respectively (Ayele Kebede, 2011). The topography of the landscape is undulating, with valleys and rolling, plateau and some with flat plains. The elevation of Gesha and Sayliem districts ranges from 1,600 to 3000m.

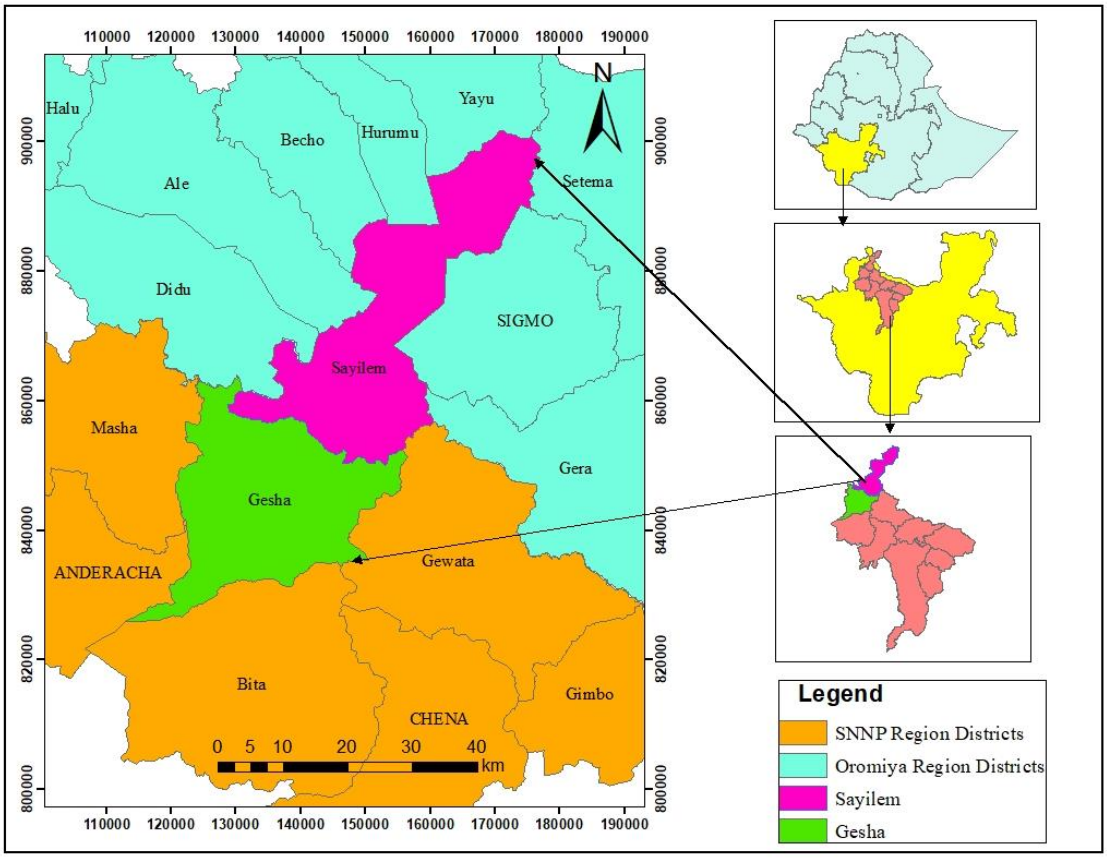



**Figure 3. Location Map of Geshaand Sayilem districts**

### 3.2.1 Climate

There are no weather stations in the study areas and hence the climate data were obtained from Masha town which are located at about 45km away from the study areas. According to the data of the past 20 years (1996-2016) obtained from the National Meteorological Services Agency (NMSA), the mean annual rainfall of study area is 2004mm and 1153mm respectively. The peak rainfall season is during May to August while the areas get lower rainshower between Decembers–February (Fig.4). The mean monthly temperature ranges between 9.5-29.5 $^{0}$C and the warmest months are during January, February and March.

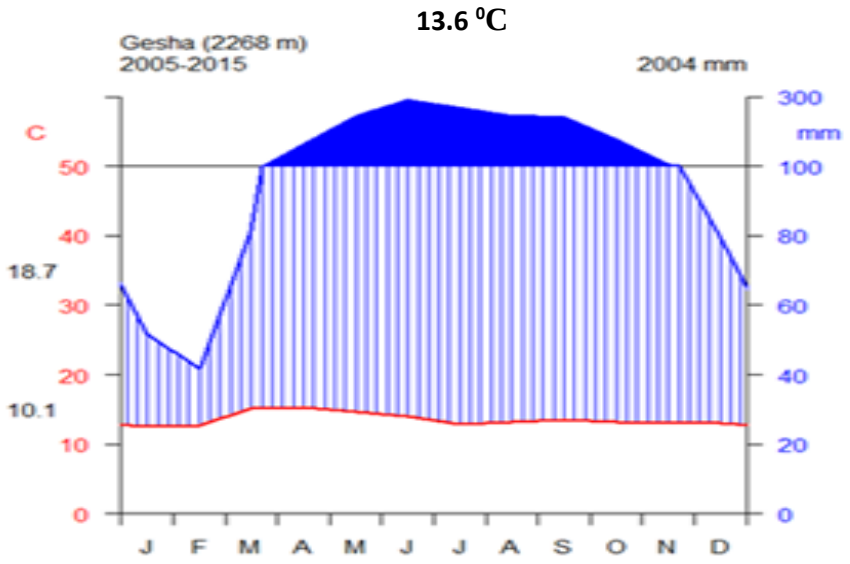



**Figure 4.The annual temperature and rainfall of the study area ( Source: NMSA,2018)**

### 3.2.2 Geology and soils

Ethiopia is belongs to a large geological structure in the Horn of Africa under the Afro-Arabian rift system (Davison and Rex, 1980). The geology of the study area is the Precambrian and the underlying basement rocks were formed from complex of metamorphic and igneous rocks (Mohr, 1971). The main volcanic rocks in the study area include rhyolites, trachytes, tuffs, agglomerates and basalts.These rocks form the substrates of the moist Afromontane forests (Friis,1992) including the Gesha and Sayilem districts.The common soil types in the study area are fertile soils of the volcanic origin of Precambrian and Metamorphic rock materials. According to FAO soil classification in southwest Ethiopia, the major soil groups are Nitisols, Acrisols, Cambisols, and Vertisols. Among these soil groups, Nitisols are agriculturally important and are the dominant soils types in the study area with high organic matter and nitrogen content.

### 3.2.3 Land use type

The study area is one of the main Ensete growing areas in the south and southwestern highlands (Westphal, 1975). According to Natural Resource Department of Kaffa

Zone.The land use types in the study districts, have been classified as cultivated land, wetlands, grazing land and forest lands. Among these, the forest land is the major land use types in Gesha and Sayilem districts accounting for 27.34 and 65.81 % respectively (Table3).The cultivation of the annual and perennial crops are also major activities in the area including root crops *(Solanum tubersum,Ipomoea batatas)* cereals (*Zea mays,Hordeum vulgare* and *Triticum aestivum)*),pulses (*Pisum sativum,Vicia faba* and *Phaseolus vulgaris*) and cash crops (*Coffea arabica* and *Aframomum corrorima)*. The area is the center of origin and diversity for Enset (*Ensete ventricosum*) a staple food crop grown in most parts of southern and southwestern Ethiopia.

**Table 3. Land use types in Gesha and Sayilem districts in Kaffa Zone**

| Land use types | Sayilem(Ha) | % | Gesha (Ha) | % |
|---|---|---|---|---|
| Annual crops | 6823 | 8.976 | 21804.630 | 30.85 |
| Perennial crops | 4,336 | 5.704 | 13282.370 | 18.79 |
| Forest land | 50029 | 65.816 | 19303.680 | 27.34 |
| Wetland | 6,829 | 8.984 | 3261.000 | 4.61 |
| Grazing land | 250 | 0.329 | 4548.200 | 6.44 |
| other lands | 7746 | 10.190 | 8468.895 | 11.98 |

**Source:** Natural Resource Department of Kaffa Zone **(**unpublished data**)**

### 3.2.4 Natural Vegetation

The vegetation of the study area is part of the Eastern Afromontane Biodiversity Hotspot which is one of the 34 worlds listed biodiversity hotspot zones (Conservation International, 2005). The forests in the study area belong to Moist Evergreen Afromontane forest (Friis *et al*.,2011), dominated by upper story species such as *Pouteria adolfi-friederici, Olea welwitschii, Cordia africana, Polyscias fulva, Croton macrostachyus, Albizia gummifera, Schefflera abyssinica, Ekebergia capensis* and *Prunus africana, a*nd *Arundinaria alpine* (Friis *et al.*,2011). These forests are found

between altitudinal ranges of 1,500 and 2,500 masl, with average annual temperatures of 18 to $20^0$C and an annual rainfall between 1,500 mm and 2,000 mm, sometimes even more (Friis, 1992).The other features that characterize these forests are the abundance of epiphytes, especially mosses and tree ferns (*Cyathea manniana*), Zewdu Yilema *etal.*(2010). The bamboo thickets are common in high areas beyond the 2300m. The image analysis from Arc GIS 2010, shows that the forest cover of Gesha-Sayilem forest cover is 860.78 $Km^2$ (86078 ha ). The forest is also a source of rivers and streams which feeds to the Gibe and Baro Akobo river systems. The major kebeles covered with dense forests in Gesha and Sayilem districts are indicated in (Fig.5).

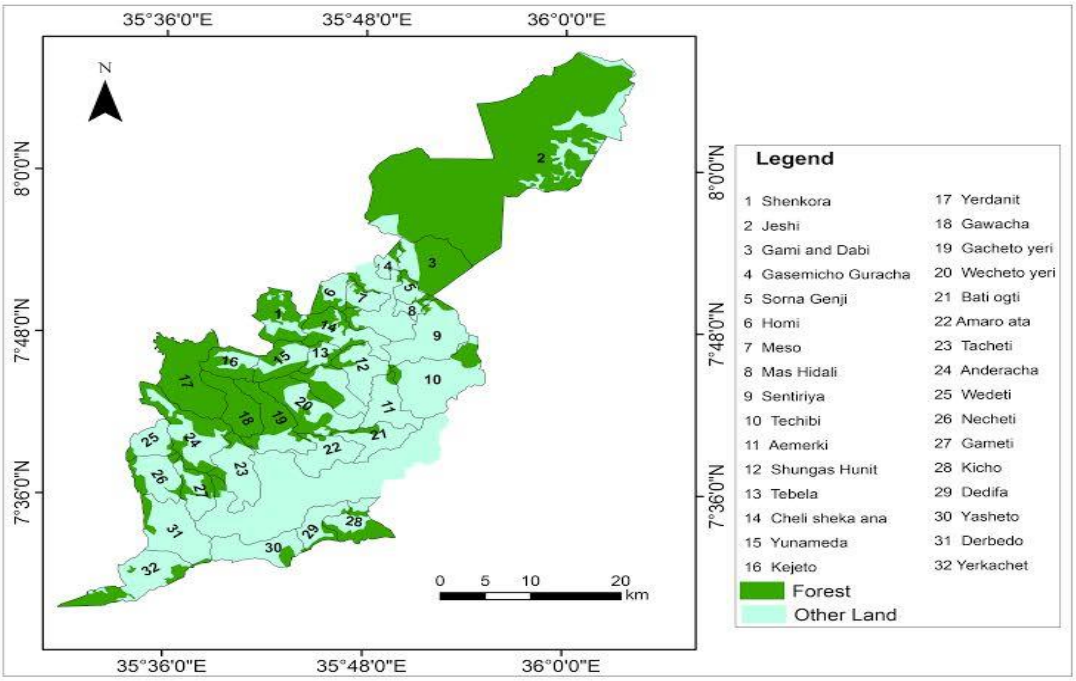



**Figure 5. Forest cover in Peasent Association of the districts**

### 3.2.5 Demography

The population in Gesha district is estimated to be 47,428, of which 23,028 are male and 24,400 female households and about 3,675 of this population are urban and 43,753 are rural dwellers (CSA,2013a). Similarly, Sayilem district has a population of 98,187

of which 47,833 are male and 50,354 female. From Sayilem population about 6,208 are urban and 91,979 rural dwellers (Table 4).The three largest ethnic groups reported in these districts are the Kafficho (88.67%), the Oromo (10.08%), and the Amhara (0.75%); all other ethnic groups make up 0.5% of the population. Kaffi nono is the major language spoken by the community followed by Afaan Oromoo.

**Table 4. Projected human population of Gesha and Sayilem districts are in the years 2014-2017.**

| District | **Gender** | | | **Urban Population** | | | **Rural Population** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Male** | **Female** | **Total** | **Male** | **Female** | **Total** | **Male** | **Female** | **Total** |
| Gesha | 23,028 | 24,400 | 47,428 | 1,699 | 1,976 | 3,675 | 21,329 | 22,424 | 43,753 |
| Sayilem | 47,833 | 50,354 | 98,187 | 3,156 | 3,052 | 6,208 | 44,677 | 47,302 | 91,979 |

### 3.2.6 Tourism

The area also has a good potential for eco-tourism, with its diverse natural landscape, attractive view of rainforest, wetlands, waterfalls, endemic birds, rivers and cultural festivals. In recent years, forests in Southwest Ethiopia are becoming destinations of many tourists interested in nature and to observe the coffee forests where coffee is said to be originated.

## 3.3 Vegetation data collection

### 3.3.1 Design of vegetation data collection

A reconnaissance survey was carried out between 25 of July to 05 of August, 2013 for the purpose of getting the overall impression of physiognomy of the forest, select sampling sites and accessibility. This helped to design the data collection methods prior to actual data collection. Because of the rugged and undulating nature of the topography of the area and its inaccessibility, collection of representative vegetaion data using

systematic sampling methods was not feasible and therefore stratified random sampling methods weres employed to collect vegetation data.This approach has been successfully used for large and heterogeneous forests with unknown patterns and is also efficient, in avoiding repeated sampling of vegetation (Kent and Coker, 1992 and Smartt, 1978). Based on this sampling procedure, the vegetation of the study area was stratified on the basis of altitudinal gradients. The altitudinal distribution of the area of the forest was extracted from Digital elevation (DEM) using ArcGIS version 2010. Contour lines were generated from the LiDAR Image Services, used to represent the elevations of a land surface above sea level.The altitude was divided into five strata at interval of 200m following the methods used by (Jarvis *et al*.,2008 cited in Desalegn Wana,2009) Fig.6.

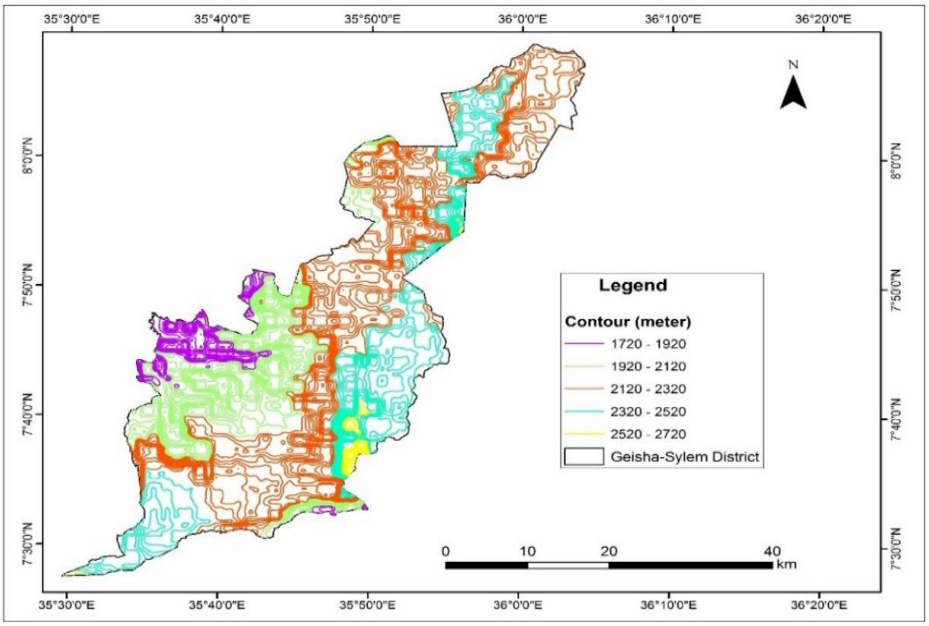



**Figure 6.Gesha-Sayilem Digital Elevation model**

The total number and distribution of sample plots for each stratum of the forest varied with the size of the strata. The number of plots was generateded randomly gerenated using the grid reference in Arc GIS and proportionally assigned to each strata depending on the size of the strata. In this sampling design more sample plots were taken, from the strata having large area coverage of the forest and low number of sample plots were taken when the size of the forest was small as shown (Table 5). Sampling was not done in Agricultural fields and plantations and a total of 90 plots were sampled for vegetation data and carbon stock determination.

**Table 5. Elevation intervals per sampling strata of the forest and no of sampling plots**

| **Strata** | **Elevation Interval(meter)** | **Area coverage of the forest strata ($Km^2$)** | **Proportion (%)** | **Number of plot** | **Proportion (%)** |
|---|---|---|---|---|---|
| 1 | 1720 – 1920 | 49.2 | 8.72 | 5 | 5.5 |
| 2 | 1920 – 2120 | 149.6 | 17.38 | 25 | 27.7 |
| 3 | 2120 – 2320 | 591.4 | 68.71 | 46 | 51.0 |
| 4 | 2320 – 2520 | 67.05 | 7.79 | 8 | 8.8 |
| 5 | 2520– 2720 | 3.35 | 0.385 | 6 | 6.6 |
| | **Total** | 860.78 | 100 | 90 | 100 |

### 3.3 Vegetation and environmental data collection

Vegetation and environmental data were collected from plot sizes of 625m$^2$ (25x25m) following the methods developed by Kent and Coker (1992). All the plant species encountered in each sample plots were recorded using vernacular names or sometimes botanical names were given depending on ease of identification in the field. Species occurring at 10m from the boundaries of the plots were recorded as present for floristic compilation and but were not included in subsequent data analysis as indicated by Tamrat Bekele, (1994) and the percentage cover of each species was visually estimated. The canopy cover values were converted into a 1-9 scales (Westhoff & van der Maarel, 1978 and Kent and Coker, 1992) as shown in (Table 6). Five representative subplots of 1 x1m (four at the four angles of the main plot and one at the center (Fig.**7**) were setup to assess herbs and soils samples (Singhal,1996). Seedling and sapling were collected from plot size of 3x3m. A total of 90 study plots were laid down in the entire study area. The location of each plot was recorded both in degree and UTM using a Geographical Positioning System (GPS). During data collection, growth forms of plants were listed. Voucher specimens were collected, pressed and dried and identified at the National Herbarium the identification of species was carried out using the account of Flora of Ethiopia and Eritrea (FEE) and by comparing them with authenticated specimens in the Herbarium.

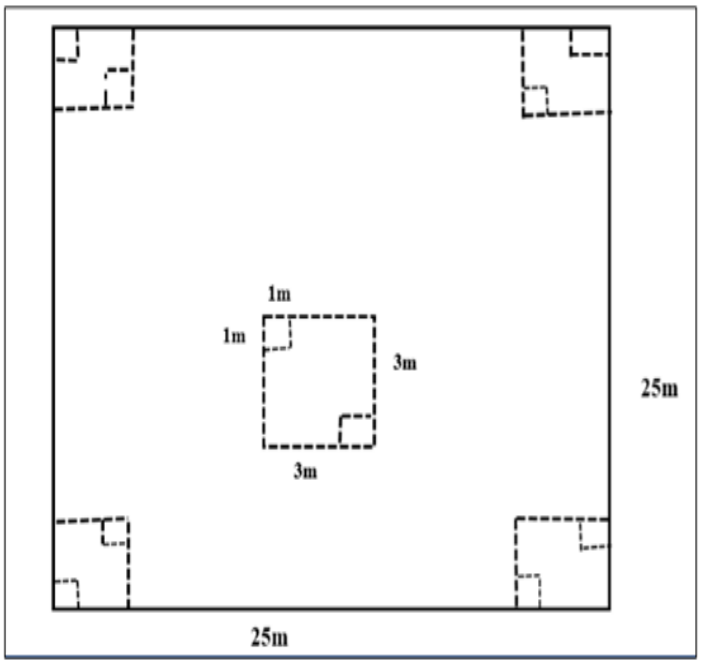



**Figure 7.The design of the sampling plots**

### Vegetation structure

The circumference of all woody species at breast height (1.3m) from the ground was measured for each tree and recorded in each sample plots. Later this was converted to diameter at breast height (DBH).Whenever trees and shrubs branched below the breast height each branch was measured as to separate tree. The total height of trees and shrubs were measured using a bamboo stick and sometimes visually estimated. Here woody plants with DBH <5cm and height > 1.5m were considered as sapling and DBH<5cm and height< 1.5m were recorded as seedling following previous studies by Tamrat Bekele, (1994) and Feyera Senbeta *et al.,(*2006).

### Environmental data on soil and disturbance

Environmental data on soil samples were taken at height of 0-15 and 15-30 cm (Brady, 1974). Soil samples were collected at four corners of the plot and one from the center

then were mixed to produce the composite soil samples. A total of 90 soil samples were collected and brought to soil Laboratory of the Ethiopian Institute of Agricultural Research (EIAR). The samples were air-dried, sieved with a mesh size of 2mm to remove coarse gravels, roots and debris prior to chemical and physical analysis.Soil analyses were conducted carried out based on standard procedures outlined in Allen,(1986).Analysis was conducted for pH,soil texture, phosphorus, available potassium, Organic matter, Electrical matter, Cation exchange capacity and total nitrogen. The pH was measured sing a pH meter 1:2:5 soil–distilled water suspensions.

The soil texture was determined using Hydrometer method with the categories sand, silt, and clay (expressed as % weight) while total nitrogen was determined using Kjeldhal method. Walkley and Black method of titration was used to determine organic matter content. Cation exchange capacity was determined using Aluminum Acetate method and available phosphorus was determined Olsen method. Slope and aspect of each plot were measured using Suunto Optical Reading Clinometer and compass, respectively. Values for aspect were coded following Zerihun Woldu *et al.*, 1989)N=0, NE= 1, E= 2, SE=3, S=4, SW=3.3, W= 2.5, NW= 1.3. The type and level of forest disturbance was determined based on Anderson and Curriers, (1973). The scores of the disturbance were determined using visible signs of, tree cutting such as the presence of fresh or old stumps, broken branches and debris, and the occurrence of trampled seedlings and presence of beehives, in each plot. These were placed and scaleof 0–5, with 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).

**Table 6. Braun-Blanquet cover scales**

| Values | Scales |
|---|---|
| 1 | Rare, generally one individual with less than 5% cover of the total plot area |
| 2 | Sporadic, with less than 5% cover the total plot area |
| 3 | Abundant, with less than 5% cover the total plat area |
| 4 | Very abundant, with less than 5% cover the total plot area |
| 5 | 5-12% covers the total plot area |
| 6 | 12-25% covers the total plot area |
| 7 | 25-50% covers of the total plot area |
| 8 | 50-75 covers of the total plot area |
| 9 | 75-100% covers of the total plot area |

**Source:**(Van der Maarel, 1979)

### 3.4 Vegetation data analysis

#### 3.4.1 Cluster analysis

Cluster analysis was performed to classify the vegetation data into community types. Using (R packages 2014).The entire data set was subjected to agglomerative Hierarchical cluster analysis using Similarity Ratio (S.R) and Ward's linkage method was applied: The difference in floristic compostion among the plant communities was tested using the non-parametric Multi-Response Permutation Procedure (MRPP). Plant community types were further refined in a Synoptic table which is a product of the species frequency and average cover abundance value. The community types were named based on the tree and shrub with high synoptic value. Finally, the community types were named after two dominant species.The indicator species analysis was performed using R

software packages version 3.4.2 and the indicator species identified were unique to each community types.The analysis of indicator value with significant indicator value ($p<0.05$) are considered as indicator species.

### 3.4.2 Ordination

Preliminary analysis of vegetation data using Detrended corresponadnce analysis (DCA) can help to determine the appropriate methods to use in 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 preferred (Ter Braak, 1995). In this study the longest gradient for Moist evergreen Afromontane data set was **5.74** indicating the data was heterogeneous. Thus, Canonical correspondence analysis (CCA) was found appropriate for this analysis since it incorporates the correlation between floristic and environmental data within the ordination axis (ter Braak and Prentice, 1988). The input to CCA consists of not only a data matrix of biplots but also a second data matrix of environmental factors. Thus 161 plant species and thirteen environmental variables from 90 plots were used for the analysis. Before running CCA ordination, thirteen environmental variables: altitude, slope, aspect, pH, sand clay, silt, electrical conductivity, CEC, total nitrogen, available phosphorus, organic carbon and potassium were tested using a Monte-carlo test to see the significance of each environmental variable prior to analysis. Pearson's product moment correlation coefficient was calculated to evaluate the relationship between the environmental variables.

A data matrix has consisted of 12 environmental factors and 90 quadrats were used. Statistically significant environmental factors were tested using the Monte Carlo

permutation test (ter Braak and Smilauer, 1998). Permutation tests were run with 99 permutations.

### 3.4.3 Floristic Richness and Diversity

As indicated by Magurran (2004), most methods for measuring diversity consist of two components of diversity.These are the species richness and the evenness of species within the sample or community.These may be examined separately or combined into some form of an index. These indices are the Simpson and Shanon-Wiener index. The floristic richness, diversity and evenness indices of the plant communities were calculated using R Package 3.4.2 (Zerhiun Woldu 2017).The Simpson index was calculated using the following formula: $\textbf{Simpson Index}(D) = \frac{1}{\sum_{i=1}^{S} \mathrm{pi} * \mathrm{pi}}$

Where pi is the proportion of the number of individuals or the abundance of the $i^{th}$ species and **S is** the number of species.

**The Shannon-Wiener index**

Shannon-Wiener index is the most commonly used diversity index and used to describe species diversity of different plant community types. A higher species diversity is generally are the reflection of a complex and stable community hence indicating the stable ecosystem. The Shannon-Wiener Index was calculated using the following formula.

$$\text{Shannon Index } (\boldsymbol{H'}) = \sum_{\boldsymbol{i=1}}^{\boldsymbol{s}} \boldsymbol{PilnPi}$$

Where **s** is the number of species, pi is the proportion of individuals or the abundance of the $i^{th}$ species, and ln is the natural log, Σ is the sum of the calculations, and **s** is the number of species.

**Evenness**

The evenness of the species within the plant community was calculated to indicate, how the cover of the plant species within a plot are distributed. Evenness values range from 0 to 1 (Kent and Coker, 1992). An evenness value of 1 indicates that plant cover within a plot is evenly shared among the species present. The higher the value of the evenness index, the more even the species in their distribution within the given area. Equitability (evenness) is calculated using the following formula:

$$J = \frac{H'}{H'max} = \frac{\sum_{i=1}^{s} \text{PilnPi}}{\text{lns}}$$

Where; H'= the value of the Shannon-Weiner diversity index, S= number of species in the community, Pi= the proportion of individuals of the $i^{th}$ species expressed as proportion of total cover, ln= log $base_n$, J=Evenness of species in sampling area, H'max= Maximum value of diversity.

### 3.4.4 Floristic similarity analysis

Plant communities can differ in species composition, richness and relative abundance of species (evenness).To estimate the similarity between the communities a number of different similarity indices were applied. Similarity coefficients measure the degree to which the species composition of quadrats or samples are alike (Kent and Coker, 1992). Dissimilarity coefficients assess the degree to which two quadrats or samples differ in composition.The most commonly used similarity coefficients is the Jaccard and Sorensen similarity coefficients which are generally applied to qualitative data. The Jaccard similarity coefficient was, developed to compare regional floras (Jaccard, 1912). Sorensen similarity (**Ss**) coefficient is a widely used index and it gives more weight to the species that are common to the samples rather than to those that only occur in either

sample (Kent and Coker, 1992). The similarity coefficient value ranges from 0 (complete dissimilarity) to 1 (total similarity). In this comparison, β-diversity between community types was also computed using the formula **β-diversity**, Where **a** is the number shared species between two sites, and **b** and **c** are the numbers of species unique to each site. High species turnover would indicate high β-diversity or a low level of similarity. Thus, the floristic similarity of the community types in the present study was assessed using the Sorenson's coefficient of similarity using statistical program in R soft ware.

The formula is:for Sorense similarity $Ss = \frac{2a}{(2a+b+c)}$

Where

a = the number of species common to both community types and

b =the number of species in one of the community to be compared

c = species present in the other site

### 3.4.5 Structural data analysis

The woody plant species recorded from sample plots were used in the analysis of vegetation structure. The frequency, density, diameter at breast height (DBH) and important value index (IVI) were used to describe the vegetation of the area.The diameter at breast height was classified into seven DBH Classes following the classification scheme used by various authors (Tamrat Bekele, 1994); (Kumelachew Yeshitela *et al.*,2002) and Feyera Senbeta, 2006. Accordingly the seven DBH classes are **1**) <20cm;**2**) 20.1-40cm;**3**)40.01-60cm;**4**)60.01-80cm;**5**)80.01-100cm;**6**)100.01-120cm;**7**) >120cm.The percentage number of individuals in each DBH class was calculated to assess and compare the structural patterns of the forest. Similarly, a tree height structure of all woody plants was characterized using classes of **1**)≤5m;**2**)5.01-10m;**3**)10.01-

15.4m;**4**)15.01-20m;**5**)20.01-25m;**6**)25.01-30m, **7**) >30m and percentage height classes for the forest was calculated. Apart from describing DBH and height other vegetation attributes were computed and summarized below:

**Frequency (F)** is The of probability of finding a species in a given sample area and it is usually expressed as a percentage and reflects the pattern of distribution over an area. It is expressed as the percentage of occurrence of a species in quadrat in which the species occurs divided by the total number of quadrat examined (Mueller-Dombois and Ellenberg 1974).

$$\mathbf{F} = \frac{\text{Number of plots in which a species occur}}{\text{Total plot examined}} X100$$

Where **F** is expressed the percentage for each species and then sorted in increasing order and grouped into five Classes: **1**)0-20;**2**) 21-40; **3**)41-60;**4**) 61-80**; 5**) 81-100 which is expressed in percentage.

Density (D) - is a measure of the number of plant individuals per unit area. It is calculated from the count of all individual from the study plots in hectare basis (Mueller-Dombois and Ellenberg,1974)

$$\text{D} = \frac{\text{Total no. of individuals of a species found}}{\text{Total area examined}} X100$$

Basal Area (BA**):**The basal area is the area outline near the surface for trees and shrubs and usually used for tree volume estimations (Mueller-Dombois &Ellenberg 1974). The analysis of the species dominance was made using basal area measurements.

$$BA = \frac{\pi d^2}{4}$$

Where: BA= Basal area in $m^2$ per hectare
d= diameter at breast height in meter
$\pi$= 3.14

**Importance Value Index (IVI)**

The important value is used to compare species and depicts the sociological structure of a population and its totality in the community. It often reflects the extent of the dominance, occurrence and abundance of a given species in relation to other associated species in an area (Kent and Coker, 1992).The importance Value Index (IVI) was calculated from the sum of relative Dominance, relative frequency and relative density (RDO + RF+ RD), Where RDO is the Relative Dominance RF is the Relative frequency. The results of IVI of woody species were grouped into five IVI classes for conservation priority

and RD is the Relative density. $\mathrm{RF} = \frac{\text{The frequency of the species}}{\text{Frequency of all species}} * 100$

$$\mathrm{RD} = \frac{\text{The number of indiviuals of the species}}{\text{Number of indiviuals of all species}} * 100$$

$$\mathrm{RDO} = \frac{\text{The total basal area of the species}}{\text{Total basal area of all species}} * 100$$

## 3.5 Carbon stock estimation

### 3.5.1 Stratification and sampling design

IPCC (2003),indicate that stratification is essential for forest carbon estimation since the variation within the strata would be lower than for the population as a whole. In order to increase precision and accuracy of measuring carbon stock, the area should be divided into substrata (Pearson, 2005). For this purpose,altitudinal stratification was taken as criterion to divide the study area into different strata in order to get homogenous sampling units. As described by MacDicken, (1997), elevation-based stratification provides more precise estimates for carbon inventory. Based on stratification principles,

therefore the study area was divided into five elevational strata and the elevation distribution was extracted from the Digital elevation model (DEM) as indicated in Figure 6 starting from the lower to the highest altitude at intervals of 200m. A nested plot design was used for the sampling of various carbon pools from different strata. It is an appropriate design for the inventory of natural forest trees and shrubs where there is high variability in tree size classes' distribution and other structural attributes MacDicken, (1997). In this study the same nested plot design used for vegetation data collection,also applied for carbon stock assessment (Adugna Feyissa, 2012). Based on this procedure a tree whose diameter were greater than 50 cm DBH, were measured 35x35m plots, whereas those with DBH between 20-50cm were measured in 25 X 25m subplots and and small sized trees between 5-20cm DBH were measured in7x7m subplot (Pearson *etal.*,2005) Fig.8.

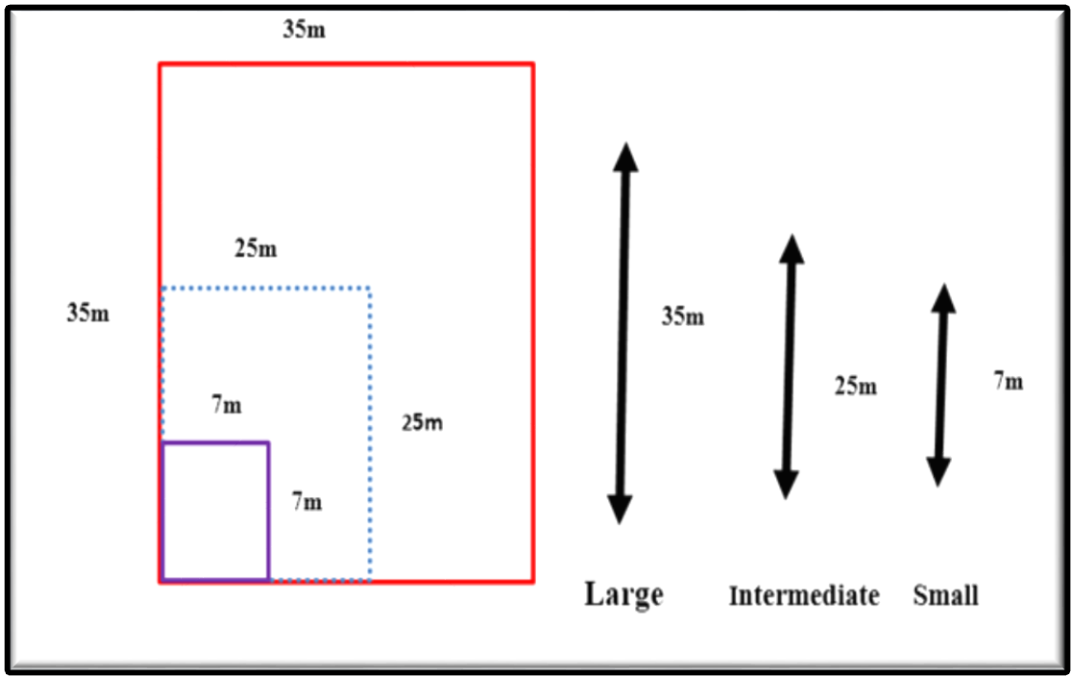



**Figure 8. A nested plot where tree and shrubs with different sizes were measured in squaredplots.**

### 3.5.2 Carbon Stock Measurement

For the sampling of carbon stock, Standard Operating Procedures (SOP) for terrestrial carbon measurement developed by Sarah *et al.*, (2012); Pearson *et al*., (2005) were followed. Carbon measurement focus was placed on above-ground tree biomass, below-ground biomass, dead wood, litter, and soil organic carbon and detailed methods are explained under the following sub-headings.

#### 3.5.2.1 Above-Ground Biomass (AGB)

The DBH and height of all the trees and shrubs encountered in the sample plots were measured. DBH is an important parameter used for estimating tree biomass and carbon stock using allometric equation (Brown *et al*., 2004). In this study DBH was measured for woody plants species encountered in the sample plots with a DBH >5cm.Those DBH below 5cm were not measured but destructively sampled for sapling and seedling biomass estimation.The measurements of DBH and height were made using a measuring tape starting from the edge and working inwards and each trees or shrub tagged to prevent measuring it twice.A tree with multiple stems diameter at breast height, were treated as a single individual (Pearson *et al*., 2005).

To estimate above ground tree biomass, selection of an appropriate allometric equation is crucial to increase the precision of the carbon stock estimation. There are a few allometric equations that havebeen developed for Africa but most of the carbon stock assessments studies have used general allometric equations despite the high degree of variability in size and growth conditions of species (Henry *et al.,* 2011). In this study the model developed by Chave *et al.,* (2014) was used to estimate the AGB due to its accuracy and the similarity of climatic zone of the study area. The model also used tree parameters such as DBH, height, and specific wood density by giving more precise

results than other allometric equations, which use DBH only (Djomo *et al*., 2010).Thus, the equation developed by Chave *et al*., (2014) was used to calculate the aboveground biomass and is presented below.

$AGBest = 0.0559 * \acute{\rho} D^2 H$

Where,

AGB= Above-ground biomass (kg); $\acute{\rho}$ = wood specific gravity ($gcm^{-3}$);

D= tree diameter at breast height (cm); and H = tree height (m).

Wood specific gravity (here defined as the oven-dry wood mass divided by its green volume and denoted as $\acute{\rho}$ is an important predictor of AGB. In this study wood specific gravity was obtained from different wood density databases. The wood density data for Ethiopian species was obtained from, the Ministry of the environment and climate change (https://www.google.com) as indicated in Annex 5. In cases where the wood density for a species was not listed, an average default value of 0.5 was used, as recommended by Chave *et al*., (2005) for trees from tropical forests. The sum of all plant species' biomass was calculated for each sample plot and the biomass density was expressed in $kg/m^2$) and finally converted to tons per hectare. The biomass stock density was converted to carbon stock densities after multiplication with the IPCC, (2006) default carbon fraction of 0.47.

**3.5.2.2 Estimating Below-Ground Biomass (BGB)**

Below ground biomass of woody plant species can be measured from the relationship of its above-ground biomass (Cairns *et al.*,1997). According to Brown, (1997) in tropical rainforests below ground biomass is estimated to be 20% of the above ground biomass.

Thus, below ground biomass (BGB) was estimated from AGB using the relationship derived for the tropics.

$$BGB = AGB \times 0.2$$

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

### 3.5.2.3 Estimating litter Biomass

The litter layer is refers to all dead organic surface material on top of the mineral soil (Pearson, 2007; MacDicken,1997). The litter biomass was estimated using a simple harvesting technique (IPCC, 2003). For the sampling of litter biomass, rectangular subplots measuring 1x1m ($1m^2$) were established at the center of each plot. Then samples were collected at five spots four from a corner of the plots and one from the center. The fresh weight of samples was weighed and recorded using a spring balance. From this fresh sample a well-mixed sub-sample of 100gm was brought to the laboratory for oven drying for 48 hours at 65°C using dry ashing method as suggested by Allen *et al.*, (1986).

$$\mathbf{LB} = \frac{\text{W field}}{A} X \frac{\text{W sub\_sample (dry)}}{\text{Wsub}_{\text{\_sample}}(\text{Fresh})} X \frac{1}{10000}$$

Where: LB = Litter biomass ($ha^{-1}$)

**W field** = weight of wet field sample of litter sampled within an area of size 1 $m^2$ (Kg)

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

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

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

For carbon content determination of litter then oven-dried samples were taken in pre-weighed crucibles. The samples were ignited at 550°C for three hours in the furnace. After cooling,the crucibles with ash were weighed and percentage of organic carbon was calculated.

**Where: LB** = Litter biomass (t $ha^{-1}$);and Carbon stock in litter biomass was then determined using the following formula:

**CL** = LB × % C)

Where: CL = total carbon stocks in the litter in t $ha^{-1}$, % C= the carbon content in forest litter was calculated by multiplying it with the carbon fraction analyzed in the laboratory.

### 3.5. 2.4 Herbaceous and shrub biomass (HSB)

Herbs and shrubs were collected within plots of 2x2m and 5x5m respectively by clipping all the vegetation in sample plots and weighed in the field using a spring balance (Pearson, 2005). A well-mixed subsample of 150 gm was taken and weighed in the field and then oven dried in the laboratory until a constant mass is achieved for the determination of oven dry biomass of the samples. The carbon fraction was determined by taking the oven-dried samples in pre-weighed crucibles. The samples were ignited at 550$^{o}$C for one hour in the muffle furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated.

### 3.5.2.5 Measuring dead wood

Dead wood is a significant component of above ground biomass. These components of dead wood can be measured in different ways. The DBH of the standing dead trees with leaves and branches were measured as live trees using the allometric equation, when a tree has no branches and just the bole, volume was estimated using truncated cone formula:

Volume Bole = $1/_3 \pi h (r1^2 + r_2^2 + r_{1X}r_2)$ as developed by Pearson, (2005)

Where: h= the height in meters $r_1$= the radius at the DBH of the tree, r2= the radius at the top of the tree.

### 3.5.2.5.1 Measuring dead on the ground

Dead wood lying on the ground was measured using the line-intersect method (Brown, 1974). To measure dead wood a subplot size of 10mx10m was laid within the main plot and along the length of the lines intersecting a piece of down dead wood diameter was measured. when measuring of the dead wood, more than 50% of the log was required to be above the soil surface, so that the sample line crosses through at least 50% of the diameter of the piece wood (Fig 9).

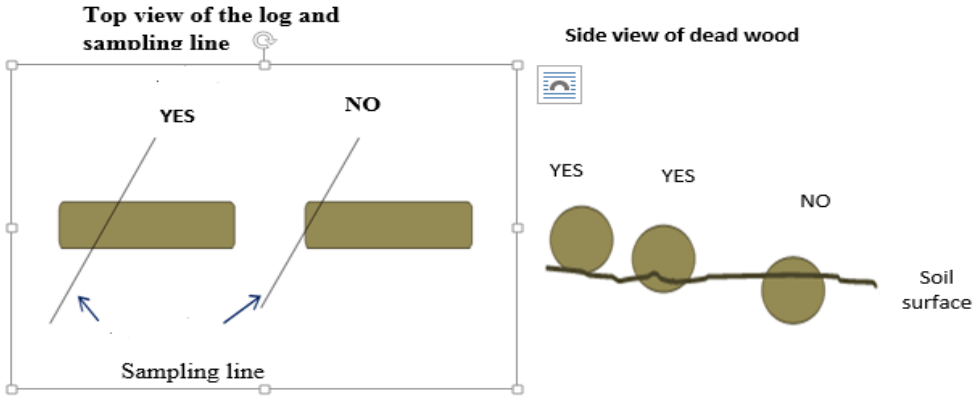



**Figure 9. Schematic diagram of which dead wood should be measured** (Source: Sarah *et al*., 2012)

### 3.5.2.5.2 Measurements dead wood density

The three density classes (sound, intermediate and rotten wood) were determined in the field using the machete test (Brown *et al.*,1989). This test involves striking of the wood with a machete. If the blade bounces off and produces sound it is considered to be sound, if it enters slightly it was intermediate, and if it causes the wood to fall apart into pieces it is rotten (MacDicken, 1997; IPCC, 2003). Based on this test, samples of dead wood were collected from each density classes and brought to the laboratory for their volume to be measuredt using the floatation method (Maniatis *et al.*,2011).The wood was oven dried

for 48 hours at  of temperature of 105 $^{o}$C. For each density class the volume was calculated using the formula developed by Brown *et al*., (2004).

$$\textbf{Volume} = \pi^2 L \left[ \frac{d_1^{2} + d^2_{2*} d^2_n}{8} \right]`$$

Where $d_1$, $d_2$, $d_n$ etc = diameters of intersecting pieces of dead

Wood in cm a nd L = length of the transect line in m.

Biomass of laying dead wood (t/ha) = volume x density

### 3.5.3 Measuring soil organic carbon

The soil samples were collected from five sub-plots in the same way as litter collection`A sample  was collected on two layers 0-15 and 15-30 cm. Five equal weights of  the sample from each subplot were taken and mixed homogeneously and a composite subsample of 100 gm from each plot was taken to the laboratory for soil analysis.The Walkley-Black method was used to determine SOC after it had been grounded and passed through a 2mm sieve. For the bulk density determination of the soil a core, sampler was used to collect soil samples and bulk density was calculated from the oven dry weight of soil after drying at $105^0$C and divided by volume of  the core sampler.The soil organic carbon was computed using the formula

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 (30 cm), and % C = Carbon concentration (%).

### 3.5.4 Data collection for biomass model development

#### 3.5.4.1 Tree selection and sampling techniques

Five dominants trees of *Apodytes dimidata,Ilex mitis, Sapium ellipticum*and shrubs (*Galiniera saxifraga* and *Vernonia auriculifera*) were selected using preferential sampling techniques in order to include indiviuals from different population needed for each targeted species. In order to minimize the sampling error , DBH distributions were taken into account during tree selection. Accordingly, the trees were classified into five DBH classes with each class having six individuals ranging from 10-20 cm; 20.1-30 cm; 30.1-40 cm; 40.1-50 cm and greater than 50cm. A total of 150 individuals, 30 from each of the targeted species were sampled.

#### 3.5.4.2 Field measurement

The study forest is part of the UNESCO Kaffa Coffee Biosphere Reserve and thus felling of trees using destructive sampling was prohibited.Thus, the semi-destructive sampling method that requires no felling of trees was used for biomass estimation following Picard *et al*., (2012 and David *et al.*, (1997).The measurement of each section of a tree including trunk, big branches and small branches (a branch comprising twigs and leaves) were done by climbing to a point within reach of the apex of the tree.

The biomass of trunk and large branches were obtained by measuring the diameter and its length. A section of 2m in length interval between trunk was used to measure diameter variation.Then biomass of the trunk and large branches was estimated from the measurement of volume and mean wood density ($\dot{\rho}$ in $gcm^{-3}$) with assumption that sections cut were considered to be cylindrical and their density considered to be the same in all compartments of the trees ( Picard *et al.* 2012). For the determination of biomass of small branches consisting of twigs and leaves, only basal diameters were

measured. For this purpose, three branches of 90 varying diameters of indiviluals of each tree were trimmed (removed)and brought to the ground and the basal diameter and the total weight of the fresh wood and leaves weight were recorded using spring weighing scales of 5 kg capacity.Then the three replicates of trimmed wood and leaves were taken randomly and placed in plastic bag and brought to the laboratory for oven drying.

**3.5.4.3 Laboratorymeasurements**

The samples of leaves and wood were taken in three replications and kept in sealed plastic bags, and then brought to the laboratory to determine their moisture content. Dry weights of the samples were obtained by drying the samples at a temperature of $105^0$C until a constant weight was achieved ( Ketterings *et al*., 2001).The total dry weight of each AGB component was calculated using the ratio of the dry and fresh weight of the sub-samples,multiplied by the total fresh weight of the respective components of trimmed branches. To determine the wood density, samples were taken from the lower, middle and upper parts of the branches and kept for 48 hours in drying oven. The volume of each sample was determined from the volume of the water displaced when submerged (Fig 10). The wood density was calculated as dry oven weight divided by saturated volume.

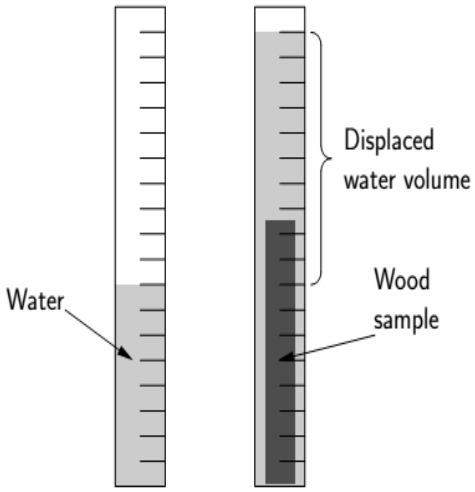



**Figure 10.Measuring wood volume by water displacement**

### 3.5.4.4 Calculation of above ground biomass of trees

The dry weight of the stem and big branches was calculated by multiplying the fresh volume of each section by wood density.The total dry weight of a tree was obtained by summing the dry weight of the stem, big branches and dry weight of, small branches ( twigs and leaves trimmed ).

Bdryweight = B trimmed dry biomass + Buntrimmed dry biomass of the tree

### 3.5.4.6 Calculation of trimmed biomass of small branches

The moisture content of **B**aliquot$_{\textbf{fresh wood}}$, $\mathbf{B}_{\textbf{aliquot fresh leaves}}$ and its dry biomass of wood were measured by the following equations.

$$\mathbf{X\ wood} = \frac{\boldsymbol{B\ alliquot\ dry\ wood}}{\boldsymbol{B\ aliquot}\ \textbf{fresh wood}} \ldots$$

Where is moisture content of the wood, and where **B**aliquot **dry wood**, is the oven-dried wood biomass of the aliquot in the sample of *i* and where **B**aliquot **fresh wood**, is the fresh wood biomass of the branch aliquot in the sample of *i*.Similarly, the moisture

content of the leaves was calculated from the fresh biomass $B_{\text{fresh leaf aliquot}}$ of the leaf aliquot and its dry biomass $B_{\text{dry leaf aliquot}}$ as follow.

$$\text{X leaf} = \frac{\text{Baliquot dry leaf}}{\text{Baliquot fresh leaf}} \quad 7)$$

Trimmed dry biomass of wood and was then determined as

$$\mathbf{B}\text{trimmed dry} = \mathbf{B\ trimmed\ fresh\ wood} \ast \mathbf{Xwood} + \text{B}_{\mathbf{\text{trimmed fresh leaf}}} \ast \text{X}\ \mathbf{leaf}$$

Where, $B_{\text{trimmed fresh wood}}$ is the fresh biomass of wood stripped from the trimmed branches and $B_{\text{trimmed fresh leaf}}$ is the fresh biomass of the leaf in trimmed small branches.

**Calculating the stem and big branches**

The biomass of the trunk and the large branches were estimated from measurements of volumes (V in $cm^3$) and mean wood density (in g $cm^{-3}$).The volume of each section was obtained by measuring its diameter (or its circumference) and its length. On the other hand the small branches 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 was estimated from the statstical model relationship between basal diameter and dry biomass of trimmed small branches.This model is established by following the same procedure as for the development of an allometric model, using a Power type $Y=a\ x^{b}$ equations which expressed as $B$ dry branch = $a+bD^{c}$ Where, a, b and c are model parameters and D branch basal diameter.

**B**untrimmed dry = Bdry section of trunk and big branch+ Buntrimmed dry small branch.

The volume of the trunk and the large branches were considered to be a cylinder of volume (Smalian's formula) for determination of volume trees.

$$\mathbf{Vi}=\frac{\pi\ Li\ (D^2_{1i}+D^2_{2li})}{8}$$

Where Vi is the volume of section *i*, its length, $\mathbf{D^2_{1i}}$**and** $\mathbf{D_{2i}}$ are the diameters of the two extremities of section *i*.

### 3.5.4.7 The sampling of shrubs for biomass determination

For the determination of the biomass of shrubs (*Galiniera saxifraga* and *Vernonia auriculifera)* DBH was measured and destructively sampled. A total of 60 individual plants were taken for biomass determination following methods by Maraseni *et al*., (2005) and Picard *et al*., (2012). The fresh weight of each stem, branches and leaves were measured on the site using a spring balance. To determine the dry matter content of the woods and leaves all branches from each stem were taken from thickest to the thinnest to make a composite sample and placed in sealed in plastic bags and transported to the laboratory.They were then oven-dried at $70^0$ C for 24 h.The carbon stock of a single tree/shrub was obtained by multiplying the respective above ground biomass by conversion factor or a default value of 0.5.

### 3.5.5 Data analysis of Carbon

### 3.5.5,1 Estimation of total Carbon Stock Density

$$Cdensity = C_{AGB} + C_{BGB} + C_L + SOC + C_H + C_{SH} \quad \text{(Equ.10)}$$

Where: Cdensity = Carbon density for all pools ($t\ C\ ha^{-1}$)

$C_{AGB}$= Carbon stock in above ground biomass ($t\ C\ ha^{-1}$)

$C_{BGB}$= Carbon stock in below ground biomass ($t\ C\ ha^{-1}$)

$C_L$=Carbon in litter biomass ($t\ C\ ha^{-1}$)

$C_H$= Carbon in herb biomass ($t\ C\ ha^{-1}$)

$C_{SH}$ = Carbon in shrub biomass (t C $ha^{-1}$)

SOC= soil organic carbon (ton/ha).

The unit of SOC and biomass carbon measurements were expressed in metric tons per hectare.The total carbon stock was then converted to tons of $CO_2$ equivalent by multiplying it 3.67 to recognize the climate change mitigation potential of the study forest as indicated by (Pearson *et al*., 2007).

**3.5.5.2 Data analysis using allometric equation**

Relationships between basal diameters and measured dry weight of trimmed branches including twigs and leaves were computed using linear regression models to obtain the model estimates for determing the biomass of the small branches including twigs and leaves. Before developing the allometric equation using the regression model, the assumptions of linear regression model was checked by observing the normal distribution of residuals on P-P plots. Because of the heteroscedasticity nature of biomass data, the data were transformed using a natural logarithm.The transformation of the data equalized the variance over the entire range of biomass values. Furthermore, Pearson correlation analysis was carried out between the response variable (Dry weight of the biomass) and the independent variables to examine whether there was the linear relationship between dependent and independent variables (Table 34). In order to identify the multicollinearity associated with log-transformed models having multiple independent variables, a collinearity diagnostic test was carried out using a variance inflation factor (Vahedi *et al.*,2014).The variance inflation factor (VIF) measures the severity of multicollinearity in the regression model. A value greater than 10 (VIF > 10) is an indication of potential

multicollinearity among independent variables. Thus, according to the smaller variance inflation factor (VIF < 10) the predictive model can be valid and applicable.

**Model selection**

Different combinations of predictor variables were tested using multiple regression models in R software and seven possible models were tested for each species (Picard *et al*., 2012). A total of 35 possible models were evaluated for five study species (Appendix 17). Eight candidate models were selected and evaluated for different tree and shrub compartments (Table7). Model selection was based on slope the coefficient of the regression,standard errors, Akaike Information Criterion (AIC), and Coefficients of determination ($R^2$).

**Table 7. Biomass models evaluated for the different tree and shrub compartments**

| Model | equation |
|---|---|
| 1 | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 log(Height) + \beta_3 \log(Height) + \varepsilon$ |
| 2 | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 \log(WD) + \varepsilon$ |
| 3 | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 \log(\text{Height}) + \beta_{3\ \log(WD))+\varepsilon}$ |
| 4 | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(\text{Height})) + \varepsilon$ |
| 5 | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_1 \log(CRA) + \varepsilon$ |
| 6 | $\text{Log}(AGB) = \beta_0 + log\beta_1 DBH + \varepsilon$ |
| 7 | $\text{Log(AGB)} = \beta_0 + \beta_2 \log(\text{DBH}) + \beta_3 \log(\text{Height}) + \beta 4 \log(\text{CRA})$ |
| 8 | $\log(AGB) = \beta_1 \log(Height) + \varepsilon$ |

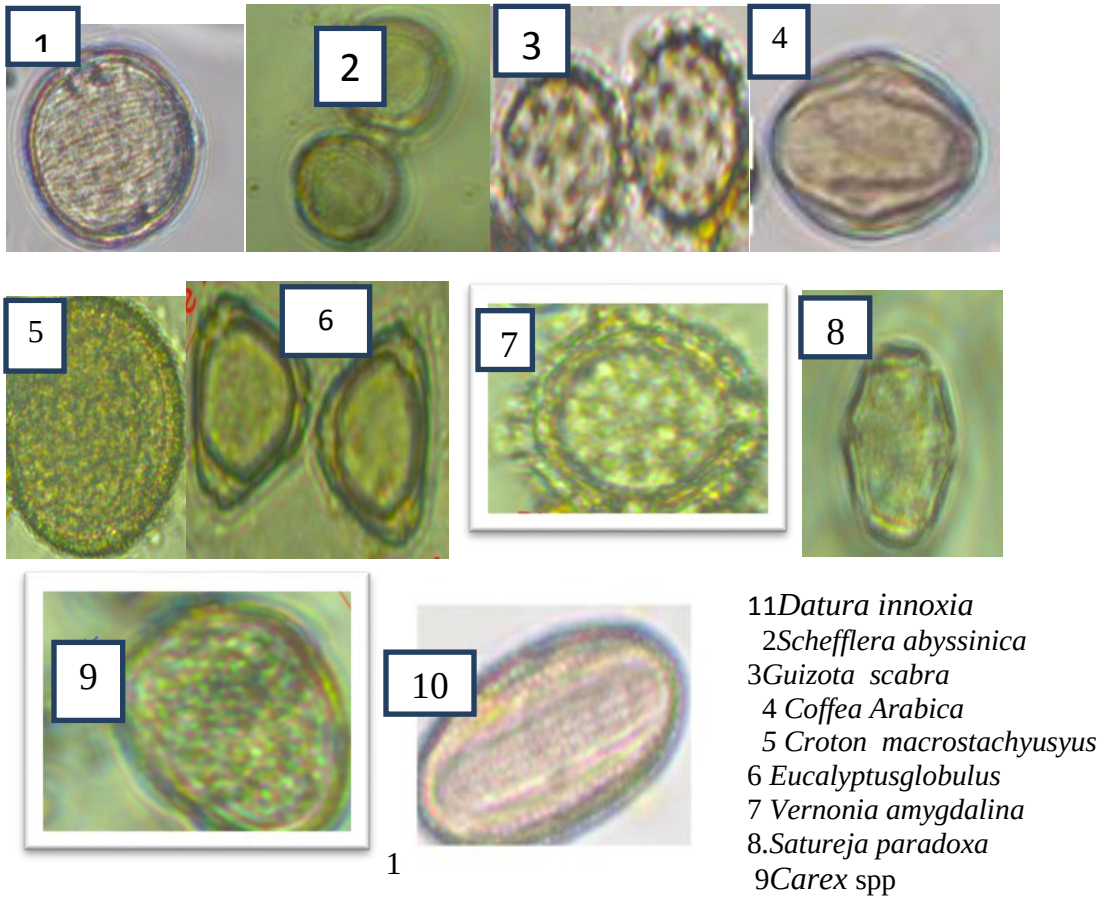
### 3.6 Bee forage data collection

#### 3.6.1 Field observation

Plants visited by honeybees were observed from September 2012- September 2013 in various sites of the study forest. During observations, the types of food source offered by plants and the behavior of the honeybees while collecting nectar and pollen were studied. Activities observed included insertion of proboscis to the corolla of flowers and the "pumping" movement of the abdomen when they were sucking the nectar.The flowering periods of plants that bee forages on were also recorded. Data records include dates of blooming and shedding of flowers that were visited by the local honeybees.

#### 3.6.2 Pollen load collection

A total of nine Zander beehives were placed at different sites of the study area and pollen traps having 16% pollen trapping efficiency were fitted at the entrance of beehives. Pollen loads were collected for 12 months from (September 2014 to September 2015). The pollen samples were placed the clean paper bags and left for 24h to dry at room temperature for drying. A total of 307 samples of bee pollen loads were collected and stored in the freezers at 2.5$^{o}$C-13.74$^{o}$C for further analysis. To identify botanical sources of the pollen loads, a sample of ripe pollen grains were collected from mature flower buds. The fat content was washed out using ether to enhance the clearness of pollen grains. The slides were covered with a coverslip and examined under a light microscope having X400 magnifications. Photos of pollen grain morphology were made using a light microscope linked with the computer program (Figure10) and pollen grains identified to genus or species level using the pollen atlas of Ethiopia ( Nuru Adigaba, 2002).




11*Datura innoxia*
2*Schefflera abyssinica*
3*Guizota scabra*
4 *Coffea Arabica*
5 *Croton macrostachyusyus*
6 *Eucalyptusglobulus*
7 *Vernonia amygdalina*
8.*Satureja paradoxa*
9*Carex* spp
10.*Hypoestes triflora*
S8pp

1

**Figure 11.The pollen grains identified from honey samples**

### 3.6.3 Proximate composition of pollen

#### 3.6.4.1 Moisture content

Moisture content was determined as suggested by Ranganna, (1977). Briefly,2gm of each bee pollen sample was weighed and placed into dishes and dried in the oven for 3h at 105 $^0$C. The dishes were cooled to room temperature in the desiccators and reweight.

#### 3.6.4.2 Ash determination

About 2 gm of bee pollen sample was placed in a quartz crucible and ashed in a muffle furnace at 550°C for 5 hrs. After they were then removed from the muffle and cooled down in the desiccators and weighed. Pollen samples in dishes were placed on the hot plate under a fume hood and the temperature was slowly increased until the smoking ceases and the sample became thoroughly charred. The amount of the total ash was calculated by using the following formula AOAC, (2000).

$$\% \text{ Ash} = \frac{(M_3 - M_1)*100}{M_2}$$

Where, M1= mass of a crucible

M2= sample mass with a crucible

M3 = final mass with a crucible

**Determination of crude protein**

The total Nitrogen was determined by the Kjeldahl method (AOAC, 2000). One gram of bee pollen sample was heated with 20 ml of sulfuric acid (95–97 %) in the presence of a catalyst (potassium sulphate, copper sulphate) for about 4 h until the solution becames clear and blue-green in color. Then it was neutralized with 90 ml NaOH (30 %). The ammonia produced was distilled and collected in boric acid solution and later tittered with standard solution of hydrochloric acid. For the conversion of nitrogen levels to protein the factor NX 6.25 was used.

**Determination of crude fat content**

Crude fat was determined by exhaustively extracting a 2 gm of pollen sample in diethyl ether (boiling point, 55$^{o}$C) in a Soxhlet extractor. The ether was evaporated from the extraction flask.The amount of fat was quantified gravimetrically and calculated from the difference in weight of the extraction flask before and after extraction as a percentage. The extraction flask was cleaned and dried in a drying-oven at 70$^{0}$C for 1 hour, cooled in a desiccator for 30 minutes and then weighed (AOAC, 2003). About 2 mg of pollen was added into extraction thimbles and then covered with about a 2 cm layer of fat-free cotton. The cooling water was switched on and a 50 mL diethyl ether was added to the extraction flask through a condenser.The percentage of fat content was determined by the following formula.

% Fat content = ($W_2$-$W_1$) X100/W

Where:

W = weight of fat;

W2=weight of extraction flask after exaction;

W1= weight of flask before extraction;

W0 of pollen sample

**3.6.3.5**

**Determination of Ash**

Ash content was obtained from the dry incineration of the samples (AOAC, 2005). The ashes were then wetted completely with 5 ml of HCL 6 N and dried at a low temperature on the hot plate until the solution boiled.The ash solution was cooled to room temperature in a hood and filtered using a filter paper. A 5 mililiter HCL 3N was added to each crucible dishe and heated until the solution boiled and then cooled down and filtered into the flask. The crucibles dishes were again washed three times with de-ionized water and then filtered

into the flask. The solution was then looled and diluted to 50 ml with de-ionized water. A blank was prepared by taking the same procedure as the sample.

**3.6.3.6 Determination of Phosphorus**

Phosphorus was determined using the molybdovanadate method (AOAC, 1990). Five mililiters were measured from the sample digested for protein determination and placed in a 100 ml volumetric flask. Ten ml of the molybdate and vanadate solution was3 added to the samples. After 10-30 minutes the color developed was measured at 460 nm wavelength in the spectrophotometer. Data from the absorbance of the blank, sample and standard were used to calculate phosphorus content using the following formula:

P (ppm) = ($c1*v_1*v_2*$ S*A)

Where:

c1 = P concentration in sample digest read from the Curve, ppm.

V1 = volume of the digest

V2 = volume of the dilution

S = weight of the pollen calcined in g

A = Aliquot

**3.6.3.9 Determination of minerals**

Determination of Fe, Na, Ca, was done using microwave assisted acid digestion and quantization (AOAC 2000). Atomic absorption spectrometry was used to read the absorbance at selected wavelength and mineral content of the sample was read from relevant calibration curve and then the mineral content of pollen was determined using the following formula.

$$\text{Mineral content mg/100gm} = \left[\frac{(a-b)*V}{10*w}\right]$$

Where W= weight (gm) of sample

V=50ml= volume of extract

A= concentration (µg/ml) of sample solution. B= Concentration (µg/ml) of blank solution

### 3.6.3.8 Determination of Vitamin C

Vitamin C determination was carried out by following the standard procedure of Vitamin determination Assay,( 1966) and the Manual for Nutrition Surveys (1963). About 5gm of pollen samples were ground in a mortar and extracted with 100ml of 6% of TCA and the solution was centrifuged. Then 1-2 drops of saturated Bromine reagent were added to the samples in a conical flask. Ten milligram of this was taken and added to 2% thiourea and from this 4ml was pipetted into test tubes. One ml of 2% DNPH was added to remaining test tubes. All the test tubes put in a water bath at $37^0$Cfor 3 hour and cool in an ice bath for approximately for 5 min. About 5ml 85% $H_2SO4$ was added slowly while the tubes are in an ice bath. 1mlof 2%DNPH was added to the blank and then all tubes are shaken and the absorbance was read at 515 nm. The Vitamin C content was calculated following formula.

mg AA/100g = [(As-Ab)*10]/[A10µg Std-Ab]

Where: As=Absorbance of samples

Ab= Absorbance of blank

A10 µg Std. Absorbance of standard

**Determination of Antioxidant and Total phenol**

Two grams of dried pollen powder was extracted by stirring with 25 ml of methanol and 25 ml of distilled water and placed at $25^0$C for 60 min maceration using temperature shaker incubator (ZHWY103B) and then filtered through Whatman No. 4 paper. The residue was then extracted with two additional 25 ml portions of methanol as described above the combined methanolic extracts were evaporated at 40°C to dryness using a rota evaporator (Stuart R3300) and re-dissolved in methanol at the concentration of 50 mg/ml and stored at 4°C for further use.

The antioxidant activity of methanol extracts was determined by 2,2-diphenyl-1-picrylhydrazyl. (DPPH) radical scavenging method as described by (Woldegiorgis *et al*.,

2014). A 0.004% solution of DPPH radical solution in methanol was prepared and then 2ml of this solution was mixed with 1ml of various concentrations (0.1–50 mg/ml) of the pollen extracts in methanol. Finally, the samples were incubated for 30 min in the dark at room temperature. Scavenging capacity was read spectrophotometrically by monitoring the decrease in absorbance at 517 nm. Ascorbic acid was used as a standard and mixture without extract as the control.The capability of samples to scavenge DPPH was obtained by comparison of sample color reduction effect with the control using the following equation and expressed as percentage values:

DPPH radical scavenging activity (%) = $(A_0-A_1)/A0x\ 100$

Where:

A0 = absorbance of the control;

A1 = absorbance of the sample.

**Determination of total polyphenols**

The phenolic compounds concentration in pollen samples were estimated with Folin-Ciocalteu reagent according to the methods as described by (Woldegiorgis *et al*., 2014) with some modification. One  ml of Folin-Ciocalteu phenol reagent was added to the mixture and shaken. After 3 minutes 1ml of saturated sodium carbonate (20%) solution was added to the mixture and adjusted to 10 ml with distilled water.The reaction was kept in dark for 90 minutes after which the absorbance was read at 725 nm. The total phenolic content of the samples was expressed in milligram per Gallic acid equivalents (GAE). The total phenolic content was calculated as Gallic acid equivalent (GAE) using the calibration equation $Y = 0.0031x + 0.8095$ ($R^2 = 0.99$).

### 3.6.4 Determination of the botanical origin of honey

The honey samples were collected from beekeeping peasant associations during the honey harvesting period (April-May). From each locality 3kg of honey, samples were collected. Pollen slides were prepared as pollen refence for the identification of pollen from honey samples.To determine botanical origin of honey, pollen slides of honey samples was prepared using the method of (Louveaux *et al.*,1978). The pollen grains extracted from honey samples were identified and compared with the reference slides collection during field observation.The percentages of pollen types in each honey samples was calculated based on the total number of different types of pollen grains counted in each sample. The pollen count was done under light microscope linked to computer.

### 3.6.5 Analysis of physico-chemical properties of forest honey

The honey quality was determined based on the harmonized methods of the International Honey commission (Bogdanov,2009).The major parameters that were considered in analysis were moisture content, electrical conductivity,hydroxymethylfurfural (HMF), pH, free acidity, enzymes (Invetase, Proline), sugars (Sucrose, fructose and glucose). The moisture content of honey samples was determined using an Abbé refractometer that can be thermostated at $20^0$ C, and regularly calibrated with distilled water. Honey samples were homogenized and placed in a water bath until all the sugar crystals were dissolved. After homogenization, of the sample the surface of the prism of the refactometer was covered with honey and after 2 minutes refractive index for moisture was determined.

Electrical conductivity of honey was determined following the procedure given Codex Alimentarius Commission Standards, (2001).The electrical conductivity of the honey was measured based on the electrical conductance of the sample using conductivity meter. pH of the honey, was determined using the methods of (Chatway (1978). For the determination

of pH of honey 10gm of honey was mixed 75ml of distilled water in a 250 ml beaker. The solution was stirred using magnetic stirrer and the pH electrodes were immersed in the solution and the pH recorded. For determination of the Hydroxymethylfurfural five gram (5gm) of honey was weighed and mixed with 25ml of distilled water.The solution was filtered using a wattmann paper and the reading was made using HPLC equipped with UV detection.

### 3.6.5 Determination of sugars

The standard of, fructose, glucose, sucrose, was purchased for determination of sugar in honey. About 5gm of honey was weighed into the beaker and dissolved in 40ml water. A 25ml of methanol was pippted into 100ml of volumetric flask and the honey solution was transferred to the flask. The methanol mixture of the honey solution was filtered using filter paper and solution is poured in vialsand stored in standard solution for determination of sugar using High Performance Liquid Chromatography (HPLC). Diastase was analyzed based on the Harmonized International Honey Commission method (HPLC).

### 3.6.6 Honey production system of studyforest

Potential sites ( Peasent Associations) were selected in Gesha and Sayilem districts based on the honey production potential and practiced of improved beekeeping.Three beekeepers were from each potential PA were selected and a total of 45 beekeepers interviewed using a semistructured questionnaire.The interviews were held in their respective peasant associations using a local language (Appendix19).The questionnaire covered beekeeping management practices, honey harvesting period, bee floral resources , poisonous honey plants, preferred trees for construction of beehives, and constraints of beekeeping in the area.

### 3.7 Data analysis

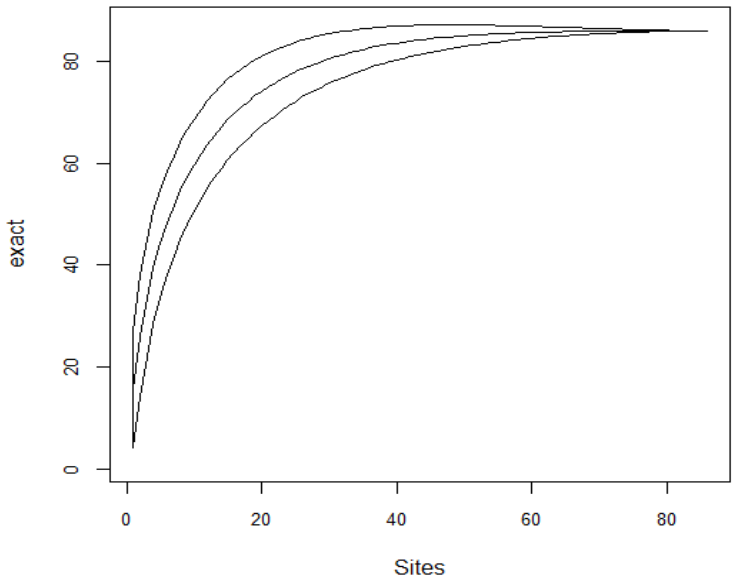
Data on nutrition, mineral and phenol content were analyzed using one-way Anova. Tukey's multiple comparison tests was applied at the significance level of 0.05 using spas software version 20.

# CHAPTER FOUR

## 4. Results

### 4.1 Species accumulation curve (SAC)

The species accumulation curves are an important part of the community ecology and used to compare the species richness and alpha diversity of the habitat. It is also applied for thorough evaluation of the minimum sampling plots required for an adequate inventory of vegetation.The Species Accumulation Curve would be level off and approach an asymptote before the total number of sampling plots is reached for accurate estimation (Fig.13). On top of this SAC may also be used to estimate the expected number of new species that may be encountered for given additional sampling efforts. Based on this a concept the species-area curve was plotted and checked whether the adequate sampling was taken to satisfy the sampling effort made during the data collection and according to our data, the curve was reached at certain points and level off indicating that enough sampling was taken.




. Figure 12.Species Accumulation curve for the Gesha-Sayilem forest

### 4.2 Floristic composition

A total of 300 plant species belonging to 239 genera, and 96 families were identified in Gesha-Sayilem forest and this accounts for about 5.3% of the total Flora of Ethiopia and Eritrea (Appendix1).These species comprised 13 pteridophyte families, 9 monocotyledons and 74 dicotyledons families. The Asteraceae, Acanthaceae, Fabaceae, Rubiaceae, Poaceae and Euphorbiaceae represented the highest number of species.These families include a number of genera and species Fig.13. Among the plant families only six plant families contributed over 31.21% of the total species composition of the area (Fig.13). All the recorded families were angiosperms except for the families Aspleniaceace, Cyatheaceae, Dennstaedtiaceae, Dryopteridaceae, Pteridaceae and Vittariaceae which are pteridophytes.The remaining families consisted of species comprising less than 2% of the total collected each having with low frequency occurrence in the area (Appendix 2).

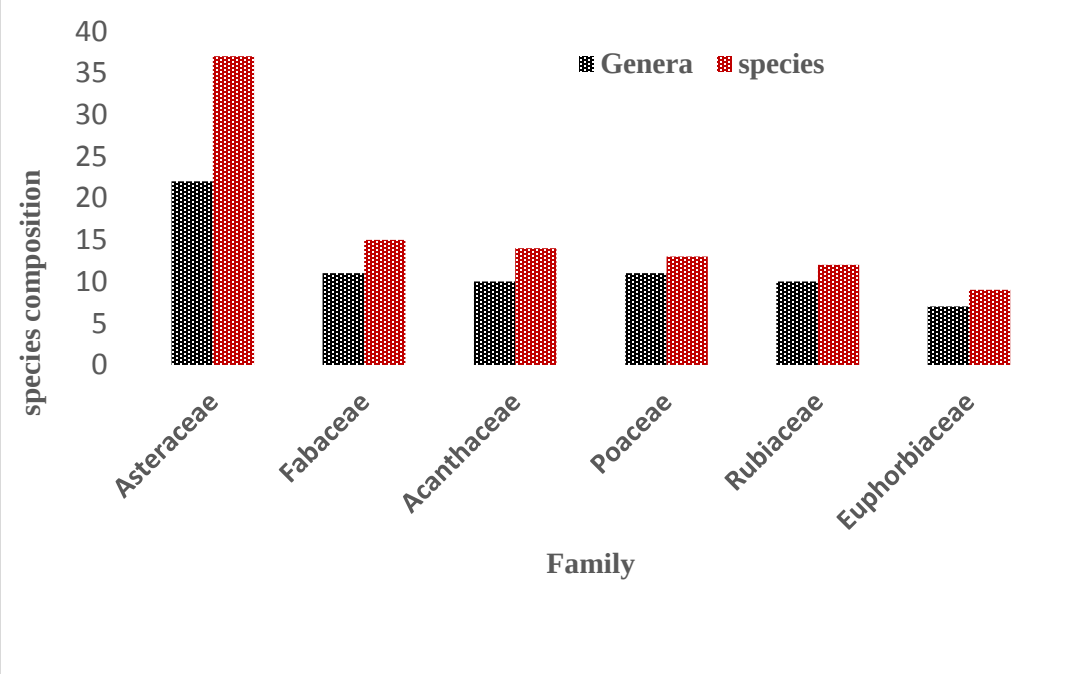



**Figure 13.Percent of species composition and number of genera in rich families in Gesha-Sayilem forest**

All species from the study area were categorized into different growth forms. Ie trees,shrubs, herbs and lianas.The analysis of growth forms of plant species from study areas is shown in (Fig.14). Herbs represented the highest floristic composition (58%), followed by shrubs 14.67) trees 16% and climbers/Lianas were11.3 %.

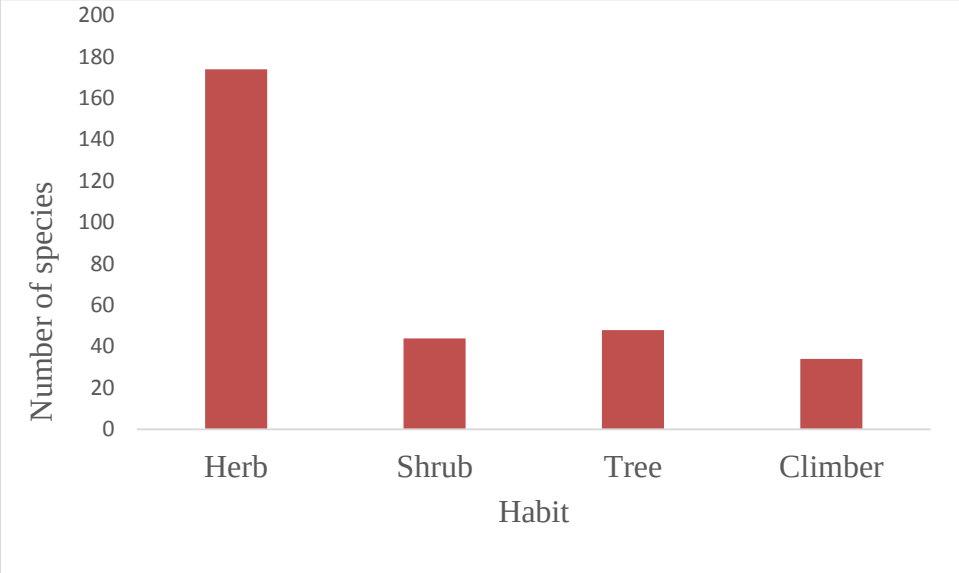



**Figure 14.The habit of plants in floristic composition of the Forest**

### 4.2.1 New records of plant species from Kaffa floristic region

Out of the total number species recorded in the study forest, 19 species belonging to 18 genera and 18 Families were found to be new recordst in the Kaffa floristic region of the Flora of Ethiopia and Eritrea (Table 8). Of these, 11 were herbs, 3 shrubs,1 a tree and 2 ferns 2 climbers and one species were the herb.

**Table 8. Plant species not recorded from Kaffa floristic regions in Flora of Ethiopia and Eritrea**

| No. | **species** | **Family** | **Habit** |
|---|---|---|---|
| 1 | *Acanthopale ethio-germanica* Ensermu | Acanthaceae | Shrub |
| 2 | *Alangium chinense* (Lour) Harms | Alangiaceae | Tree |
| 3 | *Alchemilla pedata* A. Rich. | Roseaceae | Herb |
| 4 | *Alchemilla abyssinica* Fresen. | Roseaceae | Herb |
| 5 | *Alectra vogelii*Benth. | Scrophulariaceae | Herb |
| 6 | *Allophylus rubifolius* (Hochst. ex A. Rich). Engl. | Sapindaceae | shrub |

| | | | |
|---|---|---|---|
| 7 | *Asplenium aethopicum* (Brum.f.) Bech | Aspleniaceae | Fern |
| 8 | *Ammocharis tinneana*(Kotschy and Peyr.) Milne-Redh.& Schweick | Amaryllidaceae | Herb |
| 9 | *Cucumis dipsaceus* Ehrenb. ex Spach | Cucurbitaceae | climber |
| 10 | *Helichrysum formosissimum* Sch. Bip.ex A. Rich. | Asteraceae | Herb |
| 11 | *Hibiscus deflersii* Schweinfex Cufod. | Malvaceae | Herb |
| 12 | *Lecanthus peduncularis* (Royle) Wedd | Urticaceae | Herb |
| 13 | *Oliverella hildebrandtii* (Engl.) Tieghem | Loranthaceae | Climber |
| 14 | *Peucedanum mattirolii* Chiov. | Apiaceae | Herb |
| 15 | *Pittosporum abyssinicum* Del. | Pittosporaceae | Shrub |
| 16 | *Polystichum magnificum*F. Ballard | Dryopteridaceae | Fern |
| 17 | *Rhynchospora corymbosa* (L.) Britt. | Cyperaceae | Sedge |
| 18 | *Reichardia tingitana*(L.) Roth. | Asteraceae | Herb |
| 19 | *Trifolium polystachyum* Fresen. | Fabaceae | Herb |

### 4.2.2 Endemic Plant Species

Based on the information available in the published volumes of Flora of Ethiopia and Eriterea, from the 300 species, collected 26 were endemic, comprising 8.1% of the total species composition of the study forest and 4.5% of the total endemic flora of the Ethiopia and Eritrea (Table 9). Some of these plant species have been registered in the different IUCN Red list categories reported by Vivero, *et al*., (2005). Asteraceae and Acanthaceae had the highest species representing 25% and 8.3% of the total number of species collected respectively.

**Table 9**.**Endemic plants of Ethiopia in Gesha-Sayilem forest**

| No | Plant species | Family | Habit |
|---|---|---|---|
| *1* | *Acanthopale ethio-germanica* Ensermu | Acanthaceae | Herb |
| *2* | *Aframomum corrorima* (Braun) Jansen | Zignberiliaceae | Herb |
| *3* | *Amorphophallus gallaensis*(Engl.) N. E. Br. | Araceae | Herb |
| *4* | *Bothriocline schimperi* Oliv. & Hiern ex Benth. | Asteraceae | Herb |
| *5* | *Cirsium dender*Friis | Asteraceae | Herb |
| *6* | *Clematis longicauda* Steud. ex A. Rich. | Ranunculaceae | Climber |
| *7* | *Conyza abyssinica* Sch. Bip. ex A. Rich. | Asteraceae | Herb |

| | | | |
|---|---|---|---|
| *8* | *Satureja paradoxa* (Vatke) Engl. | Lamiaceae | Herb |
| *9* | *Scadoxus nutans* (Friis & Bjornstad) Friis & Nordal | Amaryllidaceae | Herb |
| 10 | *Crotalaria rosenii* Pax Milne Redh. ex Polhill | Fabaceae | Herb |
| 11 | *Rinorea friisii* M. Gilbert | Violaceae | Herb |
| 12 | *Dorsetnia soerensenii* Friis | Moraceae | Herb |
| 13 | *Solanecio gigas* (Vatke) C. Jeffrey | Asteraceae | Tree/shrub |
| 14 | *Vepris dainellii* (Pich. -Serm.) Kokwaro | Rutaceae | Shrub |
| 15 | *Vernonia leopoldi* (Sch. Bip. ex Walp.) Vake | Asteraceae | Herb |
| 16 | *Brillantaisia grotanellii* Pich.-Serm. | Acanthaceae | Herb |
| 17 | *Euphorbia dumalis* S. Carter | Euphorbiaceae | Herb |
| 18 | *Impatiens rothii* Hook.f. | Balsaminaceae | Herb |
| 19 | *Mikaniopsis clematoides* (Sch. Bip. ex A. Rich.) Milne-Redh. | Asteraceae | Climber |
| 20 | *Millettia ferruginea* (Hochst.) Bak. | Fabaceae | Tree |
| 21 | *Peucedanum mattirolii* Chiov. | Apiaceae | Herb |
| 22 | *Psycnostachys abyssinica* Fresen. | Lamiaceae | Herb |
| 23 | *Pittosporum abyssinicum* Del. | Pittosporaceae | Shrub |
| 24 | *Solanum marginatum* L.f. | Solanaceae | Herb |
| 25 | *Vernonia filigera*Oliv. &Hiern | Solanaceae | Shrub |

### 4.2.3 Plant community types

Five community types were identified using Agglomerative hierarchical cluster analysis in R, statistical softwareversion 3.4.2 (Fig.15).The analysis is based on cover abundance values of the plant species and the data matrix containing 90 plots and 161species. The test statistic t value from MRPP technique for the five groups was -33.05 ($P < 0.001$) showing that the five groups are different and the null hypothesis of no difference among the groups can be rejected.The agreement statistics **A** which describes within-group homogeneity compared to the random expectation was 0.108.The test statistics describes the separation between the groups (McCune and Grace, 2002). The more negative it is, the stronger the separation between the clusters. The number of clusters is based on a synoptic table with the mean values of the cover abundance of Cluster groups.The communities' types were identified at 0.1 to 1.5 dissimilarity levels.The species

occurrences were summarized by synoptic cover abundance values and the communities were named after tree and shrub species with high synoptic value (Table10).

**Table 10.Species list with Synoptic cover abundance value in a cluster groups for Gesha-Sayilem forest.**

| Species | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| *Ilex mitis* | **5.85** | 1.69 | 2.47 | 0.83 | 0.5 |
| *Syzygium Guineans* | **5.30** | 1.97 | 4.13 | 0.00 | 0.2 |
| *Dracaena afromontana* | 3.56 | 2.45 | 0.93 | 0.00 | 0.2 |
| *Cyathea manniana* | 2.59 | 0.72 | 0.53 | 0.00 | 0.2 |
| *Deinbollia kilimandscharica* | 2.15 | 1.28 | 1.60 | 0.00 | 0.2 |
| *Galiniera saxifraga* | 2.48 | 2.69 | 2.60 | 1.00 | 1.1 |
| *Macaranga capensis* | 3.30 | 1.69 | 0.93 | 0.50 | 0.0 |
| *Rytigynia neglecta* | 1.37 | 1.10 | 1.00 | 0.33 | 0.3 |
| *Pouteria adolfi-friederici* | 1.78 | **5.07** | 0.93 | 0.00 | 0.2 |
| *Schefflera abyssinica* | 3.74 | **3.17** | 2.33 | 0.67 | 0.2 |
| *Allophyllus abyssinicus* | 1.48 | 2.21 | 2.07 | 0.00 | 0.2 |
| *Croton macrostachyus* | 0.81 | 2.38 | 2.20 | 0.17 | 0.2 |
| *Apodytes dimidiata* | 1.22 | 1.45 | 1.13 | 0.00 | 0.0 |
| *Cassipourea malosana* | 0.85 | 1.52 | 1.13 | 0.00 | 0.0 |
| *Ekebergia capensis* | 0.52 | 1.79 | 0.13 | 0.00 | 0.2 |
| *Elaeodendron buchananii* | 0.19 | 1.28 | 0.40 | 0.00 | 0.0 |
| *Hypoestes triflora* | 0.07 | 1.10 | 1.33 | 0.50 | 0.5 |
| *Isoglossa somalensis* | 0.96 | 1.55 | 0.53 | 0.00 | 0.0 |
| *Maytenus gracilipes* | 1.78 | 1.86 | 0.87 | 0.17 | 0.0 |
| *Millettia ferruginea* | 1.15 | 0.62 | **7.73** | 0.50 | 0.0 |
| *Sapium ellipticum* | 0.11 | 0.21 | **3.3** | 0.0 | 0.0 |
| *Bersama abyssinica* | 1.15 | 1.66 | 1.53 | 1.17 | 0.5 |
| *Lepidotrichilia volkensii* | 1.63 | 2.62 | 2.20 | 0.00 | 0.6 |
| *Albizia gummifera* | 0.22 | 0.31 | 2.00 | 0.00 | 0.0 |
| *Olea capensis* | 0.78 | 0.66 | 1.73 | 0.00 | 0.0 |
| *Oplismenus hirtellus* | 0.26 | 0.31 | 1.07 | 1.00 | 0.0 |
| *Coffea arabica* | 0.00 | 0.03 | 1.80 | 0.00 | 0.0 |
| *Alangium chinense* | 0.56 | 0.34 | 1.13 | 0.00 | 0.0 |
| *Arundinaria alpina* | 0.00 | 0.00 | 0.00 | **9.00** | 0.7 |
| *Alchemilla abyssinica* | 0.07 | 0.28 | 0.40 | **1.67** | 0.9 |
| *Maesa lanceolata* | 0.04 | 0.10 | 0.00 | 0.00 | **3.6** |
| *Schefflera volkensii* | 0.59 | 0.07 | 0.00 | 0.00 | **3.5** |
| *Schoenoplectus corymbosus* | 0.00 | 0.00 | 0.00 | 0.00 | **1.2** |
| *Alchemilla pedata* | 0.00 | 0.00 | 0.00 | 0.00 | **1.3** |

**Table 11**. **Cluster groups and number of plots per community**

| Cluster group | Altitude range | No. of plots | Plots in the community |
|---|---|---|---|
| *Ilex mitis- Syzygium guineense community* | 1712-2408 | 27 | 1,73,82,83,66,68,72,71,26,28,56,69,64,3,6,22,37,12,20,8,24,29,46,74,45,48,59 |
| *Pouteria adolfi-friederici-Schefflera abyssinica community* | 1734-2803 | 29 | 2,7,4,36,35,52,5,13,14,18,19,34,21,25,81,30,31,27,84,32,49,51,50,33,53,54,63,57,62 |
| *Millettia ferruginea-Sapium ellipticum* community | 1772-2316 | 15 | 9,11,16,10,58,80,65,70,15,60,617,38,55,67 |
| *Arundinaria alpina*community | 2143-2402 | 6 | 23,40,42,41,86,87 |
| *Schefflera volkensi-Maesa lanceolata* community | 1734-2803 | 13 | 39,89,85,88,90,43,44,47,76,78,75,77,79 |

The plant communities identified from cluster analysis as described below:

1. **The *Ilex mitis*-*Syzygium guineense* community**

This community is occurs between altitudinal ranges of 1834-2408m and found on east facing slope and there are 92 species recorded. Following this two characteristic species,*Ilex mitis* and *Syzygium guineense*. The dominant tree species in the community were *Allophllus abyssinicus, Macarnga capensis, Croton Macrostachyus* and *Apodytes dimidata while t*he shrubs include *Galiniera saxifraga, Brucea antidysenterica, Clausena anisata, Dracaena afromontana* and *Olea capensis*.The herb layer comprises *Asplenium aethopicum, Hypoestes triflora, Alchemilla pedata, Achyranthes aspera* and *Asplenium elliottii*.The Lianas common to this community were *Hippocratea africana* and *Landolphia buchananii*.

**2. The *Pouteria adolfi-friederici-Schefflera abyssinica* community**

Eighty nine (89) species are recorded and this community occurs between 1734-2803m and as found on moderate slope (26.2%) facing towards south. It is dominated in the upper canopy by *Pouteria adolfi-friederici, Schefflera abyssinica, Albizia gummifera, Ekebergia capensis, Elaeodendron buchananii,Ilex mitis, Olea welwitschii, Alangium chinense* and *Prunus africana*. Among the shrub species, *Maytenus gracilipes, Ocotea kenyensis,Oxyanthus speciosus,Pavetta abyssinica,Vernonia auriculifera* and the tree fern *Cyathea manniana*.The herb layer is dominated by *Acanthopale ethio-germanica,Acanthus eminens,Piper capense,Asplenium elliottii, Commelina benghalensis, Isoglossa somalensis* and *Pilea bambuseti*.The climbers frequent in this community were *Hippocratea africana Landolphia buchananii,Jasminum abyssinica* and *Schefflera myriantha*.

**3. The *Millettia ferriguinea-Sapium ellipticum* community type**

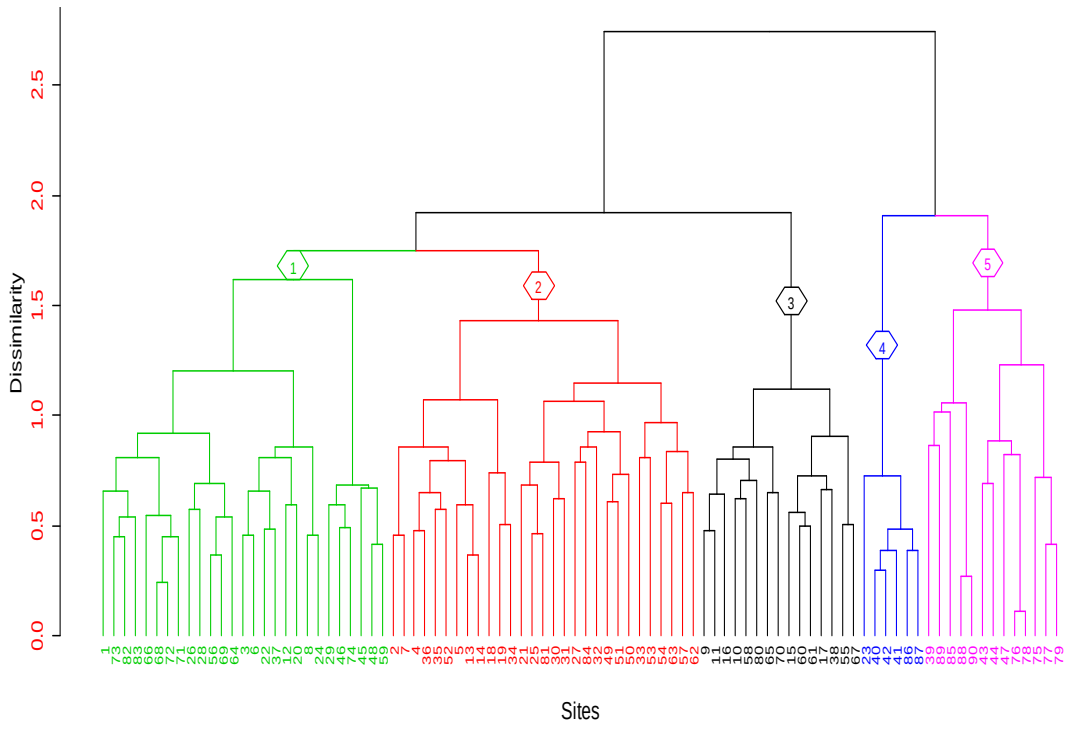
This community type is found between 1722-2316m asl. It occurs on gentle slope (22.2%). Eighty five species were recorded in it from 15 plots. The dominant trees in the in the community are *Millettia ferruginea,Ficus sur,Olea welwitschii, Albizia gummifera, Polyscias fulva* and *Sapium ellipticum* while shrubs include *Oxyanthus speciosus, Vepris dainellii, Coffea Arabica* and *Rytigynia neglecta*.The herbs comprise*Pteris pteridioides, Asplenium elliottii, Afromum kororima, Piper capense* and *Desmodium repandum.*The climbers/lianas included, *Clematis hirsuta,Landolphia buchananii, Hippocratea pallens, Jasminum abyssinicum,Urera hypselodendron* and *Tiliacora troupinii*.

**4. The *Arundinaria alpine* community type**

This community occursbetween 2350-2506m. It occurs at lower slope (17.2%) facing the southwest. Fourty three 43 species were recorded with dominant one being the highland bamboo, *Arundinaria alpina*, *Schefflera volkensii*, *Hagenia abyssinica* and *Dombeya torrida*.The shrubs are *Maesa lanceolata,Galiniera saxifraga* and *Vernonia amygdalina*.The herb layer included *Alchemilla abyssinica, Pilea bambuseti, Commelina benghalensis,Cissampelos mucronata* and *Laportea alatipes* are dominant.

***6.*** The ***Schefflera volkensi- Maesa lanceolate*** **community type**

This community type occurs between 1968-2800m and the community was distributed on medium slope (20.2%), facing towards the north east. Sixt six species recorded and the recorded dominant trees are *Hagenia abyssinica,Schefflera volkensi*, *Macaranga capensis*, *Maesa lanceolata*, *Dombeya torrida*, *Ekebergia capensis* and *Prunus africana.*The shrub layer comprises *Dracaena afromontana, Bersama abyssinica* and *Maytenus undata, Nuxia congesta* and *Hypericum revolutum*.The herb layer was dominated by *Satureja paradoxa, Trifolium polystachyum, Bidens prestinaria* and wetland species which include, *Juncus effusus*, *Cyperus fischerianus, Alchemilla pedata* and *Helichrysum formosissimum.*




$$SR = \frac{(\sum x(k,j)(\sum x(k,j)))}{(\sum x(k,i)^2 + \sum x(k,j)^2) - (\sum x(k,i)(x(k,j)))}$$

**Figure 15.Agglomerative Hierarchical Classification using SR in the Gesha-Sayilem forest**

### 4.2.4 Indicator species

The cluster one has 92 plant species and it has two indicator species namely *Brillantaisia madagascariensis* and *Sericostachys scandens.* Cluster two had no indicator species indicating each species are occurring with other communities.Cluster three has 85 species and it has four indicator species namely *Dracaena fragrans, Olea capensis* subsp. *Macrocarpa,Hallea rubrostipulata* and *Ehretia cymosa.* Cluster four has a 43 species and two indicator species namely *Dombeya torrida* and *Maesa lanceolata.* The cluster five has 66 species and it has four indicator species namely *Cyperus fischerianus, Helichrysum formosissimum,Rumex nepalensis* and *Schoenoplectus corymbosus* Table 12.

**Table 12.Indicator species for community types in the moist Afromontane forest**

| Indicator species | Cluster | Indicator value | P-value |
|---|---|---|---|
| *Brillantaisia madagascariensis* | 1 | 0.54 | 0.014 * |
| *Sericostachys scandens* | 1 | 0.51 | 0.006 ** |
| No indicator species | 2 | - | - |
| *Dracaena fragrans* | 3 | 0.57 | 0.002 ** |
| *Olea capensis* subsp. *macrocarpa* | 3 | 0.55 | 0.02 * |
| *Hallea rubrostipulata* | 3 | 0.52 | 0.005 ** |
| *Ehretia cymosa* | 3 | 0.41 | 0.035 * |
| *Dombeya torrida* | 4 | 0.63 | 0.004 ** |
| *Maesa lanceolata* | 4 | 0.56 | 0.005 ** |
| *Cyperus fischerianus* | 5 | 0.47 | 0.04 * |
| *Helichrysum formosissimum* | 5 | 0.39 | 0.02 * |
| *Rumex nepalensis* | 5 | 0.39 | 0.02 * |
| *Schoenoplectus corymbosus* | 5 | 0.39 | 0.026 * |

### 4.2.5 Species diversity, richness and evenness

The analysis of vegetation data using the Shannon Wiener diversity index revealed that community 2 has the highest species diversity followed by communities 3,1and 5. Relatively community four is lower species diversity (Table 13). The species richness also varied significantly among the communities. Community 2 had the highest number of species followed by community1, 3, 5 and the least for community 4. The community five had highest evenness, followed by community three and two whereas the community one and four relatively lower evenness value respectively. The overall plant diversity (Shannon Diversity index) and evenness in the study area are 3.56and 0.85 respectively.The beta diversity of the study area worked out was 0.73 which denotes high habitat diversity among the communities.

**Table 13. Diversity indices of the vegetation for Gesha-Sayilem forest**

| Community | Species richness | Shannon`s diversity index (H') | Simpson`s diversity index (D) | Shannon Evenness (E) | Simpson Evenness |
|---|---|---|---|---|---|
| 1 | 89 | 3.70 | 26.11 | 0.82 | 0.29 |
| 2 | 99 | 3.90 | 35.70 | 0.85 | 0.36 |
| 3 | 79 | 3.80 | 31.30 | 0.87 | 0.39 |
| 4 | 29 | 2.96 | 7.37 | 0.80 | 0.25 |
| 5 | 60 | 3.69 | 25.64 | 0.89 | 0.42 |

Tukey mean separation test results showed that the mean differences between the clusters of communities were significant ($p<0.05$) indicating that all the plant communities were different in all diversity indices (Table 14). Communities**1**and **2** were significantly different from communities three, four and five for the Shannon index while community three and four are significantly different from community **1, 2** and **5** for species richness and community four was significantly different from the rest of the communities.

**Table 14. The pooled mean differences of diversity indices between the different communities in Gesha-Sayilem forest**

| Communities | Altitudinal range (m) | Shannon | Richness | Evenness |
|---|---|---|---|---|
| 1 | 1712-2408 | 2.8 ± 0.28b | 20.56 ± 5.02b | 0.95 ± 0.017b |
| 2 | 1734-2803 | 2.9 ± 0.56b | 24.41 ± 4.5b | 0.95 ± 0.015b |
| 3 | 1772-2316 | 1.6 ± 0.12a | 5.67 ± 0.58a | 0.95 ± 0.016b |
| 4 | 2143-2402 | 1.97 ± 0.33a | 9.3 ± 0.57a | 0.907± 0.043a |
| 5 | 1734-2803 | 3 ± 0.20a | 21.36 ± 8.3b | 0.947 ±0.011b |

**Symbols' with different letters are significant at P<0.05**

### 4.2.6 Similarity among the plant communities

Pair'swise comparison of the Soressen similarity coefficient gave a higher value between the communities Table 15. Soresson index indicated more similarity in terms of species composition of the community. Thus, the communities1, 2, 3 and 5 more similar to each other as shown in Table 11. Community four is with a similarity ratio of 0.29 can be considered to be less similar from other communities other hand, the beta diversity for communities 1,2, 3 and 5 were 0.25, 0.27, 0.39 and 0.28 respectively while community four has a higher beta diversity index (0.71) and low similarity. The analysis of species composition for each community indicated that community one, two and three had highest species composition (92, 96,88) respectively followed by community four and five (30 and 70) respectively.

**Table 15. Pairwise comparison of similarity index between the community groups**

| Plant community | Community 1 | Community 2 | Community3 | Community4 | Community5 |
|---|---|---|---|---|---|
| 1 | 1 | 0.74 (0.26) | 0.68(0.32) | 0.33(0.67) | 0.51(0.49) |
| 2 | 0.75 (0.25) | 1 | 65(0.35) | 0.26(0.74) | 0.45(0.55) |
| 3 | 0.73 (0.27) | 0.66 (0.34) | 1 | 0.24 (0.76) | 0.46(0.54) |
| 4 | 0.29 (0.71) | 0.28.3(0.72) | 0.25(0.75) | 1 | 0.38(0.62) |
| 5 | 0.39 (.0.41) | 0.40(0.60) | 0.42(0.58) | 0.22(0.88) | 1 |

N.B. numbers in bracts indicate β-diversity

### 4.2.7 Phytogeographical comparison

The floristic composition of Gesha-Sayilem forest was compared with seven moist Afromontane forests. These included Godere, Gera, Masha, Harenna, and Yayu and Settma forest in Jimma Zone. The results of the analysis are presented in Table 16. From the above forest description, the Gesha-Sayilem forest are closely related to Masha and Godere forest (59% and 53%) respectively. The,Setmma and Yayu forest showed close affinity with Gesha-

Sayilem Forest with similarity ratio of 0.48 and 0.37 respectively. The floristic similarity of Harenna Forest was found to be less when compared with Gesha-Sayilemforest due to variation in altitude and topography.

**Table 16. Phytogeographical comparison of Gesha–Sayilem forest with other moist forests**

| Forest | Altitude | a | b | c | Sc | References |
|---|---|---|---|---|---|---|
| Bibita forest | 1750-2200 | 112 | 184 | 82 | 0.53 | Dereje Denu,2006 |
| Masha forest | 1700–3000 | 114 | 184 | 16 | 0.59 | Abreham Assefa,2009 |
| Yayu forest | 1250-1700 | 89 | 193 | 101 | 0.37 | Tadesse Woldemariam, |
| Harenna forest | 1300-3000 | *72* | 266 | 48 | 0.31 | Feyera Senbeta 2006 |
| Settma forest | 1500–2200 | 141 | 158 | 146 | 0.5 | Dereje Denu,2017 |
| Belete Gera forest | 1400-2200 | 83 | 216 | 68 | 0.36 | Kflay *et al.*, *(*2014) |

"a" is the number of common species to the forest of both sites, "b"is number of species found in Gesha-Sayilem forest c" is the number of species found in the vegetation of other sites in comparison with Gesha - Sayilem forest c and ''Ss'' is Sorenson's similarity index

### 4.3 Community-Environment relationship

#### 4.3.1 Ordination

DCA analysis was performed to determine whether the species were responding linearly or unimodally to environmental gradients. The DCA output of our dataset revealed that the axis length was more than 4 (Table17 showing the presence of higher beta diversity (species turn over).

**Table 17. DCA output indicating the heterogeneity of vegetation composition in the data set**

| DCA axis | DCA1 | DCA2 | DCA3 | DCA4 |
|---|---|---|---|---|
| Eigenvalues | 0.53 | 0.40 | 0.29 | 0.25 |
| Decorana values | 0.69 | 0.48 | 0.28 | 0.23 |
| Axis lengths | 5.60 | 4.90 | 2.80 | 3.50 |

The environmental variables were selected by computing variance inflation factor (vif) for their significance (Table 18).

**Table 18. Results of the variance inflation factor variables having vif values higher than 5 are less significant.**

| Variable | Variance Inflation Factor |
|---|---|
| Altitude | 1.99 |
| Disturbance | 1.46 |
| Slope | 1.24 |
| Aspect | 1.15 |
| Sand | 169.72 |
| Clay | 114.22 |
| Silt | 45.15 |
| PH | 1.731 |
| P | 1.27 |
| OM | 1.77 |
| CEC | 1.86 |
| PH | 1.73 |
| N | 1.77 |
| EC | 1.63 |
| K | 1.42 |

### 4.3.2 CCA Ordination of the Moist Afromontane forest

Canonical Corespondance analysis produced five clusters based on species composition and associated environmental variables as shown in Fig.16.The Monte Carlo test using Adonis function with automatic backward and forward selection of environmental variables showed that only five environmental factors (Altitude, disturbance, slope, phosphorus and electrical conductivity (EC) were significantly influencing the floristic composition of the plant communities ( Table 19).The remaining environmental factors had no significant effect on the floristic composition and distribution of the plant community types.

**Table 19. Result of Permutation test of Environmental variables**

| Variable | Df | Model | N. perm | pr(>F) |
|---|---|---|---|---|
| Altitude (m) | 1 | 8.63 | 199 | 0.0001 *** |
| Slope (%) | 1 | 1.91 | 199 | 0.003 ** |
| Aspect | 1 | 1.32 | 199 | 0.135 |
| Disturbance (%) | 1 | 5.47 | 199 | 0.001 *** |
| Sand (%) | 1 | 1.37 | 199 | 0.23 |
| Silt (%) | 1 | 0.85 | 199 | 0.37 |
| Clay (%) | 1 | 1.07 | 199 | 0.32 |
| pH | 1 | 0.77 | 199 | 0.510 |
| P (Ppm) | 1 | 1.82 | 199 | 0.002 ** |
| OM (%) | 1 | 0.74 | 199 | 0.79 |
| K (%) | 1 | 1.44 | 199 | 0.06 |
| CEC | 1 | 1.20 | 199 | 0.25 |
| N (%) | 1 | 1.82 | 199 | 0.748 |
| EC (mS/cm) | 1 | 1.09 | 199 | 0.020 * |
| Residual | 75 | 7.06 | | |

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

**Vegetation and Environmental relationship (CCA)**

The results from CCA analysis fig 16 plots representing community type 1 are located on the lower right side of the ordination space. Those representing community type 2 occurs on the upper lower right side. Those representing community type 3 are grouped on the upper left side and those representing community type 4 are located on the lower left side of the ordination diagram and plots representing community five are grouped on upper right-side at the ordination plots (Figure 16). Altitude and disturbance were the most important variables in influencing the patterns of species composition.

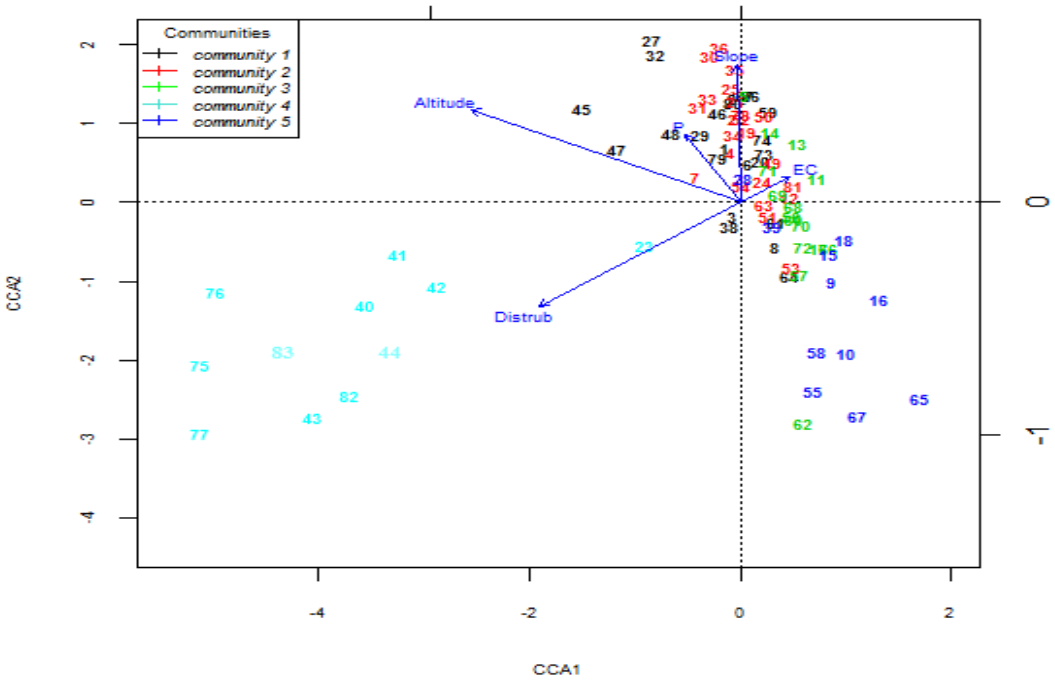



Figure 16.CCA ordination diagram of plots of the Moist Afromontane Forest with vectors of environmental factors

The eigenvalue for axis one was higher than the eigenvalues of the remaining five axes ( Table 20) showing that constraining variable were more associated with the first axis than any other axis.The cumulative proportion of variance explained by the first six axes of the shared plot in the constraining biplot was 73.42%. About 25% and 12% of the proportion of variation were explained by CCA1 and CCA2 respectively Table 20.

**Table 20. Biplot scores for the constraining variables, eigenvalues and proportion of variances explained by the first six axes**

| Variable | CCA1 | CCA2 | CCA3 | CCA4 | CCA5 | CCA6 |
|---|---|---|---|---|---|---|
| Altitude | -0.87 | 0.40 | 0.11 | 0.25 | 0.09 | 0.01 |
| Slope | -0.011 | 0.59 | 0.02 | -0.80 | 0.12 | 0.41 |
| Disturbance | -0.65 | -0.45 | 0.38 | -0.36 | 0.32 | 0.34 |
| P | -0.18 | 0.29 | 0.87 | 0.33 | 0.13 | 0.19 |
| EC | 0.16 | 0.11 | -0.12 | -0.04 | 0.97 | 0.16 |
| Eigen values | 0.41 | 0.19 | 0.14 | 0.13 | 0.12 | 0.12 |
| Proportion explained | 0.25 | 0.12 | 0.08 | 0.07 | 0.06 | 0.05 |
| Cumulative Proportion | 0.25 | 0.46 | 0.53 | 0.61 | 0.67 | **0.73** |

### 4.3.2.2 Species and environmental relationship

The CCA showing, the plant species distribution were strongly correlated with altitude were *Arundinaria alpina, Hagenia abyssinica, Dombeya torrida, Ekebergia capensis* and *Schefflera volkensii (*Fig.17*)* where as *Alchemilla pedata,Cyperus fischerianus, Maesa lanceolata, Croton macrostachyus Schoenoplectus corymbosus* and *Trifolium polystachyum were* highly correlated with disturbance with long arrow indicating the strength of the relationship. Similarly *Vepris dainellii, Pouteria adolfi-friederici, Ilex mitis,Syzygium guineense* and *Hippocratea pallens* are positively correlated with clay and silt. *Millettia ferruginea, Coffea arabica, Aframomum corrorima* and *Piper capense had* negative correaltion with pH and CEC. *Olea welwitschii, Schefflera abyssinica, Dracaena afromontana* and *Bersama abyssinica* were positively correlated with organic matter.

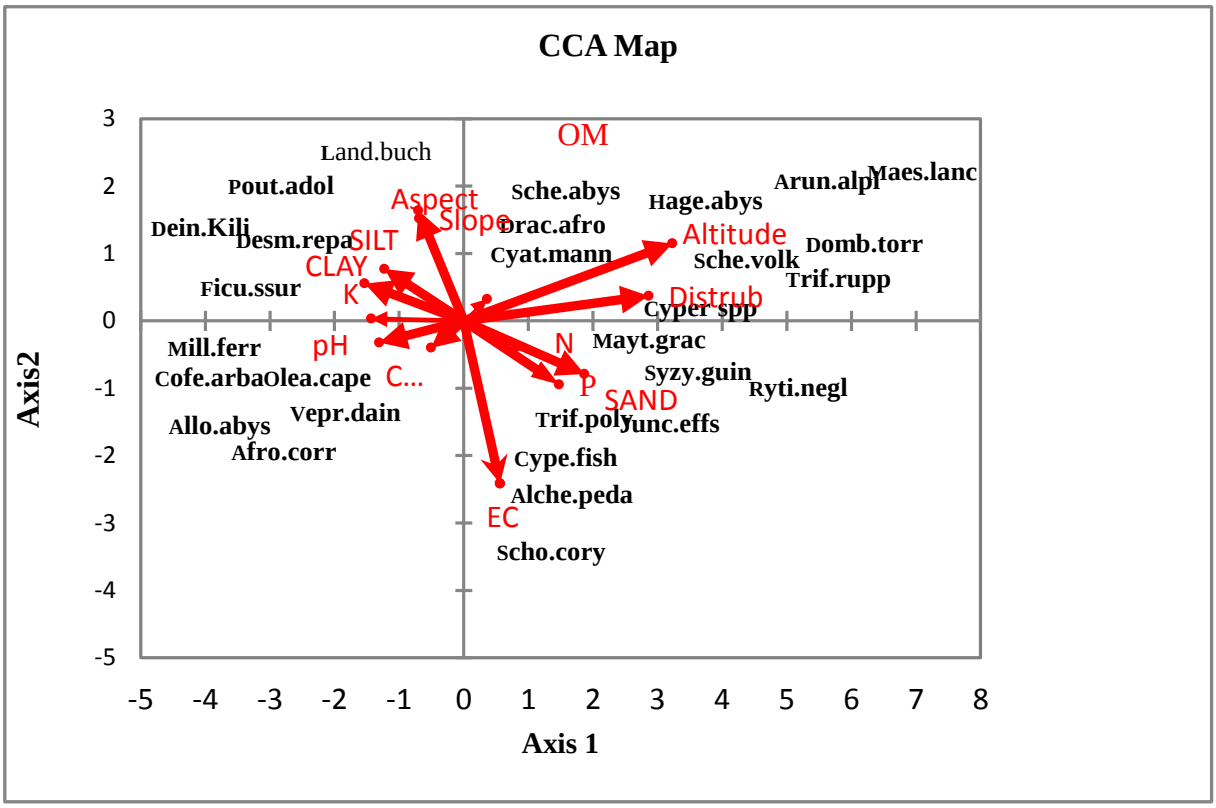



**Figure 17. CCA ordination diagram of Gesha-Sayilem forest showing the relationships between plant species distribution and environmental factors.**

#### 4.3.2.4 Plant community-environment relationship

A few environmental variables were identified as determining the pattern of species distribution and this formation of the five plant communities. The mean difference of environmental variables among the five community types was compared using one-way ANOVA. The five community types were found to differ significantly from each other with regard to altitude, disturbance, phosphorus and pH (Table 21).

**Table 21.The monte Carlo test for significance environmental variables influencing vegetaion communities in Gesha-Sayilem forest**

| Variables | df | F value | P-value |
|---|---|---|---|
| Altitude | 3 | 15.90 | 9.308e-10 *** |
| Disturbance | 3 | 1.11 | 2.2e-16 *** |
| Slope | 3 | 0.05 | 0.521 |
| EC | 3 | 0.75 | 0.55 |
| P | 3 | 3.43 | 0.02* |
| PH | 3 | 4.17 | 0.004 ** |
| OM | 3 | 0.36 | 0.83 |
| CEC | 3 | 1.20 | 0.31 |
| K | 3 | 1.33 | 0.26 |

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

### 4.3.5 Pairwise comparison between the plant communities

The five plant community types were found to differ from each other with respect to altitude and disturbance (Table22) and which could be the major environmental factors influencing the formation of these plant communities. The *Schefflera volkensi-Maesa lanceolata* differed from the *Pouteria adolfi-friederici-Schefflera abyssinica community* and the *Millettia ferruginea-Sapium ellipticum on the basis* of pH.

**Table 22.Pairwise comparison between the community types inrelation to significant environmental factors**

| Variables | Pair wise clusters | Difference | Lower | upper | P value |
|---|---|---|---|---|---|
| **Altitude** | **3-1** | **0.92** | **-1.62** | **-0.23** | **0.0032**** |
| | **4-1** | **1.01** | **0.03** | **1.98** | **0.038*** |
| | **5-1** | **1.24** | **0.52** | **1.97** | **0.00007***** |
| | **3-2** | **-0.99** | **1.68** | **-0.31** | **0.001**** |
| | **5-2** | **1.17** | **0.45** | **1.89** | **0.0001***** |
| | **4-3** | **1.93** | **0.89** | **2.97** | **0.000***** |
| | **5-3** | **2.17** | **1.35** | **2.99** | **0.000***** |
| **Disturbance** | **5-1** | **1.5** | **0.78** | **2.22** | **0.000***** |
| | **4-1** | **1.85** | **0.89** | **2.81** | **0.0004***** |
| | **4-2** | **1.83** | **0.88** | **2.79** | **0.0006***** |
| | **5-2** | **1.49** | **0.78** | **2.20** | **0.000***** |
| | **4-3** | **1.86** | **0.83** | **2.88** | **0.000***** |
| | **5-3** | **1.52** | **0.70** | **2.32** | **0.0001***** |
| **Phosphorus** | **5-1** | **1.66** | **0.94** | **2.38** | **0.000****** |
| | **5-2** | **1.88** | **1.17** | **2.60** | **0.0000***** |
| | **5-3** | **2.02** | **1.21** | **2.83** | **0.000***** |
| | **5-4** | **1.18** | **0.13** | **2.24** | **0.019*** |
| **pH** | **5-2** | **-1.11** | **-1.98** | **-0.25** | **0.005**** |
| | **5-3** | **1.18** | **-2.17** | **-0.19** | **0.010*** |

**Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1**

### 4.3.6 Pearson correlation

A strong statistically significant correlation ($P<0.05$) was observed between altitudes and sand (%) and phosphorus and pH ( Table. 23). On the other hand, negatively correlated with clay and silt.Similarly, the slope was strongly correlated with aspect, and phosphorus.The aspect was positively correlated with Phosphorus. Sand is negatively correlated with clay and silt and pH is negatively correlated with Phosphorus and potassium.

**Table 23.Pearson's correlations coefficient between environmental variables in Gesha–Sayilem Afromontane forest**

| | Distrubance | Altitude | Slope | Aspect | SAND | CLAY | SILT | pH | P | OM | K | CEC | N | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distrubance | | 0 | 0.49 | 0.75 | 0.002 | 0.005 | 0.10 | 0.21 | 0.001 | 0.30 | 0.804 | 0.52 | 0.33 | 0.57 |
| Altitude | 0 | | 0.48 | 0.76 | 0.001 | 0.000 | 0.024 | 0.053 | 0 | 0.05 | 0.254 | 0.94 | 0.040 | 0.56 |
| Slope | 0.49 | 0.496 | | 0.029 | 0.31 | 0.140 | 0.81 | 0.47 | 0.25 | 0.16 | 0.500 | 0.22 | 0.39 | 0.60 |
| Aspect | 0.75 | 0.76 | 0.029 | | 0.81 | 0.84 | 0.41 | 0.04 | 0.47 | 0.89 | 0.326 | 0.66 | 0.95 | 0.71 |
| SAND | 0.02 | 0 | 0.31 | 0.81 | | 0 | 0 | 0.09 | 0.008 | 0 | 0.342 | 0.002 | 0.48 | 0.008 |
| CLAY | 0.005 | 0.000 | 0.14 | 0.83 | 0 | | 0.55 | 0.38 | 0.04 | 0.000 | 0.895 | 0.009 | 0.09 | 0.011 |
| SILT | 0.105 | 0.024 | 0.80 | 0.41 | 0 | 0.56 | | 0.105 | 0.06 | 0.001 | 0.051 | 0.077 | 0.20 | 0.26 |
| pH | 0.21 | 0.053 | 0.47 | 0.043 | 0.09 | 0.38 | 0.10 | | 0.07 | 0.130 | 0.013 | 0.713 | 0.58 | 0.339 |
| P | 0.001 | 0 | 0.25 | 0.47 | 0.01 | 0.041 | 0.06 | 0.07 | | 0.82 | 0.379 | 0.37 | 0.005 | 0.027 |
| OM | 0.32 | 0.05 | 0.16 | 0.89 | 0 | 0.000 | 0.001 | 0.13 | 0.82 | | 0.205 | 0.009 | 0.28 | 0 |
| K | 0.80 | 0.25 | 0.50 | 0.32 | 0.34 | 0.89 | 0.051 | 0.01 | 0.37 | 0.21 | | 0.001 | 0.063 | 0.067 |
| CEC | 0.53 | 0.94 | 0.225 | 0.66 | 0.002 | 0.009 | 0.077 | 0.71 | 0.37 | 0.01 | 0.001 | | 0 | 0.001 |
| N | 0.33 | 0.04 | 0.391 | 0.95 | 0.48 | 0.093 | 0.21 | 0.58 | 0.005 | 0.29 | 0.063 | 0 | | 0.002 |
| EC | 0.57 | 0.56 | 0.606 | 0.71 | 0.008 | 0.011 | 0.26 | 0.33 | 0.027 | 0 | 0.067 | 0.001 | 0.002 | |

## 4.4 Vegetation structure

### 4.4.1 Density of woody species

The density of woody species in the forest was expressed as the number of individuals per hectare and classified into 5 density classes. A–E as follows: A > 100; B = 50.1–100; C= 10.1– 50; D= 1–10 and E (<1) (Fig.18). A great proportion of woody individuals were found in the lower density classes and decreasing towards higher density and DBH classes than higher DBH classes (Fig.18). The Density of trees with DBH greater than 2.5cm, 10cm and 20 cm was 567, 280.4 and 241.5 $ha^{-1}$ respectively (Appendix 3). The abundant species with the highest densities in the study area were *Gallineria saxifarga*, *Deinbollia kilimandscharica*,*Lepidotrichilia volkensii*, *Maytenus gracilipes*, *Dracaena afromontana*, and *Cyathea manniana* contributing for 51.3% of the forest density.

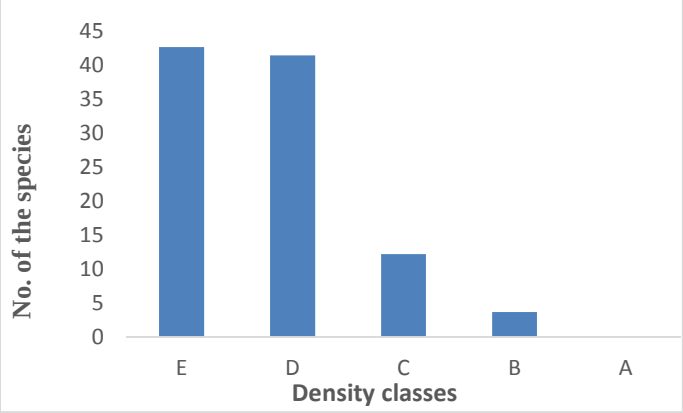



**Figure 17. Density class distribution of the woody species**

**Comparison of density classes**

The densities of species with dbh greater than 10 cm and 20 cm were **280.4** (25.7%) and **241.5** (22.5%) individuals' $ha^{-1}$, respectively and the ratio of the former to the latter was 1.15.The **a/b**ratio was compared with similar forests in Ethiopia and the studies forest has a close similarity with Bibita (Godere) and Belete Gera forests and lower than Bonga, Yayu, Masha Andracha forests (Table 24).

**Table 24.Comparative study of the density of Gesha-Sayilem forests with otherAfromontane forests in Ethiopia**

| Forest type | DBH>10cm(a) | DBH>20cm(b) | a/b |
|---|---|---|---|
| Belete Gera[1] | 229 | 202.00 | 2.13 |
| Bonga[1] | 424 | 160.00 | 3.66 |
| Yayu[1] | 317 | 132.00 | 3.14 |
| Bibita forest[2] | 550 | 265.50 | 1.90 |
| Masha Andrcha[1] | 385.7 | 160.50 | 2.40 |
| Gesha-Sayilem[3] | 306.47 | 265.36 | 1.15 |

**Source: [1]** Kumelachew Yeshitela and Taye Bekele, 2003, [2] Dereje Denu 2006,

**4.4.2 DBH class distribution**

Analysis of DBH distribution in different DBH classes shows that a greater number of individuals were distributed in the lower DBH classes 2-5-10cm (51.2%), and 10.1-20 (23. 9%).The lower percentage distribution was found at higher DBH classes than the lower DBH classes.The total density of woody individuals and their relative proportion for each DBH classes are given in (Appendix 4**)**. The general pattern of distribution of woodyspecies along the different DBH classes showed an inverted J shape (Fig.198) indicating a healthy regeneration status of the forests. The species identified to belong to

DBH classes included *Schefflera abyssinica*, *Pouteria adolfi-friederici*,*Syzygium guinnense*,*Croton macrostachyus* and *Ekbergiacapensis*,*Olea welwitschii* and *Ficus sur.*

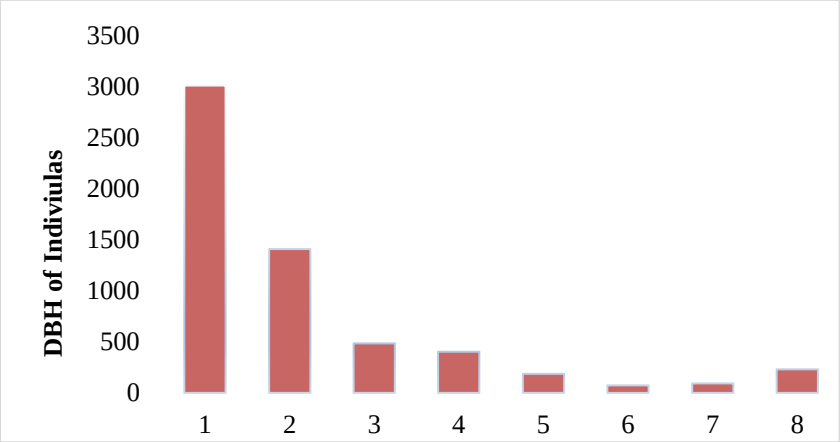



**Figure 19. Diameter class distribution of woody plants in Gesha-Sayilem forest**

(DBH) class as : 1 = 2.5-10 cm, 2 10.1-20 cm, 3= 20.1-30 cm, 4 = 30.1-50 cm, 5 = 50.1-70 cm, 6 = 70.1-90 cm, 7=90.1-110 and 8> 110 cm

### 4.4.3 Height class distribution

The first two height classes <5 and 5.1=10cm accounted for 77.8% of total individuals in the forest and a few individuals trees while largest height classes and accounting for 22.1%. The species that populated to short height classes were dominated by *Dracena afromontana, Galiniera saxifraga, Vepris daniellii,Maytenus gracilipes, Lepidotrichilia volkensii, Deinbolia kilim andscharica* and *Cyathea manniana* (Appendix5*)*.The tall height class in the upper heightclasses 6 and 7 were *Pouteria adolfi-friederici, Olea welwitschii, Croton macrostachyus, Ekbergia capensis, Schefflera abyssinica* and *Syzygium guineense*.

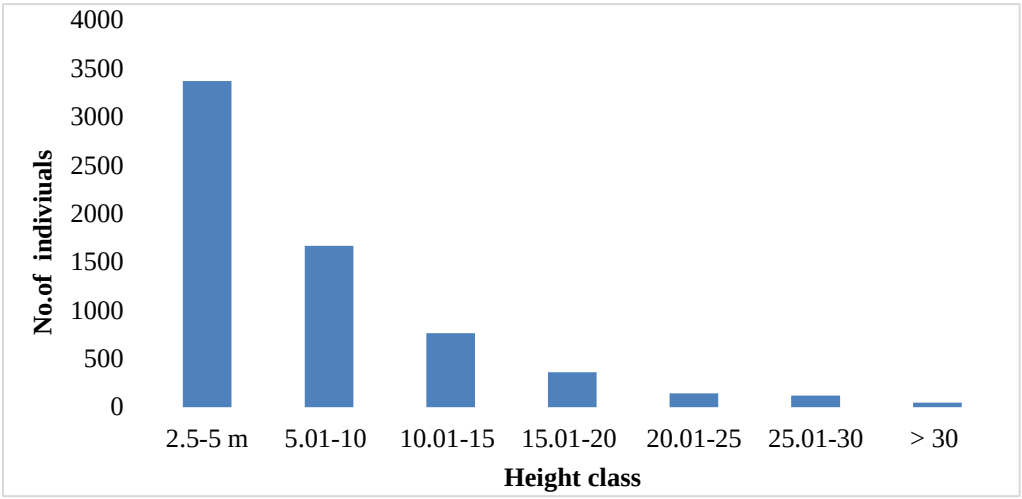



**Figure 18.Woody species density distribution by height classes**

### 4.4.4 Frequency

All woody plant species in the Afromontane rainforest of the study area were grouped into five frequency classes. These frequency classes are **E**=81-100%, D= 60-80%, C=41-60%B=20.1-40%andA=0-20% .Fig.20. Accordingly, *Galinierasaxifraga*, *Lepidotrichilia volkensii, Deinbollia kilimandscharica, Ilex mitis,Vepris danielli, Schefflera abyssinica, Syzygium guineense, Allophylus abyssinicus* and *Maytenus gracilipes* were the most frequent species in class **D** and **E.** On the other hand, the lower frequency classes comprised *Hagenia abyssinica, Ekbergia capensis, Dombeya torrida, Polysicas fulva, Hypericum revolutum in class **B** and **C**.* Apart from these the following woody plant species were the most frequent and recorded in more than 50% plots: This includes *Dracena afromontana*, *Pouteria adolfi-friederici,Rytigynia neglecta* and *Schefflera abyssinica.*

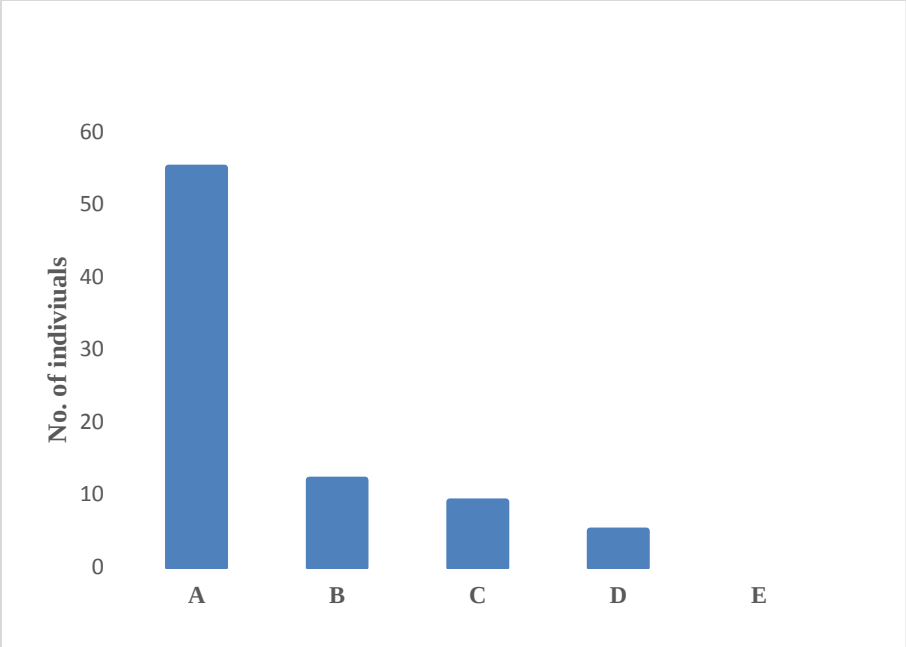



**Figure 19.Frequency distribution of woody species**

Frequency Class (A=0-20%, B= 21-40%, C= 41-60%, D =61-80%, E= 81-100%)

### 4.4.5 Basal area

The ten-top species with the largest basal area were indicated in (Table 25). About 43% of the basal area in Gesha-Sayilem Forest was contributed by *Schefflera abyssinica*, *Syzygium guineense*, *Pouteria adoferici* ,*Ilex mitis*, and *Croton macrostachyus*.Among these species, *Schefflera abyssinica* and *Syzygium guineense* had the highest dominance in the area since they had, more numbers of large-sized individuals than the other species. Small sized shrubs and trees with highest densities but with low contribution to the total basal area were *Galiniera saxifraga,Dracena afromontana* ,*Lepidotrium volkensi* and *Deinbolia kilimndascrica* with basal area values of 2%, 0.5%, 0.4 and 2.1% respectively.

**Table 25. Dominant trees with their percentage basal area and density in Gesha-Sayilem forest**

| Species | Basal ($m^2$ $ha^{-1}$) | % | Density $ha^{-1}$ |
|---|---|---|---|
| *Schefflera abyssinica* | 27 | 30 | 24.11 |
| *Syzygium guineense* | 15 | 16 | 47.00 |
| *Pouteria adolfi-friederici* | 13 | 14 | 43.00 |
| *Ilex mitis* | 9 | 10 | 53.60 |
| *Gallineria saxifraga* | 7 | 7 | 73.60 |
| *Prunus africana* | 4 | 5 | 13.21 |
| *Ekbergia capensis* | 4 | 5 | 2.70 |
| *Olea welwitschii* | 4 | 5 | 19.64 |
| *Macaranga capensis* | 4 | 5 | 41.60 |
| *Dracena afromontana* | 3 | 3 | 77.4 |
| Total | 90 | 100 | 395.86 |

### 4.4.6 Importance Value Index (IVI) of the species

The importance value index of woody species in the study area ranged from 0.04 to 12.21 (Appendix 6). The highest IVI was documented for *Schefflera abyssinica, Syzygium guineense, Pouteria adolfi-friederici,Gallineria saxifarga, Ilex mitis, Lepidotrichilia volkensii* and *Dracena afromontana*. The percentages of species in the IVI classes were 5%, 49%, 26%, 8% and 12% for class 1,2,3,4 and 5 respectively (Table 26).. The higher percentage of IVI value is found in class 4, 3, and lower IVI value was found in class 5 and 2. The rest of values found intermediate priority class (1). The highest percentage of (46.95 value in class four contributed by *Schefflera abyssinica* (12.2%), *Syzygium guineense*(8.04%),*Pouteria adolfi-friederici* (5.95%), *Gallineria saxifarga* (4.81), *Ilex mitis* (4.45), *Allophylus abyssinicus* (3.97), *Lepidotrichilia volkensii* (3.77), and *Dracena afromontana* (3.76). These species were, frequent and abundant in the forest and the list of under each IVI classes is shown in Table 27.

**Table 26.IVI classes, values, and percentage value for species belonging for each class**

| Class & values | No. of species | Sum of IVI | Percentage (%) |
|---|---|---|---|
| 5(<1) | 34 | 14 | 5 |
| 4(1-10) | 39 | 133 | 49 |
| 3(10.1-20) | 6 | 72 | 26 |
| 2(20.1-30) | 1 | 22 | 8 |
| 1(>30) | 1 | 33 | 12 |

Table 27**. List of species under each IVI priority class**

| **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|
| *Rhamnus prinoides* | *Bersama abyssinica* | *Pouteria adolfi-friederici* | *Syzygium guineense* | *Schefflera abyssinica* |
| *Teclea nobilis* | *Deinbolia kilimadcraensis* | *Gallineria saxifarga* | | |
| *Celtis africana* | *Vepris danielli* | *Ilex mitis* | | |
| *Ocotea kenyensis* | *Arundinaria alpina* | *Lepidotrichilia volkensii* | | |
| *Buddleja polystachya* | *Hippocratea pallens* | *Dracaena afromontana* | | |
| *Clerodendrum myricoide* | *Maytenus gracilipes* | | | |
| *Rubus steudneri* | *Oxyanthus speciosus* | | | |
| *Combretum paniculatum* | *Rytignia neglecta* | | | |
| *Oncoba spinosa* | *Sapium ellipticum* | | | |
| *Diosprous abyssinica* | *Hallea rubrostipulata* | | | |

### 4.4.7 Population structure of the species

In the present study, the population structure of woody species from diameter class distribution indicated, five main patterns ofpopulation distribution (Fig.21a-e). The first pattern approaches inverted J-shape pattern, where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the upper diameter classes.The species showing this pattern were *Bersama abyssinica, Dracaenaafromontana, Galiniera saxifraga*, *Deinbollia kilimandscharica*, *Millettia ferruginea* and *Oxyanthus speciosus*.The second pattern, is represented by Gauss type or bell shaped where the diameter distribution showed decrease in density from diameter class 1 and increasing in diameter class 2 and 3 and then decreases with increasing diameter and completely absent in upper diameter classes. Species exhibiting this pattern were *Croton macrostachyus,Masea lanceoata*, *Ficus sur*, *Cyathea manniana, Ehretia cymosa*, *Alangium chinense and Polysicas fulva.*The third pattern is a U-shaped, where the frequency is high in the lowest and highest DBH classes but very low in the intermediate classes.The species exhibiting such pattern is *Pittosporum viridiflorum, Dombeya torrida*, *Elaeodendron buchananii* and *Cassipoure*a *malosana*.The fourth pattern was the increasing number of individuals occurred at first two classes and then decreasing pattern up to higher classes. This pattern was represented by *Prunus africana, Schefflera abyssinica, Sapium ellipticum,* and *Olea welwitschii*.This pattern reveals that there had been selective cutting in the past and the species of this pattern has moderate reproduction and bad recruitment.The fifth type showed anirregular pattern which is represented by *Syzygium guineense* (fig 20e*).*

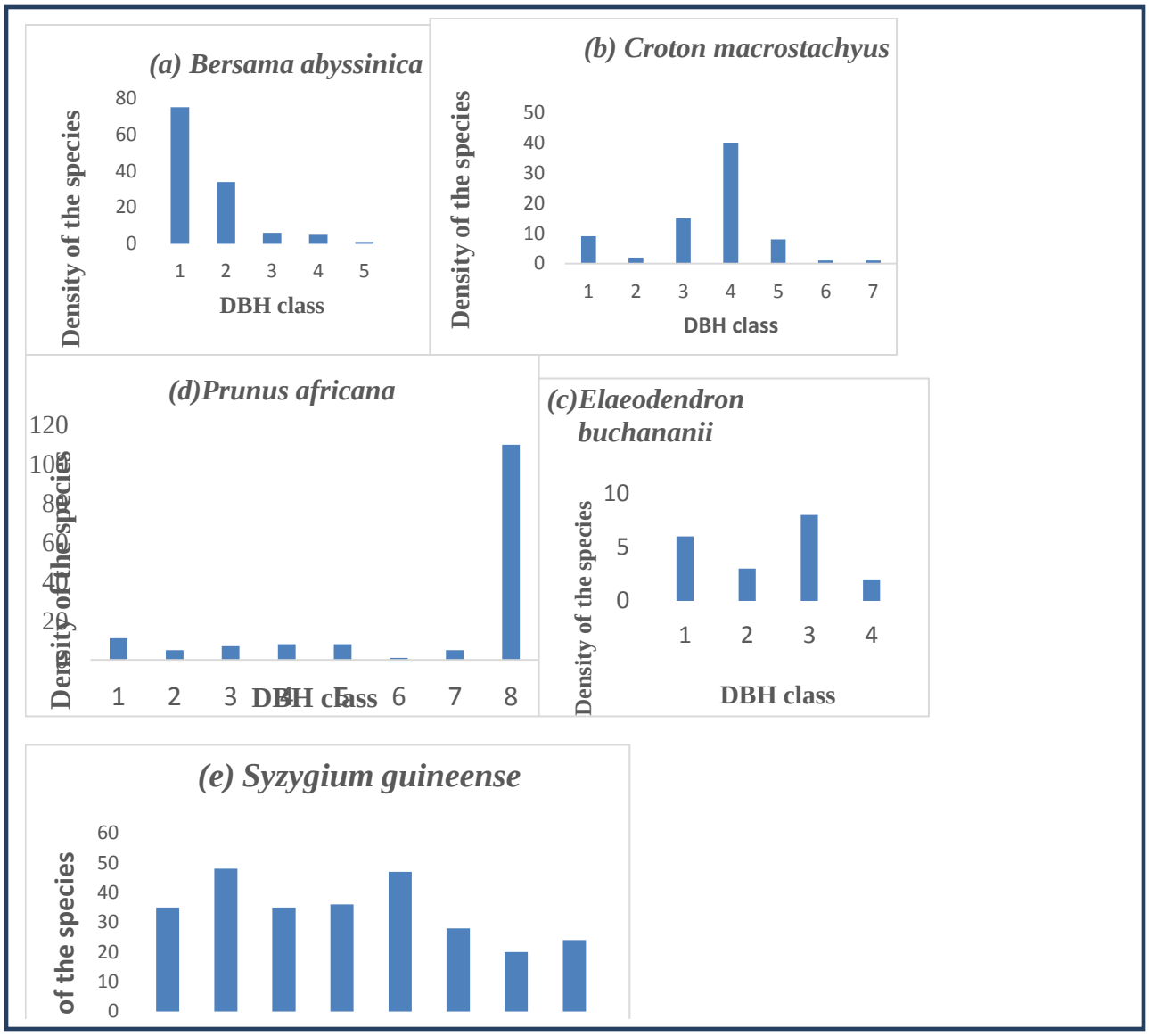



**Figure 20. Five patterns of selected population structure woody speciesbased on DBH. DBH class: 1 = 2.5-10 cm, 2 =10.1-20 cm, 3= 20.1-30 cm, 4 = 30.1-50 cm, 5 = 50.1-70 cm, 6 = 70.1-90, 7=90.1-120, 8=110-150**

### 4.4.8 Vertical structure

The vertical stratification of woody species of the study area was assessed using the IUFRO (International Union for Forestry Research Organization) Classification scheme (Lamprecht, 1989). Based on this classification, three vertical structures were identified: upper story (tree height higher than 2/3 of top height), the middle story (tree height between 1/3 and 2/3 of top height) and lower story (tree height lower than 1 /3 of the top

height). The tallest tree in the study area was *Pouteria adolfi-friedericii* with 45 meters. As the result, the upper story is represented by the height greater than 33.3,which accounts for 11.5% density of plant species whereas the middle story range from 16.6-33.3 accounting 13.09%. The lower story less than 16.6m accounting 75% of the species density. The lower story has a higher density (1056/ha) and species composition (78) as compared to the middle (182 $ha^{-1}$), with species composition of (55)and upper story (161 $ha^{-1)}$ with species composition of 19 (Table 28). All the woody species encountered in the upper story are also encountered in the middle and lower story comprising 39.2% except *Sapium ellipticum* and *Ekebergia capensis* only found in the middle and upper story. The important woody species in the upper story of forest were *Pouteria adolfi-friederici, Schefflera abyssinica,Prunus africana, Elaeodendron buchananii, Croton macrostachyus, Olea welwitschii, Ficus sur* and *Sapium ellipticum.*The species found in the middle story include *Ilex mitis, Allophylus abyssinicus, Millettia ferruginea* and *Croton macrostachyus.*Trees or shrubs found in lower story were *Vernonia auriculifera, Galinieria saxifraga,Maytenus gracilpes, Coffea arabica,Cleodendron myrioides,Pentas schimperiana, Rubus steudneri,Rhamnus prinoides* and *Deinbollia kilimandscharica.*

**Table 28. Vertical distribution of the total number of species and corresponding mean density of individuals per hectare.**

| Story | density of individuals $ha^{-1}$ | % | No. of species | % | Ratio of individuals to species ha-1 |
|---|---|---|---|---|---|
| Lower | 1056 | 84.2 | 78 | 55.3 | 1:14 |
| middle | 182 | 14.5 | 44 | 31.2 | 1:4 |
| upper | 16 | 1.3 | 19 | 13.5 | 1:.84 |
| Total | 1254 | 100 | 141 | 100 | |

### 4.4.9. Regeneration of the forest

The seedling and sapling density of 1330.6 and 661.0 were recorded from 78 woody species (Appendix 7). The ten top woody plant species contributed to 58.54% and 59% of the total seedling and sapling density respectively were *Gallineria saxifarga*, *Dracena afromontana*, *Allophylus abyssinicus*, *Phoenix reclinata*, *Pouteria adolfi-friederici*, *Syzygium guineense*, *Rytigynia neglecta*, *Maytenus gracilipes*, *Psychotria orophila*, and *Solanecio gigas*. Some species which have economic and ecological importance were absent in the regeneration assessment.These include *Schefflera absyssinica*, *Schefflera volkensii*, *Sapium ellipticum*, *Arundinaria alpina*, *Nuxia congesta* and *Diosprous abyssinica*. In analyzing the conservation status for sake of priority setting of all the species encountered in this forest, were classified into three groups based on total seedling and sapling density. Those species which are totally absent in the regeneration are grouped under **1**, others whose densities are greater than zero or less than 50 are classified in group **2**. Those greater than or equal to 50 are classified under in the group 3.Accordingly, those in group 1 are the first priority, group 2 second priority and group 3 are third priority for the conservation Table 29

**Table 29. Tree and shrub species regeneration categories for conservation priorities.**

| Group 1 | Group 2 | Group 3 |
|---|---|---|
| *Schefflera abyssinica* | *Alangium chinense* | *Ilex mitis* |
| *Arundinaria alpina* | *Lepidotrichilia volkensii* | *Syzygium guineense* |
| *Gouania longispicata* | *Millettia ferruginea* | *Pouteria adolfi-friederici* |
| *Jasminum abyssinicum* | *Olea capensis* subsp. *macrocarpa* | *Solanecio gigas* |
| *Erythrococca trichogyne* | *Croton macrostachyus* | *Maytenus gracilipes* |
| *Hallea rubrostipulata* | *Olea welwitschii* | *Phonix reclinata* |
| *Hypericum revolutum* | *Cassipourea malosana* | *Rytigynia neglecta* |
| *Schefflera myriantha* | *Vangueria apiculata* | *Allophyllus abyssinicus* |

The regeneration performance of all woody species based on seedling, sapling and mature plant in the forest were divided into five regeneration categories (Fig 21.a-e) The first category is corresponding to *Allophyllus abyssinicus (*Figure a):This pattern of distribution shows higher number of the seedlings and saplings than the mature plants.The regeneration pattern has many individuals at seedling stage and decreasing number of individual sequentially at saplings and adult stages and this revealed typical inverted J-shape curves. The plant species included in this category were *Rytigynia neglecta,Apodaytes dimidata* and *Phoenix reclinata*. The second pattern represented by *Ilex mitis* (Fig 2b) that consists of more mature individuals but with a few numbers of seedlings and saplings. Species with such type of pattern are poor in their reproduction and recruitment potential because there are not represented at the juvenile stage, which can replace mother plant. The plant species under this group includes *Olea cape*nsis subsp. *macrocarpa* and *Olea welwitschii*.The third pattern was *Schefflera abyssinica* ( fig.c) where the seedling and saplings aretotally absent andonly matured individuals are represented indicating poor reproduction and as a result the seedlings are not seen on the ground.This categories in includes, *Sapium ellipticum,Ekebergia capensis* and *Arundinaria alpina*.The fourth distribution pattern of regeneration was represented *by* Gaussians type of distribution where the number of seedling and matured trees are more than seedling (fig.d).This pattern is represented by *Maesa lanceolata* and *Solaneciogiga*s.The fifth types of regeneration pattern were represented *by* more numberof seedling and matured plantsandless number of sapling *(*fig.e*).*Species with this pattern of regeneration behavior include *Deinbollia kilimandscharica, Bersama abyssinica,*and *Croton macrostachyus* and *Vernonia auriculifera*

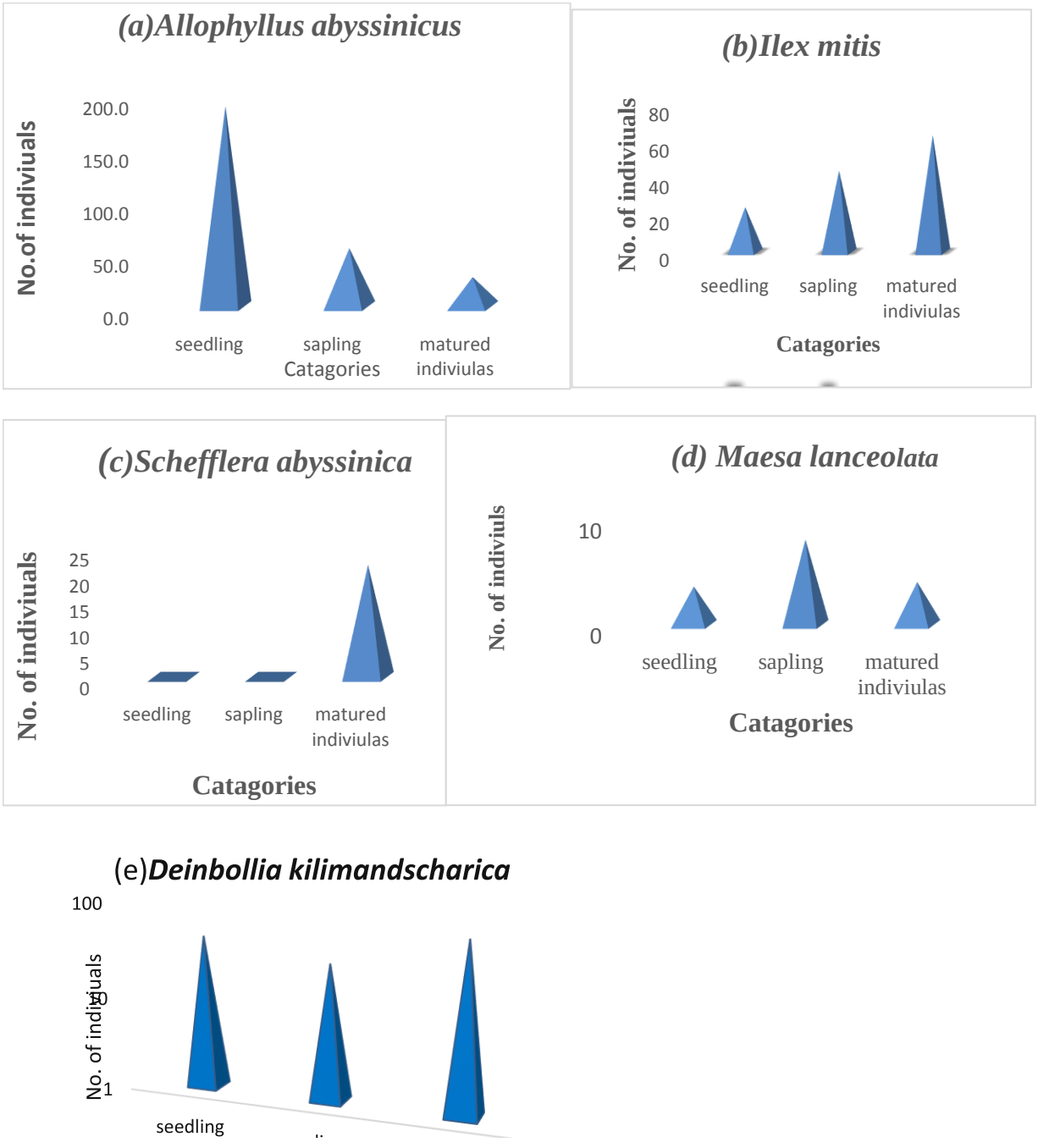



**Figure.21 (a-e).Seedlings, saplings and matured woody species distribution occurring in moist Afromontane vegetation of Gesha-Sayilemforest.**

### 4.5 Carbon Stock in the different pools

#### 4.5.1 Above ground biomass

A total of 78 woody plant species were recorded from the study plots for the above ground biomass estimation using the allometric equation developed by (Chave *et al*.,2014).The total above ground carbon density of the forest was 201.4 ton $ha^{-1}$ (Appendix 8). The minimum and maximum above ground biomass per plot were 2266.3 and 0.92 t $ha^{-1}$respectively.The mean above and below ground biomass per plot was 349.9 and 70-ton $ha^{-1}$ respectively. Similarly, the maximum and minimum carbon stock per lot was 1065 and 0.44-ton $ha^{-1}$. The mean above ground biomass and carbon stock of the study forest were found to be 349.9 and164.5-ton $ha^{-1}$ respectively (Appendix 8). The above ground biomass and carbon stock-density of the woody species vary among the plant species (Appendix 9).The highest above ground carbon density per tree was obtained for a few woody species having higher DBH value. The species with the highest carbon stock density were recorded for *Schefflera abyssinic*a (58.75t $ha^{-1}$), *Ekebergia capensis* (31.71t $ha^{-1}$), *Prunus africana* (5.6 t $ha^{-1}$),*Olea welwitschii* (42.12 t $ha^{-1}$),*Pouteria adolfi-friederici*, (10.62t $ha^{-1}$), *Syzygium guineense* (15.80t $ha^{-1}$), *Elaeodendron buchananii (*7.04 t $ha^{-1}$), *Sapium ellipticum (*7.8t $ha^{-1}$*)* and *Croton macrostachyus* (7.48 t $ha^{-1}$) (Table 30). These species contributed 65% of the total carbon stock density in the forest. The least AGC were recorded for *Rhamnus prinoides, Hypericum revolum* and *Nuxia congesta.*

**Table 30. Carbon stock (t C ha-1) of above and below groundin tree species with the highest IVI Values in Gesha-Sayilem forest.**

| **Species name** | Carbon in AGB **t/ha$^{-1}$** | Carbon in BGB **t/ha$^{-1}$** | **Total carbon t/ha/$_{tree}$** | **$CO_2$ t/ha$^{-1}$/tree** |
|---|---|---|---|---|
| *Schefflera abyssinica* | 58.75 | 27.61 | 86.36 | 316.9 |
| *Ekebergia capensis* | 31.71 | 14.91 | 46.62 | 171.1 |
| *Prunus africana* | 27 | 5.4 | 32.4 | 118.908 |
| *Olea welwitschii* | 42.12 | 19.80 | 61.92 | 227.2 |
| *Pouteria adolfi-friederici* | 10.62 | 4.99 | 15.61 | 57.3 |
| *Syzygium guineense* | 15.80 | 7.43 | 23.23 | 85.3 |
| *Elaeodendron buchananii* | 7.04 | 3.31 | 10.35 | 38.0 |
| *Sapium ellipticum* | 7.80 | 3.66 | 11.46 | 42.1 |
| *Croton macrostachyus* | 7.48 | 3.51 | 10.99 | 40.3 |
| *Elaeodendron buchananii* | 7.04 | 3.31 | 10.35 | 38.0 |
| *Apodytes dimidata* | 5.33 | 2.51 | 7.84 | 28.8 |
| *Ficus sur* | 5.33 | 2.51 | 7.84 | 28.8 |
| *Ilex mitis* | 3.15 | 1.48 | 4.63 | 17.0 |
| *Macaranga capensis* | 2.71 | 1.27 | 3.98 | 14.6 |
| *Euphorbia ampiphylla* | 2.58 | 1.21 | 3.79 | 13.9 |
| *Macaranga capensis* | 2.71 | 1.27 | 3.98 | 14.6 |
| *Euphorbia ampiphylla* | 2.58 | 1.21 | 3.79 | 13.9 |
| *Allophyllus abyssinicus* | 1.52 | 0.71 | 2.23 | 8.2 |
| *Dracena afromontana* | 0.97 | 0.46 | 1.43 | 5.2 |
| *Gallineria saxifarga* | 0.65 | 0.31 | 0.96 | 3.5 |
| *Rytignia neglecta* | 0.64 | 0.30 | 0.94 | 3.4 |
| *Millettiaferruginea* | 0.61 | 0.28 | 0.89 | 3.3 |

### 4.5.2 Carbon stock in below ground biomass

The total minimum and maximum below ground biomass of the trees and shrubs in the study forest was 0.187 and 453.2 tons per ha$^{-1}$ with a mean value of 71 tons per ha$^{-1}$. Similarly, the minimum below ground carbon was 0.08 t ha$^{-1}$ whereas the maximum below ground carbon stock was 213 t ha$^{-1}$ with mean value of 33.3 t ha$^{-1}$.

### 4.5.3 Carbon stock in Litter, herb and sapling biomass

The analysis of litter carbon concentration per sample plot gave a minimum of 0.01 ton/ha$^{-1}$ and maximum of 6 ha$^{-1}$ with a mean value of 1.5-ton ha$^{-1}$ indicating a variation

between samples plots (Appendix 11). The minimum and maximum carbon content of the herb was 0.06 and 2.04 t $ha^{-1}$and with mean value of 0.68-ton $ha^{-1}$ similarly the minimum and maximum shrub carbon stock density per plot was 0.01 and 4.2ton $ha^{-1}$ respectively with mean value of 0.46-ton $ha^{-1.}$

### 4.5.4 Soil organic carbon

Laboratory analysis of soil for soil organic carbon showed that, the mean soil organic carbon of Gesha-Sayilem forest was 6.7% with a minimum value of 2.28 to the maximum of 17%. The soil bulk density ranged from 0.5 g $cm^{-3}$ to 1.4 g /$cm^{-3}$ while the average soil bulk density was 0.7 g/ $cm^{-3}$ indicating the presence of high soil organic matter in mineral soil. The mean soil carbon stock density was 137.6 tons of carbon $ha^{-1}$, while the minimum and maximum soil carbon stock density were 302.94 and 44.16 t of carbon $ha^{-1}$ respectively (Appendix 10). This soil carbon pool sequestered a minimum and maximum $CO_2$ value of 162 t $ha^{-1}$ and 1020.85t $ha^{-1}$, respectively.

### 4.5.5 Carbon pools in dead wood

The collection of dead wood from sample plots indicated that the study forest had abundance of dead wood on the forest floor.The average carbon stock density of dead wood per plots was 23 tons/ha. The carbon density of dead wood was lying on the forest floor was higher compared to that of carbon density of standing dead wood Fig 24.

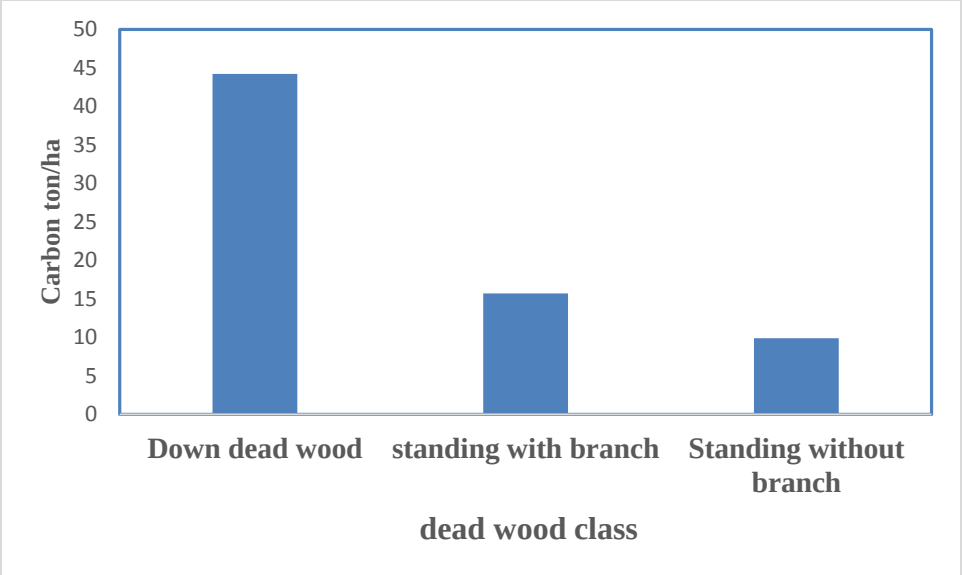



**Figure 22.Carbon stock in different deadwood classes**

### 4.5.6 Total Carbon Stock density of Gesha-Sayilem Forest

The total carbon stock of the study forest was calculated by summing of all the carbon stock value of each carbon pool (above ground and below ground carbon, litter carbon, herbs, sapling, dead wood and soil organic carbon) for all plots. The carbon stock was found to be ranged from a the minimum 69 t/ha plot 17 to a maximum of 1665.69 t/ha in plot 63 with a corresponding minimum value of 2265.53 and maximum value 6113.0823 $CO_2$ equivalents (Fig.24). This study shows that carbon stock storage capacity of the study forest varies significantly between different pools of carbon. The mean carbon density in all carbon pools of the study forest was 383.86 $ha^{-1}$ (Appendix 11). The summary of the carbon pools was given in Table 31.

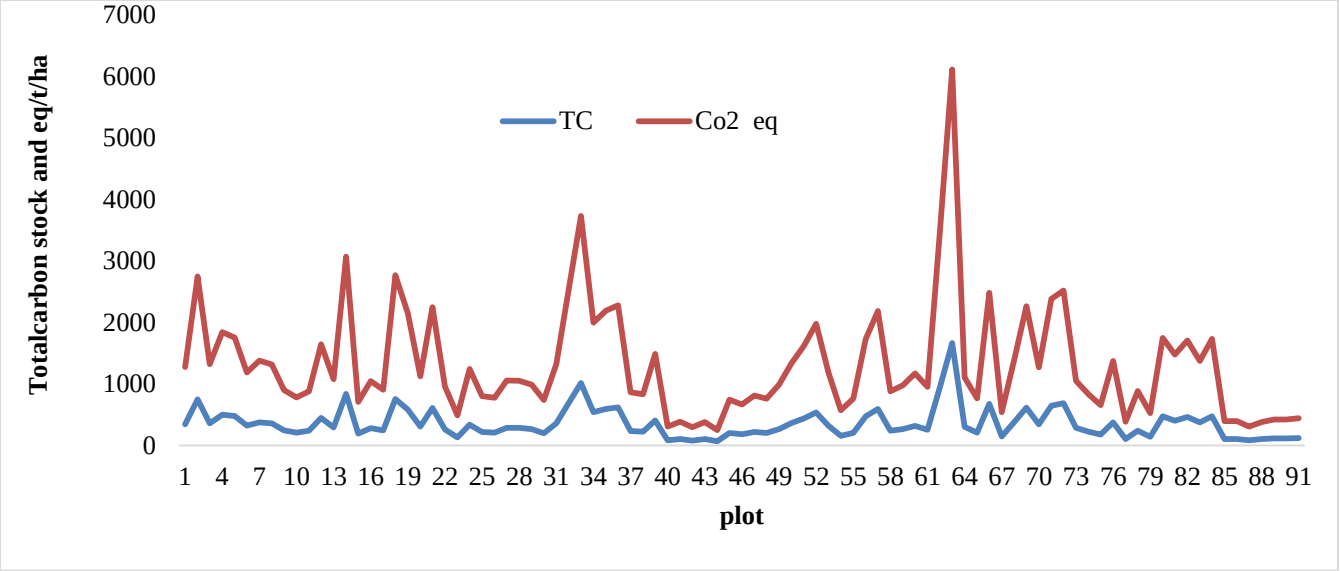



**Figure 25.Total carbon stock and $CO_2$eq. for each plot.**

**Table 31. Summary of mean biomass and carbon stock of different carbon pools in the study forest**

| **No. Plots** | Carbon pools | | | | | | | | Carbon stock |
|---|---|---|---|---|---|---|---|---|---|
| 90 | AGB | AGC | BGC | LC | HC | SAPC | Dead wood | SOC | 362.4 |
| Mean t ($ha^{-1)}$ | 349.9 | 174.95 | 34.3 | 1.27±0.54 | 0.68 | 0.47 | 23.2 | 128±40 | |
| % | | 48.19 | 9.44 | 0.33 | 0.177 | 0.122 | 6.39 | 35.5 | |

### 4.5.7 Carbon Stock and Environmental Variables

**The Effect of altitude on carbon pools of the Gesha-Sayilem forest**

The effect of altitude on Gesha–Sayilem forest for different carbon pool was determined. There was a positive and very weak relationship was observed between the above ground carbon and altitudinal gradient $F1\ 4 = 4.55$, $R^2 = 0.038$, $P < 0.05$). The linear regression result showed that altitudinal gradient has an influence on above ground carbon (Figure 23A). The similar effect of the altitudinal trend was observed for below ground carbon and it has weak relationship ($F= 4.55$, $R^2= 0.038$). The linear regression analysis between

altitude and soil organic carbon in the forest was not significant ($F$=1.34, $R^2$= 0.004, $P$ = 0.25). The regression analysis between altitude and non-tree vegetation (herb) were significant (F= 58.25, $R^2$=0.39), P-value =0.035 Fig.23B, but the altitude does not indicate any trend of increment of litter along the altitudinal gradient in Gesha–Sayilem forest (Fig25).

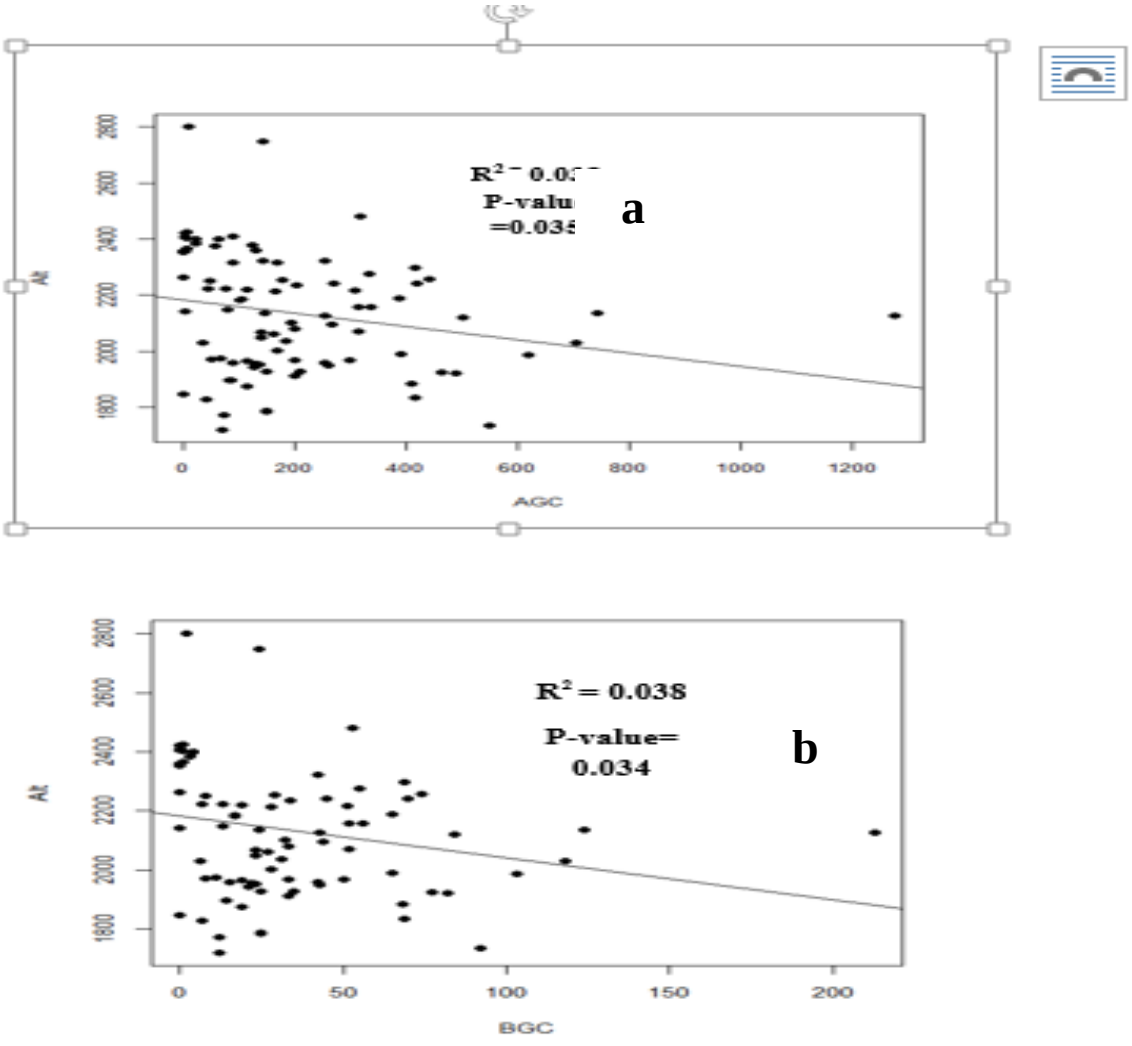



**Figure 26.The AGC and BGC against altitude (a-b) in Gesha-Sayilem forest**

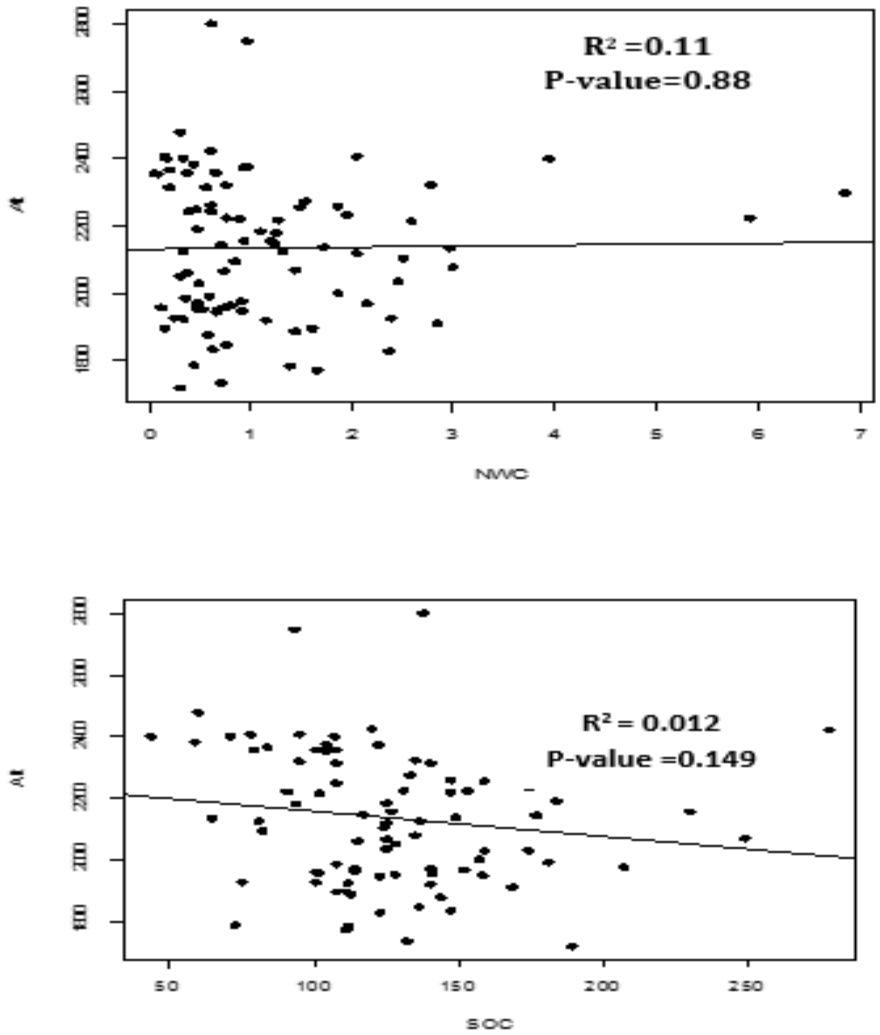



**Figure 27.The SOCand NWC against altitude (c-d) in Gesha-Sayilem forest**

The grouping of the carbon stock into lower, middle and higher altitudes indicated that the higher carbon stock recorded from middle and higher altitudes are provided 180.61±26.48and 158.83 t $ha^{-1}$ respectively as compared tolower altitudes (48.75t $ha^{-1}$) of the study forest. The litter carbon density of the forest did not show a significant variation between upper, lower and middle altitudes but it is relatively higher in the middle and higher altitudes with the mean carbon density of 3.75 t $ha^{-1}$ and 0.86 t $ha^{-1}$ respectively (Table27). The soil organic carbon density of study forest was low in lower altitude as compared to the middle and higher altitudes. The lower altitude had a soil carbon density

of 98.18 t ha-1 but middle and higher altitude stored carbon density of 127.6and 128 t $ha^{-1}$ respectively(Table 29).The overall carbon density of the forest significantly varies ($p<0.05$) between lower, middle and higher altitudes. The maximum total carbon density was recorded at middle (729.76 t $ha^{-1}$) and higher (741t $ha^{-1}$). The lower carbon stock density was recorded in lower altitudes with the mean value of 261t/$ha^{-1}$ (Table32).

**Table 32.Mean biomass and carbon stock (t $ha^{-1}$) in different pools and altitudinal gradient**

| Carbon pools | Lower | Middle | Higher | F | P-value |
|---|---|---|---|---|---|
| AGB | 103.72±35.5 | 384.47±56.3 | 337.9±42.3 | 6.23 | 0.003 |
| AGC | 48.75±16.7 | 180.61±26.48 | 158.83±19.8 | 6.24 | 0.003 |
| BGC | 9.75±3.34 | 36.13±5.2 | 36.72±6.4 | 4.507 | 0.014 |
| LC | 0.60±**0**.114 | 3.75±.3.12 | 0.860.6± 0.087 | 0.730 | 0.485 |
| SOC | 98.18±8.52 | 127.61±4.5. | 128.00±9.11 | 3.232 | 0.044 |
| HC | 0.38a±0.17 | 0.44a±0.11 | 0.19a±0.2 | 0.52 | 0.595 |
| SPC | 0.56a±0.36 | 0.81a±.61 | 0.59a±0.27 | 1.797 | 0.172 |
| Total Carbon density | 261.7±30.6 | 729.76±88.1 | 741.01±110 | 4.94 | 0.009 |

**Pearson correlation**

The analysis between carbon stock of different pools and environmental factors ( altitude, slope, aspects and disturbance and species diversity and richness indicated that a significant positive correlation was observed between altitude and AGC, BGC and but negative correlation with SOC. The slope is positively correlated with all carbon pools while aspect is negatively correlated but the correlation was not significant.The disturbance is negatively correlated for carbon pools (AGC, BGC, and SOC). A strong

positive correlation was obtained for species diversity and richness with AGC, BGC Table 33.

**Table33.Person correlation coefficients (r) between Carbon stock and environmental variables.**

| Variables | AGC | BGC | LC | SOC |
|---|---|---|---|---|
| Slope | 0.033 | 0.033 | 0.037 | 0.154 |
| Aspect | -113 | -113 | -172 | -0.176 |
| Disturbance | -0.249* | -0.249* | -0.150 | -0.300** |
| Species diversity | 0.405** | 0.405** | 0.172 | 0.176 |
| Species richness | 0.371** | 0.371** | 0.312 | 0.103 |

***P-<0.05, **P-<0.001, ***P-<0.0001**

### 4.5.8 Biomass estimation using the allometric equation

The summary of the mean, maximum and minimum DBH, height and wood density and dry weight of five plant species were summarized in Table34. The highest mean dry weight of the above ground biomass was obtained for *Apodytes dimidiata* **,** followed by *Sapium ellipticum* and *Ilex mitis*. Similarly,the highest mean above ground biomass was shrubs was obtained for G*aliniera saxifraga* and least was obtained for *Vernonia auriculifera.*

**Table 34. Summary of the mean biomass for five dominant tree and shrubs species in Gesha-Sayilem forest.**

| species | Diameter | | | Height | | | Wood density | | | Above ground (kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | mean | Min | Max | mea.n | Min | Max | mean | Min | Max | Mean |
| *Apodytes dimidiata* | 10.2 | 89.17 | 41.08±19. | 4 | 25 | 13.4±6 | 0.22 | 0.86 | 0.53 | 125 | 4668 | 959±320 |
| *Ilex mitis* | 7.3 | 80.2 | 38.91±18 | 6 | 25 | 14.7±5 | 0.21 | 0.82 | 0.45 | 14 | 6831 | 861±239 |
| *Sapium ellipticum* | 8 | 89.2 | 48.4±18 | 5 | 35 | 19±7 | 0.2 | 0.7 | 0.43 | 97 | 4226 | 553±167 |
| *Galiniera saxifraga* | 14 | 55 | 29±10 | 3 | 8 | 4±0.73 | 0.32 | 0.82 | 0.53 | 23 | 43.3 | 25.2±17 |
| *Vernonia auriculifera* | 2.16 | 19 | 36±25 | 2 | 9 | 3±1.7 | 0.23 | 0.6 | 0.33 | 7 | 40 | 19.6±10 |
| *N* | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |

**Pearson correlation of dendrometric variables to biomass compartments**

The pearson's correlation analysis between above ground biomass and dendrometric variables (DBH, Height and wood density) are shown in Table 35. The above ground biomass was strongly correlated with DBH was the most influential factors affecting the biomass of the trees and shrubs. Height is the second factor that was strongly correlated with biomass.Wood density on the otherhand was poorly correlated with above ground biomass. The analysis of sub biomass compartment of trees and shrubs showed that stem biomass was strongly correlated with DBH in all species studied. However wood density is poorly correlated in this aspect except for *Apodytes dimidiata* and *Sapium ellipticum* No significant correlation were obtained between height,.both branches and foliage's compoents positively correlated with DBH and height but no had significant correlation with wood density for *Ilex mitis, Galiniera saxifraga* and *Vernonia auriculifera*.

**Table 35.. Pearson's correlation coefficients between biomass compartments (and dendrometric variables for tree and shrub species**

| Plant species | Biomass component | Dendrometric variables | | |
|---|---|---|---|---|
| | | DBH(cm) | H(m) | WD(g·cm–3) |
| *Apodytes dimidata* | stem | 0.783*** | -0.046ns | 0.63*** |
| | branch | 0.37* | 0.49ns | -0.080 |
| | leaves | 0.74** | 0.83** | 0.48ns |
| | Above | 0.84*** | 0.69*** | 0.56** |
| *Ilex mitis* | Stem | 0.75*** | 0.79*** | 0.43* |
| | branch | 0.85*** | 0.75*** | 0.44ns |
| | leaves | 0.50** | 0.41* | 0.04ns |
| | Above | 0.84*** | 0.73*** | 0.43* |
| *Sapium ellipticum* | stem | 0.6535*** | 0.54819** | 0.336ns |
| | branch | 0.46* | 0.29ns | 0.39ns |
| | leaves | 0.69** | 0.38ns | 0.34ns |
| | Above | 0.84*** | 0.88*** | 0.83*** |
| *Galiniera saxifraga* | Stem | 0.69*** | 0.36ns | 0.39ns |
| | branch | 0.54** | 0.34ns | 0.33ns |
| | Leaves | 0.58*** | 0.39ns | 0.53** |
| | Above | 0.72*** | 0.62*** | 0.41* |
| *Vernonia auriculifera* | Stem | 0.85*** | 0.22ns | 0.12ns |
| | Branch | 0.82*** | 0.20ns | 0.12ns |
| | Leaves | 0.64*** | 0.09ns | 0.08ns |
| | Above | 0.84*** | 0.55** | 0.12ns |

ns not significant, dbh diameter at breast height, DSH stump diameter at 30 cm CA, Crown area and wood density (WD). * $p \leq 0.05$; ** $p \leq$ **$p \leq 0.001$

### 4.5.9Trimmed branch, twigs and leave biomass of the tree

The average wood aliquot moisture content from oven dry biomass varied from 0.34 in Sapium ellipticum to 0.54% in *Apodytes dimidiate* while the average leaf aliquot moisture content ranged from 0.32%, in *Ilex mitis* to 0.4% in *Apodytes dimidiate* (Table 36*)*. The mean dry wood biomass was highest for *Ilex mitis* and followed by *Sapium ellipticum* and *Galiniera saxifraga*. The lowest dry wood biomass was obtained for *Vernonia auriculifera*. Similarly, the dry leaf biomass was higher for *Ilex mitis* and relatively lower for the rest of the species. The overall dry section of trimmed branch including twigs and leave biomass highest for *Ilex mitis* (5.5kg) and *Apodytes dimidiata* (4.2 kg) and *Sapium ellipticum* (3.4) Table 36.

**Table 36.Allometric equations for determining Trimmed twigs and leavesof the tree species**

| Plant species | Mean basal diameter (cm) | Mean Fresh wood (Kg) | wood moist ure | Dry wood (Kg) | Fresh leaf (Kg) | Leaf moist ure | Dry leaf (Kg) | Total $B_{trimmed\ dry}$ (kg) |
|---|---|---|---|---|---|---|---|---|
| *Ilex mitis* | 9 | 12 | 0.4 | 4.8 | 5 | 0.32 | 1.6 | 5.5 |
| *Apodytes dimidiata* | 10 | 8.8 | 0.54 | 3.6 | 3 | 0.4 | 4.7 | 4.2 |
| *Sapium ellipticum* | 6 | 5 | 0.34 | 2.7 | 2 | 0.36 | 0.72 | 3.4 |

### 4.9.10 Regression model for determination of biomass of the small branches

From the regression model between the dry biomass of trimmed biomass and the basal diameter, values of "a" and "b" were known and the biomass of untrimmed small branches which was on the tree were determined by inserting the basal diameter to the model equations "a+bD$^{c"}$Table 37. Accordingly the average biomass of un trimmed small branches for *Ilex mitis*, *Apodytes dimidata* and *Sapium ellipticum* were 46, 121and 86 **(**kg) respectively.

**Table 37. Allometric equations for determining untrimmed dry biomass of the small branches of the species**

| Plant species | Mean basal diameter | a | b | Allometric model | P-value | Biomass of untrimmed branch | $R^2$ |
|---|---|---|---|---|---|---|---|
| *Apodytes dimidata* | 8.8±2.7 | -2.56 | 1.55 | -2.56+1.55basalD | 0.00 | 121 | 0.72 |
| *Sapium ellipticum* | 6.6±3.05 | -3.38 | 1.53 | -3.38+1.53basalD | 0.00 | 85 | 0.90 |
| *Ilelx mitis* | 4.5±1.6 | -5.37 | 1.66 | -5.37+1.66 basalD | 0.00 | 46 | 0.87 |

### 4.5.11 Biomass distribution within trees compartments

The distribution of mean biomass fractions for the trees and shrubs showed that on average stem, branch and leaf biomass contributed 70.8%. 24.6% and 1.47% of above ground biomass in *Apodytes dimidata* (47.8%, 49.2% 2.9%) in *Sapium ellipticum* (82.4, 34.7, 8.11%) in *Ilex mitis* (36.5%, 34.3 % 29.17%) in *Gallinaria saxifraga*) and 34.6%, 49.8%, 15.6% in *Vernonia auriculifera* respectively Fig.26. The highest percentage of stem biomass accumulated in *Ilex mitis, Apodytes dimidata* and *Gallinaria saxifraga*. The branch biomass was also highest in *Sapium ellipticum* and *Vernonia auriculifera*. Foliage had the lowest contribution towards the total biomass in all species.

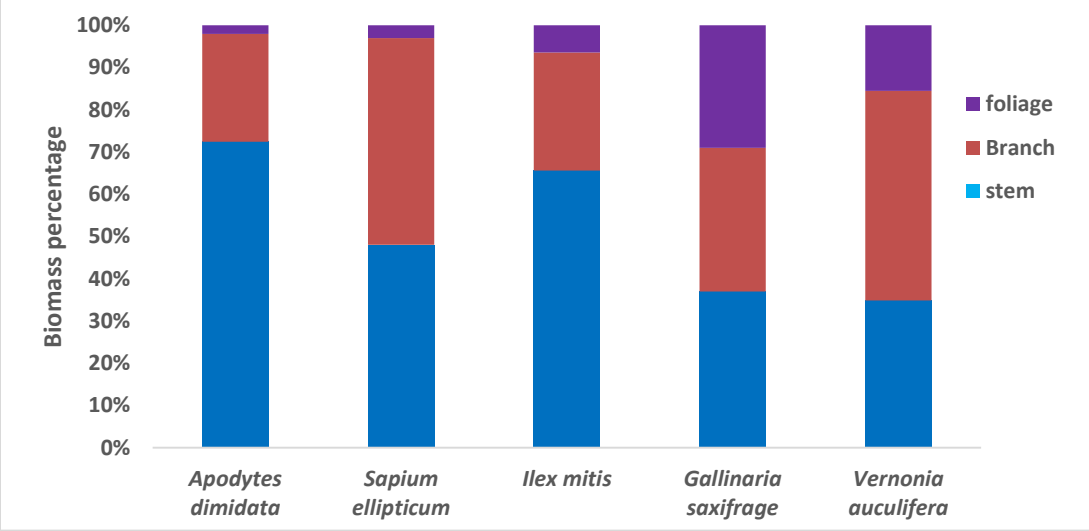



**Figure 23.Aboveground biomass partitioning for the main sampled tree and shrub species sampled**

### 4.5.12 Model selection and validation

The calculated model parameters for the above ground biomass were statistically significant ($p < 0.001$) with independent variables and the adjusted $R^2$ value ranges between 70-87 % and lower value of AIC (Akaike information criterion) were obtained ( Table 38). Accordingly,the combination of DBH, Height and wood density model provided the best fit in *Apodytes dimidata* with a $R^2$ value of 0.87 and standard error

percentage of 0.63. On the other hand, the DBH and Height were found to be the best fit variables for *Gallinaria saxifraga* and *Sapium ellipticum with* $R^2$,value of 0.73 and *0.81*and AIC value of 34.24 *and* 59.25 respectively.The DBH alone provided the best fit *in Ilex mitis and Vernonia auriculifera* with adj $R^2$ the value of 0.87, and 0.70 and lower standard error and AIC was obtained. The selected models were also validated for accuracy based on observed and predicted data with $R^2$ values Fig. 29. Furthermore, model validation also tested on the behavior of the residual errors plotted versus their fitted values (Fig. 30). The plot in a standard Q-Q plot (Fig 29-b), showed that the residual errors were normally distributed with outlayers indicating the models are fitting normally with independent variables. The scale-location plot (Fig 29-c) shows the square root of the standardized residuals as a function of the fitted values and in this graph,there was no obvious trend which is one property of good model validation.The residual versus leverage plots (fig 29-d) shows that how far away the independent variable values of an observation are different from those of the other observations.The contour lines for the Cook's distance, which is another measure of the importance of each observation to the regression. If the Cook's distances larger than 1 are suspicious and suggestthe presence of a possible outlier but our model prediction of Cook's distance between 0.5-1(Fig 27) indicating the good quality of the model. The graphical presentation of model validation for five plant species wasshown in Appendix 13. `

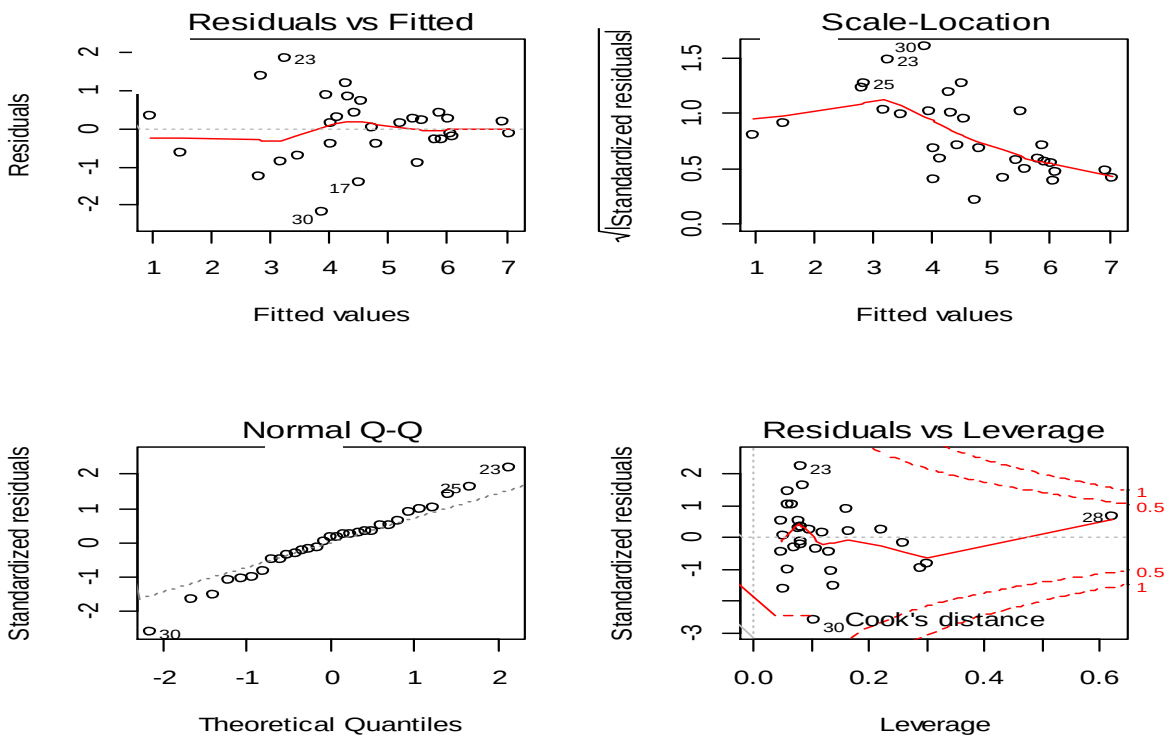
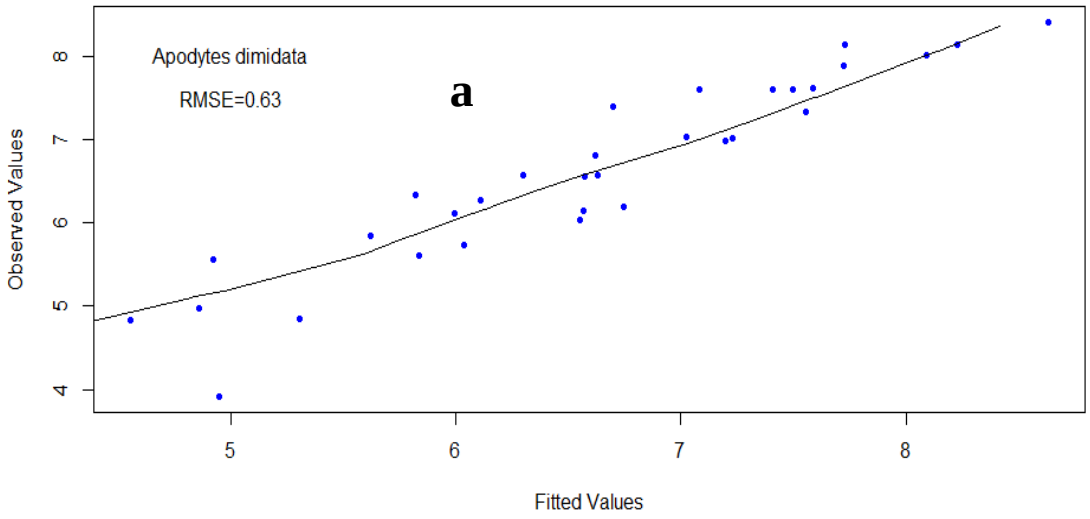
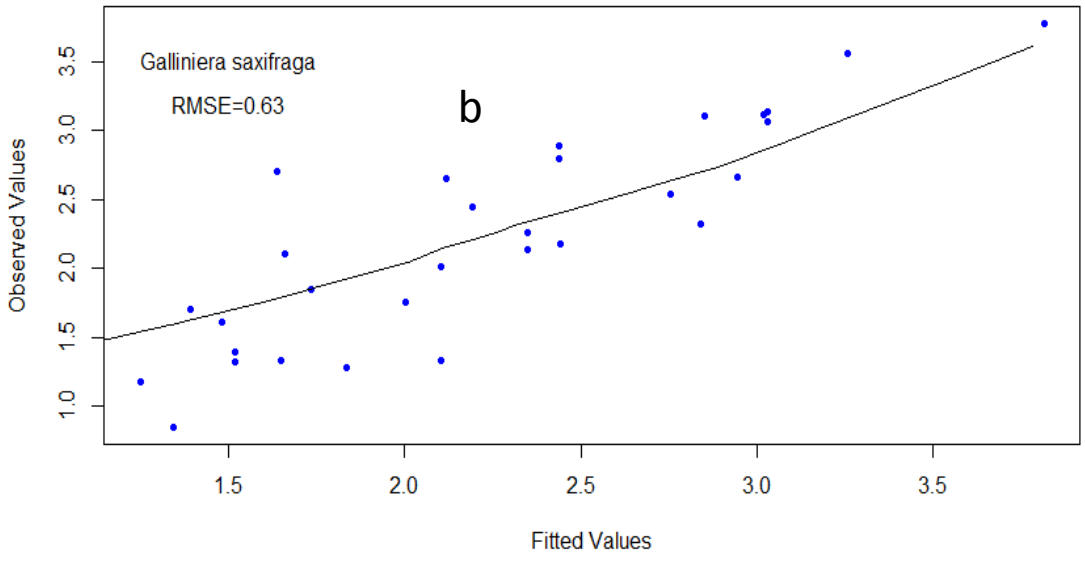


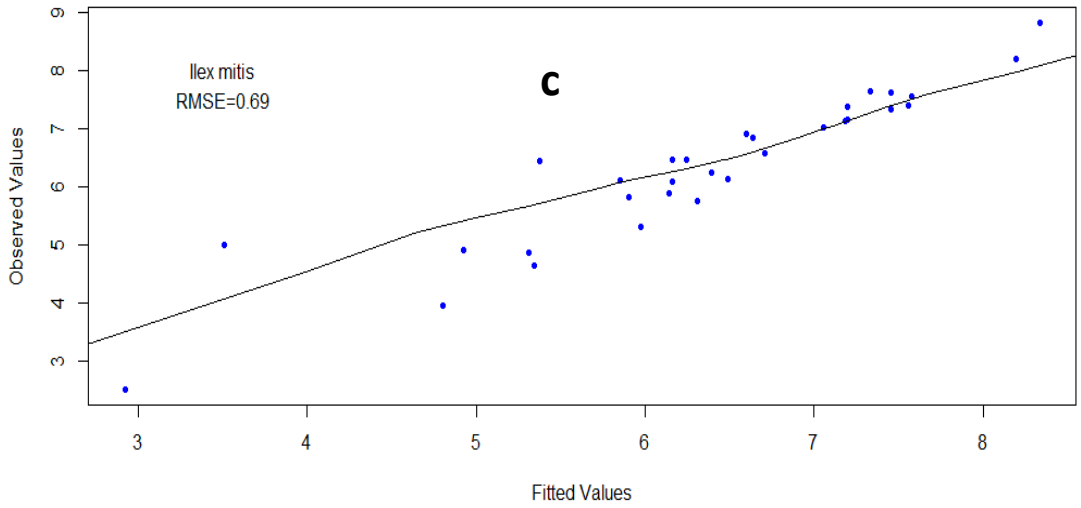

**Figure 24. Residuals plotted against fitted values (left) and quantile–quantile plot(right) and residuals versus leverag**

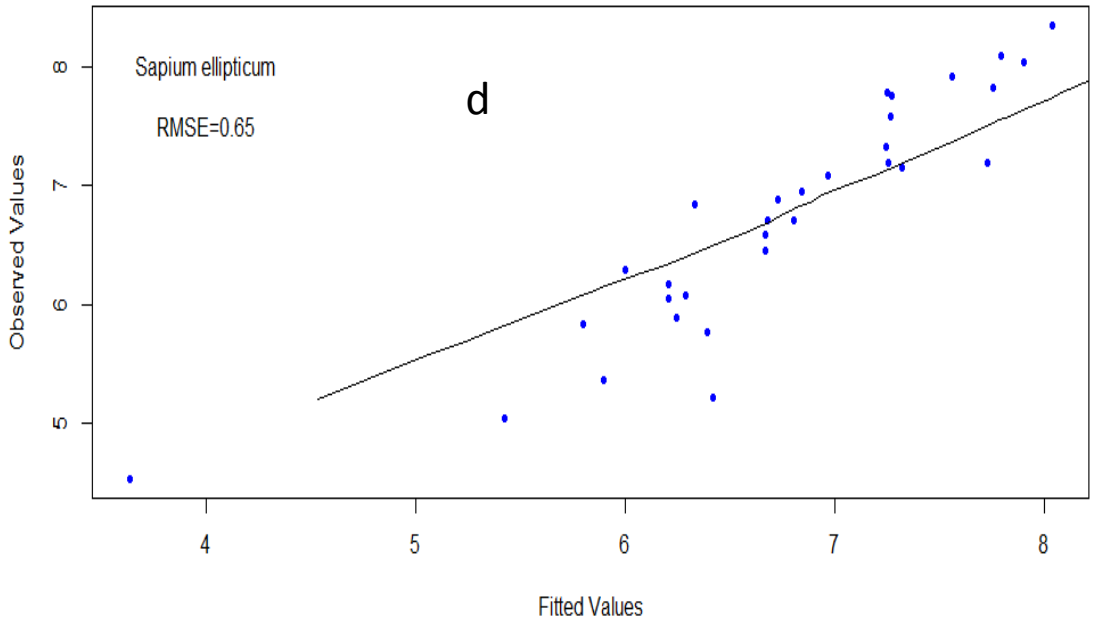
**Table 38. Model decription for the fitted models of the above ground biomass for the study species**

| *Species* | Model for total AGB | *Parameter Estimates* | | | | Model performance | | |
|---|---|---|---|---|---|---|---|---|
| | | **(*std. error*)** | **(*std. error*)** | **(*std. error*)** | **(*std. error*)** | **AIC** | **$R^2$** | *Vif* |
| *Apodytes dimidata* | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \beta_3 \log(D) + \varepsilon$ | 1.91(0.69) * | 1.08(0.21)*** | 0.56(0.20)* | 1.00(0.33)** | 37.06 | 0.87 | 1.91 |
| *Galiniera saxifraga* | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \varepsilon$ | -3.29(0.70)*** | 1.21(0.23)*** | 1.10(0.25)*** | - | 34.24 | 0.73 | 3.29 |
| *Ilex mitis* | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$ | -1.47(0.57)* | 2.20(0.16)*** | - | - | 46.36 | 0.86 | 1.121 |
| *Sapium ellipticum* | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \varepsilon$ | -0.22(0.63) | 1.17(0.26)*** | 0.88(0.28)** | - | 39.25 | 0.81 | 1 |
| *Vernonia auriculifera* | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$ | 6.00(0.30)*** | 1.51(0.18)*** | - | - | 58.97 | 0.69 | 1 |


Apodytes dimidata
RMSE=0.63
a
Observed Values
Fitted Values
4
5
6
7
8


Galliniera saxifraga
RMSE=0.63
b
Observed Values
Fitted Values
1.0
1.5
2.0
2.5
3.0
3.5


Ilex mitis
RMSE=0.69
c
Observed Values
Fitted Values
3
4
5
6
7
8
9


Sapium ellipticum
RMSE=0.65
d
Observed Values
Fitted Values
4
5
6
7
8

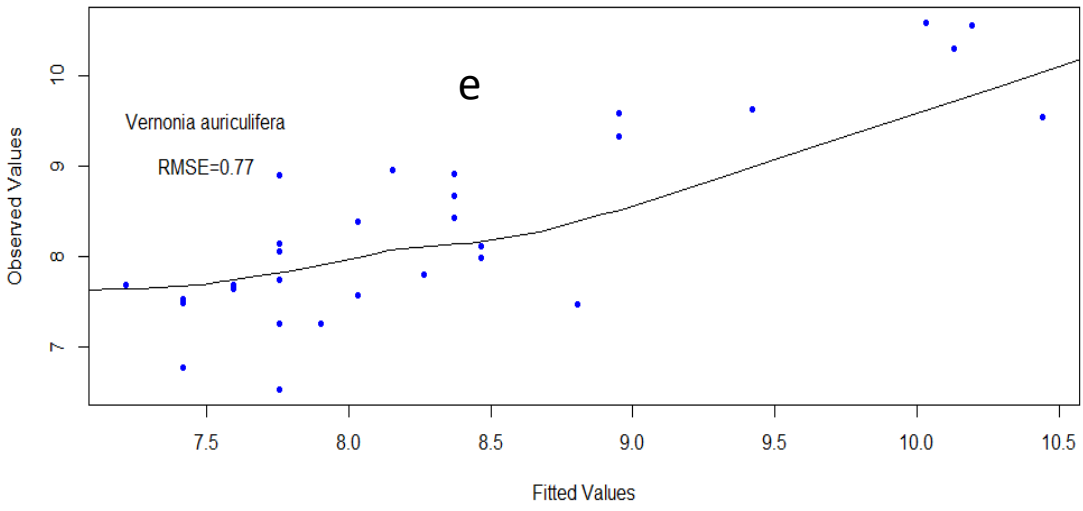



**Figure 25 (a-e).Observed against predicted values of aboveground biomass of the species**.

### 4.6 Bee forage diversity

Based on field observation and pollen load collection by honeybees a total of 79 plant species belong to 75 genera and 46 families were recorded and accounting for 29 % floristic composition of the study area (Annex 15).The growth form analysis of bee forage utilized by honeybees comprising 41.6% herb, 28.7% shrubs, 21.7% trees and 8% climbers (Fig.30).With regard to plant families, Asteraceae has the highest species richness comprisinge 19 species (24.05 %), Lamaiceae (6.33%) and Acanthaceae 4 (5.05%) of bee forage in the area. The analysis of bee forage diversity using Shannon- wiener diversity index in different plant communities indicated that community one and three have highest beeplant diversity 3.2 and 3.5 respectively. Relatively lower species diversity was recorded for community four and five (2.1 and 2.3). The species richness also varies among the plant communities. Community one, two and three have highest species richness (55, 55 and 45) respectively and lower number of species recorded for the communities four and five (14 and 11 respectively) Table 39.

**Table 39.The bee forages diversity in Gesha-Sayilem forest in different plant communties**

| Communities | Richness | Shannon | Evenness |
|---|---|---|---|
| Community one | 55 | 3.2 | 0.82 |
| Community two | 45 | 3.2 | 0.86 |
| Community three | 55 | 3.53 | 0.88 |
| Community four | 14 | 2.32 | 0.89 |
| Community five | 11 | 2.1 | 0.89 |

### 4.6 Sources of pollen availability of pollen

The highest proportion of pollen loads were collected from *Guizotia scabra,* (20.5%),*Bidens spp* (13.5%), *Croton macrostachyus* (12.7%), *Datura innoxia* (11.1%*), Syzygium guineense* (7.2%) *Eucalyptus*spp (6.5%), *Plantago lanceolata* (5.3*%), Vernonia amygdalina*(4.5%) and *Masea lanceolata* (3.7%) and th rest of the plants contributing for little proportion( Fig 31). About 42.3 % of pollen was collected from September-November, 32.2% from December to January, 18.9 % during March to May and 6.2 % of pollen during June to August (Appendix 16). Among the flowering plant species, *Eucalyptus camaludensis*, *Datura inoxia*, *Apodytes dimidata*, *Olea welwitschii* had the longest flowering period and provided continuous nectar and pollen supply for foraging honeybees.


**Figure 26.The growth forms of bee forages used for honey production**

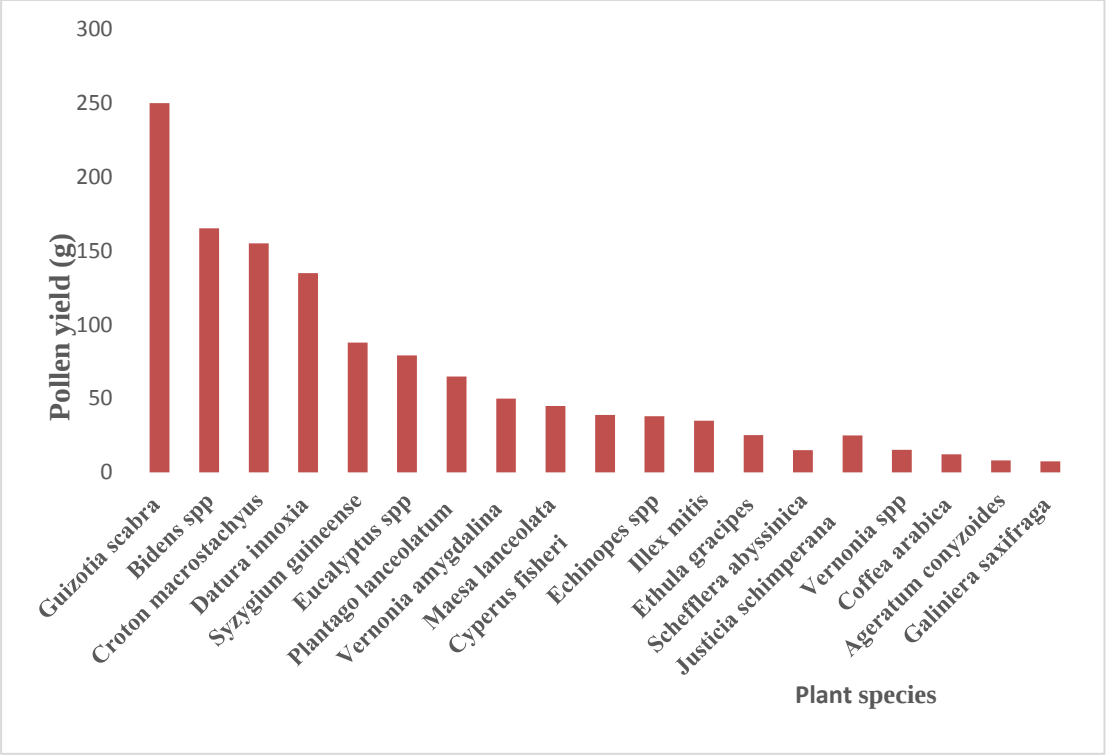



**Figure 27.The major pollen source plants identified from pollen traps**

### 4.6.1Proximatecomposition of pollen

The proximate composition of pollen varied among the selected plant species (Table 40) the detail the analytical results were presented below.

### 4.8.1 Moisture content

The moisture content in pollen ranged from 19.29–24.95%. The highest content was recorded in *Vernonia* spp (24.95 %) and the lowest in *Combretum paniculatum* (19.29 %) Table 40. The analysis of variance showed that there was no significant difference (P>0.05) in moisture content between pollen content of different plant species.

### 4.8.2 Total Protein content

The total protein content of pollen samples ranged from 15.04 -29.08% with the lowest being for *Ageratum conyzoides* (15.04 %) and the highest for *Glycine weighti* (29.08%) Table 40.The pollen protein content for *Echinopes macrostachyus*, *Croton macrostachyus* and *Vernonia* spp was significantly differ from the pollen of the other species in this study and so were those of *Glycine weighti* and *Combretum paniculatum*.

### 4.8.3 Fat content

The fat content of pollen was not significantly different between pollen source plants. The fat content ranged from 2.74 - 5.68 % with the highest value being (5.68 %) for *Croton macrostachyus* and the lowest (2.74 %) in Guizotia scabra.

### 4.8.4 Ash

The ash content of pollen ranged 1.27 in *Vernonia* spp and 3.49mg in *Combretum paniculatum* were Significantly defferent ($P<0.05$) between pollen source plants. The fat content of *Trifolium* spp and *Croton macrostachyus* were significantly differ from those of *Cyanotis barbata,Vernonia* spp, *Plantago lanceolata, Guizotia scabra, Apodytes dimidiata*, *Ageratum conyzoides*, *Vernonia amygdalina, Echinops macrochaetus* and *Hypoestes triflora*.Moreover,*Glycine wightii* and *Combretum paniculatum* also had were also significantly differe from the rest of the pollen source plants.

### Vitamin C

The vitamin C content of pollen in *Echinops macrochaetus* and *Cyanotis barbata* was significantly different from that found in the rest of the species mean value of 1.15 and 8.26mg. The highest vitamin C content in pollen was obtained from *Glycine wightii, Guizotia scabra* and *Ageratum conyzoides* and the lowest in *Echinops macrochaetus*.

**Table 40. Proximate composition of bee pollen from different taxa**

| Plant species | Moisture% | Fat% | Ash% | Protein% | Vitc mg/100g |
|---|---|---|---|---|---|
| *Vernonia amygdalina* | 22.9±0.99 | 4.25±.68 | 1.68±.0.54 | 9.38±7.47 | 15.09±1.97 |
| *Guizotia scabra* | 20.33 ±0. 15 | 2.76±.052 | 1.37±0.11 | 11.12±9.6 | 16.65±.18 |
| *Croton macrostachyus* | 20.36±.0.91 | 5.69±.02 | 2.08±0.01 | 19.2±.90 | 16.7±1.49 |
| *Glycine weightii* | 22.18±0.98 | 4.6±0.10 | 2.69±.035 | 29.08±7.03 | 16.6±.26 |
| *Combretum paniculatum* | 19.81±0.09 | 4.35±0.18 | 3.49±0.02 | 27.18±0.52 | 15.49±.56 |
| *Vernonia spp* | 24.95±3.7 | 4.17±0.05 | 1.27±0.01 | 16.16±.091 | 15.99±.29 |
| *Echinopes macrostchyus* | 22.36±0.60 | 4.26±.16 | 1.8±.02 | 16.76±0.76 | 1.16±.03 |
| *Ageratum conyzoides* | 20.95±21.0 | 4.89±.037 | 1.49±.005 | 15.43±.015 | 16.74±1.5 |
| *Hypoestes triflora* | 21.06±0.38 | 4.92±0.26 | 1.92±.06 | 2.13±.01 | 14.21±.08 |
| *Trifolium spp* | 20.98±0.56 | 4.87±0.11 | 2.07±0.01 | 3.32±.16 | 12.5±.047 |
| *Cynotis barbata* | 22.31±1.0 | 4.87±0.26 | 1.25±0.01 | 4.34±0.33 | 8.26±.055 |
| *Apodytesdimidata* | 23.20±0.32 | 4.57±0.11 | 1.44±.008 | 2.6±.158 | 16.75±.12 |
| *Planatgo lanceolatum* | 22.36±0.95 | 4.86±0.11 | 1.34±0.26 | 2.58±.020 | 14.37±.064 |

**Values with different letters are significantly different (P<0.05).**

**Pollen mineral analysis**

The mineral content of pollen in different species was significantly differed (P<0.001) (Table 40).The iron content of pollen ranged the lowest 7.87 mg /100g pollen in Vernonia spp to 28.38 mg/100gm the highest for *Combretum paniculatum*.The copper content of pollen was almost uniform in the different bee forage plants. It ranged 0. 49-1.28mg/100. The Calcium content of pollen was highest in *Combretum paniculatum* (435mg/100g) and lower in *Croton macrostachyus* (196mg/100g).The phosphorus and potassium content of the pollen ranged between 0.35-707mg/100g and 0.49-592 mg/100g of pollen respectively. The highest phosphorus content was accumulated in *Combretum paniculatum* and *Glycine wightii*). Similarly, potassium in pollen content is highest in *Combretum paniculatum*, *Croton macrostachyus* and *Guizotia scabra* and lowest in *Vernonia amygdalina*.The sodium content of pollen is higher in *Glycine wightii* (610.86mg/100g) and lower for

*Trifolium* spp (4.8mg/100g). The sodium level in the pollen for some plant species was beyond the detectable level (BID).(Table 41).

**Table 41. Mineral content of pollen samples from different taxa**

| Plant species | Iron mg/100g | Copper mg/100g | Calcium mg/100g | Potassium mg/100g | Phosphrous mg/100g | Sodium mg/100g |
|---|---|---|---|---|---|---|
| *Vernonia amygdalina* | 8.31±1.0 | 0.54±.09 | 285±52.8 | 0.58±0.03 | 164.06±32a | 338.28±22 |
| *Guizotia scabra* | 10.25±1.1 | 0.74±0.01 | 379±0.57 | .49±0.20 | 260.8±0.029 ab | 405.84±0.33 |
| *Croton macrostachyus* | 13.29±1 | 0.53±.075 | 196±72.0 05 | 0.95±0.1 | 247±2.5 | 454.42±517 |
| *Glycine weighti* | 14.29±0.95 | 0.71±.010 | 236±1. | 1.28±0.6a | 251±0.67 | 610.86±0.27 |
| *Combretum Paniculatum* | 28.38±0.061 | 0.49±.010 | 435±0.78 | 0.88±0.2c | 406 ±0.33 | BID |
| *Vernonia spp* | 7.87±0.208 | 0.95±.010 | 229.9±0. 949 | 297±0.69d | 454±0.16 | BlD |
| *Echinopes macrostchyus* | 26.45±0.06 | 1.28±.010 | 329.1±0. | 592.3±0.9 | 610.86±1.00 0bc | BlD |
| *Ageratum conyzoides* | 20.52±0.5 | 0.88±.007 | 319.23±. 5 | 384.43±0. 54 | 621±0.71 | 395.06±24 |
| *Hypoestes triflora* | 16.78±1.9 | 0.66±0.12 | 322.23±2 . | 2.44±0.21 b | 207.56±0.04 | 324.04±41.8 |
| *Trifolium spp* | 18.54±1.19 | 0.78 ± 0.2 | 232.06±5 1 | 3.78±0.23 | 0.40±.030 | 4.81±183.20 5 |
| *Cynotis barbata* | 13.32±0.352 | 0.77±.124 | 222.32±4 | 4.68±0.39 | 0.55±.061 | BID |
| *Plantago lanceolata* | 15.62±2.466 | 0.88±.072 | 214.5±5. | 5.51±0.32 | 0.35±0.02 | BID |
| *Apodytes dimidata* | 19.5±3.76 | 0.66±.118 | 211.2±1 | 4.9±0.34 | 0.64±.088 | BID |
| *Zea mays* | 10.22±2.33 | 0.87±0.12 | 160.2±29 | 6.7±0.22 | 0.54±.035 | BID |
| ***Range*** | 7.87-28.38 | 0.49-1.28 | 160-435 | 0.88-592.3 | 0.35-621 | 4.81-610. |

**Total phenolic and Antioxidant content of pollen**

The total phenolic content was expressed as milligrams of Gallic acid equivalent (GAE) per mg (mg/gm) of pollen and the antioxidant content expressed in percentage. The total phenolic content in the plant pollen analyzed ranged 19.52-39.84 mg/GAE. There was no significant variation in total phenolic content among the pollen source plants. However relatively the higher polyphenol content was recorded in *Zea mays, Guizotia* spp, *Vernonia amaygdalina, Eucalyptus spp* and *Datura innoxia*.The lowest occurred in *Echinope*s spp, *Ageratum conyzoides*, *Combretum paniculatum*, and *Trifloium* spp.The DPPH radical scavenging capacity of the analyzed pollen samples were significantly different ($P<0.05$) in different pollen source plants (Table 42). The highest antioxidant power was found in from *Vernonia amygdalina, Croton macrostachyus,Eucalyptus* spp and *Vernonia* spp. The lowes were recorded in *Datura innoxia* and *Ageratum conyzoides.*

**Table 42.Percent yield for Free radical Scavenging activity and total phenolic content of pollen samples**

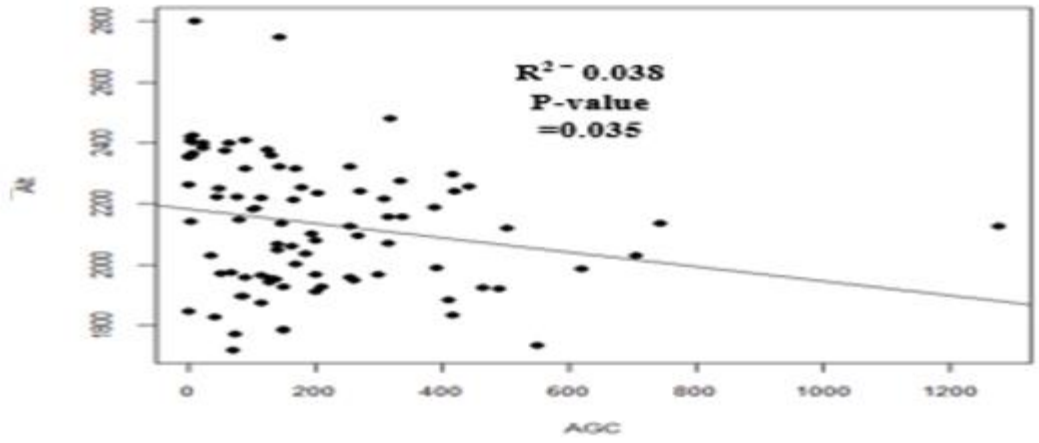
| Plant species | Phenolic content (mg GAE/g) | DPPH (EC50) % |
|---|---|---|
| *Vernonia amygdalina* | 35.65 ±0.44$^{i}$ | 93.7±0.121$^{c}$ |
| *Croton macrostachyus* | 23.06 ±.44$^{c}$ | 92.5±0.10$^{c}$ |
| *Guizotia* spp | 38.87 ±0.24 | 89±1.0a$^{b}$ |
| *Bidens* spp | 19.52 ±0.95$^{a}$ | 89±1.0$^{b}$ |
| *Ageratum conyzoides* | 24.03 ±06$^{c}$ | 83±1.5a$^{b}$ |
| *Plantago lanceolata* | 20.81 ±.06$^{b}$ | 89±.57$^{b}$ |
| *Trifolium* spp | 24.35 ±0.05$^{ef}$ | 88±1.0$^{b}$ |
| *Datura inoxia* | 26.29 ±0.080 | 86±1.0$^{a}$ |
| *Zea mays* | 39.84 ±0.06$^{i}$ | 89±0.57$^{b}$ |
| *Eucalyptus* spp | 25.00 ±0.07$^{f}$ | 93±1.0$^{c}$ |

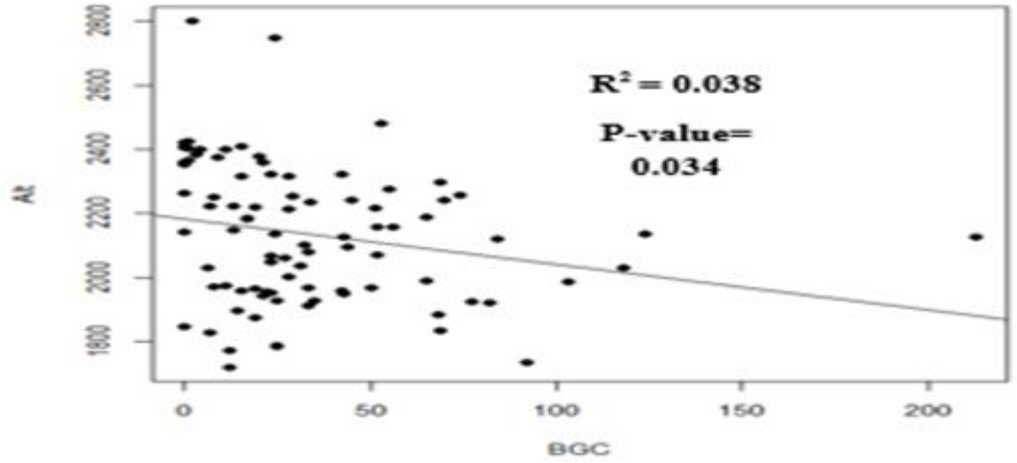
Values in a row with different letters are significantly different ($P<0.05$).

**4.6.2 Botanical origin forest honey**

From the honey pollen analysis, 47 plant species were identified from different honey samples.The identified pollen grains in honey samples were classified botanically into

two categories: forest plants and non-forest plants.The majority (86.7%) of honey samples were contributed from forest trees, while only 13.3% were from weeds and crops. The classification of pollen percentage count using Sillhouette and PCA clustering indicated that three types of honey were identified. These are *Schefflera abyssinica* honey type, *Croton macrostachyus*




oney type and *Vernonia amygdalina* honey type. Honeys from *Schefflera abyssinica* and *Croton macrostachyus* found at right side of PCA plots while *Vernonia amygdalina* was found to the left side of the PCA Fig **31**.The spider web distribution of honeybee plant pollen count for monofloral honey were shown in Fig **33**.Thepollen count percent dominance for *Schefflera abyssinica*, *Croton macrostachyus*, and*Vernonia amygdalina* honey ranged from 66.4 %to 96%, 63.4-78.2%, and,33.92-64.4% respectively. From the

total number of species of pollen grains found in the monofloral honey*Croton macrostachyus* honey was comprised of 21 species of honey plant followed by *Schefflera abyssinica* with 19 species and *Vernonia amaygalina*17 plant species.

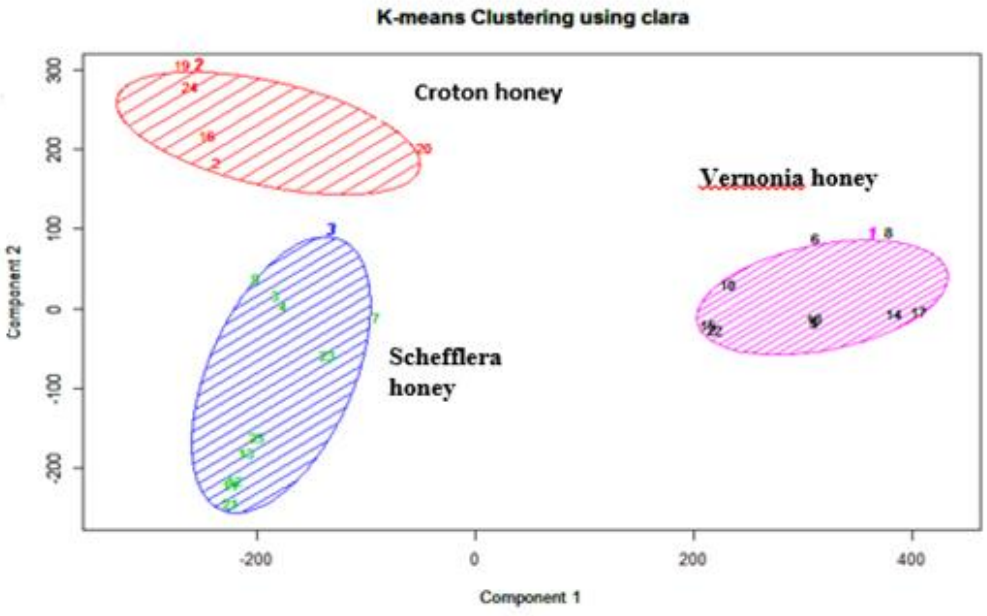
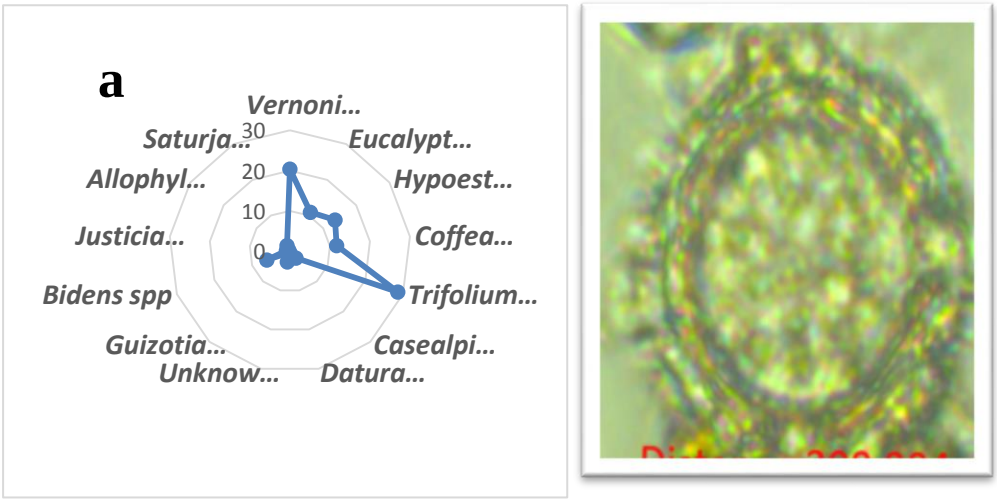
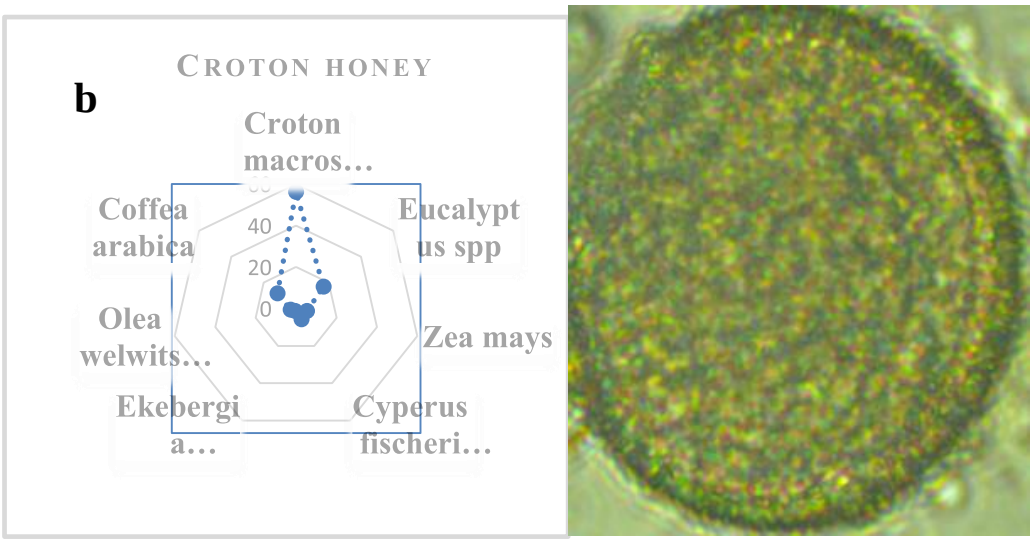
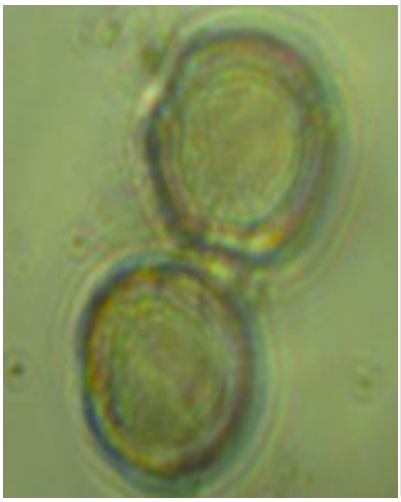



**Figure 28. PCA component plot in the function of floral origin of honey in PCA plot.**





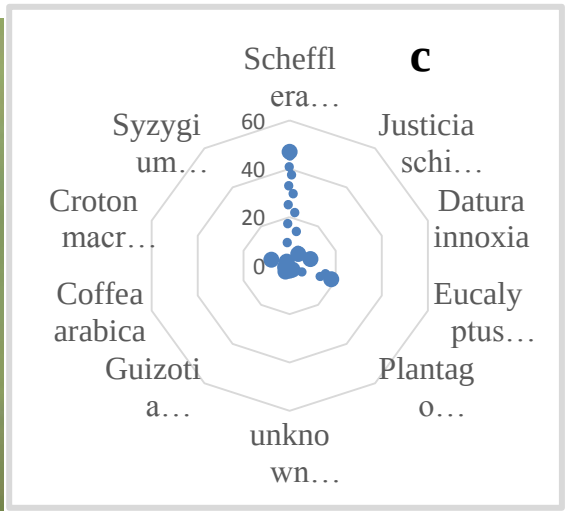



**Fig. 29(a-c ) Spider web distribution for Monofloral honey of *Schefflera abyssinica* and *Croton macrostachyus and Vernonia amygdalina honey***

### 4.9 Physicochemical properties of Gesha-Sayilem forest honey

The results of the physico-chemical analysis of the mono floral honeys for *Schefflera abyssinica*, *Croton macrostachyus* and *Vernonia amygdalina* were presented in Table 43.The laboratory analysis for honey quality parameters fulfill the national and international standards.

#### 4.9.1 Moisture

The mean moisture contents of the honey samples of *Vernonia amygdalina* honey was 18.3 ± 1.02 g/100 g (17.1to 19.1 g/100 g) , 18.1±1a(17.1-19.1 g/100 g ) for

*Schefflera abyssinica* honey while the moisture content of *Croton macrostachyus* honey ranged from 19.2 to 23.3 g/100 g with mean value of 21.2 ±1.05 g/100 g).

### 4.9.2 Hydroxymethylfurfural (HMF)

The HMF value of the Vernonia forest honey ranged from 1.1 to 1.3 mg/kg with a mean value of 1.2 ± 0.1mg/kg, *Schefflera abyssinica* honey ranged 2.2-2.5 with mean value of HMF 2.3 ± 0.15 with that of Croton honey from 2.4-2.6 mg/kg and mean value of 2.56 ± 0.15 mg/kg. The HMF of *Vernonia* honey was significantly different from that of *Schefflera* honey and *Croton* honey.

### 4.9.3 pH andFree acid

The pH of the Vernonia honey ranged from 4.01- 4.1 with mean value of 4.05± 0.04. that of *Schefflera* honey ranged from 3.95-3.98 with mean value of 3.97±0.15 while that of *Croton macrostachyus* honey ranged from 3.5-4.5 with mean value of 4 ±0.5. There was no significant difference in the variation in pH between the three types of honey and the honey types were found to be acidic.

The mean for the in free acid content of the *Vernonia amygdalina* forest honey samples was 7 ± 1 meq/kg (6–8 meq/kg) in *Schefflera abyssinica* honey was 4.1±1 and with range of 3-5 meq/kg. For *Croton macrostachyus* the mean for free acide content was 10±1 ( 9-11 meq/kg) Table 42.There was significant difference between honey types for free acid

### 4.9.4 Electrical conductivity

The electrical conductivity of Vernoni*a* honey varied from 0.13 to 0.2 mS/cm with a range of value of 0.20 ± 0.16. For *Schefflera abyssinica* the mean was 0.087 ± 0.03 mS/cm (0.07–0.09 mS/cm) while for croton honey was 0.24±0.02 ms/ with range of 0.23-0.26 mS/cm.

### 4.9.5 Invertase

The mean value of the invertase content of *Vernonia* honey was 113.6 ± 1.6 (112.3-115.5), the invertase content of Schefflera honey was 181.9±1.48 (180.3-183.2 while Croton honey was 126.6±0.90 (125.7-127.5). There was significance difference between the honey typesor invertase content.

### 4.9.6 Proline

The mean value of the proline content of Vernonia honey was 210.6±1.67 (209.2-212.4, the average proline content of *Schefflera* honey was 197.6±1.25 (196.5-198.8). The meanvalue of proline content of Croton honey was 827.3±1.2 (826.2-828.5). There was a significance difference between honey types for proline content.

### 4.9.7 Sucrose

Analysis of sucrose content is used to detect the adulteration of honey with table sugar or to determine the amount of sucrose found naturally in a given honey sample. This, the mean sucrose content for Vernonia was 3.16±0.06g/100 g, that of *Scheffleraabyssinica* was 4.8±0.1g/100 g (4.7–4.9 g/ 100).The mean sucrose content of croton honey was 3.2±0.06 (3.22-3.3392g/100 g.

### 4.9.8 Fructose and glucose

Analysis of fructose content of honey for the three types of honey showed that croton honey was significantly different from *Schefflera* and *Vernonia* honey. The mean value of fructose content of *Vernonia* honey was 38.63±0.96 and *Schefflera* and *Croton* honeys were 39.86±0.92and 37.1±1.05 respectively.Similarly the glucose content in *Vernonia amygdalin* and in *Schefflera abyssinica* 35.66±2.2 and 35.74±0.47 respectively while the mean glucose content of Croton and Verononia honey were 36.4±0.85, and 35.66±2 respectively.

**Table 43. Physiochemical properties of forest honey of Gesha-Sayilemforest**

| Parameters | *Vernonia amygdalina* | *Schefflera abyssinica* | *Croton macrostachyus* |
|---|---|---|---|
| Moisture content | 18.3±1.1a | 18.1±1a | 21.3±1.05a |
| HMF | 1.2±0.1a | 2.36±0.15b | 2.56±0.15b |
| Invertase | 113.6±1.65a | 181.9±1.48b | 126.6±0.90c |
| Proline | 210.6±1.67 | 197.6±1.25 | 827.3±1.2 |
| pH | 4.05±0.04a | 3.97±0.015a | 4±0.5a |
| Free acidity | 7±1a | 4±1b | 10±1c |
| EC | 0.16a | 0.08b | 0.24c |
| Fructose | 38.63±0.96a | 39.86±0.92a | 37.1±1.05b |
| Glucose | 35.66±2.2a | 35.74±0.47a | 36.4±0.85a |
| Sucrose | 3.16±0.06a | 4.8a±0.1b | 3.2a±0.06a |
| F+G | 74.26±0.95a | 73.86±0.81a | 73.71±0.85a |

### 4.6.4 Honey production system

Beekeeping in Gesha-Sayilem forest is undertaken three types of beehives: traditional, intermediate and modern. Beekeeping with traditional bee hive is the dominant activity accounting for 91.6% while intermediate and modern hives account for 5.5% and 2.9 % respectively. Only very few beekeepers owned intermediate and zander beehives that have been distributed by different Non-Governmental Organizations. The average traditional beehives owned by household was 66 and while intermediate and zander beehives were 4 and 2 respectively. Similarly, the average yield of traditional beehive is 18.3 kg/hive/year (range 10 to 30 kg/hive/year)while the average honey yield from intermediate beehives was 22.6kg and 31.8kg per hives was obtained from modern beehives and the annual production of honey for each beehive types was indicated in Table 44.

The traditional beekeeping practice is dominant activities and beekeepers use different trees for bee hive construction. The trees used for traditionalbeehives construction was indicated in Fig 34. About25% respondent stated that *Croton macrostachyus, Euphorbia ampilphyla* and *Pouteria adolfi-friederici*are the most commonly used

trees for bee hive constructionin the area.The construction and hanging of beehive undertake by men due to its heavy task for the women to make beehives and culture. In the study area, farmers construct traditional beehives by dividing a tree trunk into two halves and carving or making deep grooves to each half. Then the two halves brought together and then wrapped with *Arundinaria alpina* sheath.The finished loghive was tie with climber locally called *Clematis simensis* and hung in November and December for the next honey flow season in April.

**Table 44.The average number of hive owned per household and the average honey Yield (kg) in the study districts.**

| Types of hives | No of colonies | Honey yield per olony(kg) | Annual honey production (kg) |
|---|---|---|---|
| Traditional hive | 66±51 | 18±12 | 1316± 876 |
| Transitional hive | 4±3.1 | 22.6±10 | 77.05±70.7 |
| Modern beehives | 2±0.6 | 31.8±22 | 79.3±45.4 |

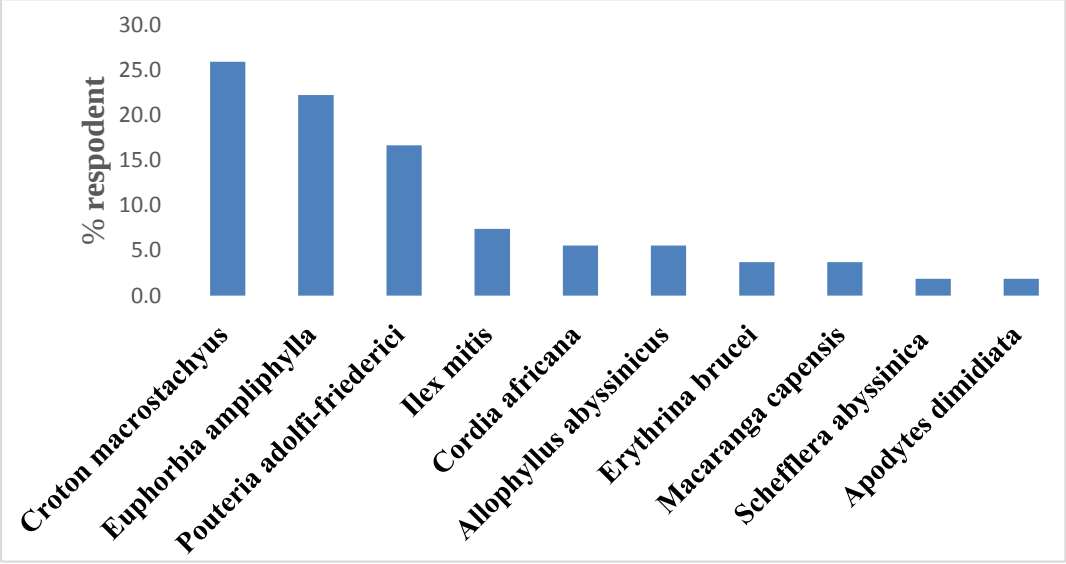



**Figure 30.The preferred tree species for bee hive construction**

The major constraints stated by the beekeepers in the area are honeybee pest, deforestation, falling from the tall tree, drought, poisonous bee plants, and lack of skills in managing modern beekeeping system, pesticide and shortage of dry season

bee forage Fig 35. According to the respondent,about 28% of the beekeepers reported that ants are serious pests that damage honey bees as well as the honey and other bee products. Rapid deforestation for expansion coffee and root crop like potato affects the destruction of honeybee trees resulting decrease of honeybee colonies and honey production. Regarding poisonous bee plants 9% of the beekeepersreported that *Euphorbia cottinifolia, Datura innoxia, Sericostachys scandens* and *Justicia schimperiana* are reported as poisonous to honeybees.When honeybees consume the pollen or nectar of *Datura innoxia*, they become irritated and unconscious for certain periods. Flower of *Euphorbia cottinifolia* is also reported to kill honeybees when they visit the flowers.

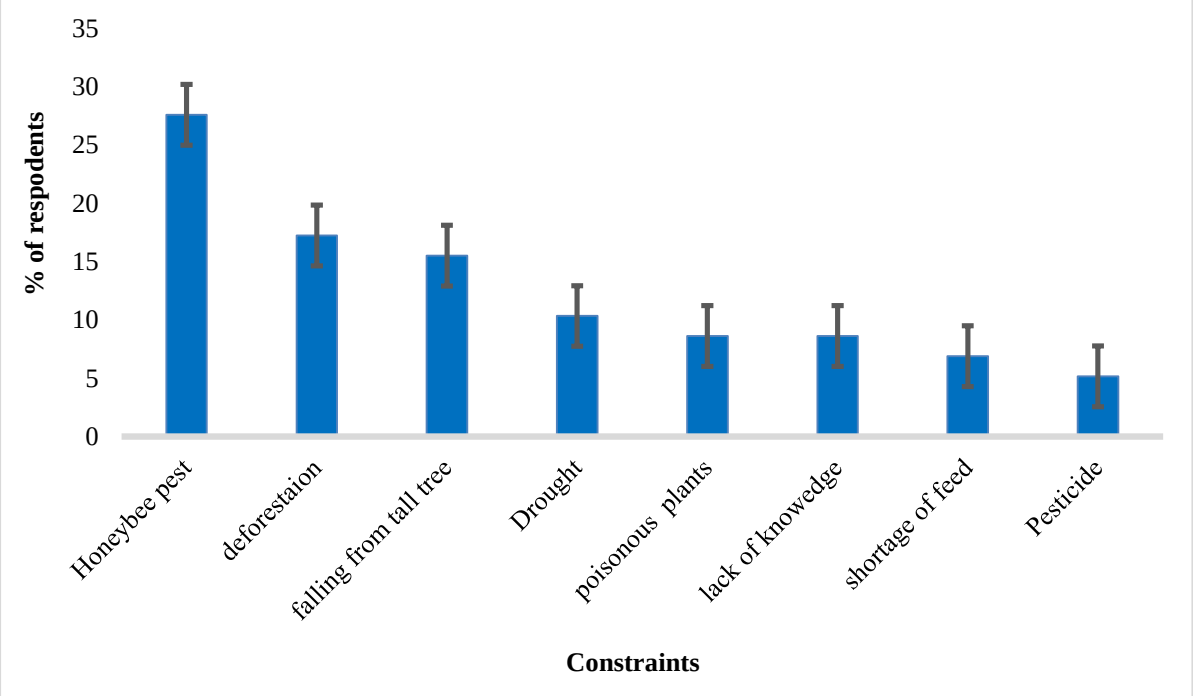



**Figure 31.Constraints of forest beekeeping**

# CHAPTER FIVE

## 5 Discussion

### 5.1 Floristic composition and diversity of Gesha-Sayilem forest

The Gesha-Sayielem forest can said to be rich in species as it has 300 different plant species which comprise 5.3% of Flora of the Ethiopia and Eritrea. According to Tadesse Woldemariam *et al*., (2008) it is not reasonable to compare the species diversity of one forest directly with other forests due to variation in size, the method of data collection and aims of the study.However, comparison of the overall species richness of the areas can give a general picture of the diversity and richness of the plants of the area.The species richness of the Gesha–Sayilem forest is very high as in compared to reported by different authors (Table 44).However, the species richness of the Gesha-Sayilem forest was lower than Masha and Yeki forest, ( Zewde Kassa,2017). The high number of species found in the study area can be attributed to its as part of the Eastern African Biodiversity hot spot. This agrees with views given by Chaffey, (1979); Friis, (1992); Lisanework Nigatu and Mesfin Tadesse, (1989); Uhlig, (1990); Zerihun Woldu *et al*.,( 1989); Kumlachew Yeshitila and Tamrat Bekele, (2002) and Sebsebe Demissew *et al.,* (2011) who reported that the montane moist forest ecosystems are the most diverse ecosystems in composition, structure and habitat types due to the existence of a widerange of ecological gradients. The availability of a large complex of mountains has also contributed to the higher plant diversity and richness in the study area. Out of the many plant families identified, only six plant families were contributed over 28.17% of the total number of species in the forest.These are the families Asteraceae, Fabaceae, Acanthaceae, Rubiaceae, Poaceae and Euphorbiaceae which are also reported to be the most species-rich families in the Flora of Ethiopia and Eritrea (Ensermu Kelbessa,

Pers.comm). The dominance of these families has been previously reported by Kumelachew Yeshitela and Tamrat Bekele, 2002 in the moist Afromontane and Transitional Rainforest of southwestern Ethiopia. Asteraceae is one of the largest families of vascular plants with about 1535 genera and 23,000 species in the temperate and tropical regions (Bremer, 1994). In Ethiopia, it is one of the most species rich families comprising 133 genera and 472 species (Mesfin Tadesse 2004, Ensermu Kelbessa and Sebsebe Demissew 2014). The genera and the species composition of family Asteraceae in current study comprise 22 genera, 37 species. The dominance of this family were also reported by different authors in Afromontane rainforest namely: Godere forest (13 species and 6.6%), Dereje Dennu, 2007, Gura-Lopho Moist Afromontane (12 species and 8.33%), Lamessa Kumessa, 2010, Dense Forest(20species, 27%), Erimas Lulkal,2014, Komto Forest (17species,9.44%), Fekadu Gurmessa,2012).

The Asteraceae became one of the successful families in Angiosperm phylogeny due to mode of pollination, seed dispersal and adaption to different ecological niche. The mentioned families have attractive flower color enabled the plant to be pollinated by different insect pollinators and wind. Moreover, development of morphological adaption for light and smaller sized seeds that can be blown by the wind for the long-distance dispersal and subsequent colonization of the new habitat. This is in agreement with (Hedberg, 1964), seed dispersal by wind is the main mechanisms affecting long-distance dispersal for Asteraceae in Afro-alpine flora. The same is expected in Moist Afromontane Forest.

Analysis of growth habit in the study forest reveled that the herbaceous flora contributes for 56% of the total species composition of the area. This could be due to disturbance and the presence of gaps in the Forest.h similar studies of the dominance

of herbaceous flora with other forests in Ethiopia was reported by Haile Yineger *et al*., 2008; Fekadu Gurmessa *et al*.,2012; Ermias Lulekal, 2014)

**Table 45.Comparison of the floristic richness of different Afromontane rain forest with Gesha–Sayilem forest**

| Forest types | Richness | References |
|---|---|---|
| Afromontane and transitional rainforest | 139 | Kumelachew Yeshitela and Tamrat Bekele, (2002) |
| Godere forest | 196 | Dereje Denu (2007) |
| Masha forest | 130 | Abreham Assefa (2009) |
| Yayu forest | 220 | Tadesse Woldemariam (2003) |
| Komto forest | 180 | Fekadu Gurmessa et al., (2012) |
| Sigmo-Setma forest | 287 | Dereje Denu, 2016 |
| Jibat Forest | 131 | Tamrat Bekele, 1994 |
| Dello Menna forest | 171 | Motuma Didita et al. (2010) |
| Bonga Forest | 285 | FeyeraSenbeta, 2006 |
| Masha and Yeki forests | 500 | Zewde Kassa(2017) |

Twenty six 26 plant species were to be endemic plants of the study area which accounting for 4.3% endemic of Flora of Ethiopia and Eritrea. Out of the identified endemic plant species, 8 are in IUCN Red List Categories of Flora of Ethiopia and Eritrea Vivero *et al*. (2005).The presence of higher number of endemic flora is due to the fact that the area is located in one of the Eastern biodiversity hotspots.The occurrence of wide variety of flora and endemism in the Afromontane regions could be due to adaptations of plants to topographic features and geological changes which can also lead to evolution and speciation of flora (Hedberg, 1986; Kruckeberg and Rabinowitz,1985).

### 5.1.2 Plant community types

In this study,five different plant community types were identified using hierarchical cluster analysis and ordination techniques.The identified plant communities are diverse and rich in species. However the difference could be directly related to environmental factors that make the plant communities have their own distinct or characteristic species (Feyera Senebeta, 2006). The *Ilex mitis-Syzygium guineense*

*(*communityone) and the *Pouteria adolfi-friederici-Schefflera (*community two) had the highest number of plant species compared to other communities. This could be be attributed due to their location away from human disturbances.These communities are located in difficult terrains (slopy and deep gorges) which are not frequently exposed to less disturbances condition.These communities are holds economically important tree species such as *Schefflera abyssinica* and *Pouteria adolfi-friederici* for honey production and traditional beekeeping is widely exercised in these plant communities.The traditional beekeeping might have contributed to the diversity and richness of the community through pollination services of honeybees and other pollinators. Additions the community three (*Millettia ferruginea-Sapium ellipticum* community type) is found at gentle slopes and dominated by economically important plant species such as *Coffea arabica*, *Piper capense* and *Aframomum corrorima* and it is protected by the local communities for coffee and spice production.

Most of the plots in which (*Arundinaria alpina* community type) is found at higher altitudes and grew its location at higher altitudes and this community comprises a low number of species compared to ther plant communities.This is in agreement with common views that the species richness tends to decrease at higher elevations (Vetaas and Gryytnes, 2002). In addition,this community is highly disturbed due to anthropogenic influences and grazing pressures. Personal communication with elders in the area suggested that 40 years ago that there area were to be bamboo forest However these have been changed to small bamboo patches and some of them on regenerating from seed bank and currently area has been delineated by NABU under UNESCO, Kaffa Coffee Biosphere Reserve for conservation.This community is dominated by *Arundinaria alpina* which provides materials used for house construction, fencing, and beehive making, floor mat, chairs and baskets.

The *Scheffleravolkensi-Maesa lanceolata* community is distributed in wide ranging altitudes between1968-2800m.This community is shares certain species with wetland species. It is dominated by smaller sized plant species classes and could be late succession where a large number species co-exist and grow together. This agrees with views that species diversity is high in successional communities (Bazzaz, 1975;Ricklefs, 1977;Silvertown,2004).This community is also the most disturbed community due to settlement and overgrazing by livestock.

### 5.1.3 Species diversity and Richness

Species diversity is an important factor for the stability and proper functioning of ecosystems and plays a critical role in the assessment of human impact on ecological systems (Leitner and Turner, 2001 Schläpfer *et al.,* 1999). The analysis of species diversity in five plant communities identified in this study indicated that the higher number of species per plot was occurred in *Pouteriaadolfi-friederici-Scheffler aabyssinica* community).The *Ilexmitis-Syzygiumguineense* community,the *Milleitia ferriguinea-Sapium ellipticum* community) and community **5** (*Schefflera volkensii-Maesa lanceolata*).The lower number of species per plot was obtained for *Arundinaria alpina* community).The highes species diversity of the communities was attributed due to topographic, climatic and edaphic differences.

Species richness is considered as an important factor in community productivity and stability. Studies by (Cristofoli, 2010) and Gong *et al.,* (2008) have shown that topographic variables (slopes, aspects, and altitude) have an affect on plant diversity. In view of this, five plant communities had variation in species diversity and richness due to the fact that each plant communities occure at different types of land escape and hence exposed to different levels of disturbances.Those plant communities found in very steep slopes e.g (*Pouteriaadolfi-friederici-Schefflera abyssinica* community),

on deep gorges, along streams and rivers e.g *Millettia ferruginea-Sapium ellipticum*community on gentle slopes (*Ilex mitis-Syzygium guineense* community), are have with higher plant diversity and species richness indices since they are located far. from human stettment, Thus not exposed to frequent distrbances. On the other hand, the *Arundinaria alpine* community type had the lowest species diversity and richness index which can be attributed to human activities and the fact that high-altitude areas are devoid of vegetation or low-level richness. The beta diversity of the study area was found to be 0.73 which indicates high species turn over and suggest high habitat diversity within the communities.

### 5.1.5 Plant community and environmental relationship

The analysis of vegetation data using cluster analysis and ordination techniques can provide more detailed and inclusive information on the patterns of vegetation and the response of plant species to the principal environmental factors (Ter Braak, 1995). In the current study, analysis of vegetation using ordination techniques indicated that the pattern of plant species distribution was mainly influenced by environmental factors such as altitude, slope, aspect, disturbance and soil factors. Among these factors, altitude is an important topographical variable since it affects atmospheric pressure, moisture and temperature, which govern the growth and the distribution of plant. Previous studies by Bonnefille *et al*., (1993), Kumelachew Yeshitela and Tamrat Bekele (2002) noted that the vegetation types in Southwest Ethiopia are mainly delimited by microclimatic conditions associated with altitude.This also supported with similar studies in Afroalpine vegetation by (Hedberg,1964) altitudinal gradient are found to be the most complex environmental gradients encompassing many different interacting factors.

The CCA analysis of environmental, edaphic and topographic data from the forest suggested that the formation of five plant communities was influenced by different environmental factors due to variation in topographical features. This consequently could have created the heterogeneous habitat needed for the formation of different plant communities.The five communities was shown by the long length of the DCA axis is an indication of the influence of environmental factors harbouring species compostion and high species diversity in five plant communities.

The significant positive correlation was observed between altitude, sand, phosphorus and pH but negative with clay and silt. The negative correlation between altitude and clay were explained by the fact that, at high altitude and rainfall normally result in high erosion which creates the silt and clay content of the soil to be washed down to the lower altitudes. pH of the soil was positively correlated with altitude indicating that the soil pH increase with increasing altitude.The acidity of the soil in southwest Ethiopia is relatively higher as compared to other parts of the country ranges due to the breakdown of organic matter and the washing of considerable amounts of exchangeable base-cations like calcium, magnesium, sodium and potassium from the surface of topsoil (Achalu *et al*.,2012). The pH of the soil can affect the chemical reaction between plant roots and nutrients, availabile in the soil for plant use and for microbial activity. Donahue *et al.(*1983) showed that nutrient solubility; organic matter decomposition and some physical properties of soil are affected by soil pH. Positive correlation between altitude with N, P and OM due to the low temperature at the higher altitude which decreases the rate at which complex chemical reaction responsible for the availability of nitrogen and phosphorous in the soil solution take place.This agree with finding of (Tamrat Bekele,1994) in vegetation study on the forest of the central Ethiopian plateau.

The result from CCA show that most of the variation in the pattern of plant distribution was explained by CCA (Table 10). Environmental variables highly correlated with axis one were largely responsible for explaining CCA having higher score of axis. Among these variables, altitude was the one that in explained variation in species distribution and the pattern of plant community formation in the study area.The eigenvalue of the first axis of the CCA was much higher than the eigenvalues of the second axis 0.198 Table16. This shows that the first axis has the strongest influence on the variation and hence, it is the most important environmental variable contributing about 33.4% of the total variation.The main environmental variables that affecting the distribution of plant communities in the study area were altitude disturbance, slope phosphorus and EC. Altitude emerged as be highly significant environmental factors affecting community formation,and this possibly the cause for the formation of the coomunities in the in the study forest and the role by altitude gradients in shaping the distribution of vegetation in East African mountain had been previously reported by (Zerihun Woldu *et al*.,1989; Lisanework Nigatu and Mesfin Tadesse, 1989; Kumelachew Yeshitila and Tamrat Bekele, 2002; Tadesse Woldemariam *et al*.,2008).

Another equally important factor in the study forest was human influences the distribution pattern of plant communities which was found to be the disturbance Through personal communication with local elders and field observation, the area may have been fully covered with forest in the past three decades ago but this now only restricted to relatively inaccessible areas due to population growth, settlements, overgrazing and expansion of the coffee cultivation.Tadesse Woldemariam, (2008) observed that in the past, as the result of the human disturbance, the natural forest of the southwest Ethiopia were fragmented into small isolated forest patches now largely

restricted in the gorges and other inaccessible areas. Variation in slope has a strong influence on soil chemical properties since the soil on steeper slopes are influenced by bedrock and tend to be less moist and less acidic (Tewolde Berhane G/Egziabher, 1989).

### 5.1.6 Species and environmental correlation

The presence of *Arundinaria alpina*, *Hagenia abyssinica*, *Dombeya torrida*, *Ekebergia capensis* and *Schefflera volkensii* shown positive correlation with altitude above 2400m.The species *Alchemilla pedata,Cyperus fischerianus,Maesa lanceolata,Croton macrostachyus* and *Schoenoplectus corymbosus* and *Trifolium polystachyum* are appear to correlate with some disturbance had occured.Some of the species like *Cyperus fischerianus,Schoenoplectus corymbosus*, *Alchemilla pedata* and *Trifolium polystachyum* usually grows on the forest margins that often grazed by livestock.The presence and abundance of *Maesa lanceolata* and *Croton macrostachyus* are an indication of past disturbance by human and given that these plants are pioneers in areas for secondary succession. The presence of *Vepris dainellii*, *Pouteria adolfi-friederici*, *Ilex mitis*, *Syzygium guineense,Hippocratea pallens were* highly correlated with habitat that had clay and silt. They grow on the lower slopes where due to erosion in high altitudes and plants are adapted in growing soil with high clay and silt content. The occurance of *Millettia ferruginea*, *Coffea arabica*, *Aframomum corrorima* and *Piper capense correlated with areas with soil had low pH*. *Olea welwitschii*, *Schefflera abyssinica*, *Dracaena afromontana* and *Bersama abyssinica* usually grow along the streams and rivers and hence there is less decomposition of organic matter due to high water content leading to high accumulation of organic matter. The ouurance of these species are highly correlated with presence of organic matter.

### 5.1.7 Vegetation structure

#### 5.1.7.1 Size class distribution

The distribution of DBH class in woody species showed that an inverted J-shape distribution (Fig.18). This is DBH class distribution pattern in which the majority of woody species have the maximum number of individuals in lower DBH classes and there is a gradual decline towards the upper classes. This kind of size class distributions indicates that a good reproduction and recruitment potential in the forest. The same kind of diameter and height class distribution pattern has previously been reported by (Feyera Senbeta, 2006; Abreham Assefa, 2009; Abayneh Derero, 2003; and Ensermu Kelbessa and Teshome Soromessa 2008).The DBH and height class distribution with population structure of most tropical tree species and it is an indication of healthy regeneration status of forest (Cesar, 1992). Height class distribution is the main indicator of the role of a species for the forest structure since each of species represents different layer and determines the vertical variation in the structure of stand Pascal and Pelissier,(1996). However, DBH and height class distribution does not necessarily indicate the pattern of population dynamics and recruitment of a given species.

#### 5.1.7.2 Population structure

Information about the population structure of a tree species indicates the history of disturbance of the species in the past and it is used to speculate the future trend of the population of that species. Population structure can also show the productivity of the forest land since it is characterized by a sufficient number of individuals in each category of plant' growth forms within a forest community.The pattern of species population structure can be interpreted as an indication of the variation in the population dynamics in the forest (Popma *etal.*,1988) cited in Getinet Masrsha (2014). This had significant implication for their management, sustainable use and

conservation. On top of this the patterns of population structure of species could provide a valuable information about their regeneration and recruitment character that could further be used for planning conservation and management strategies (Demel Teketay, 2005; and AbiyuTilahun *et al*.,2011).

The analysis of the population structure based on DBH distribution showed a variable pattern of population structure, implying different dynamics among the species as shown (Figure 20A-F). In this analysis, five general patterns of population structure were recognized. The first was an inverted J-shaped curve which showed a pattern in which where species frequency distribution has the highest in the lower density classes and then a gradual decrease towards the upper diameter classes which suggested good reproduction and healthy regeneration potential and less disturbed (Figure 20). Similar population structures have been reported by Tamrat Bekele, 1994 for Chilimo,Menagesha,Wof-washa, and Jibat forest and Kumelachew Yeshitela and Taye Bekele, 2003 for Masha-Anderacha forest. The second pattern is represented by Gauss type or bell-shaped distribution pattern where the diameter distribution showed a decrease in density from diameter class 1 and increasing in diameter class 2 and 3 and then decreases with increasing diameter and completely absent in upper diameter classes.This pattern indicates a poor reproduction and recruitment of species which may be associated with intense competition from surrounding trees or other related disturbances.Feyera Senbeta *et al..(*2007), has also reported similar justification for bell-shaped population structure. The third pattern is a U-shaped distribution pattern, where the frequency is high in the lowest and highest DBH classes but very low in the intermediate classes. This due to intermediately sized individuals has been removed by selective cutting or a poor reproduction capacity due to the overharvesting of seed-bearing individuals. The similar pattern of population structure was reported by

Tamrat Bekele, 1994 in the Jibat forest.The fourth pattern was the increasing of individuals occurred at first two classes and then decreasing pattern up to class 6 but a few individuals were frequent at the highest DBH class7. This pattern indicates the existence of very big trees, which were no longer reproducing. This might be due to unfavorable, climatic condition and disturbance in the form of grazing trampling and selective removal of individuals in the lower and higher diameter.The fifth type is irregular distribution pattern and represented by *Syzygium guineense*. This tree is commonly used by the local people for house construction,firewood and charcoal production.In general, from the analysis of the result, the population structure of selected species showed that there was variation of population structure among the plant species due to disturbances caused by human influences or natural factors such as poor reproduction, fire and seed predation. Previous studies of plant population structure on moist Afromontane forests of southwest Ethiopia (Feyera Senbeta, 2006; Abayneh Derero, 2003; Fekadu Gurmessa *et al.*,2012) reported more or less similar results.On top of this similar patterns of species population structures have been reported for dry Afromontane forests by, (Demel Teketay, 1997; Abate Ayalew, 2003; Simon Shibru and Girma Balcha, 2004; Ermias Lulekal, 2005) suggesting for possible conservation actions.

#### 5.1.7.3 Frequency

In the present study, high frequency values were obtained in lower frequency classes whereas low-frequency values were obtained in higher-frequency classes Fig 20 indicating the existence of floristic heterogeneity. *Allophyllus abyssinicus,Galiniera saxifraga, Deinbollia kilimandscharica, Lepidotrichilia volkensii were* found to be the most frequent woody species occurring in 70% of the sampled plots. This might be attributed to its usual occurrence of plant species at widerange of altitude, seed dispersal capacity, germination vigor and resistant to pests and pathogen are some of

the factors contributing for the higher frequency of the species. In addition, the high frequency of a species always depends on habitat preferences, adaptation and availability of appropriate conditions for regeneration.

#### 5.1.7.4 Density

Density is defined as a measure of the number of individuals of plant population per unit area. It is a count of individuals of a species within the sample plot (Kent and Coker 1992) usually expressed in hectare basis. Based on this, mature plant densities of the forest was divided into five density classes. In general it was found that most of the woody species included in the lower density classes where represented by small number of individuals contributing relatively smaller amount to the total density of the woody species.Intermediate density classes contained variable number of species and contributing to a large percentage to the total density. Higher density classes, a few numbers of species contribute more to the total density of the forest.

#### 5.1.7.5 Basal area

The total basal area of the Gesha-Sayilem forest was about 115 $m^2$ $ha^{-1}$ (Appendix 6). These are more or less similar with other Afromontane forests such as Masha forest, Godere forest and Wof-Washa Forest (about 102 $m^2$ $ha^{-1}$), but higher than Jibat Forest (about 50 $m^2ha^{-1}$), Menagesha Forest (about 36 $m^2ha^{-1}$), Chilimo Forest (about 30 $m^2ha^{-1}$) (Tamrat Bekele, 1993), Denkoro Forest (45 $m^2$ $ha^{-1}$) (Abate Ayalew, 2003) and Mana Angetu Forest (94 $m^2ha^{-1}$) (Ermias Lulekal, 2005).

Species with the largest contribution to basal area can be considered as the most important woody species in the forest. In this regard, the basal area of all woody species was calculated found to be **115 $m^2$**/ha. The basal area value of study forest is relatively high as compared to normal the basal area value for virgin tropical forests in Africa is 23–37$m^2$ /ha (Dawins, 1959; cited in Lamprecht, (1989) due to presence

of aged and large-sized trees that contributed a considerable amounts to the total basal area of the forest. *Schefflera abyssinica, Syzygium guineense, Olea welwitschii, Pouteria adolfi-friederici, Ekebergia capensis* and *Prunus africana* were the most important species contributing a greater proportion to the basal area of the forest. These trees are found in deep gorges and inaccessible areas and as a result they attained large size. The comparison of the basal area of the current study with different forest types of Ethiopia showed that the Gesha-Sayilem forest has similar basal area with Belete Gera (103.2m**²**/ha), (Kflay Gebrehiwot *et al.*,2014) and Masha forest (142.6$m^2$) Abreham Assefa but higher than; Yayu (46.2$m^2$ ), (Tadesse Woldemariam, 2003); Abayneh Derero (2003), Bonga forest (42.5$m^2$), Komto forest (50.72$m^2$) Fekadu Gurmessa *et al*., (2012). The difference in the basal area of the forest types is due to variation in management of the forest, level of disturbance and location of the forest from human impacts.

Considering the IVI value of species of entire study area, the most ecologically significant woody species based on their higher IVI value were *Schefflera abyssinica, Syzygium guineense,Pouteria adolfi-friederici, Galiniera saxifraga, Ilex mitis, Allophyllus abyssinicus* and *Lepidotrichilia volkensii* comprising 35% IVI in the forest. The IVI of these species is attributed to their abundance in the forest. This in agreement with (Simon Shibru and Girma Balcha, 2004) that showed species with great importance value are the most dominant and successful in the forest community. The five dominant species of *Schefflera abyssinica,Syzygium guineense,Pouter adolfi-friederici, Gallineria saxifarga, Ilex* mitis,*Lepidotrichilia volkensii* and *Dracena afromontana* comprised 42.9% of the IVI in the forest. The high important value index of the two species *Gallineria saxifarga* and *Dracena afromontana that contributed to 8.58%* due to their abundance in the forest. On the other hand the high IVI value of the

three species *Schefflera abyssinica, Syzygium guineense* and *Pouteria adolfi-friederici*, are highly attributed due to their higher basal area of 27$m^2$, 15$m^2$ and 13 $m^2$ /ha respectively and contributed to 38.75% basal area of the forest.

### 5.1.7 Regeneration

The current study comprises a density of **1330.6** seedlings and **661 saplings**/ha were recorded from 78 woody species. The top ten woody plant species with higher seedling and sapling density were *Gallineria saxifarga*, *Dracena afromontana*, *Allophylus abyssinicus, Phoenix reclinata, Pouteria adolfi-friederici*, *Syzygium guineense*, and *Maytenus gracilipes*, due to high reproductive potential of the mother trees, and their resistance to various disturbances. On other hand some species having economic and ecological importance trees/shrub species were absent neither in seedling nor in sapling stages.These include *Schefflera abyssinica*, *Hallea rubrostipulata*, *Arundinaria alpina, Hagenia abyssinica*, *Sapium ellipticum* and *Celtis africana*.This is due to the plant species are exposed to high level of disturbance or the failure in the establishment of seedlings in the site and it might be attacked by seed pathogens.This is in agreement with (Demel Teketay, 1997) natural regeneration of forest trees and shrubs are influenced by the frequency and magnitude of the disturbance including seed predation, seed mortality and size and germination problems. In addition, similar observations were reported for *Schefflera abyssinica* and *Albizia guimmfera* by (Abayne Derero, 2003) in Bonga moist afromontane forests in southwest Ethiopia.

The separate analysis of the regeneration status of woody species with respect to seedling, sapling and matured indiviuals in the forest studied showed that the frequency distribution of seedling, sapling and adult stages decrease successively from lower to higher age classes (Fig. 18a and b). This regeneration pattern was an inverted J-shape (Fig.19a) which showed the highest density in the lower size classes with a gradual

decrease towards the bigger size classes. This pattern showed healthier regeneration status of the species where there were a large number of seedlings established,an adequate number of saplings be reach to the adult stages which in turn would produce seeds for the continuity of the generation. Such kind of population structure was reported by (Tamrat Bekele, 1994; Demel Teketay,1997) indicating the stable and healthier condition and with minimum disturbances.*Allophyllus abyssinicus*,*Galiniera saxifraga* and *Dracaena afromontana* were examples of species exhibiting this pattern. The second regeneration pattern exhibited the maximum density of sapling and adult plants when compared with densities of seedling (Fig.19b). Such pattern reveals good reproduction potential of the species might be interrupted by wildlife damage or by trampling before reaching the stage of saplings. The species exhibiting such pattern was *Ilex mitis.* The third type of regeneration pattern (Fig.19c) was shown in *Maesa lanceolata,* having few numbers of seedlings and adult plants compared to saplings.This pattern indicated a poor reproduction and recruitment of species which may be associated with intense competition from the surrounding trees or overgrazing (Feyera Senbeta *et al.*, 2007).The fourth pattern of regeneration (Fig.19e), was represented by adult individuals with no or few number of individuals in the lower classes or absence of seedling and sapling due to poor reproduction potentialcaused by disturbances, seed mortality and poor reproductive potential.This pattern in agreement with (Bhuyan *et al.*, 2003; Khumbongmayum *et al.*,*(*2006) reported the reasons for inadequate seedlings and saplings might be seed predation, lack of safe sites for seed recruitment, grazing, moisture stress and lack of sufficient seedlings. The fifth pattern was where the densities of seedlings and mature trees have exceeded densities of sapling frequency which indicates poor regeneration and caused by selective cutting of young individuals. The species included inthis pattern is *Deinbollia kilimandscharica*.

### 5.1.8 Carbon stock of Gesha–Sayilem forest

#### 5.1.8.1 Above ground Biomass

Sixty five percent above ground was contributed by *Schefflera abyssinica, Pouteria adolfi-friederici*, *Olea welwitschii*, *Ekbergia capensis*, *Syzygium guineense*, *Elaeodendron buchananii*, *Ilex mitis* and *Croton macrostachyus*.These species are dominant in the study forests have the highest IVI values and comprising a few large-sized individuals that contributed the largest proportion of the total biomass of the forest.The high carbon stock potential of trees in the forest was attributed to the density, age, and DBH of the tree species. Similar study by Shrestha and Singh, (2008) reported that the size and age of trees, could affect the carbon stock in the forest ecosystem. The carbon stored in the aboveground living biomass of trees is impacted by deforestation and degradation (Gibbs *etal*., 2007). Forest disturbance significantly affects the carbon storage of the forest and the major contributors of carbon emission in tropics and important contributors to climate change in tropical countries.The variation of belowground biomass and carbon due to variation in tree size, density and productivity of the forest area.

#### 5.1.8.2 Litter carbon

Litter carbon concentration per sample plot in this study comparable to those reported for tropical rainforests (1.4 ton/ha) (Lüet *et al*.,2010) and tropical secondary forest in Philippines (1.9 ton/ha) Lasco *et al*., (2004). However, the mean carbon stock in litter pool of the study was less compared to values recorded for selected church forests in Addis Ababa (Tulu Tolla, 2011) and tropical dry forests (2.1 ton $ha^{-1}$), (IPCC, 2006).The low carbon stock in litter can probably be attributed to the high decomposition rate and with less amount of litterfall. Since the area is in tropical, the rate of decomposition is relatively fast and all the litter carbon could have converted to soil carbon (Fisher and Binkly, 2000). In addition, the tree stands in the

forest may not be matured and this could result in a low amount of litterfall leading to less amount of carbon.

### 5.1.9.3 Non-tree carbon biomass (herbs and shrubs)

The amount of herbaceous and shrub carbon in this study was low when compared to a mean 0.57 t $ha^{-1}$ from a dipterocarp forest in the Philippines (Lasco *et al*., 2006). However, it was higher than that found in a secondary forest in the Philippines (Lasco *et al*., 2004) and a tropical forest in Eastern Panama (Kirby and Potvin, 2007) which had the mean values of 0.07 t and 0.11 t $ha^{-1}$respectively.The decrease in non-tree biomass and carbon may be attributed to the shading effect of the canopy trees which reduce light penetration and significantly affect the physical and chemical soil properties for the growth of herbs and grasses.

### 5.1.8.4 Soil organic carbon

The average amount of soil organic carbon in the study forest was determined 128 ton/ha, which is lower than the carbon density estimates for the Afromontane Rain Forests of the Eastern Arc Mountains which was found to be between 252 and 581 ton/ha (Munishi, 2001; Munishi and Shear,2004). The variation in SOC between different vegetation types is considered to be due to the presence of different tree species, moisture, soil nutrient availability, climate, topography and disturbance regime (Houghton, 2005). The soil bulk density ranged from minmum of 0.32g cm-3 to maximum of 1.1 g cm-3 e (Appendix 4) with a mean value of, 0.64 g cm-3 which is an indication of high soil organic matter in mineral soils (Brady, 1974).

### 5.1.9.5 Total Carbon Stock of Gesha-Sayilem forest

When the carbon stock of the study forest is compared with that of different forest types (dry and moist Afromontane forests) in Ethiopia, the mean carbon stock in the above and below ground biomass is greater than Menagasha Suba State Forest,

selected church forests in Addis Ababa, Semien mountain, Masha forest and lower than Gergeda and Anbessa forests (Tamene Yohannes, 2016), Egdu forest Table 46.The above ground carbon of this study also falls within ranges reported for the global above ground carbon stock in tropical dry and wet forests which range between 13.5-122.85t ha-$^{1}$ and 95-527.85 t ha$^{-1}$, respectively.The variation in carbon stock between different forest types can be propobaly due to in accurate measurements of tree variables, in efficiency of allometric models, presence of bigger sized trees with higher basal area,a higher density of woody species and anthropogenic disturbances. This agrees with Lasco *et al.,* (2000; Yitebitu Moges *et al.,(*2010) who reported that different types of models used for biomass estimation would have an impact on the value of carbon stock estimated in a given forest. Furthermore, forest carbon stocks also vary with slope, elevation, drainage class, and soil type and land-use history.

**Table 46. Carbon stock comparison of the study forest with other forest types in Ethiopia**

| **Forest type** | AGC | BGC | LC | SOC | Carbon stock ton ha$^{-1}$ | References |
|---|---|---|---|---|---|---|
| Egdu forest | 278.08 | 55.62 | 3.47 | 277.56 | 614.73 | Adugna Feyissa *et al.*,(2013) |
| Simien mountain National park | 57.83 | 13.88 | 0.85 | 92.7 | 165.26 | Habtamu Assaye *et al.,2016)* |
| Gera forest | 217.27 | 43.54 | 5.08 | 172.62 | 440.71 | Nesru Hasssen, 2015 |
| Anbessa forest | 169.02 | 34 | 1.15 | 149 | 353 | Tamene Yohannes, 2017 |
| Masha forest | 155 | 31 | - | - | 186 | Zewdu Yilma *et al*., (2010) |
| Selected church forest in Addis Ababa | 122.85 | 25.97 | 4.95 | 135.94 | 289.6 | Tulu Tola, 2011 |
| Congo forest | 168.60 | 39.55 | - | - | 207 | Liu*et al*., (2014) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Bangladesh Forest | 96.48 | 14.61 | 4.21 | 168.15 | 283.45 | Ullah*et al*.,(2012) |
| Gesha-Sayilem forest | 164.5 | 32.9 | 1.27 | 137.67 | 362.4 | Present study |

#### 5.1.8.6 Relationship between Carbon stock and environmental factors

Altitude is known to have a major effect on the biomass and carbon stock in forest ecosystems (Alves*et al*., 2010).There was a positive correlation though weak (($R^2$ = 0.03) between above ground biomass and altitude.This is can be attributed to variation in altitude, species richness and the presence of large sized trees and soil variation at plot level.This study shows that higher carbon stock occurs in the mid altitudes as compared to the low and high altitude can be explained by the fact that most woody plant species with higher DBH class were recorded in middle altitudes. Brown and Lugo, (1992) showed that the presence of large individuals of trees can contribute for large proportion of the above and below ground carbon.The carbon stock density of the forest decreases beyond 2300m due to reduction in forest trees and dominacy of wetlands and bamboos thickets.

Litter carbon was high at low and mid altitude but a decreasing trend was recorded with increasing altitude and this indicated that at high-altitude,there were a few large trees and this accounts for the lower litter accumulation. The Soil organic carbon negatively correlated with altitude it was relatively high at lower and middle altitudes but low at higher altitudes. This is can be explained by the fast decomposition of organic matter due to high temperature at low and mid altitudes however decreased at higher altitude due to low temperatures and increasing precipitation which prevent decomposition of organic matter (Zhu *et al.*,2011). Slope gradient is also another environmental factor that affects and limits the distribution of carbon stock in the study area. The high amount of carbon was found at middle and higher slopes since these slope classifications found at dense forest of the study area. In a steep slope the above ground and below ground

carbon pool reduced due to less vegetation coverage as a result of soil erosion, on other hand the middle and higher slopes the above and below ground biomass and carbon density showed higher values because of having better vegetation coverage. Similar pattern has been observed in the litter and soil organic carbon with the same reason mentioned above.

### 5.1.9.7 Correlation of carbon stock with environmental variables

The correlation coefficients between altitude, slope and aspects and carbon pools (AGB, AGC, BGC, LC, and SOC).There was positive relationship between altitude and carbon pools. Since the distribution of plants is affected by different altitudinal gradient. In this study, SOC and litter biomass decreases with altitude increases. This decrease in the SOC due to decrease in canopy cover, litter biomass and species diversity. The amount of above ground carbon stock also varied with different disturbance levels with increase in altitude. The highest amount of AGC stock was recorded at less disturbed forest. This is due to limited anthropogenic influences such as collection of firewood, logging as well as forest encroachment. This is in agreement with (Chemuku *et al.* 2016) natural disturbance and logging practice strongly affects the forest carbon stocks. Similarly,Carbon sequestration capacity and the amount of carbon sequestered not only related to the type of vegetation but also related to the plant diversity and the type of species within it. The result of correlation analys is between carbon stock density and species diversity in Gesha-Sayilem forest indicated that there is positive correlation between carbon stock and species diversity. This is in agreement with ( Hicks *et al.*, 2014), globally there is a positive relationship between carbon stocks and biodiversity. This to say a forest, having diverse plant species may produce more biomass resulting for higher carbon stock.

### 5.1.9.7 Development of Allometric equation

The biomass models for moist forest species of the southwest Ethiopia are valuable tools for the estimation of carbon stocks to mitigation climate change and of fuelwood utilization. Different authors have attempted to generate biomass equations for tropical forests for the estimation of aboveground biomass (Brown *et al*., 1989, 1997; Chave *etal.*, 2005, 2014; Djomo *et al.*, 2010; Henry *et al*., 2011) and these equations may not accurately be revealed the tree biomass in a specific region due to variability in wood density and the architecture of trees among and within species (Henry *et al*., 2011). However little attention has been given to delopment of species-specific biomass equation and only species-specific allometric equations are available for 1% of tree species of Sub sahran Africa (Henry *et al*., 2011). Biomass equations were developed for the above-ground biomass of the study species (*Apodytes dimidiata*, *Ilex mitis*, *Sapium ellipticum*, *Galiniera saxifraga* and *Vernonia auriculifera*). A goodness of fit, statistics using multiple regression model showed that combination of DBH, Height and wood density provided best fit for *Apodytes dimidata* and while DBH and height provided the best fit for *Galiniera saxifraga and Sapium ellipticum.* On the otherhand only DBH showed the best fit for *Ilex mitis*, and *Vernonia auriculifera* (Table 37). The inclusion of the wood density provided best fit for *Apodytes dimidata*, which increased the aboveground biomass prediction significantly with an adjusted $R^2$ of values of 0.73 and an average deviation of 16.9% and 18.2% respectively. This is in agreement with (Chave *et al*., 2005, 2014) and Brown *et al*., 1989) obseverd that the equation including wood density improved biomass in moist forest of tropical Africa and Asia.Wood density is an important factor for converting forest volume data to biomass data; it may depend on location, climate, management scenarios, and is a good indicator for life history strategy for tree species (Mani Parthasarathy, 2007). In this study, wood density differed between and within trees species. Thus, introducing wood density as a biomass predictor may

explain the site variations, species variations and increase precision of the estimations. Alvarez *et al*., (2012) also indicated in the Amazonian watershed, the inclusion of wood density height revealed spatial biomass and carbon patterns of the forest.The addition of the height in the biomass model also affected the biomass estimation for *Sapium ellipticum* and *Galiniera Saxifraga*.The height of the trees could include information about competition or fertility of the site and may yield less-biased estimates. Though accurate measurement of total height may be challenging in the field. According to Chave *et al*., 2005 observed a standard error reduction across all tropical forests types from 19.5 % when total height was not included to 12.5 % when total height was available.

The variation in aboveground biomass was also explained by DBH for *Ilex mitis* and *Vernonia auriculifera*. DBH is the best predictor variable for above ground biomass in allometric models because it is strongly correlated with biomass and it can be easily measured in the field. (Brown, 2002),indicated that DBH is highly pertinent variable for estimating above ground biomass in a highly diverse forest ecosystem while (Navar, 2009) showed that the observed variation in biomass of the trees are explained by diameter at breast height (DBH).

The high proportion of biomass was accumulated in the stem and big branches of *Apodytes dimidata, Ilex mitis and Sapium ellipticum*. The branch biomass of *Ilex mitis* is largest as compared to others due to spreading canopy that holds more branches and leaves and also it might be protected from external disturbances (pruning, damage from the wild animal). This is in agreement with (Dieler and Pretzsch, 2013) and Mehari Tesfaye,2016 reported that herbivores and inter-plant competition can affect the branch biomass and crown geometry. The smaller biomass was accumulated in small branches and leaves. The reason for this is due to the fact that in dense forests with strong competition for light and space, the trees tend to develop smaller branches and foliage which resulted for the lower

biomass. This study is in agreement with (Henry *et al*., 2010) found percentage stem biomass is found to higher than for branch and leaf.

### 5.1.10 Bee forage compositions

The southwestern parts of the country have relatively high percentage forest cover that makes the area highly suitable for beekeeping. According to the secondary data collected from the District office of the MOA, the forest cover varies from 22% to 70% of the total land area which makes the area is an ideal for beekeeping. Only seventy- nine (79) plant species,in this stud area were identified as nectar and pollen providers to honeybees. However this is relatively smaller as compared to the floristic richness of the forest in the area. This is attributed due to a floral preference of honeybees, nectar and pollen production of the plants and climatic factors of the area.This is in agreement with Free, 1970 and Hein rick, 1975 reported that honeybees largely forage on more productive and profitable plants that provide necessary nutrition for honeybees.

Thrity six plant species were identified as the source of the pollen load found on honeybees.The highest proportion of pollen come from only a few of these plants mainly comprised from forest trees, weeds and hedge plants. These included *Guizotia scarba*, *Vernonia* spp, *Datura innoxia (*introduced and planted a live fence*),Trifolium polystachyum*, *Zea mays,Ilex mitis Apodytes dimidata* and *Croton macrostachyus* yield more pollenfor honeybees. The rest of plant species may contribute little amount of pollen or provide the high amount of nectar.The highest pollen load is collected from September to January and April to May and lowest during dry and rainy months (February and July). The highest pollen yield was consisting of during October and November due to the fact that the majority of plant species flower after the long rainy season (June-August) and the short rainy season (March to April) flowering reaches peak in October and April. On the other hand the lowest pollen yield was recorded June to August which is the main rainy

season in the area. The rain affects the flight conditions of honeybees which in turn reduces their capacity for pollen collection. Similar study has been reported by (Debissa Lamessa and Admassu Addi (2008) during the rainy season, low temperatures possibly inhibit the growth and flowering of the plant species whereas the higher temperature during the dry period result in water deficiency in plants resulting in low nectar secretion and pollen collection.

#### 5.1.9.1 Proximate composition of pollen

**Moisture content**

The moisture content of pollen was found to vary among the plant species depending on the environmental condition where the plant grows and hygroscopic property of the pollen. The moisture content of pollen is relatively higher for all plant species since the study area is located in one of the higher rainfall regions of the country and hence it receives substantial amount rainfall for nine months contributing for higher pollen moisture which might have an impact on pollen quality. This is in agreement with (Solange, 2009) which indicates that pollen moisture content could affect the pollen quality and favor microbiological contamination, particularly by fungi and yeasts. The protein content of pollen of study plant species ranges from 20-30% which is within the accepted range of International food safety control.The total protein content was highest for *Glycine weightii* (29.09%) and lowest for *Ageratum conyzoides* (15.87%). The variation in the protein content of pollen reflects the difference in plant origin and environmental factors such as climatic and soil conditions (Bosi Ricciar delli D'Albore, 1975 and Szczęsna, 2006). A similar study was reported by (Debissa *et al*., 2008) where the crude protein content of pollen vary from 13.25% to 28.68% for pollen producing plants in central parts of Ethiopia.

Mineral content of pollen in studied species was variable due to the difference in the floral source and growth conditions ofthe plants such as soil and Agroecology.The amounts of minerals determined in pollen give an added value to the product when used

for human for nutrition. Pollen also varies with their relative proportion of fatty acid content. Several factors may affect the type and proportion of the fat content of pollen such as type of soil and climatic condition the season of the year (Schmidt and Buchmann 1992).

#### 5.4.9.1.2 Total phenolic content

It has been recognized that total phenolic content of pollen extract is associated with their antioxidant activities due to their redox properties which allow them to act as reducing agent's hydrogen donors.The pollen collected by honeybees from different taxa in this study shows variation in the amount of total polyphenols. (Bogdanov *et al*., 2004; Atip *et al*., 2012) have also reported of similar rsults that there was varation in the polyphenol content from different plants due to variation in the chemical composition of pollen from different locations.

Apart from this the total phenolic content of pollen extracts was solvent-dependent. Campos, *et al.(*,1997) showed that phenolics in pollen are species-specific and contribute to the fingerprint of each taxon. This can be used to identify floral origin of honey.

#### Antioxidant

Pollen samples analyzed in this study from various plant species showed considerable variations in their antioxidant content. A significant correlation between the total phenolic content and antioxidant activity in bee pollen has been reported by (Bogdanov, 2011). However the variation in the antioxidant activity of mentioned species were not correlated with the variation in the levels of phenolic compounds present in samples, neither with vitamin C, or any of their constiutes as proteins or fat content. This will stimulate further investigation to have the full understanding of the mechanisms involved in this bioactivity.

#### 5.1.9.1.4 Botanical origin of honey

An analysis of honey samples can reveal the botanical source of the pollen and possibily area where particular honey was produced. *Schefflera abyssinica,* contributed more than 60% of the pollen count.The dominance of pollen from the *Schefflera abyssinica* can be attributed to widespread distribution in moist highlands of SouthWest and SouthEastern parts of Ethiopia (Nuru Adigaba *et al.,* 2001). *Schefflera abyssinica* honey is considered as to be a mono-floral honey and it is extra white with a characteristic aroma and very pleasant taste (Abera Belay, 2007). The honey contains very little amount of pollen and easy to strain, thus when it is in liquid state it is clear and transparent.The honey commonly harvested after the flowering period of the plant which is takes place between April–May.

*Croton macrostchyus* honey was the second dominant honey in the mid-altitude areas of districts.. The crystallization of the honey is very coarse with rough and sandy texture. Since this honey is harvested during rainy period, the moisture content is also relatively high. The main harvesting time for honey is starting mid May to June.

Vernonia honey is the third dominant honey mainly from *Vernonia amygdalina.* However, different species of Vernonia spp including *Vernonia auriculifera, Vernonia thomsoniana, Vernonia schimperi, Vernonia rueppellii* and other are contributing for the production of Vernonia honey.Vernonia honey is mostly harvested at mid-altitude and growing in secondary vegetation, where there are high disturbances at the edge of natural forest due to intensive cultivation of crops. In some localities, there is overlapping of flowering period with other honey plants such as *Coffea arabica*. As a result, there is some degree of mixing of Vernonia honey with Coffee honey. Vernonia honey is very dark in color even after crystallization and it tends to granulate uniformly. The honey has very strong flavor and bitter taste and traditionally, Vernonia honey is well known for its medicinal property. Vernonia honey is commonly harvested between the months of February–March.

### 5.1.10.2 Physiochemical properties of forest honey

**Moisture content**

The analysis of moisture content of three honey types identified in the study forest was found to be within an accepted range of Ethiopian honey quality standards (Nuru Adigaba 1999), However the moisture content of *Croton ,macrostachyus* honey was relatively higher than the *Vernonia amygdalina* and *Schefflera abyssinica* honey since the harvesting time of the honey of this species coincides with short rainy season.Thus honey became with higher moisture contentdue to haygroscopic properties of honey.The variation of the moisture content of honey among different honey source plants is due to harvesting of unripe honey, unsuitable honey storagecontainers and storage places and humidity from the air surrounding the beehives.The mean moisture content of honey was also lower than the moisture content of the country's average, 20.6 g/100 g, (Nuru Adigaba, 1999). The maximum limit for moisture content set by the International Honey Commission is 20 g/100 g (IHC, 2002).

The average HMF value of honey samples analyzed for Vernonia honey was 1.1 to 1.3 mg/kg with a mean value of 1.2 ± 0.1mg/kg, 19.52 ± 9.41mg/kg, ranging between 2.2- 36.15 mg/kg and the HMF content of *Schefflera abyssinica* honey ranges 2.2-2.5 with mean value of 2.3 ± 0.15 and similarly the HMF of croton honey ranges from 2.4-2.6 mg/kg and mean value of 2.56 ± 0.15 mg/kg. The value of HMF in above honey types are found within an acceptble range of Ethiopian honeys qualities set by Ethiopian quality control agencies and as well as International honey quality standards of EU and Codex Alimentarius .

Electrical conductivity depends on ash, organic acids, proteins, some complex sugars and polypheols contents, and varies with botanical origin. The electrical conductivity of the honey analyzed for this study was found to be less than 0.8 mS $cm^{-1}$ which is an indication of nectar honey. Thus electrical conductivity of honey samples in the Gesha-Sayilem forest was found

to be within an international range with the maximum limit of 0.8 mS/cm for most nectar honey.Thus the honey of the study forest satisfied the Codex Alementrius and EU standards.

All the three types of honey (*Vernonia*, *Schefflera* and *Croton)* are found to be acidic with a pH-value ranging between 3.9-4.5, due to the presence of organic acids that contributes to honey aroma and stability against fermentation by microorganisms (Abera belay *et al.*, 2007). The mean pH value of the honey from the study area is in line with world standard, between 3.2 and 4.5 (Bogdanov *et al.*,1999).

**Free acid**

There was a significant difference in the free acid content of honeysamples due to botanical origin of honey and sampling locations ($p < 0.05$). According to Baltac and Candan (2007), lower value of acid indicates the absence of undesirable fermentation. The mean free acid value of the current study was below the national average, 39.9 meq/kg (Nuru Adigaba, 1999), and satisfied the CA, EU and Ethiopian standards.The maximum limit for free acid set by the CA is50 meq/kg of honey, while the EU and Ethiopian standard is40 meq/kg of honey. Free acidity of honey is due to the presence of organic acids andinorganic ions such as the gluconic acid with their lactones or esters, phosphate and chloride.

**Sucrose in honey**

The level of sugar content in honey varies according to the origin of the nectar source plants and it is used to identify adulteration in honey by adding sugar cane or other sugars. The mean sucrose content of analyzed honey samples of *Vernonia*, *Schefflera* and *Croton* honeys ranged between 3.16-4 g/100 g.The mean apparent sucrose content of the honey was lower than the national average of 3.6% (Nuru Adgaba, 1999). The present result is lower than (Chala Kinat, 2010) who reported with mean value of 7.55 for Gomma district.The result revealed that honey produced from Gesha-Sayilem forest was natural and not adulterated and

satisfied the Codex, E.U and the Ethiopian standards. The CA, E.U and Ethiopia standard has a maximum limit of 5 g/100 g of honey (Bogdanov, 2001)

**Enzymes**

The enzyme level of the honey is important parameters affecting the physico-chemical properties of honey.There was significant difference between the honey types for invertase and proline content.This could have been due to the differences in their botanical and geographical origin of honey.

#### 5.1.9.3 Honey production system in Gesha–Sayilem forest

Beekeeping in Gesha-Sayilem forest is the main pillar of income generation for the rural household in southwest Ethiopia. Forest beekeeping isusually done in remote areas which are far away from homesteads. Forest beekeeping requires staying overnight stat in the forest and climbing of very tall trees traditionally practiced by men (Nuru Adigaba, 2007). On the other hand climbing on trees for hanging traditional hives is culturally considered as a taboo for females (Chala *et al*., 2012). Hence, the role of women in forest beekeeping system is very low and as a result, women are not economically empowered through beekeeping (Awaris Getachew *et al,* 2012).

According to about 93.3% of respondents the total honey produced comes from traditional beehives and the contribution of intermediate and modern hives are insignificant. This shows that large proportion of the respondents had little exposure to improved beekeeping practices most likely due to little attention is given to the sector so far. Therefore, the sources of beekeeping skill and knowledge in the area are mainly transferred from family to generations with little or no change. Honey harvesting period varies from place to place in the area. Beekeepers identify honey season based on experiences taking into consideration and the environmental condition, such as clustering of the high population of bees at the entrance of

the beehives, increasing the defensive behavior of honeybees and completion of flowering periods of honey plants in the surrounding areas.

Assessment of honeybee flora of the study area showed that the area has abundance of forest plant that can have a huge potential as bee forage plants that can help in the production of the large volume of organic honey production which can be supplied to the National and International markets.The main bee forage plants reported by the beekeepers were *Schefflera abyssinica, Croton macrostachyus, Syzygium guineense, Vernonia amygdalina, Pouteria adolfi-friederici* and *Ekebergia capensis* and this report also corresponds with plant species identified from pollen analysis of honey and pollenload collection. However, some plant species are reported to be poisonous to honeybees. Introduced poisonousbee forage such as *Euphorbia cottinifolia* is widely grown as life fence in the districts. This plantis easily propagated by cuttings and also they adapt very easily. About 28% of the respondents stated that a major problems of beekeeping in the study area were honeybee enemies such as ants, honey badgers, birds and small hive beetles. This is in agreement with (Desalegn Begna, 2007),ants attack is the most serious problem in beekeeping sector in Ethiopia.

In the present study beekeepers usually construct a large number of traditional log hives from selected indigenous tree species: namely, *Croton macrostachyus, Pouteria adolfi-friederici* and *Euphorbia ampliphylla* trees.The construction of log hives leads to a higher consumption of forest resources and a great concern todestructionof honey beeflora without additional returns (Hartmann, 2004) and also disturbing the forest biodiversity and species composition of the forests.

## 5.2 Conclusion and Recommendation

Gesha-Sayilem forest is one of the remaining moist Afromontane Forests in southwest Ethiopia and is rich in plant biodiversity with 300 species of vascular plants identified.This high species diversity is attributed to habitat heterogeneity including topographic and climatic diffrences.

The forest or part of forest needs to be protected as it is home for some endemic plant species including *Clematis longicauda, Scadoxus nutans* and *Rinorea friisii,* which are found in a few plots within a forest and the forest vegetaion.

Some of the plant species being new records in the Kaffa floristic region is indicating that there is need for further extensive botanical exploration in the area. This also indicates there could be practical activity for the exploration of new species to science.

Among the fourty environmental factors included altitude, slope, disturbances, Phosphorus and EC were the most important in differentiating plant community types.

The five dominant species with higher IVI value for source for carbon sinks found in the forest are *Schefflera abyssinica, Syzygium guineense, Pouteria adolfi-friederici, Gallineria saxifarga, Ilexmitis, Lepidotrichilia volkensii* and *Dracena afromontana.*These plant species need to be protected for their economical, ecological and social services.

The pollen analysis of honey indicated that *Schefflera abyssinica, Croton macrostachyus* and *Vernonia amygdalina* were the major sources of monofloral honey in the area due to the abundance and high nectar yielding potential of these species.The distribution of each of species needed to be mapped areas with species need to be protected.

The pollen identification using pollen traps indicated that *Guizotia scabra, Bidens* spp., *Croton macrostachyus, Datura innoxia, Eucalytus globulus, Plantago lanceolata* were the potential sources of pollen for honeybees in the area. The proximate composition analysis of pollen content from the above mentioned plant species suggested that they are rich in protein, vitamins, phenols and antioxidants that can be used as food supplement for humans.

Traditional beekeeping is the dominant beekeeping practice in the area. Key informants explained that low level of improved beekeeping intervention, deforestation and drought are the major constraints of beekeeping in the area.

### 5.3 Recommendations

- Intiating conservation areas such as Biosphere reserves in areas that are found to be rich in plant biodiversity including endemic, rare and economically important plant species, but affected by the local people through extraction of fuelwood and agricultural expansion.
- Plant communities holding important trees such as *Schefflera abyssinica, Syzygium guinnese, Poueria adolfi-friederici* and *Il*ex *mitis, Croton macrostachyus* and *Olea welwitschii* are the major carbon sink species as well as high potential honey source plants in the area and protection and raising and planting of seedlings are important.
- The Gesha-Sayilem Afromontane Forest has high potential to store carbon stock of 362.46 ton/ha and this carbon stock should be included in the National carbon stock database for the implementation of $REDD^{+}$ with relevant organizations to benefit the local communities from carbon trade.
- Introducing to farmers improved beekeeping technologies to increase the honey production and reducing pressure on the forest biodiversity.
- The pollen nutritional analysis from *Guizotia scabra, Bidens* spp., *Croton macrostachyus,* and *Eucalytus globulus* showed acceptable nutritional, antioxidant and

phenol levels. However, further study of the amino acid profile and storage and handling of pollen for the human.

## REFERENCES


Abate Ayalew, Tamrat Bekele, Sebsebe Demissew (2006). The undifferentiated Afromontane Forest of Denkoro in the Central Highland of Ethiopia: Floristic and Structural Analysis SINET*: Ethiopian Journal of Science* 29: 45–56.

Abayneh Derero, Tamrat Bekele and Bert-Ake Nasulund (2003). Population structure and regeneration of woody species in broad leaved Afromontane rain forests in Southwest Forest. *Ethiopian Journal of Natural Resources5:*255-280.

Abel Girma, Teshome Soromessa and Tesfaye Bekele (2014). Forest Carbon Stocks in Woody Plants of Mount Zequalla Monastery and its Variation Along Altitudinal Gradient: Implication of Managing Forests for Climate Change Mitigation. *Journal of STAR* 3(2): 132-140.

Abera Belay, Solomon Worku, Geremew Bultossa, Nuru Adgaba and Samuel Melaku (2007). Physicochemical properties of the Harenna forest honey, Bale, Ethiopia, *Journal of Food Chemistry* 141:3386–3392.

Abiyou Tilahun,Teshome Soromsa, Ensermu Kelbessa and Abyot Dibaba (2011). Floristic composition, and community analysis of Menagesha Amba Mariam Forest in central Shewa, Ethiopia. *Ethiopia.J.Biol.Sci*. 7(3): 111-136.

Abraham Assefa (2009). Floristic Composition and Structure of Masha Forest, Southwest Ethiopia. MSc Thesis Addis Ababa University School of Graduate Studies.

Achalu Chimdi, Heluf Gebrekidan, Kibebew Kibret and Abi Tadesse (2012). Effects of Liming on Acidity-Related Chemical Properties of Soils of different Land Use Systems in Western Oromia, Ethiopia. *World* J. *Agric. Sci*. 8:560-567.

Admassu Addi, Kibebew Wakjira, Ensermu Kelbssa and Amssalu Bezabeh (2014). *Honeybeeof Ethiopia*. Holeta Bee Research and National Herbarium of Addis Ababa University, Addis Ababa, Ethiopia.

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.

Ahmed Abdikadir (2013). Diversity and distribution of the Afroalpine flora of eastern Africa with special reference to the taxonomy of the genus *Pentaschistis* (Poaceae). M.Sc. Thesis, Kenyatta University, Kenya.

Alvarez, E. Duque, A., Saldarriaga, J., Cabrera, K., del Valle, G., Lema, A., Moreno, F., Orrego, S., Rodríguez, L., (2012). Tree above-ground biomass allometries for carbon stocks estimation in the natural forests of Colombia. *For. Ecol. Manage*. 267:297– 308

Almeida-Muradian, L. B; Pamplona, L C; Coimbra, S; Barth, O M (2005). Chemical composition and botanical evaluation of dried bee pollen pellets. *Journal of Food Composition* and *Analysis*18: 105–111.

Allen, S.E., Grimshaw, H.M. and Rowland, A.P. (1986). *Chemical analysis, in Methods in Plant Ecology*(2nd eds P.D. Moore and S.E. Chapman), Blackwell Scientific, London, pp. 285–344.

Alves, L. F., Vieira, S. A., Scaranello, M. A., Camargo, P. B., Santos, F. A. M., Joly, C. A. and Martinelli, L. A. (2010). Forest structure and live aboveground biomass variation along an elevational gradient of tropical Atlantic moist forest (Brazil). *Forest Ecology Management*260: 679–691.

Andreas E.; Gemma R.; ULF P, REINER Z.; Anderas H. and Markus F. (2015). Effect s of elevation and land use on the biomass of trees, shrubs and herb s at Mo unt Kilimanjaro. *Ecosphere* 6(3):45.

Amssalu Bezabeh, Nuru Adigba, Radloff S.E, Hepburn H.R (2004). Multivariate morphometric analysis of honeybees (Apis mellifera) in the Ethiopian region.*Apidologie* 35: 71–81

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

AOAC (2003). Official methods of analysis of AOAC International. 17th edition.

AOAC, (2000). Official Methods of Analysis, Arlington, VA, USA.Aouali, N., Laporte.

AOAC (2005). Official Methods of Analysis of AOAC. In International18th edition.

AOAC (1990). Official Methods of Analysis of the Association of Official Analytical Chemists 15th Edition Washington D.C .USA.

Atip Chantarudee, Preecha Phuwapraisirisan, Kiyoshi Kimura, Masayuki Okuyama, Haruhide Mori, Atsuo Kimura and Chanpen Chanchao (2012). Chemical constituents and free radical Scavenging activity of corn pollen collected from *Apis mellifera* hives compared to floral corn pollen at Nan, Thailand 12:45-52

Augspurger, C.K& Kelly, C.K. (1984).Pathogen mortality of tropical tree seedlings: experimental studies of the effects of dispersal distance, seedling density, and light conditions. *Oecologia* 62: 775-788.

Awraris Getachew, Yemisrach Getachew, Dejen Assefa, Nuru Adigaba, Gebeyehu Ganga and Workneh Abebe (2012). Honey production system in Kaffa, Sheka and Bench Majii Zones.*Journal of Agricultural Extension and Rural Development* 4(19): 528-541.

Ayele Kebede (2011). Delimiting the Interface between Garden Coffee Expansion and Forest Coffee Conservation and its Implication for Protected Area Management: The Case of KafaCoffee Biosphere Reserve. Msc thesis,University of Klagenfurt, Austria.

Bale Eco-Region Sustainable Management Program (BERSMP) (2010). Bale Mt's REDD project: Structuring, marketing and development preparation phase, FARM Africa / SOS Sahel Ethiopia.

Baltac, C., & Candan, F. (2007). Biological activities and chemical composition of three honey of different types from Anatolia.*Journal of Food Chemistry*, 100:526–534

Barthlott A. (1998). The uneven distribution of global biodiversity: A challenge for industrial and developing countries. In: Ehlers T. and Krafft E.(Eds.). German National committee on Global Change Research, Bonn, Germany pp 36.

Barkman JJ,(1989). A critical evaluation of minimum area concept. *Vegetatio*85:89–104

Bayat, T. A. (2007). Carbon Stock in an Apennine Beech Forest. M.Sc. Thesis

Barbour, M.G. and Billings, W.D. (1988). North American Terrestrial Vegetation, Cambridge University Press, New York.

Bazzaz, F. (1991). Regeneration of tropical forests: physiological responses of pioneer and secondary species. In: Gomez-pompa, A., Whitmore, T and Hadley, M. (eds.), Rainforest Regeneration and management. Parthenon Publishers, UNESCO, Paris. pp. 91-118.

Bazzaz, F.A. (1975). Plant species diversity in old field ecosystems in southern. *Illinois. Ecology*, 485–488.

Basuki, T. M., Van Laake, P. E., Skidmore, A. K., & Hussin, Y. A. (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *Forest Ecology and Management*, 257(8), 1684-1694.

Belay Melese Wolde, Ensermu Kelbessa and Teshome Soromessa (2014). Forest Carbon Stocks in Woody Plants of Arba Minch Ground Water Forest and its Variations along Environmental Gradients. *Sci. Technol. Arts Res. J.*, 3(2):141-147.

Badege Bishaw (2001). Deforestation and land degradation in the Ethiopian highlands: a strategy for physical recovery. Northeast African Studies 8(1): 7-26.

Bhuyan P., Khan M.L & 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. *Biodiversity Conservation,*12(8)1753–1773.

Bogdanov, S. (2011).Pollen Nutrition, Functional Properties, Health: A Review. Bee Product Science, Available online: http://www.bee- hexagon.net/files/file.

Bogdanov, S.; Bieri, K; Gremaud G; Iff, D; Kanzig, A; Seiler, K; Stockkli, H. Zurcher,K. (2004). Swiss Food Manual: Pollen Bienenprodukte, BAG Berne.

Bogdanov S. (2001). Codex Alimentarius: Draft Revised Standard for Honey Bee Department.

Bogdanov S(1999). Honey quality and international regulatory standards: review of the work of the International Honey Commission. Mitteilungenaus dem Gebiete der Lebensmittelunter suchung und Hygiene 90(1):108–125

Brady, N. C. (1974). The Nature and Properties of Soils; 8th ed., Macmillan, New York.

Bosi G., Ricciardelli D'Albore G. (1975). Quantitative determination of amino acids in some beecollected pollens. XXXV Int. Beekeep. Congr. Apimondia.

Brown, J.H. and Lomolino, M.V. (1998). *Biogeography*, 2nd ed. Sinauer Associates, Inc. Publishers, Sunderland MA.

Brown, j. k. (1974). Handbook for inventorying downed woody material. General Technical Report INT-16. Ogden, Utah: USDA Forest Service Intermountain Forest and Range Experiment Station.

Brown, S. and Lugo A. E. (1992). Above-ground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia* 17:8-18.

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

Brown, S., Gillespie, A.J.R., and Lugo, A.E., (1989). Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*35(4): 881–902.

Brown, S. (1997). Estimating biomass and biomass change of tropical forests: *A Primer. FAO Forest Paper* 134, FAO, Rome

Brown, S. (2002). Measuring carbon in forests: current status and future challenges.

*Environmental Pollution*, 116(3): 363-372.

Brown, S., Shoch, D., Pearson, T. and Delaney, M. (2004). Methods for Measuring MonitoringForestry Carbon Projects in California,FinalProject Report.Winrock International Publishing, Arlington, Virginia.

Gibbs, H.K., Brown, S., Niles, J.O., & Foley, J.A. (2007). Monitoring and Estimating Tropical Forest Carbon Stocks: Making REED a Reality, *Environ. Res. Lett.* 2: 1–13.

Barkman, J. J. (1979). The investigation of vegetation texture and structure. In: Werger, M. J. A. (ed.), The study of vegetation, pp. 123–160. Junk, The Hague.

Bonnefille R, Buchet G, Friis I, Ensermu Kelbessa, Mohammed MU (1993). Modern pollen rain on an altitudinal range of forests and woodlands in southwest Ethiopia. *Opera Bot*. 121:71 -84.

Campos, M. G.; Markham K. R.; Mitchell, K. A.; Cunha, A. P. (1997). An approach to the Characterization of bee pollens via their flavonoid/phenolic profies. Phytochemical Analysis, Hoboken, 8 (3): 181-18551.

Cairns, M. A., Brown S. Helmer E. H, and Baumgartner G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia*111:1-12.

Cain, S. A., &Castro, G. M. O. (1959). *Manual of Vegetation Analysis*. New York:

Harper & Brothers.

Centeral Stastics Agency (2015). Federal Democratic Republic of Ethiopia Report On: Livestock and Livestock Characteristics (Private Peasant Holdings). Addis Ababa.

Centeral Stastics Agency, (2017). Federal Democratic Republic Of Ethiopia Report On: livestock and Livestock Characteristics, Addis Ababa.

Cesar, S. (1992). Regeneration of tropical dry forests in Central America, with examples from Nicaragua. *Journal of Vegetation Science* 3:407-416.

Chaffey, DR. (1979). Southwest Ethiopia Forest Inventory Project, a Reconnaissance Inventory of Forest in South-West Ethiopia Ministry of overseas Development Land Resources Development Centre, Project Report 31:1-316.

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

Chave J, Rie´ ra B, Dubois MA (2001). Estimation of biomass in a Neotropical forest of French Guiana: spatial and temporal variability. *J Trop Ecol*17:79–96.

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 Biol*20:3177– 3190

Chapman, J.L. and Reiss, M.J. (1992). *Ecology: Principles* and *Applications*, Cambridge University Press, Cambridge.

Chemuku W., Nereoh L. Elias M., Bernard K., Gabriel M.,Musingo Mb.Ben Ch. (2016). Effects of Forest Disturbance on Vegetation Structure and Above-Ground Carbon in Three Isolated Forest Patches of Taita Hills.

Clements, F.E. (1936). Nature and structure of the climax community. *Journal of Ecology* 24(1):252-284.

Chataway H.D (1978).The determination of moisture content in honey.*Canadian Journal of Research 6:* 532-547.

Conservation International (2005). Available at:http://www.conservation.org/

Collins, S.L., Glenn, S.M. and Roberts, D.W. (1993). The hierarchical continuum concept. *Journal of Vegetation Science* 4(2):149-156.

Crane, E. (1990). Bees and beekeeping: Science, Practice and World Resources. Corn stock Publ., Ithaca, NY., USA. pp. 593

Cristofoli S., Monty A. and Mahy G. (2010). Historical landscape structure affects plant species richness in wet heathlands with complex landscape dynamics. Landscape Urban Plann. 98:.92–98

CSA (2013a). Population projection of Ethiopia for all regions at Wereda level from 2014–2017. Federal Democratic Republic of Ethiopia Central Statistical Agency, Addis Ababa,Ethiopia. pp. 118.

David, R.V., Peter, A.P. and Richard, G. S. (1997). Allometric equations for two South American Conifers: Test of non-destructive method. *Forest Ecology and Management* 106: 55–71

Davison, A. and Rex, D.C. (1980). Age of volcanism and Rifting in Southwestern Ethiopia. *Nature*283: 657-658.

Dawit Tekele (2014).Allometric equation for biomass estimation of *Allophylus abyssinicus* and *Croton macrostachyus* in Arba Gugu forest, Arsi Zone Oromia Region, Ethiopia. MSc Thesis, Addis Ababa University

Debissa Lemessa. &Yayehyirad Teka. (2017). Patterns of the Diversity of Characteristic Species Across Vegetation Ecosystems of Ethiopia. *Ecology and Evolutionary Biology*,2(3): 34-44.

Debissa Lemessa, Negussie Achalu and Admassu Addi (2008). Honey pollen and bee pollen Load Analysis for Vegetation Characterization and Implications for Honey Plant Growing and Conservation: The Case of Walmara Woreda, Central Ethiopia. *Ethiopian Journal of Natural Resources.*32:249–265

Demel Teketay &Tamrat Bekele (1995). Floristic composition of WofWasha natural forest, Central Ethiopia: implications for the conservation of biodiversity. *Feddes Repertorium*106:27-147.

Demel Teketay (1996). Seed Ecology and Regeneration in Dry Afromontane Forests of Ethiopia.Ph.D. Thesis, Swedish University of Agricultural Sciences, Uppsala.

Demel Teketay (2000).Vegetation types and forest fire management in Ethiopia. In: Proceedings of the Round Table Conference on Integrated Forest Fire Management in Ethiopia. Ministry of Agriculture (MOA), Addis Ababa, Ethiopia.

Demel Teketay (2005). Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production - Population structures.*Tropical Ecology* 46(1): 29-44.

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

Delaney, M., Brown, S., Lugo, A.E., Torres-Lezama, A. Bello Quintero, N., (1998). The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. 30(1):2-11

Desalegn Wana (2009). Plant Species and Functional Diversity along Altitudinal Gradients, Southwest Ethiopian Highlands PhD Dissertation.

Dessie G. (2007). Forest decline in South and Central Ethiopia: Extent history and process. Ph.D. dissertation. Department of Physical Geography and Quaternary Geology. Stockholm University, Stockholm, Sweden

Dereje Tadesse and Tadesse Woldemariam Gole (2008). Customary Forest Tenure in Southwest Ethiopia. *Forests, Trees and Livelihoods*, 7: 325-338.

Dereje Denu (2007). Floristic Composition and Ecological Study of Bibita Forest, Southwest Ethiopia. Unpublished MSc. Thesis, Addis Ababa.

Dereje Denu(2017). Impact of climate and land use on plant diversity, carbon storage and leaf area index in the Jimma Highlands, Southwest Ethiopia, PhD thesis.

Dereje Woltedji (2004). Assessment of beekeeping management systems and potential honey source plants Integrated with agro-forestry farming in Ethiopia; A case study at Butajira. MSc. Thesis. Stuuttgart, Germany.

Devi P. S. (2009).Aboveground biomass and net primary production of semi-evergreen tropical forest of Manipur, north-eastern India.

Díaz, S., Hector, A. and Wardle, D. A., (2009). Biodiversity in forest carbon sequestration initiatives: not just a side benefit. *Current Opinion in Environmental Sustainability* 1: 55-60.

Dieler J, Pretzsch H (2013). Morphological plasticity of European beech (Fagus sylvatica L.) in pure and mixed-species stands. *For Ecol Manage* Pp97–108.

Djomo AN, Ibrahima A, Saborowski J, Gravenhorst G (2010) Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa. *Forest Ecology and Management*, pp. 1873–1885.

Donahue RL, Miller RW and Shikluna JC (1983). *Soils*. An introduction to soils and plant growth. Prestice Hall of India, New Delhi.

EFAP (1994). *The Challenges for Development*, Volume 2. Ministry of Natural Resources Development and Environmental Protection EFAP Secretariat, Addis Ababa.

Ensermu Kelbessa and Teshome Soromessa (2008). Interfaces of Regeneration, structure, Diversity and uses of some plants species in Bonga Forest. A Reservoir for wild Coffee Gene Pool. *SINET, Ethiopia. J. Sci.*31:121-134.

Ensermu Kelbessa, Sebsebe Demissew, Zerihun Woldu & Edwards, S. (1992). Some threatened Endemic Plants of Ethiopia. In: Edwards, S., Asfaw, Z.(eds.). The Status of Some Plants in Parts of Tropical Africa.*Botany2000:* NAPREC Monograph Addis Ababa University: pp.35−55.

Ensermu Kelbessa and Sebsebe Demisew (2014). Diversity of Vascular Plant Taxa of the Flora of Ethiopia and Eritrea. *Ethiop. J. Biol. Sci.* 13: 37-45.

Erdtman, G. (1969). *Handbook of palynology*. Muntisguard, Copenhangen. PP 486.

Ermias Lulekal (2005). Ethnobotanical study of medicinal plants and floristic composition of the Mena Angetu moist montane forest, Bale, Ethiopia. (Unpublished MSc. thesis), Addis Ababa University.

Ermias Lulekal (2014). Plant diversity and ethnobotanical study of medicinal plants in AnkoberDistrict, North Shewa Zone of Amhara Region, Ethiopia. Addis Ababa University, Addis Ababa, Ethiopia. PhD Thesis.

Eyosias Worku and Teshome Soromessa (2015). Allometric Equation for Biomass Determination in *Juniperus procera* and *Podocarpus falcatus* of Wof-Washa Forest: Implication for Climate Change Mitigation. *American Journal of Life Sciences*3(3): 190-202.

EWNHS (1996). Ethiopian Wildlife and Natural History Society,. Important Bird Areas of Ethiopia, A First Inventory, .Semayata Press, Addis Ababa, Ethiopia

Faegri,K., and L. Vander P. (1979). The principles of pollination ecology, 3rd revised ed.Pergamon press, Oxford.

FAO (2000). Manual on integrated soil management and conservation practices. *Land and Water Bulletin* 8, FAO, Rome, Italy.

FAO (2001).*Trees outside forests: Towards rural and urban integrated resources management.* Rome, Italy.

FAO (2004). Assessing carbon stocks and modelling win-win Scenarios of carbon sequestration through land use changes, Rome, Italy.

FAO (1997). Estimating biomass and biomass change of tropical forests*: A Primer Brown, S. FAO Forestry Paper Rome*, Italy.

FAO (2010). Challenges and Opportunities for Carbon Sequestration in Grass Land Systems: a Technical report on grassland management and climate change mitigation, Rome, Italy.

FAO (2010). Global Forest Resource Assessment. Country Report Ethiopia. FRA2010/065. FAO,Rome.

FAO (2000). Manual on integrated soil management and conservation practices. *Land and Water Bulletin* 8, FAO, Rome, Italy.

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

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* (2012) 23(2): 205−216

Feyera Senbeta (2006). Biodiversity and Ecology of Afromontane Rain Forest with Wild *Coffea arabica* L. Populations in Ethiopia. Dench M, Martius C, Rodgers C (eds.). *Ecology Development Series* No 38. Bonn.

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

Forrester, D.I, Bauhus, J., Cowie, A.L. and Vanclay, J.K., (2006). Mixed species plantations of Eucalyptus with nitrogen-fixing trees: a review. For. Ecol. Manage. pp 211-230.

Franklin JF, Spies TA, Van Pelt R, Carey AB, Thornburgh DA, Berg DR, Lindenmayer DB,Harmon ME, Keeton WS, Shaw DC, Bible K, Chen JQ (2002). Disturbances and structuraldevelopment of natural forest ecosystems with silvicultural implications, using Douglas-firforests as an example. *Forest Ecol Manage* 155:399–423

Free, J.B. (1970). *Insect pollination of the crops*. London.

Friis Ib (1992). Forest and forest trees of north-east Tropical Africa. *Kew Bull. Additional Ser*. pp. 1-396

Friis, Ib and Sebsebe Demissew (2001). Vegetation maps of Ethiopia and Eritrea. A review of existing maps and the need for a new map for the flora of Ethiopia and Eritrea. *Biologiske Skrifter* 54: 399-439

Friis, Ib., Sebsebe Demissew and van Bruegel, P. (2010). Atlas of the Potential Vegetation of Ethiopia. The Royal Danish Academy of Science and letters, Denmark.

Friis Ib (1992). Forest and forest trees of north-east Tropical Africa. *Kew Bull. Additional Ser*.pp. 1-396.

Friis Ib (1986).Ethiopia in regional phytogeography. *Symbolae Bot.Uppsal*. 26 (2):31-47.

Friis Ib, Rasmussen F.N. and Vollesen K. (1982). Studies on the flora and vegetation of Southwest Ethiopia. *Opera Bot*. 63:1-70.

Friis, Ib. Sebsebe Demissew and Breugel, P. (2011). *Atlas of the Potential Vegetation of Ethiopia*. Addis Ababa University Press, Sharma Books, Addis Ababa, Ethiopia.

Gemechis Legesse Yedeta(2014). Review of progress in Ethiopian honey production and marketing. Holeta Bee Research Center (HBRC), Holeta.

Getachew Tesfaye (2012).Ecology of Regeneration and Phenology of seven indigenous tree species in a dry tropical Afromontane forest, Southern Ethiopia. Doctoral dissertation Submitted to the school of graduate studies, Addis Ababa University, Addis Ababa, Ethiopia.

Getachew Desalegn, Melaku Abegaz, Demel Teketay and Alemu Gezahgne, (2012).

Commercial timber species in Ethiopia: Characteristics and uses. A handbook for forestindustries, construction sectors, foresters and other stakeholders [In press], Addis Ababa,Ethiopia.

Getinet Masresha (2014). *Diversity, Regeneration, and Status of Vegetation in Simien MountainsNational Park, Northern Ethiopia*. Doctoral Dissertation. Thesis, Addis Ababa University, Addis Ababa. Unpublished.

Gibbs, K. H., Brown, S., Niles, O. J. and Foley, A. J. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality, *Environmental Research Letters 2*. SOP Publishing Ltd, UK

Giorddano G. (1940). Cenni Monographic sulle piante foretali e sui legnami dell' A.O. *Riv. Forest. Ital.*183-188.

Goldsmith, F.B., Harriso, C.M. and Morton A.J. (1986). Descriptions and analysis of vegetation.In: *Methods in plant Ecology*. 2nd ed. pp 437.

Gomes,L.G.Dias,L.Moreira,P.Rodrigues,andEstevinho,(2010). Physicochemical, microbiological and antimicrobial properties of commercial honeys from portugal,"*Food and Chemical Toxicology,* 48: 544–548."

Habtamu Assaye and Zerihun Asrat (2016).Carbon Storage and Climate Change Mitigation Potential of the Forests of the Simien Mountains National Park, Ethiopia.A*griculture, Forestry and Fisheries* 5( 2):8-17

Haile Adamu, Tamrat Bekele and Gemedo Dalle (2012). Floristic diversity, regeneration status,and vegetation structure of woodlands in Metema Area, Amhara National Regional State, and Northwestern Ethiopia.*Journal of Forestry Research*23(3): 391-398.

Haile Yinger, Ensermu Kelbessa, Tamirat Bekele and Ermias Lulekal (2008a). Floristic

Composition and structure of the Dry Afromontane forest at Bale Mountain National Park.*Journal ofethnopharmacology* 112: 55-70.

Harper, J. (1977). *Population Biology of Plants.* Academic Press, London.Silverto population ecology. Longman Group, NY.

Hamere Yohannes, Teshome Soromessa and Argaw Mekuria (2015). Carbon Stock Analysis along Slope and Aspect Gradient in Gedo Forest: Implications for Climate Change Mitigation. *Earth Sci Clim. Change* pp 305.

Hartmann, In. (2004).“No Tree, No Bee – No Honey, No Money”: *The Management of Resources*andMarginalization in Beekeeping Societies of South West Ethiopia. Paper submitted to the Conference: Briding Scales and Epistemologies, Alexandria.

Hartmann, Ingrid, (2002). “Perceptions of illegal wood cutting and their effect on bee-keeping socities in Southwestern Ethiopia.

Harmon, M. E. and Sexton, J. (1996). Guidelines for measurements of woody detritus in forest ecosystems.

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

Hedberg, O. (1986). The afroalpine flora of Ethiopia. *SINET: Ethiopian Journal of Science* 9: 105-110.

Hedberg, O. (1964). Features of Afro alpine plant ecology. *Acta Phytogeogr. Suec*. 49:1-144.

Hedberg, I., Friis, I. and Persson, S. (eds.) (2009). *Flora of Ethiopia*, Vol.1, *Lycopodiaceae*to*Pinaceae*. Appendix-Additional and amendment to Vols. 2-7.The National Herbarium, Addis Ababa, Ethiopia; Uppsala, Sweden.

HeinricK (1975). Bee flowers: A hypothesis on flower variety and blooming times. *Evolution* 29: 325-334.

Herbert, E.W. (1992). Honeybee nutrition. In: Graham, J.M. (ed), *The hive and the honeybee*. Dadant Hamilton. Pp.197- 224

Hicks C., Woroniecki S., Fancourt M., Bieri M, Garcia R.H., Trumper K. and Mant R. (2014). The Relationship between biodiversity, carbon storage and the provision of other ecosystem services: Critical Review for the Forestry Component of the International Climate Fund. Cambridge, UK.

Henry, M., Picard, N., Trotta, C., Manlay, R. J., Valentini, R., Bernoux, M., & Saint-André,L.(2011). Estimating tree biomass of sub-Saharan African forests: a review of available allometric equations. *Silva Fennica*, pp, 477-569.

Henry, M., Besnard, A., Asante, W. A., Eshun, J., Adu-Bredu, S., Valentini, R., & Saint-Andre, L. (2010).Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. *Forest Ecology and Management*260: 1375-1388.

Houghton R A (2005). Tropical deforestation as a source of greenhouse gas emissions. *Tropical Deforestation and Climate Change*d 11: 945-958.

Houghton, R. A. (2007). Balancing the global carbon budget. *Annual Review of Earth* and*Planetary Sciences* 35:313–347.

Hubbell, S. and Foster, R. (1986). Mortality rates of 205 Neotropical tree and shrub Species and the impact of severe drought. *Ecol. Monogr.* 65:419–439

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

IPCC (2000). *Land Use, Land-Use Change, and Forestry*. Edited by Watson R.T, Nobel I.R, Bolin B, Ravindranath N.H, Verardo D.J, Dokken D.J, Cambridge University Press, Cambridge.

IPCC (2001). *Climate Change Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Intergovernmental Panel on Climate Chang*e, Third Assessment Report. Cambridge, Univ. Press, UK.

IPCC (2007). *Climate change: synthesis report*- contribution of Working Groups 1, 2 and 3 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva.

IPCC (2003).*Good Practice Guidance for Land Use, Land-Use Change and Forestry*, Prepared by the National Greenhouse Gas Inventories Programme.

IUCN (1990). Ethiopia National Conservation Strategy phase one. March 1990, Gland,

Switzerland. pp 275.

IHC(2002). Harmonized Methods of the International HoneyCommission.URL <http://www.apis.admin.ch/english/host/pdf/honey/HMFabstract.pdf>).

Jaccard, P. (1912). The distribution of the flora of the alpine zone. *New Phytologist* 11:37–50.

Jeffries MJ (ed) (2005). Biodiversity and conservation,. Routledge, New York, pp. 1-236

Jarvis A., Reuter H. J., Nelson E. & Guevara E. (2008). Hole-filled seamless SRTM data version 4. International Center for Tropical Agriculture (CIAT) available http://srtm.csi.cgiar.org.

Karousakis, K. (2009). "Promoting Biodiversity Co-Benefits in REDD". ENV Working Paper No. 11. OECD Publishing, Paris.

Ketterings, Q.M., Coe, R., Noordwijk, M., Ambagau, Y. and Palm, C.A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting aboveground tree biomass in mixed secondary forests. *Forest Ecology and Management* 146: 199-209

Kent, M. and Coker R. (1992). *Vegetation description and analysis*: *A practical approach*. CRC Press, Inc., London.

Kent, M. & Ballard, J. (1988). Trends and problems in the application of classification and ordination methods in plant ecology. *Vegetatio*78**:** 109–124.

Kflay Gebrehiwot1 and Kitessa Hundera (2014).Species composition, Plant Community structure and Natural regeneration status of Belete Moist Evergreen Montane Forest, Oromia Regional state, Southwestern Ethiopia.

Kirby, K.R. and C. Potvin (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.

Kitessa Hundera (2003). Floristic composition and structure of the Dodola Forest, Bale

Zone, Oromiya Regional State. (Unpublished MSc.thesis), Addis Ababa University.

Krebs, C. J. (1999). *Ecological Methodology*. 2nd ed. Addison-Welsey Educational Publishers, U.S.A. 620pp.

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

Kumelachew Yeshitela and Taye Bekele (2003). The woody species composition and structure of Masha-Anderacha Forest, South-western Ethiopia. *Ethiop. J. Biol. Sci.*2(1): 49-60.

Khumbongmayum, M.L., Khan, M.L & Tripathi, R.S. (2006). Biodiversity conservation in sacred Groves of Manipur, north-east India: Population structure and regeneration status of woody Species. *Biodiversity and Conservation,*15:2439-2456.

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

Lamessa Kumessa (2010). Floristic Composition and Structure of Gura-Lopho Moist Afromontane Forest, Horo-Guduru Wollega Zone, Oromia Region, Western Ethiopia. Unpublished MSc thesis, Addis Ababa University, Ethiopia.

Lasco RD, Macdicken KG, Pulhin FB, Guillermo IQ, Sales RF, Cruz RVO (2006). Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. *J. Trop. Forest Sci*.18(4): 166-172.

Lamrecht and F.B.Pulhin. (2004). Carbon budgets of tropical forest ecosystems in Southeast Asia: implications for climate change. In: *Forestry for poverty reduction: opportunities with clean development mechanism, environmental services and biodiversity*, (Eds.): Sim, H.C., S. Appanah and Y.C. Youn. *RAP Publication*, pp.61-75

Lasco R.D Pulhin FB, Visco RG, RACelis DA, Guillermo IQ, Sales RF,(2000). Carbon stocks assessment in Philippines forest Ecosystem. Paper presented at the science-policy workshop on terrestrial carbon assessment for possible carbon trading Bogor pp.28-29

Lamrecht, H. (1989). Silviculture in the tropics. Tropical forest ecosystems and their tree speciesPossibilities and methods in the long-term utilization. Germany, pp. 296.

Lal R (2012). Carbon sequestration in Urban Ecosystem. In:*Phil Trans. R. Soc. B.* pp: 815-830

Lal, R. (2006). *Soil Quality and Soil Erosion*. CRC press.

Lal,, R. (2008). Sequestration of atmospheric $CO_2$ in global carbon pools.

Leps, J. (2005). Diversity and ecosystem function, in˘ *Vegetation Ecology* (ed. E. van

der Maarel), Blackwell Publishing, Oxford, pp. 199–237

Leitner W., W .R. Turner (2001). Measurement and analysis of biodiversity. In: Levin S.A. (Ed.) *Ecyclopedia of biodiversity*, Vol. 4. Academic Press, Princeton, pp. 123-144.

Lisanework Nigatu (1987). An ecological study of the vegetation of the Harenna forest.

MSc.Thesis, Department of Biology, Addis Ababa University, Addis Ababa,

Ethiopia.

Lisanework Lisanework Nigatu. and Mesfin Tadesse (1989). An ecological study of the vegetation of the Harennaforest, Bale, Ethiopia. *SINET: Ethiop. J. Sci.* 12(1): 63-93.

Logan, W.E.M. (1946). An introduction to the forests of central and southern Ethiopia. *Imperial Forest Research Institute* Paper No 24: 1-58.

Louveaux J., Maurizio, A., and Vorwohl, G. (1978). Methods of Melissopalynology. *Bee world,* 19: 57–61

Liu, X., Ekoungoulou, R. Loumeto, J.J., Ifo S.A, Bocko Y.E. Koula. F.E (2014).

Evaluation of Carbon stocks in above- and below-ground biomass in Central

Africa: case study of Lesio-louna Tropical rainforest of Congo11 (7): 10703-10735

Lüet, Yin JX, Jepsen MR and TangJW, (2010). "Ecosystem carbon storage and partitioning in a Tropical seasonal forest in Southwestern China". *Forest Ecology and Management* 260: 1798–1803.

Lukoschus F.S. and Keularts L.W, (1968). Further function of the mandibular glands of worker Honeybees (*Apis mellifera* L.): Production of a substance inhibiting pollen germination.*Ztschr. F. Bienenforsch*, Pp 333-343.

Luo, T. X., Brown, S., Pan, Y. D., Shi, P. L., Ouyang, H., Yu, Z. L., Zhu, H. Z.( 2005).

Root biomass along subtropical to alpine gradients: global implication from Tibetantransects studies. *Forest Ecology Management* 206:349–363.

Luo, Y. and Zhou, X. (2006). Soil respiration and the Environment. Elsevier Inc., 316pp.

Maggi, O., Persiani, M. A., Casado, M. A. and Pineda, F. D. (2005). Effects of elevation, slope position and livestock exclusion on micro fungi isolated from soils of Mediterranean grasslands. The Mycological Society of America, Lawrence. *Mycologia*97(5): 984–995.

Magurran, A.E. (2004). *Measuring Biological Diversity* (2nd ed), Blackwell, Oxford.

Mate R, Johansson T, Sitoe A (2014). Biomass equations for tropical forest tree species in Mozambique. *Forests*5:535-556

MacDicken, K. (1997). *A Guide to Monitoring Carbon Storage in Forestry and AgroforestryProjects*. Forest Carbon Monitoring Program. Winrock International, Arlington, VA, USA.

Mani, S. & Parthasarathy N (2007). Above-ground biomass estimation in ten tropical dry Evergreen forest sites of peninsular India. *Biomass and Bioenergy* pp. 284-290

Maniatis, D., Saint-André, L., Temmerman, M., Malhi, Y. & Beeckman, H. (2011). The potential of using xylarium wood samples for wood density calculations: a comparison of approaches for volume measurements. *Forest – Biogeosciences and Forestry* 4: 150–159.

McCune, B. and Grace, J.B. (2002). *Analysis of Ecological Communities*. Version 5.0 MjM Software design, USA. Pp. 304

McCune B. and Mefford M. J. (1999). Multivariate Analysis of ecological Data Version 4.20, MjM software, Gleneden Beach, Oregon, USA.

Maestre, F.T., Quero, J.L., Gotelli, N.J., Escudero, A. and Ochoa, V., (2012). Plant Species Richness and Ecosystem Multifunctionality in Global Drylands. Science 335: 214-218

Maraseni T.N, Cockfield G., Apan A. Mathers N. (2005). Estimation of Shrub Biomass: Development and Evaluation of Allometric Models Leading to Innovative

Teaching Methods. *International Journal of Business & Management*

*Education ISSN* 1832-0236.

Mesfin Sahile (2011). Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in the Menagesha Suba State Forest. MSc.Thesis, Addis Ababa University, Addis Ababa.

Mesfin Tadesse (2004). Asteraceae (Compositae). In:Hedberg, I, Friis, I.B. and Edwards, S. (eds.). *Flora of Ethiopia and Eritrea Volume 4, part 2.* The National Herbarium, Addis Ababa University, Ethiopia, Uppsala, Sweden.

Mehari Alebachew, Andr´es B, Bravo.Fe. Ricardo Ru. (2016).Aboveground biomass equations for sustainable production of fuelwood in a native dry tropical afro-montane forest of Ethiopia. 3(2): 411-423.

MEFCC, (2015). Mid-term Progress Report of Ethiopia's R-PP Implementation.Federal Democratic Republic of Ethiopia Ministry of Environment, Forest and Climate Change Addis Ababa, Ethiopia.

Michael A. H. &, Gregg M.L. (2003).Carbon management and biodiversity.*Journal of Environmental Management* 67:77–86.

Mohr P. A. (1971).*The Geology of Ethiopia*. Second edition. University College of Addis Ababa Press, Addis Ababa.

Motuma Didita, Sileshi Nemomsa and Tadesse Woldemariam Gole (2010). Floristic and Structural analysis of the woodland vegetation around Dello Menna, southeast Ethiopia. *Journal of Forestry Research* 21(4):395–408

Munishi, P.K.T. and Shirima, D.D. (2009). Valuation, mapping and conservation of carbon stocks and other ecosystem services: The eastern arc mountains of Tanzania. University of Leeds, UK and Sokoine University of Agriculture, Tanzania.

Munishi PKT (2001). The Eastern Arc Mountains Forests of Tanzania: Their Role in Biodiversity and Water Resources Conservation and Net Contribution to

Atmospheric Carbon. PhD Thesis, North Carolina State University, Raleigh, NC USA. pp. 128

Munishi PKT, Shear T (2004). Carbon Storage of two Afromontane rain forests in the Eastern Arc Mountains of Tanzania. *J. Trop. Forest Sci.* 16(1): 78-93. Munishi PKT, Mri.

Mueller-Dombois, D. and Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology*, John Wiley and Sons Ltd, New York.

Murphy,P. and Lugo, A. (1986). Ecology of tropical dry forest. *Annual Review of Ecology and Systematics* 17: 67-88.

Navar J. (2009): Allometric equations for tree species and carbon stocks for forests of

Northwestern Mexico. *Forest Ecology and Management*, 257(2): 427–434

NABU (2012).Kaffa Biosphere Reserve, Southern Nations and Nationalities Peoples region, Ethiopia Progress Report.

NBSAP (2005). *National Biodiversity Strategy and Action Plan.* Addis Ababa: Institute of Biodiversity Conservation, Addis Ababa. pp 103.

Nesru Hassen (2015). Carbon Stock Estimation along an Altitudinal Gradient in Gera Moist Ever Green Afromontane forest, Southwest Ethiopia M.Sc. Thesis, Addis Ababa University.

Ngomanda A, Engone-Obiang NL, Lebamba J, Moudounga Mavouroulou Q, Gomat H,Mamkou GS, Loumeto R, Midoko Iponga D, Kossi Ditsouga R, Zinga Koumba R, Botsika Bobé KH, Mikala Okouyi C, Nyangadouma R, Lépengué N, Mbatchi B, Picard N (2012). Site specific versus pantropical allometric equations: which option to estimate the biomass of a moist central Africa forest. *For, Ecol Manage* 312 (5): 1-9.

Nuru Adgaba (2007). Atlas of pollen grains of major honey bee flora of Ethiopia. Oromia Agricultural Research Institute, Addis Ababa Ethiopia pp 200.

Nuru Adgaba and Randall HB (2002). Pollen grains of some poisonous bee plants of Ethiopia. Rhodes University, Grahamstown, South Africa.

Nuru Adigaba and Desalegn Begna (2001). Spatial analysis of Apiculture resource potentialin Kaffa, Sheka and Bench Maji zone. South nations and Nationalities peoples Region, SNV BOAM.

Nuru Adigaba (1999). Quality State and Grading of Ethiopian Honey. In: Proceeding of 1st National Conference of Ethiopian Beekeepers Association pp. 74–82, Addis Ababa, Ethiopia.

NTFP (2006). Non-Timber Forest Product Research and Development Project Progress Report August 2005 July 2006 Mizan-Teferi, Ethiopia.

Nyssen J., Poesen J. Moeyersons J. Deckers J. Haile M. & Lang A. (2004). Human impact on the environment in the Ethiopian and Eritrean highlands. a state of the

art Earth Science Reviews 64: 273–320.

Ohe, W.V.D., Oddo, M.L., Piana, M., (2004).Harmonized methods of mellisopalynology. *Apidologie*, 25:18-25.

Ordóñez, J.A.B.de Jong, B.H.J.García-Oliva, F.Aviña, F.L (2008). Carbon content in Vegetation, litter, and soil under 10 different land-use and land-cover classes. Forest Ecology and Management, 255: 2074–2084.

Palace, M., Keller, M., Asner, G. P., Silva, J. N. M. and Passos, C. (2007). Necromass inUndisturbed and logged forests in the Brazilian Amazon. *Forest Ecology and Management*238: 309–318.

Pascal and Pelissier (1996). Structure and floristic composition of a tropical evergreen forest in Southwest India. *Journal of forest ecology.*12(2): 191-214.

Pearson, T.R.H., Brown, S. L., Birdsey, R. A. (2007). Measurement guidelines for the Sequestration of forest carbon. *General Technical Report- NRS-18*, USDA Forest Service, Northern Research Station Newtown Square, USA.

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, and pp. 19-35.

Pernal, S.F. Currie R.W.( 2001). The influence of Pollen quality on foraging behavior in honeybees (*Apis mellifera* L.).*Behav. Ecol. Sociobiol.* 51: 53- 68.

Perschel, R.T., Alexander, M.E. and Marcia J.S. (2007).Climate Change, Carbon and the Forests of the Northeast. *Forest Guild*. pp. 1-10.

Pichi-Sermolli, R. (1957). Una carta geobotanica dell' Africa Orientale (Eritrea, Ethiopia and Somalia).*Webbia*pp. 15-132.

Picard, N., Saint André, L., Henry, M. (2012). Manual for building tree allometric equations: from the field to the prediction, Food and Agriculture Organization of the United Nations, Centre deco operation International en Recherche Agronomique.

Poorter L., Bongers, F., van Rompaey, A. and Deklerk, M. (1996). Regeneration of canopy tree Species at five sites in West African moist forest. *Forest Ecology and Management*pp. 61-69.

Pokhriyal P, Uniyal P, Chauhan DS & Todaria NP (2010). Regeneration status of tree species in Forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya. *Current Science*pp.171–174.

Ryan CM, Saldarriaga JG, Vieilledent G (2014). Improved allometric models to estimate theaboveground biomass of tropical trees. *Global Change Biol*pp.3177– 3190

Radford AE, Dickinson WC, Massey JR, Bell CR (1974).*Vascular plant systematics*.New York, Harper and Row.

Ranganna, S. (1977). Plant Pigments. Manual of Analysis of fruit vegetable products pp. 77-79.

Ravindranath, N.H and Ostwald, M. (2008). Carbon inventory methodsHandbook for Greenhouse gas inventory, carbon mitigation and round wood production projects. In: Global Change Research, Springer Verlag, Berlin, 304.

Rcciardelli d'Albore G. (1997). Textbook of melissopalynology, *Apimondia*, Bucharest

Reinhard F. and Admassu Addi (1994). *Honeybee Flora of Ethiopia.* Margraf Verlag, Germany. pp. 510.

Reusing, M. (1998). Monitoring forest resources in Ethiopia. Ministry of Agriculture, Addis Ababa, Ethiopia.

Reyes, G., Brown, S., Chapman, J. and Lugo, A.E. (1992).Wood densities of Tropical Tree Species. General Technical Report SO-88. USDA Forest Service, Southern Forest Experiment Station, New Orleans, USA.

Riechmann, D. (2007). Literature Survey on biological data and research carried out in Bonga area, Kaffa, Ethiopia.

Ricklefs, R.E. (1977). Environmental heterogeneity and plant species diversity: A hypothesis. *Amer. Natur*. pp. 376–381.

Roberts, D.W. (1987). A dynamical systems perspective on vegetation theory. Vegetation pp. 27-34.

Sarah M.W, Timothy RH. Felipe M C, Nancy Ha, Silvia P., Alex G., Erin S., Mike N., Katherine M., Brown S. (2012).Standard Operating Procedures for Terrestrial Carbon Measurement (SOP).WIN ROCK INTERNATIONAL.

Schmidt, J.O. and Buchmann, S.L. (1992). Other products of the hive. In: The hive and the Honeybee J.M. Graham, (ed.) Dadant & Sons, Hamilton, Illinois, USA. pp 927-988.

Schumacher, B. A. (2002). Methods for the Determination of Total Organic Carbon (TOC*) in* Soils and Sediments, Ecological Risk Assessment Support Center (ERASC), Office of Research and Development, Las Vegas.

Schmitt C. B. (2006). Montane rainforest with wild *Coffea arabica* in the Bonga region: plant diversity, wild coffee management and implications for conservation, Ecology and Development Series No. 47. Cuvillier Verlag Göttingen.

Schläpfer, F., B. Schmid, and I. Seidl. (1999). Expert estimates about effects of biodiversity on Ecosystem processes and services. *Oikos*pp346-352.

Sebsebe Demissew (1998). A study of vegetation and floristic composition of Southern Wello, Ethiopia. *Journal of Ethiopian Studies* pp.118-141.

Sebsebe Demissew, Mengistu Wondafrash and Yilma Dellelegn (1996*).* Ethiopia's Natural Resource base.In: *Important Bird Areas of Ethiopia: A First Inventory*. Ethiopian Wildlife and Natural History Society, Addis Ababa. pp.36-53.

Sebsebe Demissew; Cribb, P. and Rasmussen, F. (2004). *Field guide to Ethiopian orchids.* Royal Botanic gardens, Kew, UK. pp 304.

Sebsebe Demissew and Friis, I. (2009). Natural vegetation of the Flora area. In: *HedbergFriisI, Persson E, eds. Flora of Ethiopia and* Eritrea (vol. 8). General part and index to volumes1-7. Addis Ababa and Uppsala: The National Herbarium, pp. 27-32.

Shannon CE, Wiener W (1949). The Mathematical Theory of Communication. University of Illinois, Chicago, USA.

Sharma, S.K. Ghildiyal, S. Gairola,CM (2009).Vegetation structure, composition and diversity in relation to the soil characteristics of temperate mixed broad-leaved

forest along an altitudinal Gradient in Garhwal Himalaya Indian Journal of Science and Technology, pp. 39-45.

Shrestha BM, Singh BR (2008).Soil and vegetation carbon pools in a mountainous watershed of Nepal.81:179–191.

Shipley, B. and Keddy, P. (1987). The individualistic and community unit concepts as falsifiable Hypotheses. *Vegetatio* 69: 47-55.

Sharmon, M. E. and Sexton J. (1996). Guidelines for Measurements of Woody Detritus in Forest Ecosystems. US LTER Publication No. 20. US LTER Network Offi, University of Washington, Seattle, USA.

Silvertown, J. (1982). Introduction to plant population ecology. Longman group, N,Y

Silvertown, J. (2004). Plant coexistence and the niche. *Trends in Ecology and Evolution* pp, 605–611.

Sisay Nune (2007). Ethiopian government efforts to increase forest cover: a policy oriented discussion paper. In Proceedings of workshop: Policies to increase forest cover in Ethiopia pp 2-22.

Sisay Nune (2008).Flora Biodiversity Assessment in Bonga, Boginda and Mankira Forest, Kafa,Ethiopia.

Sisay Nune (2007). Ethiopian government efforts to increase forest cover: a policy oriented discussion paper. In Proceedings of workshop: Policies to increase forest cover in Ethiopia pp 2-22.

Sheikh, M. A., Kumar, M. and Rainer, W. and Bussmann, R. W. (2009). Altitudinal variation in Soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. Department of Forestry, HNB Garhwal University, Srinagar Garhwal, Uttarakhand, India.

Simpson, E. H. (1949). Measurement of diversity.*Nature*, pp 163- 688.

Simon Shibru and Girma Balcha (2004). Composition, structure and regeneration status of woody Species in Dindin natural forests, conservation. *Ethiop.J. Biol. Sci*3(1): 15-35.

Singhal, R.M. (1996). *Soil and Vegetation Studies in Forests*. ICFRE Publications, Debra Dun, pp. 62-65.

Singh, V., Tewari, A., Ram, J. and Singh, C. (2009). Aspect Related Changes in Biomass Stocks and Carbon Sequestration Rates of Shorea robusta (Sal) forest of Central Himalaya. Report and Opinion, pp. 56-60.

Solange, T.C, Rosicler, B., Severino Matias A., Maria Lúcia, M. (2009). Study of preparations of bee pollen extracts, Antioxidant and Antibacterial activity. *Ciênc. agrotec*., Lavras,v. pp.1818-1825

South wood, T.R.E. and Henderson, P.A. (2000). *Ecological Methods* (3rd edn), Oxford, Blackwell Science.

Smith, K. A. (1999). After the Kyoto Protocol: Can soil scientists make a useful contribution?*Soil use and Management* pp. 71-75.

Smartt, P.F.M. (1978). Sampling for vegetation survey: a flexible systematic model for sample Location. *Journal of Biogeography pp.*43-56.

Spies, T.A. (1998). Forest Structure: A Key to the Ecosystem. USDA, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon, USA.

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

Sutcliffe, J.P. (2009) "The extent and economic costs of deforestation in the Baro-Akobo Basin in south-west Ethiopia." NTFP-PFM R&D Project, MizanTeferi.

Swaine, M. (1996). *The Ecology of Tropical Forest Tree Seedlings*. Parthenon Publishers, Unesco, Paris.

Szczęsna T. (2006). Protein content and amino acid composition of bee collected pollen from Selected botanical origins. *Journal of Apicultural Science*, 50(2):81-90.

Tadesse Woldemariam, (2003).Vegetation of the Yayu Forest in Southwest Ethiopia: Impacts of Human Use and Implications for Insitu Conservation of Wild *Coffea arabica* L. Populations. cology and Development Series.

Tadesse Woldemariam, Borsch, T., Denich, M & Demel Teketay. (2008). Floristic Compositionand environmental factors characterizing coffee forests in southwest Ethiopia. *Forest Ecology and Management*255(2). 2138-2150

Tafesse Asres (1996). Agro ecological Zones of South western Ethiopia. PhD. Thesis, University of Trier, Germany.

Tamene Yohannes (2016).Plant Diversity and Carbon Stock Analysis along Environmental Gradients: the case of Gergeda and Anbessa Forests in Western Ethiopia. PhD thesis,Centerfor Environmental Science Addis Ababa University.

Tamrat Bekele (1994). Phytosociology and Ecology of Humid Afromontane Forest on the Central plateau of Ethiopia. *J. Veg. Sci.*5(1):87- 98.

Talemos Seta (2017). Forest Structure, Carbon Stocks and Leaf Litter Decomposition of two Selected Afromontane Forests in the Western Escarpment of Central Rift Valley and the Gibe Watershed, Ethiopia.PhD Thesis, Addis Ababa University

Tesfaye Awas (2007). Plant diversity in western Ethiopia: Ecology, ethnobotany and Conservation. PhD dissertation, Faculty of Mathe matics and Natural sciences, University of Oslo, Norway.

Tesfaye Bekele (2000). Plant population dynamic of *Dodonaea angustifolia* and *Olea europaea* ssp.*cuspidata* in Dry Afromontane Forests of Ethiopia. Actae University Upsaliensis Upsala, Sweden.

Tesfaye Bekele (2003).The potential of Bonga forest for certification: A Case Study. National Stakeholders Workshop on Forest Certification: Organized by Institute of Biodiversity Conservation and Research (IBCR), FARM Africa and SOS Sahel.

Tsegaye Tadesse (2010). Bale Eco-region Sustainable Management Programme. http://www.pfmpfarmsos.org/Publication.html.

ter Braak C. J. F. (1995). Ordination. In: Jongman, R. H. G., Ter Braak, C. J. F. and vanTongeren, O. F. R. (Eds.) Data Analysis in community and landscape ecology. Cambridge University Press, Cambridge, UK, pp. 91-173.ter Braak, C.J.F. and Smilauer, P. (1998). *CANOCO* Reference *Manual and User's Guide to Canoco for Windows:* Microcomputer Power, Ithaca.

ter Braak, C.J.F. (1986) Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67: 1167–1179.

Terrab, A., B. Valdes, D.M.J. (2003). Pollen analysis of honey from Mamora Forest Region (NW Morocco). *Grana,* 42: 47-54

Ensermu Kelbessa and Teshome Soromessa (2008). Interfaces of Regeneration, Structure, Diversity and uses of some plants species in Bonga Forest. A Reservoir for wildCoffee Gene Pool. *SINET, Ethiopia*. J. Sci. 31(2):121 -134.

Teshome Gemechu, Ensermu Kelbessa and Teshome Soromessa (2014).Floristic composition and Community analysis of Gendo Moist Montane Forest of East Wellega. *Journal of Natural Sciences Research,* 5(15): 153-170.

Teshome Soromessa, Demel Teketay and Sebsebe Demissew (2004). Ecological Study of the Vegetation in Gamo Gofa Zone, Southern Ethiopia. *Tropical Ecology* 45(2): 209-221.

Tewolde BG Egziabher (1991). Diversity of Ethiopian flora. *In:* Engels JMM, Hawkes JG, Melaku W (eds.) *Plant Genet. Res. Ethiop*. pp.75- 81.

Tulu Tolla (2011). Estimation of Carbon Stock in Church Forests: Implications for ManagingChurch Forest for Carbon Emission Reduction. MSc. Thesis, Addis Ababa University, Addis Ababa.

Ulrika S.G,, Peter A. H, Sileshi Nemomissa and Kristoffer H, (2014). Dominance of the semi-wild Honeybee as coffee pollinators across a gradients of Shade tree structure in Ethiopia. *Journal of Tropical Ecology* 30(5) 401–408.

UNFCCC. (2007). Vulnerability and adaptation to climate change in small island developing states Background paper for the expert meeting on adaptation for Small Island developing States UNFCCC Secretariat. Bonn, Germany.

UNCED (1992). Agenda 21, Chapter 26: Recognizing and Strengthening the Role of Indigenous People and their Communities. United Nations Conference on Environment and Development,Rio de Janerio, Brazil.UNFCCC Climate change Impacts, vulnerability and adaption in developing countries.

Uhlig S, and Uhlig K, (1990). The floristic composition of a natural montane forest in Southeastern Ethiopia. *Feddes Repertorium*101(2) 85-88.

Ullah, M.R. &Al-Amin, M. (2012). Above- and below-ground carbon stock estimation in a natural forest of Bangladesh. J. FOR. SCI., 2: 25-38

van der Maarel, E. (1979). Transformation of cover-abundance values in phytosociology and its effects in community similarity. Vegetatio 39: 97-114.

Vaughn, M. and Bryant, Jr. (2001). "Pollen Contents of Honey". *CAP Newsletter* pp.10–24.

Vahedi A.A, Matajil A., Babayi-Kafakil S., Eshaghi-Rad J., Hodjati S.M., Dojmo A. (2014). Allometric equations for predicting above ground biomass of beech-horn beamstands in the Hycanian forests of Iran. Journal of forest Science 60: 236–247.

Vetaas OR, Grytnes JA (2002). Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. Global Ecol Biogeogr 11: 291–301.

Von Breitenbach F. (1963). The Indigenous trees of Ethiopia. Addis Ababa: Ethiopian Forestry Association.

Vivero, J.L., Ensermu Kelbessa and Sebesebe Demissew (2005). The Red list of Endemic Trees and Shrubs of Ethiopia and Eritrea. Fauna and Flora International, Cambridge, UK. pp 23.

Walter, H. (1985). *Vegetation of the Earth and Ecological Systems of the Geobiosphere,* 3rd ed. SpringerVerlag, Berlin.

WBISPP (2004). *Forest Resources of Ethiopia*. Woody Biomass Inventory and Strategic Planning Project, MoARD, Addis Ababa, Ethiopia.

WCMC (1994). Biodiversity Data Sourcebook. World Conservation Monitoring Centre, World Conservation Press, Cambridge, UK.

Westphal, (1975). Agricultural systems in Ethiopia. Poduc, Wageningen

White F. (1983). *The Vegetation of Africa*. A Descriptive Memoir to Accompany the Unesco/AETFAT/UNSO Vegetation Map of Africa. UNESCO, Paris.

White J.W.JR and Landis W. Doner. (1980). Honey composition and Properties. Beekeeping in United States Agriculture hand book Number 335, pp.82-91

Westhoff, V. & van der Maarel, E. (1978). *The Braun-Blanquet approach*. In: Whittaker, R. H. (ed.) Classification of Plant Communities. The Hague, pp. 287-399

Whittaker, R.H. (1967). Gradient analysis of vegetation. *Biological Review* 42(2):.207–264

Woldegiorgis,Dawit Abate, Gulelat Haki, D. Gregory R. Ziegler (2014). Antioxidant property of edible mushrooms collected from Ethiopia.

Whittaker, R. (1975). Communities and Ecosystems. Second ed. Machmillan, London.

Walter, H., (1985). Vegetation of the Earth and Ecological Systems of the Geobiosphere (3rd ed.). Springer-Verlag, Berlin, New York.

Woldeyohannes Enkossa (2008). Floristic analysis of Alata-Bolale Forest in Gudaya Billa Woreda, East Wollega, Oromia Regional State. M.Sc. Thesis. Addis Ababa University.

Yitebitu Moges, Zewdu Eshetu and Sisay Nune (2010). Ethiopia Forest Resources: current status and future management options in view of Access to Carbon Finances. A literature review Prepared for the Ethiopian climate research and networking and the United Nations Development Programme.

Young, A. (1991). Soil monitoring: a new basic task for soil surveys, soil use and Management pp.126-130.

Zewdu Yilma, Temesgen Yohannes & Peter Sutcliffe (2010).Forest inventory in Ethiopian Montane Cloud Forest.MizanTeferi, Ethiopia.

Zerihun Woldu (1999). Forest vegetation types of Ethiopia and their status in the geographical context. In: Edwards S, Abebe D, Taye B, Gunther, H. (eds.), and Proceedings of the National Forest Genetic Resources conservation Strategy Development Workshop. June 21 –22, Addis Ababa Ethiopia. pp. 1-39

Zerihun Woldu, Feoli, E. and Lisanework Nigatu (1989). Partitioning an Elevational Gradient of Vegetation from Southeastern Ethiopia by Probabilistic Methods. Vegetatio, 81:189-198

Zerihun Woldu and Backeus, I. (1991).The shrub land vegetation in Western Shewa, Ethiopia and its possible recovery. Journal of vegetation science2: 173-180.

Zerihun Woldu (2017). Comprehensive Analysis of Vegetation and Ecological Data-Basic, Concepts, Methods. Addis Ababa University Press, Rehobot Printing.

Zenebon O. Pascuet N, S. (2005). Methods of fisico-quimicos para analise dealimentos.

Zewde Kassa (2017). Plant diversity and Ethnobotanical study of Medicinal and wild edible plants in Sheka Zone, Southern Nationalities and Peoples regional state, Ethiopia.PhD Thesis, Addis Ababa University

Zhu, B., XiangpingW., Jingyun F., Shilong P., Haihua,S.,Shuqing Z.,Changhui P.(2011). Altitudinal changes in carbon storage of temperate forests on Mt Changbai, Northeast China. 123(4):439-522

# APPENDICES

## Appendix 1. List of plant species recorded from Gesha-Sayilem forest

| No. | Plant species | Family | Local name in Kaffa | Habit |
|---|---|---|---|---|
| 1 | *Acanthopale ethio-germanica* Ensermu | Acanthaceae | Huxxo | Shrub |
| 2 | *Achyrospermum schimperi* (Hochst. ex Briq.) Perkins | Lamiaceae | | Herb |
| 3 | *Achyranthes aspera* L. | Amaranthaceae | Gecoo | Herb |
| 4 | *Acanthus eminens* C.B.Clarke | Acanthaceae | Pheeco | Herb |
| 5 | *Acmella caulirhiza* Del. | Asteraceae | Shishimo | Herb |
| 6 | *Adenostemma mauritianum* DC. | Asteraceae | metni | Herb |
| 7 | *Aerangis brachycarpa* (Rich) Reichb.f. | Orchidaceae | Gaashino | Herb |
| 8 | *Aframomum corrorima* (Braun) Jansen | Zignberiliaceae | Ogiyo | Herb |
| 9 | *Aframomum zambesiacum* (Baker) K. Schum. | Zignberiliaceae | Yexi ogio | Herb |
| 10 | *Ajuga integrifolia* Buch-Ham, ex D. Don | Lamiaceae | | Herb |
| 11 | *Alangium chinense* (Lour.) Harms | Alangiaceae | Shotto | Tree |
| 12 | *Ageratum conyzoides* L. | Asteraceae | | Herb |
| 13 | *Albizia gummifera* (J.f. Gmel.) C.A. Sm. | Fabaceae | Catto | Tree |
| 14 | *Albizia schimperiana* Oliv. | Fabaceae | Catto | Tree |
| 15 | *Alchemilla pedata* A. Rich. | Roseaceae | | Herb |
| 16 | *Alchemilla abyssinica* Fresen. | Roseaceae | | Herb |
| 17 | *Alchemilla fischeri* Engl. | Roseaceae | | Herb |
| 18 | *Alectra vogelii* Benth. | Scrophulariaceae | | Herb |
| 19 | *Allophyllus abyssinicus* (Hochst.) Radlk. | Sapindaceae | Sheoo | Tree |
| 20 | *Allophylus rubifolius* (Hochst. er A. Rich). Engl. | Sapindaceae | | shrub |
| 21 | *Ammocharis tinneana* (Kotschy & Peyr.) Milne-Redh.& Schweick | Amaryllidaceae | Shexi dukisho | Herb |
| 22 | *Amorphophallus gallaensis* (Engl.) N. E. Br. | Araceae | shibishexxo | Herb |
| 23 | *Antrophyum mannianum* Hook.. | Vittariaceae | | Herb |
| 24 | *Apodytes dimidiata* E. Mey. ex Arn. | Icaccinaceae | Wundefo | Tree |
| 25 | *Arundinaria alpina* K. Schum. | Poaceae | Shinatto | Tree |
| 26 | *Asparagus africanus* Lam. | Asparagaceae | Uffo | Herb |
| 27 | *Asparagus setaceus* (Kunth) Jessop | Asparagaceae | Uffo | Herb |
| 28 | *Asplenium aethopicum* (Brum.f.) bech. | Aspleniaceae | Gixoo | Herb |
| 29 | *Asplenium bugoiense* Hieron. | Aspleniaceae | Gixxo | Herb |
| 30 | *Asplenium anisophyllum*Kunze | Aspleniaceae | Gixoo | Herb |
| 31 | *Asplenium sandersonii* Hook. | Aspleniaceae | Gixxo | Herb |
| 32 | *Adianthum thalictroides* Schltdl. | Adianthaceae | Gixxo | Herb |
| 33 | *Asplenium erectum* Willd. | Aspleniaceae | Gixxoo | Herb |
| 34 | *Asplenium friesiorum* C. Chr. | Aspleniaceae | Gixxo | Herb |
| 35 | *Basella alba* L. | Basellaceae | Nopho | Climber |
| 36 | *Bersama abyssinica* Fresen. | Melianthaceae | Boqqo | Tree |
| 37 | *Bidens prestinaria(Sch. Bip.)* Cufod. | Asteraceae | Kello | Herb |
| 38 | *Bothriocline schimperi* Oliv.& Hiern ex Benth. | Asteraceae | shittoo | Herb |

| | | | | |
|---|---|---|---|---|
| 39 | *Brillantaisia madagascariensis T.* Anders. ex Lindau | Acanthaceae | Kokaro | Shrub |
| 40 | *Brucea antidysenterica* J. F. Mill. | Simaroubaceae | Nukisho | Tree/shrub |
| 41 | *Buddleja polystachya* Fresen. | Loganiaceae | Ataaro | Tree |
| 42 | *Canarina eminii* Schweinf. | Campanulaceae | | Herb |
| 43 | *Canthium oligocarpum* Hiern | Rubiaceae | Xixiribbo | Tree/Shrub |
| 44 | *Cassipourea malosana* (Baker) Alston | Rhizophoraceae | Werallo | Tree |
| 45 | *Carduus nyassanus* (S. Moore) R.E. Fr. | Asteraceae | Ombello | Herb |
| 46 | *Carduus leptacanthus* Fresen. | Asteraceae | Kuchino | Herb |
| 47 | *Cayratia gracilis* (Guill. & Perr.) Suesseng. | Vitaceae | Ceeco | Climber |
| 48 | *Cyathula cylindrica* Moq. | Amaranthaceae | Gecco | Herb |
| 49 | *Celtis africana* Burm. f. | Ulmaceae | Uffo | Tree/shrub |
| 50 | *Chamaecrista mimosoides* (L.) Green | Fabaceae | Majii garo | Climber |
| 51 | *Chionanthus mildbraediin* (Gilg & Schellenb.) Stearn | Oleaceae | Shigiyo | Tree/shrub |
| 52 | *Chlorophytum tuberosum* (Roxb.) Baker | Anthericaceae | | Herb |
| 53 | *Carex chlorosaccus* C.B., Clarke | Cyperaceae | Micco | Herb |
| 54 | *Cirsium dender* Friis | Asteraceae | Ombello | Herb |
| 55 | *Cissampelos mucronata* A. Rich. | Menispermaceae | Hikko | Climber |
| 56 | *Clausena anisata (*Willd.) Benth. | Rutaceae | Emmico | Shrub |
| 57 | *Clematis simensis* Fresen. | Ranunculaceae | qombo | Climber |
| 58 | *Clematis longicauda* Steud. ex A. Rich. | Ranunculaceae | Sheggo | Climber |
| 59 | *Clerodendrum alatum* Gürke | Verbenaceae | Agiiyyo | Shrub |
| 60 | *Clerodendrum myricoides* (Hochst.) Vatke | Verbenaceae | Agiiyyo | Shrub |
| 61 | *Culcasia falcifolia* Engl. | Araceae | - | Climber |
| 62 | *Coffea arabica* L. | Rubiaceae | Bunoo | Shrub |
| 63 | *Combretum paniculatum* Vent. | Combreataceae | Baggo | Climber |
| 64 | *Commelina benghalensis* L. | Commelinaceae | Nalatto | Herb |
| 65 | *Commelina diffusa* Burm.f. | Commelinaceae | Nalaxxo | Herb |
| 66 | *Commelina subulata* Roth. | Commelinaceae | Nalaxxo | Herb |
| 67 | *Coniogramme africana* Hieron. | Hemionitidaceae | Gixxo | Herb |
| 68 | *Conyza attenuata* DC. | Asteraceae | | Herb |
| 69 | *Conyza bonariensis* (L.) Cronq. | Asteraceae | | Herb |
| 70 | *Conyza abyssinica* Sch. Bip. ex A. Rich. | Asteraceae | | Herb |
| 71 | *Cordia africana* Lam. | Boraginaceae | Dioo | Tree |
| 72 | *Crassocephalum macropappum* (Sch.Bip. ex A. Rich.) S. Moore. | Asteraceae | Mandello | Herb |
| 73 | *Crassocephalum crepidioides* (Benth.) S. Moore. | Asteraceae | | Herb |
| 74 | *Crotalaria incana* L. | Fabaceae | | Herb |
| 75 | *Crotalaria rosenii* (Pax*)* Milne-Redh. *ex* Polhill | Fabaceae | | Herb |
| 76 | *Croton macrostachyus* Del. | Euphorbiaceae | Waggo | Tree |
| 77 | *Cryptotaenia africana* (Hook f.) Drude | Apiaceae | | Herb |
| 78 | *Cucumis dipsaceus* Ehrenb. ex *S*pach. | Cucurbitaceae | Gato | Herb |
| 79 | *Cyathea manniana* Hook. | Cyatheaceae | Sheshino | Tree |
| 80 | *Cynoglossum amplifolium* Hochst. ex A.DC. | Boraginaceae | Caqqo | Herb |
| 81 | *Cynoglossum lanceolatum* Forssk. | Boraginaceae | Gecco | Herb |

| | | | | |
|---|---|---|---|---|
| 82 | *Cynodon dactylon(L.)* Pers. | Poaceae | | Herb |
| 83 | *Cyathula polycephala*Bak. | Amaranthaceae | Gecco | Herb |
| 84 | *Cyphostemma cyphopetalum* (Fresen.) Desc. ex Wild & Drummond | Vitaceae | | Climber |
| 85 | *Cyperus fischerianus* A. Rich. | Cyperaceae | Occo | Herb |
| 86 | *Dryopteris tricellularis* J.P.Roux | Dryopteriaceae | | Herb |
| 87 | *Digitaria abyssinica* (Hochst. ex *A. Rich*.) Stapf | Poaceae | | Herb |
| 88 | *Dorsetnia soerensenii* Friis | Moraceae | | Herb |
| 89 | *Dissotis canescens* (Graham) Hook.f. | Melistostomaceae | | Herb |
| 90 | *Dalbergia lactea* Vatke | Fabaceae | Gimiro | Shrub |
| 91 | *Datura innoxia* Mill. | Solanceae | | Shrub |
| 92 | *Deinbollia kilimandscharica* Taub. | Sapindaceae | Qasso | Shrub |
| 93 | *Desmodium repandum* (Vahl) DC. | Fabaceae | qoro | Herb |
| 94 | *Dicliptera maculata* Nees | Acanthaceae | mocco | Herb |
| 95 | *Diospyros abyssinica* (Hiern) F.White | Ebenaceae | Gayo | Tree |
| 96 | *Dombeya torrida* (J.F. Gmel.) P.Bamps | Sterculiaceae | Boyo | Tree |
| 97 | *Dracaena afromontana* Mildbr. | Dracaenaceae | Emmo | shrub |
| 98 | *Dracaena fragrans* (L.) Ker-Gawl. | Dracenaceae | Coqimatto | Shrub |
| 99 | *Dracaena steudneri* Engler | Dracaenaceae | Yuddo | Tree |
| 100 | *Drymaria cordata(L.)* Schultes | Caryophyllaceae | Mocco | Herb |
| 101 | *Drynaria volkensii* Hieron | Polypodiaceae | Okkoo | Herb |
| 102 | *Dryopteris concolor* (langsd. &Fisch.) Kuhn in Vonder Decken | Dryopteridaceae | Gixxo | Herb |
| 103 | *Dregea schimperi* (Decne.) Bullock | Asclepiadaceae | qombo | Climber |
| 104 | *Ehretia cymosa* Thonn. | Boraginaceae | Wagamo | Tree |
| 105 | *Ekebergia capensis* Sparrm. | Meliaceae | Ororo | Tree |
| 106 | *Elaeodendron buchananii* (Loes.) Loes. | Celastraceae | Washo | Tree |
| 107 | *Elatostemma monticolum* Hook.f. | Urticaceae | mocco | Herb |
| 108 | *Embelia schimperi* Vatke | Myrsinaceae | Dupho | Climber |
| 109 | *Ensete ventricosum* (Welw.) Cheesman | Musaceae | Eppo | Herb |
| 110 | *Eragrostis botryodes* W.D. Clayton | Poaceae | | Herb |
| 111 | *Erythrococca trichogyne* (Muell. Arg.) | Euphorbiaceae | Biccerikucco | Shrub |
| 112 | *Eriosema cordifolium* Hochst. ex A. Rich. | Fabaceae | | Herb |
| 113 | *Euphorbia ampliphylla* Pax. | Euphorbiaceae | Gacho | Tree |
| 114 | *Euphorbia dumalis* S. Carter | Euphorbiaceae | Kulare ejjo | Herb |
| 115 | *Euphorbia schimperiana*Scheele | Euphorbiaceae | | Herb |
| 116 | *Ficus ovata* Vahl. | Moraceae | Caarro | Tree |
| 117 | *Ficus sur* Forssk. | Moraceae | Canno | Tree |
| 118 | *Ficus thonningii* Blume | Moraceae | Xigago | shrub |
| 119 | *Flacourtia indica* (Burm.f.) Merr | Flacourtiaceae | Anamishikko | shrub |
| 120 | *Galinsoga quadriradiata* Ruiz & Pavon | Asteraceae | Magashiimo | Herb |
| 121 | *Galiniera saxifraga* (Hochst.) Bridson | Rubiaceae | Diido | shrub |
| 122 | *Girardinlia divetsifolia* (Link) Friis | Urticaceae | Shinberko | Herb |
| 123 | *Gouania longispicata* Engl. | Rhamnaceae | Achimano | Climber |

| | | | | |
|---|---|---|---|---|
| 124 | *Glycine wightii* (Wight & Am.) Verdc. | Fabaceae | Tuffo | Herb |
| 125 | *Guizotia scabra* (Vis.) Chiov. | Asteraceae | | Herb |
| 126 | *Hagenia abyssinica* (Bruce) J. F. Gmel. | Roseaceae | Habessho | Tree |
| 127 | *Hallea rubrostipulata* (K. Schum.) J. F. Leroy | Rubiaceae | Oppo | Tree |
| 128 | *Habenaria quartiniana* A.Rich. | Orchidaceae | | Herb |
| 129 | *Helichrysum formosissimum* Sch. Bip. ex A. Rich. | Asteraceae | | Herb |
| 130 | *Helichrysum stenopterum* DC. | Asteraceae | | Herb |
| 131 | *Helichrysum forsskahlii(J.F. Gmel.)* Hilliard &Burtt | Asteraceae | | Herb |
| 132 | *Hibiscus berberidifolius* A. Rich. | Malvaceae | Togo | Herb |
| 133 | *Hibiscus ludwigii* Eckl.&Zeyh. | Malvaceae | | Herb |
| 134 | *Hibiscusmicranthus* L.f. | Malvaceae | | Herb |
| 135 | *Hibiscus deflersii* Schweinf ex Cufod. | Malvaceae | | Herb |
| 136 | *Hippocratea africana* (Willd.) Loes. | Celastraceae | | Climber |
| 137 | *Hippocratea goetze*i Loes. | Celastraceae | Qawee qomo | Climber |
| 138 | *Hippocratea pallens* Planchon ex Oliv. | Celastraceae | Qawee qomo | Climber |
| 139 | *Huperzia dacrydiodes (*Baker) Pic. Serm. | Lycopodiaceae | | Herb |
| 140 | *Hyparrhenia hirta* (L.) Stapf | Poaceae | Shutto | Herb |
| 141 | *Hypericum revolutum* Vahl | Hypericaceae | Danjiwuxaamoo | Shrub |
| 142 | *Hypericumpeplidifolium* A. Rich. | Hypericaceae | | Herb |
| 143 | *Hypoestes forskaolii (Vahl).* R.Br. | Acanthaceae | Qoro | Herb |
| 144 | *Hypoestes triflora* (Forssk.) Roem &Schult | Acanthaceae | Qoro | Herb |
| 145 | *Indigofera tinctoria*L. | Fabaceae | Wushwusho | Herb |
| 146 | *Indigofera scandiflora* Poir. | Fabaceae | Wushwusho | Herb |
| 147 | *Ilex mitis* (L.) Radlk. | Aquifoliaceae | Qetoo | Tree |
| 148 | *Impatiens ethiopica* Grey-Wilson | Balsaminaceae | Eqeqoo | Herb |
| 149 | *Impatiens hochstetteri* Warb. | Balsaminaceae | Eqeqoo | Herb |
| 150 | *Impatiens rothii* Hook.f. | Balsaminaceae | Shakindo | Herb |
| 151 | *Ipomea purpurea* (L.) Roth. | Convolvulaceae | Kallalo | Climber |
| 152 | *Ipomea indica* (Burm.f)Merrill | Convolvulaceae | Kallalo | Climber |
| 153 | *Isoglossa somalensis* Lindau | Acanthaceae | Qorro | Herb |
| 154 | *Isoglossa punctata* (Vahl) Brummitt & Wood | Acanthaceae | Dolli mocco | Herb |
| 155 | *Jasminum abyssinicum*Hochst. ex DC. | Oleaceae | Awutee qombo | Climber |
| 156 | *Juncus effusus* L. | Juncaceae | Kexiimo | Herb |
| 157 | *Justicia ladanoides* Lam. | Acanthaceae | | Herb |
| 158 | *Justicia schimperiana* (Hochst. ex Nees) T. Anders. | Acanthaceae | Sharisharo | Herb |
| 159 | *Justicia unyorensis* S. Moore | Acanthaceae | | Herb |
| 169 | *Laggera crispata* (Vahf) Hepper & Wood | Asteraceae | Hupichoo | Shrub |
| 161 | *Landolphia buchananii* (Hall. F.) Stapf. | Apocynaceae | Yeme qombo | Climber |
| 162 | *Lecanthus peduncularis* (Roy/e) Wedd | Urticaceae | shimbriko | Herb |
| 163 | *Leucas deflexa* Hook. f. | Lamiaceae | | Herb |
| 164 | *Lepidotrichilia volkensii* (Gurke) Leroy | Meliaceae | Shaheiyo | Tree/shrub |
| 165 | *Lobelia giberroa* Hemsl. | Lobeliaceae | Tinbbo | shrub |
| 166 | *Loxograme abyssinica* (Baker) M.C. price | polypodiaceae | Gixxo | Herb |
| 167 | *Lycopodium dacrydioides* Bak. | Lycopodiaceae | - | Herb |

| | | | | |
|---|---|---|---|---|
| 168 | *Lysimachia ruhmeriana* Vatke | Primulaceae | - | Herb |
| 169 | *Macaranga capensis* (Baill.) Sim. | Euphorbiaceae | Shakaro | Tree |
| 170 | *Maesa lanceolata* Forssk. | Myrsinaceae | Caggoo | Shrub |
| 171 | *Malva verticillata* L. | Malvaceae | | Herb |
| 172 | *Marattia fraxinea* Sm. | Marattiaceae | Gixxo | Herb |
| 173 | *Maytenus gracilipes* (Welw. ex Oliv.) Exell | Celastraceae | shikko | Shrub |
| 174 | *Maytenus undata* (Thunb.) Blakelock | Cleastraceae | Geto | Tree |
| 175 | *Mimulopsis solmsii* Schweinf | Acanthaceae | Qoradi | Herb |
| 176 | *Microglossa pyrifolia (Lam*.) Kuntze | Asteraceae | | Shrub |
| 177 | *Momordica foetida* Schumach. | Cucurbitaceae | Yumbao | Herb |
| 178 | *Micractis bojeri* DC. | Asteraceae | | Herb |
| 179 | *Mikaniopsis clematoides* (S'ch. Bip. ex A. Rich.) Milne-Redh. | Asteraceae | | Climber |
| 180 | *Millettia ferruginea* (Hochst.) Bak. | Fabaceae | Bibero | Tree |
| 181 | *Monothecium glandulosum* Hochst. | Acanthaceae | - | Herb |
| 182 | *Myrsine africana* L. | Myrsinaceae | - | Shrub |
| 183 | *Pilea bambuseti* Engl. | Urticaceae | Narinaro | Herb |
| 184 | *Nuxia congesta* R. Br. *ex* Fresen. | Loganaceae | Ciiwoo | Shrub |
| 185 | *Ocimum urticifolium* Roth | Lamiaceae | | Herb |
| 186 | *Ocimum lamiifolium* Hochst. ex Benth. | Lamiaceae | Daamo | Herb |
| 187 | *Ocotea kenyensis* (Chiov.) Robyns & Wilczek | Lauraceae | Najjoo | Tree |
| 188 | *Olea capensis* subsp. *macrocarpa* (C. A. Wright) Verdc. | Oleaceae | Shigiyo | Tree |
| 189 | *Olea welwitschii* (Knobl.) Gilg & Schellenb. | Oleaceae | Yaahoo | Tree |
| 190 | *Olea mildbraedii* (Gilg & Schellenb.) Knobl. | Oleaceae | | Tree |
| 191 | *Oliverella hildebrandtii* (Engl.) Tieghem | Loranthaceae | | Climber |
| 192 | *Oenanthe palustris(*Chiov.*)* Norman | Apiaceae | | Herb |
| 193 | *Oncoba spinosa* Forssk. | Flacourtiaceae | Shuurato | shrub |
| 194 | *Oplismenus hirtellus* (L.) P. Beauv. | Poaceae | Yawuloo | Herb |
| 195 | *Oplismenus burmannii* (Retz.) P. Beauv. | Poaceae | Machi shuttee | Herb |
| 196 | *Oxyanthus speciosus* DC. | Rubiaceae | Dibbo | Shrub |
| 197 | *Panicum maximum* Jacq. | Poaceae | | Herb |
| 198 | *Panicum hochstetteri* Steud. | Poaceae | | Herb |
| 199 | *Pavetta abyssinica* Fresen. | Rubiaceae | Tushmo | Shrub |
| 200 | *Parochaetus communis* D. Don | Fabaceae | Yemedr-koso | Herb |
| 201 | *Pavonia schimperana* Hochst. Ex A. Rich. | Malvaceae | | Herb |
| 202 | *Pavonia urens* Cav. | Malvaceae | | Herb |
| 203 | *Pentas lanceolata* (Forssk.) Defl. | Rubiaceae | | Shrub |
| 204 | *Pentas schimperiana* (A.Rich.) Vatke | Rubiaceae | Naachi Buuxo | Shrub |
| 205 | *Peucedanum mattirolii* Chiov. | Apiaceae | Timberko | Herb |
| 206 | *Peperomia retusa* (L.f) A. Dietr. | Piperaceae | Gergeyo | Herb |
| 207 | *Peperomia abyssinica* Miq. | Piperaceae | Gashaano | Herb |
| 208 | *Peperomia tetraphylla* (Forster) Hook. & Arn. | Piperaceae | | Herb |
| 209 | *Peponium vogelii* (Hook.f.) Engl. | Cucurbitaceae | Tojjoo | Herb |
| 210 | *Periploca linearifolia* Quart.Dill& A. Rich. | Asclepiadaceae | | Climber |

| | | | | |
|---|---|---|---|---|
| 211 | *Pergularia daemia(*Forssk.*)* Chiov. | Asclepiadaceae | | Climber |
| 212 | *Phaulopsis imbricata* (Forssk.) Sweet | Acanthaceae | mocoo | Herb |
| 213 | *Phoenix reclinata* Jacq. | Arecaceae | Yebbo | Tree |
| 214 | *Phyllanthus fischeri* Pax | Euphorbiaceae | | Herb |
| 215 | *Phyllanthus ovalifolius* Forssk. | Euphorbiaceae | | Herb |
| 216 | *Pilea rivularis* Wedd. | Urticaceae | - | Herb |
| 217 | *Pilea bambuseti* Engl. | Urticaceae | - | Herb |
| 218 | *Phytolacca dodocandra* L 'Herit. | Phytolaccaceae | Yingamo | Climber |
| 219 | *Piper capense* L.f. | Piperaceae | Turfo | Herb |
| 220 | *Pittosporum viridiflorum* Sims. | Pittosporaceae | Shollo | Tree |
| 221 | *Pittosporum abyssinicum* Del. | Pittosporaceae | Shollo | Tree |
| 222 | *Plantago palmata* Hook.f. | Planaginaceae | | Herb |
| 223 | *Plectrantus assurgens* (Bak.) Morton | Lamicaceae | | Herb |
| 224 | *Plectranthus schimperi* Chiov. | Lamiaceae | | Herb |
| 225 | *Polystichum magnificum* F. Ballard | Dryopteridaceae | | Herb |
| 226 | *Polyscias fulva* (Hiern) Harms | Araliaceae | Karashoo | Tree |
| 227 | *Pouteria adolfi-friederici (Engl.) Baehni* | Sapotaceae | Sha'oo | Tree |
| 228 | *Premna schimperi* Engl. | Verbenaceae | Xumo | Shrub |
| 229 | *Prunus africana* (Hook. f.) Kalkm. | Roseaceae | Ommo | Tree |
| 230 | *Psophocarpus grandiflorus* Wilczek | Fabaceae | | Climber |
| 231 | *Psychotria orophila* Petit | Rubiaceae | Aa'imato | Shrub |
| 232 | *Pteris pteridioides* (Hook.) Ballard | Pteridaceae | Gixxo | Herb |
| 233 | *Pteris concolor* Langsd & Fisch | Pteridaceae | Gixxo | Herb |
| 234 | *Pteris concolor* Langsd & Fisch | Pteridaceae | Gixxo | Herb |
| 235 | *Pycnostachys abyssinica* Fresen. | Lamiaceae | Yeaaroo | Herb |
| 236 | *Pycnostachys eminii* Gurke | Lamiaceae | kakoo | Shrub |
| 237 | *Ranunculus multifidus* Forssk. | Ranunculaceae | Hooqiyo | Herb |
| 238 | *Rhamnus prinoides* L'Herit. | Rhamnaceae | Gesho | Shrub |
| 239 | *Rinorea friisii* M. Gilbert | Violaceae | | Shrub |
| 240 | *Rhynchospora corymbosa* (L.) Britt. | Cyperaceae | | Herb |
| 241 | *Ritchiea albersii* Gilg | Cappridiaceae | | Shrub |
| 242 | *Rothmannia urcelliformis* (Hiern) Robyns | Rubiaceae | Dibbo | shrub |
| 243 | *Rubus steudneri* Schweinf. | Roseaceae | Garoo | Shrub |
| 244 | *Rumex nepalensis* Spreng. | polygonaceae | Guphi | Herb |
| 245 | *Rytigynia neglecta* (Hiern) Robyns | Rubiaceae | Mesho | Tree |
| 246 | *Salix subserrata* Willd. | Salicaceae | | Shrub |
| 247 | *Salvia nilotica* Juss. ex Jacq. | Lamiaceae | | Herb |
| 248 | *Sapium ellipticum* (Krauss) Pax | Euphorbiaceae | Sheddo | Tree |
| 249 | *Satureja paradoxa* (Vatke) Engl. | Lamiaceae | Naddo | Herb |
| 250 | *Scadoxus nutans* (Friis & Bjornstad) Friis & Nordal | Amarylidaceae | - | Herb |
| 251 | *Scadoxus multiflorus* (Mart.) Raf. | Amarylidaceae | | Herb |
| 252 | *Scadoxus puniceus*(*L.*) Friis & Nordal | Amarylidaceae | | Herb |
| 253 | *Schefflera abyssinica (*Hochst . ex A.Rich.) Harms | Araliaceae | Butto | Tree |
| 254 | *Schefflera myriantha* (Bak.) Drake | Araliaceae | Dochigaryo | Tree |
| 255 | *Schefflera volkensii* (Engl.) Harms | Araliaceae | Qero | Tree |

| | | | | |
|---|---|---|---|---|
| 256 | *Schoenoplectus corymbosus* (Roem. & Schult.) Rayn. | Cyperaceae | Disho | Herb |
| 257 | *Selaginella kraussiana* (Kunte) A.Braun | Selaginellaceae | | Herb |
| 258 | *Selaginella kalbreyeri* Bak.` | Selaginellaceae | | Herb |
| 259 | *Setaria megaphylla* (Steud.) Th. Dur. & Schinz | Poaceae | Shotto | Herb |
| 260 | *Sida acuta* Burm.f. | Malvaceae | | Herb |
| 261 | *Sida rhombifolia* L. | Malvaceae | | Herb |
| 262 | *Sida schimperiana* Hochst. ex A. Rich. | Malvaceae | | Herb |
| 263 | *Solanecio mannii* (Hook. f.) C. Jeffrey | Asteraceae | Eqqibalo | Shrub |
| 264 | *Solanecio gigas* (Vatke) C. Jeffrey | Asteraceae | Dombrako | Shrub |
| 265 | *Solanum marginatum* L.f. | Solanaceae | Qumbaffo | Herb |
| 266 | *Solanum adoense*Hochst. ex A. Rich | Solanaceae | Qumbaffo | Herb |
| 267 | *Sonchus bipontini* Asch. | Asteraceae | | Climber |
| 268 | *Sphaeranthus suaveolens* (Forssk.) DC. | Asteraceae | | Herb |
| 269 | *Stachys aculeolata* Hook.f. | Lamiaceae | | Herb |
| 270 | *Stellaria mannii* Hook.f. | Caryophylaceae | Mocco | Herb |
| 271 | *Stephania abyssinica* (Dill & A. Rich.) Walp. | Menispermaceae | | Climber |
| 272 | *Sericostachys scandens* Gilg & Lopr. | Amarnthaceae | shudi | Climber |
| 273 | *Syzygium guineense* (Willd.) DC. | Myrtaceae | Yinoo | Tree |
| 274 | *Tapinanthus heteromorphus* (A. Rich.) Danser | Loranthaceae | | Climber |
| 275 | *Teclea nobilis* Del. | Rutaceae | Shengaaro | Shrub |
| 276 | *Tectraia gemmifera* (Fee) Alston | Tectraiaceae | | Herb |
| 277 | *Thalictrum rhynchocarpum* Dill. & A. Rich. | Ranunculaceae | Digaree atto | Herb |
| 278 | *Tiliacora troupinii* Cufod. | Menispermaceae | Caamoo | Liana |
| 279 | *Reichardia tingitana(L.)* Roth | Asteraceae | | Herb |
| 280 | *Trema orientalis* (L.) Bl. | Ulmaceae | - | Tree |
| 281 | *Trifolium usambarense* Taub. | Fabaceae | | Herb |
| 282 | *Trifolium polystachyum* Fresen. | Fabacea | | Herb |
| 283 | *Trilepisium madagascariense* DC. | Moraceae | Kuroo | Tree |
| 284 | *Tristemma mauritianum* J. F. Gmel. | Melastomataceae | - | Herb |
| 285 | *Triumfetta brachyceras* K. Schum. | Tiliaceae | Mogecco | Climber |
| 286 | *Typha latifolia* L. | Typhaceae | | Herb |
| 287 | *Urera hypselodendron* (A. Rich.) edd. | Urticaceae | Imamoo | Climber |
| 288 | *Vangueria apiculata* K. Schum | Rubiaceae | Gujimatto | Tree |
| 289 | *Vepris dainellii* (Pich.-Serm.) Kokwaro | Rutaceae | - | Tree |
| 290 | *Vernonia amygdalina* Del. | Asteraceae | Girawoo | Tree |
| 291 | *Vernonia auriculifera* Hiern | Asteraceae | Dangretto | Shrub |
| 292 | *Vernonia hochstetteri* Sch. Bip. ex Walp. | Asteraceae | - | Shrub |
| 293 | *Vernonia ituriensis* Muschl. | Asteraceae | | Shrub |
| 294 | *Vernonia leopoldi* (Sch. Bip. ex Walp.) Votke | Asteraceae | | Shrub |
| 295 | *Vernonia bifare* Oliv.& Hiern | Asteraceae | | climber |
| 296 | *Vernonia wollastonii* .S'. Moore | Asteraceae | Majji qombo | Climber |
| 297 | *Viscum congolense* De Wild. | Viscaceae | | Herb |
| 298 | *Vittaria guineensis* Desv. | Vittariaceae | | Herb |
| 299 | *Vittaria volkensi* Hieron | Vittariaceae | | Herb |

| | | | | |
|---|---|---|---|---|
| 300 | *Zehneria minutiflora(Cogn*.) C. Jeffrey | Cucurbitaceae | | Climber |

**Appendix 2. List of plant families with their number of genera and species occurred in Gesha-Sayilem forest.**

| Family | Genera | species | Percentage (%) | Family | Genera | species | Percentage (%) |
|---|---|---|---|---|---|---|---|
| Acanthaceae | 10 | 14 | 4.62 | Flacourtiaceae | 2 | 2 | 0.66 |
| Asteraceae | 22 | 37 | 12.21 | Urticaceae | 4 | 5 | 1.65 |
| Lamiaceae | 8 | 11 | 3.63 | Rhamnaceae | 2 | 2 | 0.66 |
| Amaranthaceae | 3 | 4 | 1.32 | Malvaceae | 4 | 10 | 3.30 |
| Zignberiliaceae | 1 | 2 | 0.66 | Solanceae | 2 | 3 | 0.99 |
| Alangiaceae | 1 | 1 | 0.33 | Myrsinaceae | 3 | 3 | 0.99 |
| Fabaceae | 11 | 15 | 4.95 | Cucurbitaceae | 4 | 4 | 1.32 |
| Roseaceae | 4 | 6 | 1.98 | Sterculiaceae | 1 | 1 | 0.33 |
| Marattiaceae | 1 | 1 | 0.33 | Dracaenaceae | 1 | 3 | 0.99 |
| Scrophulariaceae | 1 | 1 | 0.33 | Caryophyllaecae | 2 | 2 | 0.66 |
| Sapindaceae | 2 | 3 | 0.99 | Lobeliaceae | 1 | 1 | 0.33 |
| Amaryllidaceae | 1 | 3 | 0.99 | Lycopodiaceae | 2 | 2 | 0.66 |
| Araceae | 2 | 2 | 0.66 | Primulaceae | 1 | 1 | 0.33 |
| Icacinaceae | 1 | 1 | 0.33 | Celastraceae | | | |
| Poaceae | 11 | 13 | 4.29 | Guittiferae | 3 | 6 | 1.98 |
| Asparagaceae | 1 | 2 | 0.66 | Aquifoliaceae | 1 | 2 | 0.66 |
| Aspleniaceae | 1 | 6 | 1.98 | Balsaminaceae | 1 | 1 | 0.33 |
| Tectraiaceae | 1 | 1 | 0.33 | Asclepiadaceae | 1 | 4 | 1.32 |
| Adianthaceae | 1 | 1 | 0.33 | Apocynaceae | 3 | 3 | 0.99 |
| Basellaceae | 1 | 1 | 0.33 | Piperaceae | 1 | 1 | 0.33 |
| Melianthaceae | 1 | 1 | 0.33 | Pittosporaceae | 2 | 4 | 1.32 |
| Meliaceae | 2 | 2 | 0.66 | Ebenaceae | 1 | 2 | 0.66 |
| Simaroubaceae | 1 | 1 | 0.33 | Plantaginaceae | 1 | 1 | 0.33 |
| Loganiaceae | 1 | 1 | 0.33 | Dryopteridaceae | 1 | 1 | 0.33 |
| Campanulaceae | 1 | 1 | 0.33 | Arecaceae | 1 | 1 | 0.33 |
| Rubiaceae | 10 | 12 | 3.96 | Musaceae | 1 | 1 | 0.33 |
| Polypodiaceae | 2 | 2 | 0.66 | Juncaceae | 1 | 1 | 0.33 |
| Rhizophoraceae | 1 | 1 | 0.33 | Convolvulaceae | 1 | 2 | 0.66 |
| Salicaceae | 1 | 1 | 0.33 | Lauraceae | 1 | 1 | 0.33 |
| Vitaceae | 2 | 2 | 0.66 | | | | |
| Ulmaceae | 2 | 2 | 0.66 | | | | |
| Mimosoideae | 1 | 1 | 0.33 | | | | |
| Oleaceae | 3 | 4 | 1.32 | | | | |
| Anthericaceae | 1 | 1 | 0.33 | Loranthaceae | 3 | 3 | 0.99 |
| Cyperaceae | 4 | 4 | 1.32 | polygonaceae | | | |
| Menispemaceae | 3 | 3 | 0.99 | | 1 | 1 | 0.33 |

| Family | Genera | species | Percentage (%) | Family | Genera | species | Percentage (%) |
|---|---|---|---|---|---|---|---|
| Rutaceae | 3 | 3 | 0.99 | Selaginellaceae | 1 | 2 | 0.66 |
| Ranuculaceae | 3 | 4 | 1.32 | Myrtaceae | 1 | 1 | 0.33 |
| Verbenaceae | 2 | 3 | 0.99 | Sapotaceae | 1 | 1 | 0.33 |
| Araceae | 2 | 2 | 0.66 | Capparidaceae | 1 | 1 | 0.33 |
| Combretaceae | 1 | 1 | 0.33 | Tiliaceae | 1 | 1 | 0.33 |
| Commelinaceae | 1 | 3 | 0.99 | Typhaceae | 1 | 1 | 0.33 |
| Hemionitidaccae | 1 | 1 | 0.33 | Viscaceae | 1 | 1 | 0.33 |
| Boraginaceae | 3 | 4 | 1.32 | Vittariaceae | 2 | 3 | 0.99 |
| Euphorbiaceae | 7 | 9 | 2.97 | Orchidaceae | 2 | 2 | 0.66 |
| Cyatheaceae | 2 | 2 | 0.66 | | | | |
| Melastomataceae | 2 | 2 | 0.66 | | | | |

**Appendix 3. Density of woody species in Gesha-Sayliem forest**

| Species | DBH > 2 cm | | DBH > 10 cm | | DBH > 20 cm | |
|---|---|---|---|---|---|---|
| | Individuals/ha | % | Individuals/ha | % | Individuals/ha | % |
| *Allophyllus abyssinicus* | 9 | 2 | 7 | 2.5 | 11.3 | 4.66 |
| *Phonix reclinata* | 2 | 0 | 7.1 | 2.5 | 3.6 | 1.48 |
| *Dracaena afromontana* | 40 | 7 | 32 | 11.4 | 5.4 | 2.22 |
| *Galiniera saxifraga* | 63 | 11 | 23.8 | 8.5 | 2.1 | 0.86 |
| *Pouteria adolfi-friederici* | 14 | 2 | 15 | 5.3 | 24.5 | 10.13 |
| *Syzygium guineense* | 6 | 1 | 8 | 2.9 | 32.9 | 13.6 |
| *Schefflera abyssinica* | 1 | 0 | 2.3 | 0.8 | 19.3 | 7.98 |
| *Rytigynia neglecta* | 17 | 3 | 6.4 | 2.3 | 5.2 | 2.14 |
| *Ilex mitis* | 9 | 2 | 20.7 | 7.4 | 34.4 | 14.24 |
| *Solanecio gigas* | 1 | 0 | 0.9 | 0.3 | 0.4 | 0.145 |
| *Psychotria orophila* | 8 | 1 | 0.9 | 0.3 | 0 | 0 |
| *Vepris dainellii* | 8 | 1 | 12 | 4.3 | 3.4 | 1.4 |
| *Macaranga capensis* | 8 | 1 | 6.4 | 2.3 | 13.6 | 5.61 |
| *Apodytes dimidiata* | 7 | 1 | 3.8 | 1.3 | 3.9 | 1.62 |
| *Cyathea manniana* | 23 | 4 | 29.8 | 10.6 | 0 | 0 |
| *Maytenus gracilipes subsp. gracilipes* | 40 | 7 | 3.6 | 1.3 | 0.7 | 0.29 |
| *Cassipourea malosana* | 8 | 1 | 1.4 | 0.5 | 4.6 | 1.9 |
| *Landolphia buchananii* | 22 | 4 | 2.7 | 1 | 0.4 | 0.14 |
| *Lepidotrichilia volkensii* | 55 | 10 | 12 | 4.3 | 2.5 | 1.03 |
| *Vangueria madagascariensis* | 3 | 1 | 3 | 1.1 | 0.2 | 0.07 |
| *Urera hypselodendron* | 4 | 1 | 0.9 | 0.3 | 0.4 | 0.15 |
| *Solanecio mannii* | 4 | 1 | 0.2 | 0.1 | | 0 |
| *Ocotea kenyensis* | 0 | 0 | | 0 | | 0 |
| *Deinbollia kilimandscharica* | 58 | 10 | 2.1 | 0.8 | | 0 |
| *Croton macrostachyus* | 2 | 0 | 1.8 | 0.6 | 11.6 | 4.8 |
| *Brucea antidysenterica* | 0 | 0 | 0.7 | 0.3 | 0.2 | 0.074 |
| *Bersama abyssinica* | 4 | 1 | 5.9 | 2.1 | 2.1 | 0.89 |
| *Ekebergia capensis* | 0 | 0 | 1.1 | 0.4 | 4.3 | 1.776 |
| *Pavetta abyssinica* | 3 | 0 | 0.7 | 0.3 | 0.2 | 0.07 |
| *Embelia schimperi* | 1 | 0 | 0.2 | 0.1 | 0.2 | 0.07 |

| Species | DBH > 2 cm | | DBH > 10 cm | | DBH > 20 cm | |
|---|---|---|---|---|---|---|
| | Individuals/ha | % | Individuals/ha | % | Individuals/ha | % |
| *Oxyanthus speciosus* | 5 | 1 | 5 | 1.8 | 0.4 | 0.15 |
| *Vernonia auriculifera* | 8 | 1 | 0.7 | 0.3 | 0 | 0 |
| *Arundinaria alpina* | 41 | 7 | 1 | 0.4 | 0.2 | 0.07 |
| *Prunus africana* | 2 | 0 | 1.3 | 0.4 | 7.5 | 3.1 |
| *Alangium chinense* | 2 | 0 | 1.6 | 0.6 | 0 | 0 |
| *Vernonia amygdalina* | 3 | 1 | 1.6 | 0.6 | 0 | 0 |
| *Brillantaisia grotanellii* | 1 | 0 | | 0 | | 0 |
| *Millettia ferruginea* | 12 | 2 | 7.9 | 2.8 | 1.8 | 0.73 |
| *Clausena anisata* | 7 | 1 | 1.1 | 0.4 | | 0 |
| *Tiliacora troupinii* | 4 | 1 | 0.4 | 0.1 | | 0 |
| *Albizia gummifera* | 5 | 1 | 2.3 | 0.8 | 4.1 | 1.7 |
| *Albizia schimperiana* | 1 | 0 | 0.4 | 0.1 | 0.7 | 0.3 |
| *Clematis longicauda* | 1 | 0 | | 0 | | 0 |
| *Sericostachys scandens* | 6 | 1 | 0.4 | 0.1 | | 0 |
| *Celtis africana* | 1 | 0 | | 0 | | 0 |
| *Canthium oligocarpum* | 1 | 0 | 0.4 | 0.1 | 0.5 | 0.22 |
| *Combretum paniculatum*. | 0 | 0 | 0.4 | 0.1 | | 0 |
| *Elaeodendron buchananii* | 2 | 0 | 2.1 | 0.8 | 4.6 | 1.92 |
| *Olea capensis* subsp. *macrocarpa* | 16 | 3 | 1.3 | 0.4 | 0.5 | 0.22 |
| *Ehretia cymosa* | 0 | 0 | 2.1 | 0.8 | | 0 |
| *Euphorbia ampliphylla* | 1 | 0 | 2 | 0.7 | | 0 |
| *Pittosporum viridiflorum* | 3 | 1 | 2 | 0.7 | | 0 |
| *Rothmannia urcelliformis* | 6 | 1 | 2 | 0.7 | | 0 |
| *Olea welwitschii* | 1 | 0 | 0.5 | 0.2 | 6.6 | 2.73 |
| *Gouania longispicata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Maesa lanceolata* | 2 | 0 | 5.2 | 1.8 | 10 | 4.14 |
| *Schefflera volkensii* | 1 | 0 | 0.9 | 0.3 | 4.6 | 1.9225 |
| *Maytenus undata* | 0 | 0 | 0.7 | 0.3 | 0 | 0 |
| *Oncoba spinosa* | 0 | 0 | 0.4 | 0.1 | 0 | 0 |
| *Teclea nobilis* | 0 | 0 | | 0 | | 0 |
| *Hallea rubrostipulata* | 0 | 0 | 0 | 0 | 8.9 | 3.69 |
| *Polyscias fulva* | 1 | 0 | 1.3 | 0.4 | 0.2 | 0.074 |
| *Clematis simensis* | 1 | 0 | 0.4 | 0.1 | 0.4 | 0.15 |
| *Nuxia congesta* | 0 | 0 | 0.9 | 0.3 | 1.4 | 0.59 |
| *Hagenia abyssinica* | 3 | 1 | 13.6 | 4.8 | 0 | 0 |
| *Ficus sur* | 1 | 0 | | 0 | | 0 |
| *Schefflera volkensii* | | 0 | 1.1 | 0.4 | | 0 |
| *Jasminum abyssinicum* | 1 | 0 | 0.5 | 0.2 | 1.1 | 0.44 |
| *Diospyros abyssinica* | 0 | 0 | 0.2 | 0.1 | | 0 |
| *Dombeya torrida* | 6 | 1 | 1.1 | 0.4 | | 0 |
| *Buddleja polystachya* | 1 | 0 | | 0 | | 0 |
| *Erythrococca trichogyne* | 1 | 0 | | 0 | | 0 |
| *Hypericum revolutum* | 1 | 0 | | 0 | | 0 |
| *Sapium ellipticum*. | 0 | 0 | 5.9 | 2.1 | 0.9 | 0.37 |
| *Coffea arabica* | 2 | 0 | | 0 | | 0 |
| *Rubus steudneri* | 0 | 0 | | 0 | | 0 |
| *Clerodendrum myricoides* | 0.2 | 0 | | 0 | | 0 |
| *Rhamnus prinoides* | 0 | 0 | | 0 | | 0 |
| Total | 567 | | 280.4 | | 241.5 | 99.984 |

**Appendix 4. DBH distribution of Gesha-Sayilem forest**

| Scientific Name | 2.5-10 | 10.1-20 | 20.1-30 | 30.1-50 | 50.1-70 | 70.1-90 | 90.1-110 | 110-130 | >130 |
|---|---|---|---|---|---|---|---|---|---|
| *Allophyllus abyssinicus* | 50 | 39 | 31 | 24 | 7 | 2 | | | |
| *Phonix reclinata* | 10 | 39 | 17 | 3 | | | | | |
| *Dracaena afromontana* | 219 | 191 | 23 | 10 | | | | | |
| *Galiniera saxifraga* | 358 | 134 | 12 | | | | | | |
| *Pouteria adolfi-friederici* | 80 | 81 | 30 | 36 | 26 | 8 | 15 | 7 | 5 |
| *Syzygium guineense* | 35 | 48 | 35 | 36 | 47 | 28 | 20 | 17 | 7 |
| *Schefflera abyssinica* | 5 | 13 | 10 | 15 | 11 | 5 | 17 | 16 | 37 |
| *Rytigynia neglecta* | 93 | 35 | 21 | 6 | 3 | | | | |
| *Ilex mitis* | 49 | 116 | 72 | 50 | 40 | 14 | 15 | 2 | |
| *Solanecio gigas* | 11 | | | | | | | | |
| *Psychotria orophila* | 48 | 5 | | | | | | | |
| *Vepris dainellii* | 44 | 67 | 10 | 6 | | | | | |
| *Macaranga capensis* | 46 | 36 | 26 | 16 | | | | | |
| *Apodytes dimidiata* | 40 | 20 | 6 | 8 | 4 | 4 | | | |
| *Cyathea manniana* | 124 | 167 | 1 | | | | | | |
| *Maytenus gracilipes*subsp. *gracilipes,* | 228 | 20 | 3 | 1 | | | | | |
| *Cassipourea malosana* | 44 | 8 | 22 | 3 | 1 | | | | |
| *Landolphia buchananii* | 124 | 16 | 1 | 1 | 1 | | | | |
| *Lepidotrichilia volkensii* | 302 | 71 | 12 | 2 | 1 | | | | |
| *Vangueria madagascariensis* | 19 | 17 | 4 | 0 | 1 | | | | |
| *Urera hypselodendron* | 24 | 5 | 2 | | | | | | |
| *Solanecio mannii* | 22 | 1 | | | | | | | |
| *Ocotea kenyensis* | | 1 | | | | | | | |
| *Deinbollia kilimandscharica* | 323 | 10 | 1 | | | | | | |
| *Croton macrostachyus* | 9 | 2 | 15 | 40 | 8 | 1 | 1 | 1 | 1 |
| *Brucea antidysenterica.* | 4 | 5 | 1 | | | | | | |
| *Bersama abyssinica* | 75 | 34 | 6 | 5 | 1 | | | | |
| *Ekebergia capensis* | 2 | 6 | 3 | 2 | 2 | 2 | 7 | 1 | 9 |
| *Pavetta abyssinica* | 14 | 3 | | | | | | | |
| *Embelia schimperi* | 6 | 1 | | | | | | | |
| *Oxyanthus speciosus* | 117 | 27 | 2 | | | | | | |
| *Vernonia auriculifera* | 35 | 4 | | | | | | | |
| *Arundinaria alpina* | 115 | 1 | 1 | | | | | | |
| *Prunus africana* | 11 | 5 | 7 | 8 | 8 | 1 | 5 | 11 | |
| *Alangium chinense* | 9 | 11 | 7 | | | | | | |
| *Vernonia amygdalina* | 16 | 7 | 1 | | | | | | |
| *Brillantaisia grotanellii* | 7 | | | | | | | | |
| *Millettia ferruginea* | 66 | 44 | 7 | 3 | 0 | | | | |
| *Clausena anisata* | 33 | 6 | | | | | | | |
| *Tiliacora troupinii* | 20 | 4 | | | | | | | |
| *Albizia gummifera* | 7 | 8 | 2 | 2 | 0 | 0 | 2 | 1 | |

| Scientific Name | 2.5-10 | 10.1-20 | 20.1-30 | 30.1-50 | 50.1-70 | 70.1-90 | 90.1-110 | 110-130 | >130 |
|---|---|---|---|---|---|---|---|---|---|
| *Albizia schimperiana* | 2 | 1 | 1 | | | | | | |
| *Clematis longicauda* | 3 | | | | | | | | |
| *Sericostachys scandens* | 18 | 1 | 1 | | | | | | |
| *Celtis africana* | 3 | | | | | | | | |
| *Canthium oligocarpum* | 2 | 4 | 1 | 1 | | | | | |
| *Combretum paniculatum*. | 1 | | | | | | | | |
| *Elaeodendron buchananii* | 5 | 3 | 4 | | | | | | |
| *Olea capensis* subsp. *macrocarpa* | 15 | 4 | | | | | | | |
| *Ehretia cymosa* | 1 | 7 | 1 | | | | | | |
| *Euphorbia ampiphylla* | 0 | 5 | 1 | 4 | | | | | |
| *Pittosporum viridiflorum* | 14 | 2 | | | | | | | |
| *Rothmannia urcelliformis* | 16 | 3 | | | | | | | |
| *Olea welwitschii* | 5 | 0 | 0 | 1 | 2 | 3 | 1 | 1 | 3 |
| *Gouania longispicata* | 5 | | | | | | | | |
| *Maesa lanceolata* | 10 | 29 | 28 | 23 | 4 | 1 | | | |
| *Schefflera volkensii* | 3 | 5 | 12 | 4 | 3 | 2 | 2 | 3 | |
| *Maytenus undata* | 0 | 1 | 4 | 1 | 3 | | | | |
| *Oncoba spinosa* | 2 | | | | | | | | |
| *Teclea nobilis* | 1 | | | | | | | | |
| *Hallea rubrostipulata* | 0 | 0 | 0 | 50 | | | | | |
| *Polyscias fulva* | 4 | 7 | 1 | | | | | | |
| *Clematis simensis* | 1 | | | | | | | | |
| *Nuxia congesta* | 4 | 3 | 1 | | | | | | |
| *Hagenia abyssinica* | 0 | 6 | 3 | 1 | 1 | | 0 | 1 | |
| *Ficus sur* | 17 | 19 | 22 | 33 | 11 | 2 | 4 | 3 | 1 |
| *Jasminum abyssinicum* | 8 | | | | | | | | |
| *Diospyros abyssinica* | | | 3 | 3 | | | | | |
| *Dombeya torrida* | 2 | 1 | 2 | 1 | | | | | |
| *Buddleja polystachya* | | 1 | | | | | | | |
| *Erythrococca trichogyne* | 10 | | | | | | | | |
| *Hippocratea pallens* | 6 | | | | | | | | |
| *Hippocreta africana* | 5 | | | | | | | | |
| *Hypericum revolutum* | 3 | | | | | | | | |
| *Sapium ellipticum*. | | | | 1 | 2 | 1 | 1 | | |
| *Coffea arabica* | 3 | 1 | | | | | | | |
| **Total** | 3013 | 1411 | 1498 | 286 | 90 | 89 | 78 | 64 | 68 |

**Appendix 5 Height class distribution**

| Plant species | 2.5-5 m | 5.01-10 | 10.01-15 | 15.01-20 | 20.01-25 | 25.01-30 | > 30 |
|---|---|---|---|---|---|---|---|
| *Allophyllus abyssinicus* | 58 | 62 | 22 | 11 | 0 | 1 | 1 |
| *Phonix reclinata* | 15 | 20 | 31 | 2 | 1 | | |

| Plant species | 2.5-5 m | 5.01-10 | 10.01-15 | 15.01-20 | 20.01-25 | 25.01-30 | > 30 |
|---|---|---|---|---|---|---|---|
| *Dracaena afromontana* | 322 | 53 | 1 | | | | |
| *Galiniera saxifraga* | 445 | 60 | 1 | | | | |
| *Pouteria adolfi-friederici* | 59 | 94 | 60 | 30 | 15 | 29 | 12 |
| *Syzygium guineense* | 43 | 89 | 76 | 35 | 15 | 7 | 3 |
| *Schefflera abyssinica* | 8 | 29 | 32 | 29 | 19 | 7 | 2 |
| *Rytigynia neglecta* | 95 | 49 | 9 | 4 | | | |
| *Ilex mitis* | 81 | 162 | 75 | 21 | 4 | 1 | 1 |
| *Solanecio gigas* | 11 | | | | | | |
| *Psychotria orophila* | 49 | 3 | | | | | |
| *Vepris dainellii* | 190 | 73 | 4 | | | | |
| *Macaranga capensis* | 46 | 73 | 26 | 13 | 2 | | |
| *Apodytes dimidiata* | 34 | 17 | 16 | 11 | 6 | 3 | |
| *Cyathea manniana* | 193 | 95 | 2 | | | | |
| *Maytenus gracilipes* subsp. *gracilipes* | 235 | 11 | 4 | 2 | | | |
| *Cassipourea malosana* | 50 | 17 | 4 | 7 | | | |
| *Landolphia buchananii* | 14 | 24 | 56 | 29 | 9 | 7 | |
| *Lepidotrichilia volkensii* | 317 | 60 | 10 | | | | |
| *Vangueria madagascariensis* | 26 | 13 | 2 | | | | |
| *Urera hypselodendron* | *5* | 7 | 13 | 4 | 1 | | |
| *Solanecio mannii* | 22 | 1 | | | | | |
| *Ocotea kenyensis* | 1 | | | | | | |
| *Deinbollia kilimandscharica* | 329 | 6 | | | | | |
| *Croton macrostachyus* | 6 | 23 | 26 | 18 | 8 | 1 | |
| *Brucea antidysenterica.* | 8 | 3 | | | | | |
| *Bersama abyssinica* | 63 | 41 | 7 | | | | |
| *Ekebergia capensis* | 4 | 5 | 4 | 4 | 15 | | |
| *Pavetta abyssinica* | 19 | | | | | | |
| *Embelia schimperi* | 0 | 2 | 0 | 5 | 0 | 0 | 0 |
| *Oxyanthus speciosus* | 126 | 19 | 2 | | | | |
| *Vernonia auriculifera* | 37 | 7 | 1 | | | | |
| *Arundinaria alpina* | 25 | 130 | 64 | 11 | 1 | | |
| *Prunus africana* | 5 | 8 | 18 | 5 | 5 | 9 | 7 |
| *Alangium chinense* | 4 | 14 | 7 | 2 | 3 | 1 | |
| *Vernonia amygdalina* | 13 | 13 | 1 | | | | |
| *Brillantaisia grotanellii* | 7 | 1 | | | | | |
| *Millettia ferruginea* | 32 | 82 | 15 | 6 | | | |
| *Clausena anisata* | 41 | 3 | | | | | |
| *Tiliacora troupinii* | 2 | 2 | 9 | 3 | 5 | 2 | 1 |
| *Albizia gummifera* | 23 | 14 | 6 | 7 | 5 | | |
| *Albizia schimperiana* | 2 | 2 | 2 | 2 | | | |
| *Clematis longicauda* | | | 1 | | | 2 | 1 |
| *Sericostachys scandens* | 5 | 8 | 8 | 9 | | | |

| Plant species | 2.5-5 m | 5.01-10 | 10.01-15 | 15.01-20 | 20.01-25 | 25.01-30 | > 30 |
|---|---|---|---|---|---|---|---|
| *Celtis africana* | 1 | 3 | | | | | |
| *Canthium oligocarpum* | 4 | 6 | 1 | | | | |
| *Combretum paniculatum*. | 1 | 1 | | | | | |
| *Elaeodendron buchananii* | 12 | 15 | 3 | 4 | 0 | 10 | 5 |
| *Olea capensis* subsp. *macrocarpa* | 89 | 16 | | | | | |
| *Ehretia cymosa* | 4 | 10 | | | | | |
| *Euphorbia ampliphylla* | | 6 | 4 | 5 | 3 | | |
| *Pittosporum viridiflorum* | 18 | 3 | | | | | |
| *Rothmannia urcelliformis* | 21 | 21 | | | | | |
| *Olea welwitschii* | 5 | 3 | 3 | 5 | 8 | 16 | 7 |
| *Gouania longispicata* | 2 | 1 | 2 | | | | |
| *Maesa lanceolata* | 21 | 42 | 17 | 2 | | | |
| *Schefflera volkensii* | 1 | 19 | 5 | 4 | 3 | | |
| *Maytenus undata* | 3 | 3 | 2 | 1 | | | |
| *Oncoba spinosa* | 2 | | | | | | |
| *Teclea nobilis* | 1 | | | | | | |
| *Hallea rubrostipulata* | | 1 | 3 | 5 | 0 | 4 | |
| *Polyscias fulva* | 3 | 5 | 3 | | | | |
| *Clematis simensis* | 1 | | | | | | |
| *Nuxia congesta* | 5 | 3 | | | | | |
| *Hagenia abyssinica* | 4 | 4 | 3 | 2 | | | |
| *Ficus sur* | 11 | | | | | | |
| *Jasminum abyssinicum* | 14 | 32 | 45 | 11 | 2 | 3 | 1 |
| *Diospyros abyssinica* | 1 | 1 | 3 | 3 | | | |
| *Dombeya torrida* | 1 | 5 | | | | | |
| *Buddleja polystachya* | 4 | 5 | 3 | | | | |
| *Erythrococca trichogyne* | 1 | | | | | | |
| *Hippocratea pallens* | 40 | 1 | | | | | |
| *Hippocreta africana* | 5 | 41 | 40 | 29 | 4 | 8 | 1 |
| *Hypericum revolutum* | 5 | 13 | 6 | 8 | 1 | 1 | 1 |
| *Sapium ellipticum*. | 4 | | | | | | |
| *Coffea arabica* | 1 | 10 | 6 | 11 | 7 | 8 | 3 |
| Total | 3355 | 1665 | 764 | 360 | 142 | 120 | 46 |

**Appendix 6. The basal area and IVI values of the study forest**

| Species | Family | Basal area | Rel frequency | Rel Density | R DO (RBA) | IVI | % IVI |
|---|---|---|---|---|---|---|---|
| *Schefflera abyssinica* | Araliaceae | 27.1 | 3.65 | 0.31 | 29.00 | 32.96 | 12.21 |
| *Syzygium guineese* | Myrtaceae | 15 | 3.58 | 3.88 | 14.22 | 21.68 | 8.03 |
| *Pouteria adolfi-friederici* | Spotaceae | 13 | 2.90 | 3.88 | 9.26 | 16.04 | 5.94 |
| *Gallineria saxifarga* | Rubiaceae | 6.80 | 5.00 | 7.32 | 0.66 | 12.98 | 4.81 |
| *Ilex mitis* | Aquafoliaceae | 9.31 | 3.98 | 0.89 | 7.12 | 11.99 | 4.44 |
| *Lepidotrichilia volkensii* | Meliaceae | 0.29 | 4.12 | 5.60 | 0.46 | 10.18 | 3.77 |
| *Dracena afromontana* | Dracenaceae | 3.46 | 2.84 | 6.41 | 0.91 | 10.15 | 3.76 |
| *Millitia ferruginea* | Fabaceae | 1.40 | 1.82 | 5.02 | 0.45 | 7.30 | 2.70 |
| *Olea welwitschii* | Oleaceae | 3.92 | 0.74 | 0.68 | 5.71 | 7.13 | 2.64 |
| *Ficus sur* | Moraceae | 1.88 | 2.50 | 1.56 | 2.93 | 7.00 | 2.59 |
| *Allophylus abyssinicus* | Anacaridaceae | 2 | 3.44 | 2.20 | 1.30 | 6.94 | 2.57 |
| *Prunus africana* | Roseaceae | 4.26 | 1.62 | 1.04 | 4.01 | 6.68 | 2.47 |
| *Ekebergia capensis* | Meliaceae | 4.10 | 1.35 | 0.55 | 4.62 | 6.52 | 2.42 |
| *Croton macrostachyus* | Euphorbiaceae | 1.91 | 2.57 | 1.22 | 1.95 | 5.73 | 2.12 |
| *Bersama abyssinica* | Meliaceae | 0.36 | 2.97 | 1.77 | 0.33 | 5.06 | 1.88 |
| *Deinbolia kilimadcraensis* | Sapindaceae | 0.16 | 4.05 | 0.83 | 0.15 | 5.03 | 1.86 |
| *Vepris dainellii* | Rutaceae | 0.5 | 3.85 | 0.66 | 0.48 | 5.00 | 1.85 |
| *Arundinaria alpina* | Poaceae | 0.20 | 0.61 | 3.85 | 0.18 | 4.64 | 1.72 |
| *Hippocratea pallens* | Celastraceae | 0.09 | 2.43 | 1.93 | 0.08 | 4.44 | 1.64 |
| *Maytenus gracilipes* | Celastraceae | 0.19 | 3.17 | 0.74 | 0.20 | 4.12 | 1.52 |
| *Oxyanthus speciosus* | Rubiaceae | 0.15 | 1.76 | 2.13 | 0.14 | 4.02 | 1.49 |
| *Rytignia neglecta* | Rubiaceae | 0.39 | 3.11 | 0.39 | 0.46 | 3.95 | 1.46 |
| *Sapium ellipticum* | Euphorbiaceae | 2.15 | 0.68 | 0.72 | 1.97 | 3.36 | 1.25 |
| *Hallea rubrostipulata* | Acanthaceae | 2.90 | 0.27 | 0.22 | 2.66 | 3.14 | 1.16 |
| *Albizia gummifera* | Fabaceae | 1.51 | 0.74 | 0.94 | 1.38 | 3.06 | 1.13 |

| Species | Family | Basal area | Rel frequency | Rel Density | R DO (RBA) | IVI | % IVI |
|---|---|---|---|---|---|---|---|
| *Olea capensis subsp. Macrocarpa* | Oleaceae | 0.08 | 1.42 | 1.52 | 0.08 | 3.02 | 1.12 |
| *Landolphia buchananii* | Apocynaceae | 0.15 | 2.36 | 0.35 | 0.14 | 2.86 | 1.06 |
| *Elaeodendron buchananii* | Celastraceae | 1.24 | 0.95 | 0.69 | 1.14 | 2.78 | 1.03 |
| *Maesa lanceolata* | Myrsinaceae | 0.91 | 0.61 | 1.19 | 0.84 | 2.63 | 0.97 |
| *Cassipourea malosana* | Rhizophoraceae | 0.27 | 2.16 | 0.19 | 0.25 | 2.60 | 0.96 |
| *Macaranga capensis* | Euphorbiaceae | 3.6 | 2.63 | 0.40 | 2.45 | 5.48 | 2.03 |
| *Schefflera volkensii* | Araliaceae | 1.47 | 0.61 | 0.48 | 1.35 | 2.43 | 0.90 |
| *Vernonia auriculifera* | Asteraceae | 0.03 | 1.28 | 0.67 | 0.03 | 1.98 | 0.73 |
| *Phonix reclinata* | Araliaceae | 0.990 | 0.61 | 1.00 | 0.30 | 1.91 | 0.71 |
| *Erythrococca trichogyne* | Euphorbiaceae | 0.04 | 1.22 | 0.61 | 0.03 | 1.86 | 0.69 |
| *Sericostachys scandens* | Amaranthaceae | 0.05 | 1.28 | 0.52 | 0.04 | 1.85 | 0.68 |
| *Vangueria apiculata* | Alangiaceae | 0.15 | 1.01 | 0.59 | 0.00 | 1.61 | 0.60 |
| *Urera hypselodendron* | Urticaceae | 0.03 | 1.08 | 0.43 | 0.03 | 1.55 | 0.57 |
| *Clausena 219nisate* | Rutaceae | 0.03 | 0.81 | 0.64 | 0.03 | 1.48 | 0.55 |
| *Brillantaisia grotanellii* | Acanthaceae | 0.001 | 1.08 | 0.35 | 0.00 | 1.43 | 0.53 |
| *Rothmannia urcelliformis* | Rubiaceae | 0.05 | 0.54 | 0.61 | 0.04 | 1.19 | 0.44 |
| *Solanecio manni* | Asteraceae | 0.012 | 0.81 | 0.33 | 0.01 | 1.15 | 0.43 |
| *Vernonia amygdalina* | Asteraceae | 0.04 | 0.73 | 0.39 | 0.03 | 1.15 | 0.43 |
| *Alangium chinense* | Alangiaceae | 0.15 | 0.51 | 0.45 | 0.14 | 1.09 | 0.40 |
| *Tiliacora troupinii* | Menispermaceae | 0.07 | 0.68 | 0.35 | 0.07 | 1.09 | 0.40 |
| *Hippocreta africana* | Celastraceae | 0.09 | 0.81 | 0.09 | 0.04 | 0.94 | 0.35 |
| *Pavetta abyssinica* | Rubiaceae | 0.03 | 0.54 | 0.28 | 0.03 | 0.84 | 0.31 |
| *Apodytes dimidata* | Icaccinaceae | 1.1 | 2.57 | 0.21 | 0.82 | 3.60 | 1.33 |
| *Pittosperum virvdiflorum* | Pittosporaceae | 0.02 | 0.47 | 0.30 | 0.02 | 0.80 | 0.30 |
| *Hagenia abyssinica* | Roseaceae | 1.88 | 0.29 | 0.19 | 0.27 | 0.75 | 0.28 |
| *Euphorbia ampliphylla* | Euphorbiaceae | 0.24 | 0.27 | 0.26 | 0.22 | 0.75 | 0.28 |

| Species | Family | Basal area | Rel frequency | Rel Density | R DO (RBA) | IVI | % IVI |
|---|---|---|---|---|---|---|---|
| *Psychotria orophila* | Rubiaceae | 0.028 | 0.54 | 0.13 | 0.03 | 0.69 | 0.26 |
| *Dombeya torrida* | Sterculiaceae | 0.17 | 0.34 | 0.17 | 0.15 | 0.66 | 0.25 |
| *Brucea antidysenterica* | Simaroubaceae | 0.02 | 0.47 | 0.14 | 0.02 | 0.64 | 0.24 |
| *Polyscias fulva* | Araliaceae | 0.04 | 0.41 | 0.16 | 0.03 | 0.60 | 0.22 |
| *Clematis simensis* | Ranuaculaceae | 0.001 | 0.10 | 0.01 | 0.00 | 0.11 | 0.04 |
| *Solanecio gigas* | Asteraceae | 0.005 | 0.54 | 0.03 | 0.00 | 0.57 | 0.21 |
| *Ehretia cymosa* | Boraginaceae | 0.04 | 0.27 | 0.20 | 0.04 | 0.51 | 0.19 |
| *Justicia schimperiana* | Acanthaceae | | 0.34 | 0.16 | 0.00 | 0.50 | 0.18 |
| *Canthium oligocarpum* | Rubiaceae | 0.07 | 0.27 | 0.16 | 0.06 | 0.49 | 0.18 |
| *Maytenus undata* | Celastraceae | 0.001 | 0.34 | 0.13 | 0.00 | 0.47 | 0.17 |
| *Cyathea manniana* | Cyatheaceae | 0.50 | 1.22 | 0.73 | 0.46 | 2.40 | 0.89 |
| *Jasminum abyssinicum* | Oleaceae | 0.001 | 0.34 | 0.12 | 0.00 | 0.46 | 0.17 |
| *Embelia schimperi* | Myrsinaceae | 0.01 | 0.34 | 0.10 | 0.01 | 0.45 | 0.16 |
| *Schefflera mriantha* | Araliaceae | 0.01 | 0.34 | 0.09 | 0.01 | 0.43 | 0.16 |
| *Hypericum revolutum* | Guittiferae | 0.001 | 0.34 | 0.07 | 0.00 | 0.41 | 0.15 |
| *Coffea arabica* | Rubiaceae | 0.02 | 0.22 | 0.17 | 0.01 | 0.41 | 0.15 |
| *Gouania longispicata* | Rhamnaceae | 0.001 | 0.27 | 0.07 | 0.00 | 0.35 | 0.13 |
| *Alblzia schimperiana* | Fabaceae | 0.08 | 0.14 | 0.06 | 0.08 | 0.27 | 0.10 |
| *Clematis longicauda* | Ranuaculaceae | 0.001 | 0.20 | 0.06 | 0.00 | 0.26 | 0.10 |
| *Nuxia congesta* | Loganaceae | 0.001 | 0.10 | 0.12 | 0.02 | 0.24 | 0.09 |
| *Diosprous abyssinica* | Ebenaceae | 0.04 | 0.07 | 0.12 | 0.03 | 0.22 | 0.08 |
| *Oncoba spinosa* | Flacourtiaceae | 0.001 | 0.14 | 0.03 | 0.0006 | 0.16 | 0.06 |
| *Combretum paniculatum* | Combreataceae | 0.001 | 0.14 | 0.03 | 0.0006 | 0.16 | 0.06 |
| *Rubus steudneri* | Rubiaceae | 0.001 | 0.14 | 0.03 | 0.0006 | 0.16 | 0.06 |
| *Clerodendrum myricoide* | Verbanaceae | 0.001 | 0.10 | 0.01 | 0.0006 | 0.11 | 0.04 |
| *Octea kenyensis* | Lauraceae | 0.001 | 0.07 | 0.01 | 0.0006 | 0.08 | 0.03 |
| *Celtis africana* | Ulmaceae | 0.001 | 0.07 | 0.01 | 0.0006 | 0.08 | 0.03 |
| *Teclea nobilis.* | Rutaceae | 0.001 | 0.07 | 0.01 | 0.0006 | 0.08 | 0.03 |

**Appendix 7. Seeding and sapling density of forest**

| Woody species | No.seedling | Density | No. sapling | Density | No. matured plants | Density |
|---|---|---|---|---|---|---|
| *Allophyllus abyssinicus* | 1060 | 189.3 | 307 | 54.8 | 159 | 28.39 |
| *Phonix reclinata* | 505 | 90.2 | 130 | 23.2 | 50 | 8.93 |
| *Dracaena afromontana* | 523 | 93.4 | 185 | 33.0 | 436 | 77.86 |
| *Galiniera saxifraga* | 943 | 168.4 | 461 | 82.3 | 484 | 86.43 |
| *Pouteria adolfi-friederici* | 206 | 36.8 | 86 | 15.4 | 298 | 53.21 |
| *Syzygium guineense* | 718 | 128.2 | 309 | 55.2 | 290 | 51.79 |
| *Schefflera abyssinica* | 0 | 0.0 | 0 | 0.0 | 121 | 21.61 |
| *Rytigynia neglecta* | 195 | 34.8 | 146 | 26.1 | 97 | 17.32 |
| *Ilex mitis* | 137 | 24.5 | 250 | 44.6 | 357 | 63.75 |
| *Solanecio gigas* | 10 | 1.8 | 35 | 6.3 | 12 | 2.14 |
| *Psychotria orophila* | 190 | 33.9 | 67 | 12.0 | 51 | 9.11 |
| *Vepris dainellii* | 177 | 31.6 | 66 | 11.8 | 256 | 45.71 |
| *Macaranga capensis*sub sp *kilimandscharica* | 47 | 8.4 | 67 | 12.0 | 52 | 9.29 |
| *Apodytes dimidiata* | 191 | 34.1 | 73 | 13.0 | 89 | 15.89 |
| *Cyathea manniana* | 0 | 0.0 | 0 | 0.0 | 120 | 21.43 |
| *Maytenus gracilipes sub sp. gracilipes* | 263 | 47.0 | 280 | 50.0 | 263 | 46.96 |
| *Cassipourea malosana* | 59 | 10.5 | 107 | 19.1 | 73 | 13.04 |
| *Landolphia buchananii* | 200 | 0.0 | 11 | 2.0 | 130 | 23.21 |
| *Lepidotrichilia volkensii* | 440 | 78.6 | 197 | 35.2 | 160 | 28.57 |
| *Vangueria madagascariensi* | 50 | 8.9 | 10 | 1.8 | 48 | 8.57 |
| *Urera hypselodendron* | 0 | 0.0 | 0 | 0.0 | 30 | 5.36 |
| *Solanecio mannii* | 0 | 0.0 | 20 | 3.6 | 18 | 3.21 |
| *Ocotea kenyensis* | 0 | 0.0 | 0 | 0.0 | 1 | 0.18 |
| *Deinbollia kilimandscharica* | 241 | 43.0 | 154 | 27.5 | 336 | 60.00 |
| *Croton macrostachyus* | 44 | 7.9 | 25 | 4.5 | 92 | 16.43 |
| *Brucea antidysenterica* | 18 | 3.2 | 15 | 2.7 | 8 | 1.43 |
| *Bersama abyssinica* | 110 | 19.6 | 34 | 6.1 | 116 | 20.71 |
| *Ekebergia capensis* | 0 | 0.0 | 4 | 0.7 | 37 | 6.61 |

| Woody species | No.seedling | Density | No. sapling | Density | No. matured plants | Density |
|---|---|---|---|---|---|---|
| *Pavetta abyssinica* | 44 | 7.9 | 32 | 5.7 | 18 | 3.21 |
| *Embelia schimperi* | 0 | 0.0 | 0 | 0.0 | 9 | 1.61 |
| *Oxyanthus speciosus* | 540 | 96.4 | 175 | 31.3 | 147 | 26.25 |
| *Vernonia auriculifera* | 28 | 5.0 | 10 | 1.8 | 43 | 7.68 |
| *Arundinaria alpina* | 0 | 0.0 | 0 | 0.0 | 168 | 30.00 |
| *Prunus africana* | 15 | 2.7 | 18 | 3.2 | 69 | 12.32 |
| *Alangium chinense* | 0 | 0.0 | 17 | 3.0 | 21 | 3.75 |
| *Vernonia amygdalina* | 50 | 8.9 | 30 | 5.4 | 26 | 4.64 |
| *Brillantaisia grotanellii* | 0 | 0.0 | 0 | 0.0 | 11 | 1.96 |
| *Millettia ferruginea* | 221 | 39.5 | 85 | 15.2 | 177 | 31.61 |
| *Clausena anisata* | 0 | 0.0 | 0 | 0.0 | 26 | 4.64 |
| *Tiliacora troupinii* | 0 | 0.0 | 0 | 0.0 | 15 | 2.68 |
| *Albizia gummifera* | 67 | 12.0 | 44 | 7.9 | 63 | 11.25 |
| *Albizia schimperiana* | 0 | 0.0 | 0 | 0.0 | 9 | 1.61 |
| *Clematis longicauda* | 0 | 0.0 | 0 | 0.0 | 4 | 0.71 |
| *Sericostachys scandens* | 0 | 0.0 | 0 | 0.0 | 9 | 1.61 |
| *Celtis africana* | 0 | 0.0 | 0 | 0.0 | 1 | 0.18 |
| *Canthium oligocarpum* | 65 | 11.6 | 33 | 5.9 | 43 | 7.68 |
| *Combretum paniculatum* | 0 | 0.0 | 0 | 0.0 | 9 | 1.61 |
| *Elaeodendron buchananii* | 0 | 0.0 | 0 | 0.0 | 2 | 0.36 |
| *Olea capensis* subsp. *macrocarpa* | 5 | 0.9 | 44 | 7.9 | 87 | 15.54 |
| *Ehretia cymosa* | 0 | 0.0 | 0 | 0.0 | 9 | 1.61 |
| *Euphorbia ampliphylla* | 0 | 0.0 | 4 | 0.7 | 7 | 1.25 |
| *Pittosporum viridiflorum* | 0 | 0.0 | 0 | 0.0 | 21 | 3.75 |
| *Rothmannia urcelliformis* | 45 | 8.0 | 33 | 5.9 | 35 | 6.25 |
| *Olea welwitschii* | 2 | 0.4 | 6 | 1.1 | 33 | 5.89 |
| *Gouania longispicata* | 0 | 0.0 | 0 | 0.0 | 5 | 0.89 |
| *Maesa lanceolata* | 20 | 3.6 | 45 | 8.0 | 27 | 4.82 |
| *Schefflera volkensii* | 0 | 0.0 | 0 | 0.0 | 29 | 5.18 |
| *Maytenus undata* | 29 | 5.2 | 12 | 2.1 | 9 | 1.61 |
| *Oncoba spinosa* | 0 | 0.0 | 0 | 0.0 | 1 | 0.18 |
| *Teclea nobilis* | 0 | 0.0 | 0 | 0.0 | 1 | 0.18 |
| *Hallea rubrostipulata* | 0 | 0.0 | 0 | 0.0 | 5 | 0.89 |
| *Polyscias fulva* | 0 | 0.0 | 0 | 0.0 | 11 | 1.96 |
| *Clematis simensis* | 0 | 0.0 | 0 | 0.0 | 1 | 0.18 |
| *Nuxia congesta* | 0 | 0.0 | 2 | 0.4 | 5 | 0.89 |
| *Hagenia abyssinica* | 0 | 0.0 | 0 | 0.0 | 8 | 1.43 |
| *Ficus sur* | 0 | 0.0 | 0 | 0.0 | 108 | 19.29 |
| *Jasminum abyssinicum* | 128 | 0.0 | 0 | 0.0 | 9 | 1.61 |

| Woody species | No.seedling | Density | No. sapling | Density | No. matured plants | Density |
|---|---|---|---|---|---|---|
| *Diospyros abyssinica* | 0 | 0.0 | 0 | 0.0 | 7 | 1.25 |
| *Dombeya torrida* | 10 | 1.8 | 4 | 0.7 | 12 | 2.14 |
| *Buddleja polystachya* | 0 | 0.0 | 0 | 0.0 | 3 | 0.54 |
| *Erythrococca trichogyne* | 90 | 16.1 | 49 | 8.8 | 31 | 5.54 |
| *Hippocratea pallens* | 32 | 5.7 | 0 | 0.0 | 109 | 19.46 |
| *Hippocreta africana* | | 0.0 | 0 | 0.0 | 1.1 | 1.96 |
| *Hypericum revolutum* | 0 | 0.0 | 0 | 0.0 | 12 | 2.14 |
| *Sapium ellipticum* | 0 | 0.0 | 8 | 1.4 | 9 | 1.61 |
| *Schefflera mriantha* | 0 | 0.0 | 0 | 0.0 | 3 | 0.54 |
| *Coffea arabica* | 50 | 8.9 | 10 | 1.8 | 9 | 1.61 |
| *Clerodendrum myricoides* | 5 | 2 | 0 | 0.0 | | 0.54 |
| *Rubus steudneri* | 0 | 0 | 0 | 0 | 5 | 0.89 |
| **Total** | **7775** | **1330** | **3702** | **661** | **5680** | **1014.29** |

**Appendix 8.The above and below ground carbon stock of Gesha-Sayilem forest**

| Plot No. | AGB(Kg/$m^2$) | AGB(Kg/ha) | AGB (ton/ha) | AGC(ton/ha) | BGB(ton/ha) | BGC(ton/ha) | Total AGC |
|---|---|---|---|---|---|---|---|
| 1 | 38230.19 | 312083.2 | 312.08 | 146.68 | 62.42 | 29.34 | 176.01 |
| 2 | 109212.7 | 891532.9 | 891.53 | 419.02 | 178.31 | 83.80 | 502.83 |
| 3 | 43069.75 | 351589.8 | 351.59 | 165.25 | 70.32 | 33.05 | 198.30 |
| 4 | 67972.58 | 554878.2 | 554.88 | 260.79 | 110.98 | 52.16 | 312.95 |
| 5 | 42091.3 | 343602.4 | 343.60 | 161.49 | 68.72 | 32.30 | 193.79 |
| 6 | 36590.89 | 298701.3 | 298.70 | 140.39 | 59.74 | 28.08 | 168.47 |
| 7 | 40058.69 | 327009.7 | 327.01 | 153.70 | 65.40 | 30.74 | 184.43 |
| 8 | 43272.31 | 353243.4 | 353.24 | 166.02 | 70.65 | 33.20 | 199.23 |
| 9 | 17547.32 | 143243.5 | 143.24 | 67.32 | 28.65 | 13.46 | 80.79 |
| 10 | 18470.72 | 150781.4 | 150.78 | 70.87 | 30.16 | 14.17 | 85.04 |
| 11 | 24419.19 | 199340.4 | 199.34 | 93.69 | 39.87 | 18.74 | 112.43 |
| 12 | 56435.28 | 460696.1 | 460.70 | 216.53 | 92.14 | 43.31 | 259.83 |
| 13 | 25049.79 | 204488 | 204.49 | 96.11 | 40.90 | 19.22 | 115.33 |
| 14 | 134576.8 | 1098586 | 1098 | 516.34 | 219.72 | 103.27 | 619.60 |
| 15 | 15424.92 | 125917.7 | 125.92 | 59.18 | 25.18 | 11.84 | 71.02 |
| 16 | 32229.67 | 263099.3 | 263.10 | 123.66 | 52.62 | 24.73 | 148.39 |
| 17 | 32144.89 | 262407.2 | 262.41 | 123.33 | 52.48 | 24.67 | 148.00 |
| 18 | 119396.6 | 974666.2 | 974.67 | 458.09 | 194.93 | 91.62 | 549.71 |
| 19 | 84306.37 | 688215.3 | 688.22 | 323.46 | 137.64 | 64.69 | 388.15 |
| 20 | 22633.86 | 184766.2 | 184.77 | 86.84 | 36.95 | 17.37 | 104.21 |
| 21 | 90781.16 | 741070.7 | 741.07 | 348.30 | 148.21 | 69.66 | 417.96 |
| 22 | 9365.2 | 76450.61 | 76.45 | 35.93 | 15.29 | 7.19 | 43.12 |
| 23 | 168.05 | 1371.837 | 1.37 | 0.65 | 0.27 | 0.13 | 0.77 |
| 24 | 29981 | 244742.9 | 244.74 | 115.03 | 48.95 | 23.01 | 138.03 |

| Plot No. | AGB(Kg/ $m^2$) | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC |
|---|---|---|---|---|---|---|---|
| 25 | 16970.7 | 138536.3 | 138.54 | 65.11 | 27.71 | 13.02 | 78.13 |
| 26 | 16272.25 | 132834.7 | 132.84 | 62.43 | 26.57 | 12.49 | 74.92 |
| 27 | 24953.8 | 203704.4 | 203.70 | 95.74 | 40.74 | 19.15 | 114.89 |
| 28 | 35852.41 | 292672.7 | 292.67 | 137.56 | 58.53 | 27.51 | 165.07 |
| 29 | 30537.82 | 249288.3 | 249.29 | 117.17 | 49.86 | 23.43 | 140.60 |
| 30 | 12004.26 | 97993.96 | 97.99 | 46.06 | 19.60 | 9.21 | 55.27 |
| 31 | 43866.5 | 358093.9 | 58.09 | 168.30 | 11.62 | 5.46 | 173.76 |
| 32 | 96013 | 783779.6 | 783.78 | 368.40 | 156.76 | 73.68 | 442.08 |
| 33 | 161069 | 1314849 | 1314.85 | 617.90 | 262.97 | 123.60 | 741.50 |
| 34 | 73197.68 | 597532.1 | 597.53 | 280.84 | 119.51 | 56.17 | 337.01 |
| 35 | 68004.39 | 555137.9 | 555.14 | 260.92 | 111.03 | 52.18 | 313.10 |
| 36 | 90257 | 736791.8 | 736.79 | 346.29 | 147.36 | 69.26 | 415.55 |
| 37 | 10417.92 | 85044.26 | 85.04 | 39.97 | 17.01 | 7.99 | 47.97 |
| 38 | 21722.9 | 177329.8 | 177.33 | 83.35 | 35.47 | 16.67 | 100.01 |
| 39 | 57795.9 | 471803.3 | 471.80 | 221.75 | 94.36 | 44.35 | 266.10 |
| 40 | 147.7 | 1205.714 | 1.21 | 0.57 | 0.24 | 0.11 | 0.68 |
| 41 | 114.65 | 935.918 | 0.94 | 0.44 | 0.19 | 0.09 | 0.53 |
| 42 | 345.2 | 2817.959 | 2.82 | 1.32 | 0.56 | 0.26 | 1.59 |
| 43 | 4778.398 | 39007.33 | 39.01 | 18.33 | 7.80 | 3.67 | 22.00 |
| 44 | 4455.45 | 36371.02 | 36.37 | 17.09 | 7.27 | 3.42 | 20.51 |
| 45 | 26608.64 | 217213.4 | 217.21 | 102.09 | 43.44 | 20.42 | 122.51 |
| 46 | 13816.7 | 112789.4 | 112.79 | 53.01 | 22.56 | 10.60 | 63.61 |
| 47 | 27788 | 226840.8 | 226.84 | 106.62 | 45.37 | 21.32 | 127.94 |
| 48 | 19121.8 | 156096.3 | 156.10 | 73.37 | 31.22 | 14.67 | 88.04 |
| 49 | 31741.27 | 259112.4 | 259.11 | 121.78 | 51.82 | 24.36 | 146.14 |
| 50 | 55334.04 | 451706.4 | 451.71 | 212.30 | 90.34 | 42.46 | 254.76 |
| 51 | 66402.2 | 542058.8 | 542.06 | 254.77 | 108.41 | 50.95 | 305.72 |
| 52 | 72254.5 | 589832.7 | 589.83 | 277.22 | 117.97 | 55.44 | 332.67 |
| 53 | 34809.17 | 284156.5 | 284.16 | 133.55 | 56.83 | 26.71 | 160.26 |
| 54 | 7471.68 | 60993.31 | 60.99 | 28.67 | 12.20 | 5.73 | 34.40 |
| 55 | 8484.97 | 69265.06 | 69.27 | 32.56 | 13.85 | 6.51 | 39.07 |
| 56 | 64675.17 | 527960.6 | 527.96 | 248.14 | 105.59 | 49.63 | 297.77 |
| 57 | 84527.8 | 690022.9 | 690.02 | 324.31 | 138.00 | 64.86 | 389.17 |
| 58 | 10865.5 | 88697.96 | 88.70 | 41.69 | 17.74 | 8.34 | 50.03 |
| 59 | 28246.1 | 230580.4 | 230.58 | 108.37 | 46.12 | 21.67 | 130.05 |
| 60 | 32630 | 266367.3 | 266.37 | 125.19 | 53.27 | 25.04 | 150.23 |
| 61 | 29282.8 | 239043.3 | 239.04 | 112.35 | 47.81 | 22.47 | 134.82 |
| 62 | 153316 | 1251559 | 1251.56 | 588.23 | 250.31 | 117.65 | 705.88 |
| 63 | 277623.9 | 2266318 | 2266.32 | 1065.16 | 453.26 | 213.03 | 1278.19 |
| 64 | 30457.82 | 248635.3 | 248.64 | 116.86 | 49.73 | 23.37 | 140.23 |

| Plot No. | AGB(Kg/ $m^2$) | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC |
|---|---|---|---|---|---|---|---|
| 65 | 14950.75 | 122046.9 | 122.05 | 57.36 | 24.41 | 11.47 | 68.83 |
| 66 | 90468.31 | 738516.8 | 738.52 | 347.10 | 147.70 | 69.42 | 416.52 |
| 67 | 912468.2 | 6382.12 | 523.00 | 125.00 | 104.60 | 49.16 | 174.16 |
| 68 | 45183.72 | 368846.7 | 368.85 | 173.36 | 73.77 | 34.67 | 208.03 |
| 69 | 100920.3 | 823839.4 | 823.84 | 387.21 | 164.77 | 77.44 | 464.65 |
| 70 | 42977.85 | 350839.6 | 350.84 | 164.89 | 70.17 | 32.98 | 197.87 |
| 71 | 88925.67 | 725923.8 | 725.92 | 341.18 | 145.18 | 68.24 | 409.42 |
| 72 | 106430.2 | 868818 | 868.82 | 408.30 | 173.76 | 81.67 | 489.97 |
| 73 | 106430.2 | 868818 | 868.82 | 408.34 | 173.76 | 81.67 | 490.01 |
| 74 | 27208.9 | 222113.5 | 222.11 | 104.39 | 44.42 | 20.88 | 125.27 |
| 75 | 19179.06 | 156563.8 | 156.56 | 73.59 | 31.31 | 14.72 | 88.30 |
| 76 | 140474 | 114673.3 | 11.67 | 53.90 | 2.33 | 1.10 | 54.99 |
| 77 | 30761.1 | 251111 | 251.11 | 118.02 | 50.22 | 23.60 | 141.63 |
| 78 | 2036.4 | 16623.67 | 16.62 | 7.81 | 3.32 | 1.56 | 9.38 |
| 79 | 18992.5 | 155040.8 | 155.04 | 72.87 | 31.01 | 14.57 | 87.44 |
| 80 | 292.3 | 2386.122 | 2.39 | 1.12 | 0.48 | 0.22 | 1.35 |
| 81 | 36788.64 | 300315.4 | 300.32 | 141.15 | 60.06 | 28.23 | 169.38 |
| 82 | 68697.05 | 560792.2 | 560.79 | 263.57 | 112.16 | 52.71 | 316.29 |
| 83 | 58383.3 | 476598.3 | 476.60 | 224.00 | 95.32 | 44.80 | 268.80 |
| 84 | 55203.6 | 450641.6 | 450.64 | 211.80 | 90.13 | 42.36 | 254.16 |
| 85 | 1450.6 | 11841.63 | 11.84 | 5.57 | 2.37 | 1.11 | 6.68 |
| 86 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 87 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 88 | 1226.8 | 10014.69 | 10.02 | 4.71 | 2.00 | 0.94 | 5.65 |
| 89 | 1209 | 9869.388 | 9.87 | 4.64 | 1.97 | 0.93 | 0.00 |
| 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average | 42862.5 | 349898 | 349.9 | 164.5 | 71 | 33.3 | 201.4 |

**Appendix 9. Mean AGB/tree, carbon/ treeand $CO_2$ per tree species**

| No. | Species name | AGB (ton/ total tree) | AGC (ton/total tree) | AGB ton/tree | AGC (ton)/tree | $CO_2$(ton)/tree |
|---|---|---|---|---|---|---|
| 1 | *Syzygium guineense* | 844.1 | 396.7 | 8.6 | 4.1 | 14.9 |
| 2 | *Schefflera abyssinica* | 829.0 | 389.6 | 16.5 | 7.7 | 28.4 |
| 3 | *Olea welwitschii* | 419.2 | 197.0 | 11.5 | 5.4 | 19.8 |
| 4 | *Pouteria adolfi-friederici* | 233.2 | 109.6 | 10.8 | 5.1 | 18.6 |
| 5 | *Prunus africana* | 219.59 | 103.2 | 12 | 5.6 | 20.7 |
| 6 | *Ilexmitis* | 184.9 | 86.9 | 3.2 | 1.5 | 5.5 |
| 7 | *Ekebergia capensis* | 147.7 | 69.4 | 16.4 | 7.7 | 28.3 |

| No. | Species name | AGB (ton/ total tree) | AGC (ton/t otal tree) | AGB ton/tre e | AGC (ton)/tr ee | $CO_2$(ton )/tree |
|---|---|---|---|---|---|---|
| 8 | *Sapium ellipticum* | 98.49 | 46.3 | 5.23 | 2.5 | 9.02 |
| 9 | *Croton macrostachys* | 78.5 | 36.9 | 4.4 | 2.0 | 7.5 |
| 10 | *Eleodedron buchanai* | 40.9 | 19.2 | 7.2 | 3.4 | 12.5 |
| 11 | *Allophylus abyssinicus* | 39.2 | 18.4 | 2.2 | 1.1 | 3.9 |
| 12 | *Dracena afromontana* | 37.3 | 17.5 | 0.3 | 0.1 | 0.4 |
| 13 | *Phonix reclinata* | 35.9 | 16.9 | 3.6 | 1.7 | 6.2 |
| 14 | *Macarnga capensis* | 32.8 | 15.4 | 3.4 | 1.6 | 5.9 |
| 15 | *Apodytes dimidata* | 32.7 | 15.3 | 3.5 | 1.6 | 6.0 |
| 16 | *Ficus sur* | 23.5 | 11.1 | 3.9 | 1.8 | 6.7 |
| 17 | *Caythea maniana* | 21.8 | 10.2 | 0.3 | 0.2 | 0.6 |
| 18 | *Maytenus undata* | 20.96 | 9.85 | 2.3 | 1.08 | 0.5 |
| 19 | *Millitia ferrugnea* | 17.8 | 8.3 | 4.0 | 1.9 | 6.8 |
| 20 | *Rytigynia neglecta* | 14.2 | 6.7 | 0.6 | 0.3 | 1.1 |
| 21 | *Arundinaria alpina* | 13.3 | 6.3 | 0.1 | 0.0 | 0.1 |
| 22 | *Schefflera volkensii* | 10.9 | 5.1 | 0.5 | 2.0 | 7.2 |
| 23 | *Dracena fragnus* | 10.2 | 4.8 | 0.15 | 0.07 | 0.3 |
| 24 | *Alangium chinense* | 9.5 | 4.5 | 5.9 | 2.8 | 10.1 |
| 25 | *Masea lanceolata* | 9.4 | 4.4 | 3.7 | 1.7 | 6.4 |
| 26 | *Hippocreta pallens* | 9.2 | 4.3 | 1.0 | 0.5 | 1.7 |
| 27 | *Cassipourea malosana* | 9.1 | 4.3 | 0.5 | 0.2 | 0.8 |
| 28 | *Dracena studneri* | 7.6 | 3.57 | 0.55 | 0.26 | 0.9 |
| 29 | *Hippocratea goetze*i | 7.2 | 3.4 | 0.2 | 0.1 | 0.4 |
| 30 | *Rothmannia urcelliformis* | 5.28 | 2.48 | 0.27 | 0.13 | 0.5 |
| 31 | *Embelia schimperi* | 4.6 | 2.16 | 1.53 | 0.72 | 2.64 |
| 32 | *Celtis africana* | 4.1 | 1.9 | 4.1 | 1.9 | 7.0 |
| 33 | *Bersama abyssinica* | 3.9 | 1.8 | 0.4 | 0.2 | 0.7 |
| 34 | *Dombeya torrida* | 3.6 | 1.7 | 1.5 | 0.7 | 2.6 |
| 35 | *Vepris dainelli* | 3.2 | 1.5 | 0.9 | 0.4 | 1.5 |
| 36 | *Maytenus gracilpes* | 3.0 | 1.4 | 0.1 | 0.1 | 0.0 |
| 37 | *Oxycanthus specious* | 3.0 | 1.4 | 0.1 | 0.0 | 0.1 |
| 38 | *Hagenia abysinica* | 2.63 | 1.24 | 0.3 | 0.141 | 0.5 |
| 39 | *Urea hypselodendron* | 1.9 | 0.9 | 0.9 | 0.4 | 1.6 |
| 40 | *Landolphia buchananii* | 1.7 | 0.8 | 0.6 | 0.3 | 1.0 |
| 41 | *Octea kensyis* | 1.2 | 0.6 | 1.2 | 0.56 | 2.1 |
| 42 | *Erythrococca trichogyne* | 1.06 | 0.50 | 0.49 | 0.23 | 0.85 |
| 43 | *Gallinaria saxifraga* | 0.9 | 0.4 | 0.1 | 0.0 | 0.1 |
| 44 | *Solancio manni* | 0.7 | 0.3 | 0.1 | 0.0 | 0.1 |
| 45 | *Ehretia cymosa* | 0.66 | 0.31 | 0.29 | 0.14 | 0.50 |
| 46 | *Clematis longicauda* | 0.65 | 0.3 | 0.65 | 0.3055 | 0.1 |
| 47 | *Olea capensis* | 0.6 | 0.3 | 0.2 | 0.1 | 0.3 |
| 48 | *Lepidotrichilia volkensii* | 0.5 | 0.2 | 0.1 | 0.0 | 0.1 |

| No. | Species name | AGB (ton/ total tree) | AGC (ton/t otal tree) | AGB ton/tre e | AGC (ton)/tr ee | $CO_2$(ton )/tree |
|---|---|---|---|---|---|---|
| 49 | *Pittosporum virvdiflorum* | 0.46 | 0.2162 | 0.031 | 0.015 | 0.1 |
| 50 | *Coffee arabica* | 0.36 | 0.17 | 0.36 | 0.17 | 0.1 |
| 51 | *Polysicas fulva* | 0.4 | 0.2 | 0.3 | 0.1 | 0.5 |
| 52 | *Deinbolia killimndascrica* | 0.3 | 0.2 | 0.0 | 0.0 | 0.1 |
| 53 | *Psychotria orophila* | 0.3 | 0.2 | 0.1 | 0. 0 | 0.1 |
| 54 | *Schefflera myriantha* | 0.3 | 0.1 | 0.1 | 0.05 | 0.2 |
| 55 | *Brucea antidysenterica* | 0.092 | 0.043 | 0.092 | 0.043 | 0.2 |
| 56 | *Solancio gigas* | 0.1 | 0.0 | 0.1 | 0.04 | 0.1 |
| 57 | *Nuxia congestsa* | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 |
| 58 | *Clausena anisata* | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| 59 | *Jasminium abyssinicum* | 0.05 | 0.0212 | 0.05 | 0.021 | 0.1 |
| 60 | *Vernonia amygdalina* | 0.0 | 0.0 | 0.0 | 0.01 | 0.0 |
| 61 | *Brillanthesia madacarenss* | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| 62 | *Hypericum revolutum* | 0.006 | 0.003 | 0.001 | 0.000 | 0.002 |
| 63 | *Rhamnus perinodes* | 0.008 | 0.004 | 0.001 | 0.000 | 0.001 |

**Appendix 10. The soil oranic carbon in study plots**

| Plot no. | Volume | Soil depth(cm) | bulk density | %Carbon | SOC |
|---|---|---|---|---|---|
| 1 | 98.1 | 30 | 0.9 | 8.03 | 211.894 |
| 2 | 98.1 | 30 | 0.6 | 9.59 | 159.41 |
| 3 | 98.1 | 30 | 0.7 | 6.08 | 125.07 |
| 4 | 98.1 | 30 | 0.5 | 9.75 | 134.61 |
| 5 | 98.1 | 30 | 0.9 | 8.97 | 248.51 |
| 6 | 98.1 | 30 | 0.9 | 4.56 | 123.82 |
| 7 | 98.1 | 30 | 0.9 | 5.7 | 156.52 |
| 8 | 98.1 | 30 | 0.6 | 6.44 | 125.19 |
| 9 | 98.1 | 30 | 0.9 | 5.69 | 151.54 |
| 10 | 98.1 | 30 | 0.6 | 6.47 | 111.31 |
| 11 | 98.1 | 30 | 0.8 | 5.67 | 142.16 |
| 12 | 98.1 | 30 | 0.9 | 5.42 | 144.35 |
| 13 | 98.1 | 30 | 0.9 | 5.85 | 157.77 |
| 14 | 98.1 | 30 | 0.9 | 4.95 | 132.17 |
| 15 | 98.1 | 30 | 0.9 | 3.82 | 107.58 |
| 16 | 98.1 | 30 | 0.9 | 4.21 | 111.22 |
| 17 | 98.1 | 30 | 0.7 | 3.71 | 72.69 |
| 18 | 98.1 | 30 | 0.9 | 4.21 | 111.87 |
| 19 | 98.1 | 30 | 1.1 | 4.17 | 131.48 |
| 20 | 98.1 | 30 | 1.1 | 5.73 | 184.18 |
| 21 | 98.1 | 30 | 0.7 | 6.08 | 124.89 |
| 22 | 98.1 | 30 | 0.8 | 8.73 | 204.28 |

| Plot no. | Volume | Soil depth(cm) | bulk density | %Carbon | SOC |
|---|---|---|---|---|---|
| 24 | 98.1 | 30 | 0.7 | 8.11 | 177.26 |
| 25 | 98.1 | 30 | 0.6 | 6.94 | 125.34 |
| 26 | 98.1 | 30 | 0.8 | 5.12 | 122.88 |
| 27 | 98.1 | 30 | 0.8 | 6.04 | 152.91 |
| 28 | 98.1 | 30 | 0.7 | 4.445 | 90.49 |
| 29 | 98.1 | 30 | 0.8 | 4.5 | 102.35 |
| 30 | 98.1 | 30 | 0.7 | 6.28 | 134.96 |
| 31 | 98.1 | 30 | 0.6 | 5.01 | 92.33 |
| 32 | 98.1 | 30 | 0.9 | 6.7 | 174.34 |
| 33 | 98.1 | 30 | 0.8 | 6.16 | 147.09 |
| 34 | 98.1 | 30 | 0.9 | 5.42 | 149.33 |
| 35 | 98.1 | 30 | 1.4 | 7.14 | 302.94 |
| 36 | 98.1 | 30 | 0.6 | 5.98 | 107.64 |
| 37 | 98.1 | 30 | 0.8 | 8.34 | 200.16 |
| 38 | 98.1 | 30 | 0.4 | 8.44 | 107.48 |
| 39 | 98.1 | 30 | 0.4 | 7.02 | 93.91 |
| 40 | 98.1 | 30 | 0.7 | 5.53 | 112.81 |
| 41 | 98.1 | 30 | 0.5 | 6.65 | 104.43 |
| 42 | 98.1 | 30 | 0.8 | 6.08 | 145.92 |
| 43 | 98.1 | 30 | 0.5 | 5.14 | 77.57 |
| 44 | 98.1 | 30 | 0.5 | 2.88 | 44.17 |
| 45 | 98.1 | 30 | 0.9 | 4.52 | 117.97 |
| 46 | 98.1 | 30 | 0.7 | 5.1 | 103.82 |
| 47 | 98.1 | 30 | 0.6 | 7.64 | 137.52 |
| 48 | 98.1 | 30 | 0.8 | 12.04 | 288.96 |
| 49 | 98.1 | 30 | 0.8 | 8.71 | 209.04 |
| 50 | 98.1 | 30 | 0.6 | 6.24 | 112.32 |
| 51 | 98.1 | 30 | 0.4 | 6.94 | 81.16 |
| 52 | 98.1 | 30 | 0.5 | 9.01 | 147.29 |
| 53 | 98.1 | 30 | 0.5 | 8.32 | 133.20 |
| 54 | 98.1 | 30 | 0.6 | 6.67 | 115.16 |
| 55 | 98.1 | 30 | 0.8 | 6.62 | 158.68 |
| 56 | 98.1 | 30 | 0.6 | 6.52 | 122.95 |
| 57 | 98.1 | 30 | 0.9 | 5.1 | 140.35 |
| 58 | 98.1 | 30 | 1.0 | 6.33 | 180.99 |
| 59 | 98.1 | 30 | 0.5 | 7.59 | 113.85 |
| 60 | 98.1 | 30 | 0.5 | 8.59 | 140.68 |
| 61 | 98.1 | 30 | 0.5 | 6.19 | 101.19 |
| 62 | 98.1 | 30 | 0.5 | 8.15 | 128.24 |
| 63 | 98.1 | 30 | 0.8 | 7.25 | 173.78 |
| 64 | 98.1 | 30 | 0.8 | 5.71 | 137.04 |
| 65 | 98.1 | 30 | 0.7 | 6.2 | 127.54 |

| Plot no. | Volume | Soil depth(cm) | bulk density | %Carbon | SOC |
|---|---|---|---|---|---|
| 66 | 98.1 | 30 | 0.9 | 6.95 | 189.14 |
| 67 | 98.1 | 30 | 0.6 | 7.96 | 146.94 |
| 68 | 98.1 | 30 | 0.8 | 5.77 | 136.36 |
| 69 | 98.1 | 30 | 0.6 | 4.11 | 74.55 |
| 70 | 98.1 | 30 | 0.7 | 5.44 | 112.16 |
| 71 | 98.1 | 30 | 0.6 | 9.63 | 168.62 |
| 72 | 98.1 | 30 | 0.7 | 5.67 | 112.82 |
| 73 | 98.1 | 30 | 0.6 | 7.46 | 139.99 |
| 74 | 98.1 | 30 | 0.7 | 6.07 | 123.01 |
| 75 | 98.1 | 30 | 0.6 | 5.55 | 101.77 |
| 76 | 98.1 | 30 | 1.4 | 6.91 | 290.22 |
| 77 | 98.1 | 30 | 0.6 | 5.52 | 93.45 |
| 78 | 98.1 | 30 | 0.8 | 5.49 | 137.81 |
| 79 | 98.1 | 30 | 0.9 | 5.38 | 140.32 |
| 80 | 98.1 | 30 | 0.5 | 17.08 | 278.16 |
| 81 | 98.1 | 30 | 0.6 | 4 | 69.67 |
| 82 | 98.1 | 30 | 0.6 | 5.46 | 95.10 |
| 83 | 98.1 | 30 | 0.5 | 6.29 | 97.62 |
| 84 | 98.1 | 30 | 0.4 | 16.34 | 176.07 |
| 85 | 98.1 | 30 | 0.4 | 7.82 | 100.54 |
| 86 | 98.1 | 30 | 0.5 | 6.08 | 83.76 |
| 87 | 98.1 | 30 | 0.4 | 5.14 | 55.07 |
| 88 | 98.1 | 30 | 0.8 | 6 | 144.00 |
| 89 | 98.1 | 30 | 0.8 | 6 | 144.00 |
| 90 | 98.1 | 30 | 0.8 | 6 | 144.00 |
| Average | | | | | **137.6** |

**Appendix 11. Total carbon stock of Gesha-Sayilem forest**

| Plot No. | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | $CO_2$(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC | BGC | SOC | LC | HC | ShC | Total carbon stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 312083.18 | 312.08 | 146.68 | 538.31 | 62.42 | 29.34 | 176.01 | 29.34 | 139.62 | 0.63 | 0.87 | 0.63 | 347.1 |
| 2 | 891532.99 | 891.53 | 419.02 | 1537.81 | 178.31 | 83.8 | 502.82 | 83.8 | 159.41 | 1.06 | 0.99 | 1.06 | 749.15 |
| 3 | 351589.8 | 351.59 | 165.25 | 606.46 | 70.32 | 33.05 | 198.3 | 33.05 | 125.07 | 1.3 | 1.7 | 1.3 | 360.73 |
| 4 | 554878.2 | 554.88 | 260.79 | 957.11 | 110.98 | 52.16 | 312.95 | 52.16 | 134.61 | 1 | 0.44 | 1 | 502.16 |
| 5 | 343602.45 | 343.6 | 161.49 | 592.68 | 68.72 | 32.3 | 193.79 | 32.3 | 248.51 | 1.12 | 1.39 | 1.12 | 478.22 |
| 6 | 298701.17 | 298.7 | 140.39 | 515.23 | 59.74 | 28.08 | 168.47 | 28.08 | 123.82 | 1.74 | 0.13 | 1.74 | 323.96 |
| 7 | 327009.71 | 327.01 | 153.69 | 564.06 | 65.4 | 30.74 | 184.43 | 30.74 | 156.52 | 1.21 | 1.25 | 1.21 | 375.36 |
| 8 | 353243.35 | 353.24 | 166.02 | 609.31 | 70.65 | 33.2 | 199.23 | 33.2 | 125.19 | 0.47 | 0 | 0.47 | 358.55 |
| 9 | 143243.43 | 143.24 | 67.32 | 247.08 | 28.65 | 13.46 | 80.79 | 13.46 | 151.54 | 0.16 | 0 | 0.16 | 246.11 |
| 10 | 150781.39 | 150.78 | 70.87 | 260.08 | 30.16 | 14.17 | 85.04 | 14.17 | 111.31 | 0.28 | 1.33 | 0.28 | 212.41 |
| 11 | 199340.33 | 199.34 | 93.69 | 343.84 | 39.87 | 18.74 | 112.43 | 18.74 | 108.14 | 0.11 | 0.47 | 0.11 | 240 |
| 12 | 460696.16 | 460.7 | 216.53 | 794.65 | 92.14 | 43.31 | 259.83 | 43.31 | 144.35 | 0.1 | 0.82 | 0.1 | 448.5 |
| 13 | 204488.08 | 204.49 | 96.11 | 352.72 | 40.9 | 19.22 | 115.33 | 19.22 | 157.77 | 0.81 | 0 | 0.81 | 293.95 |
| 14 | 1098586.2 | 1098.59 | 516.34 | 1894.95 | 219.72 | 103.27 | 619.6 | 103.27 | 113.48 | 0.36 | 0 | 0.36 | 837.06 |
| 15 | 125917.7 | 125.92 | 59.18 | 217.2 | 25.18 | 11.84 | 71.02 | 11.84 | 107.5 | 0.55 | 1.11 | 0.55 | 192.65 |
| 16 | 263099.35 | 263.1 | 123.66 | 453.82 | 52.62 | 24.73 | 148.39 | 24.73 | 111.22 | 0.45 | 0 | 0.45 | 285.24 |
| 17 | 262407.27 | 262.41 | 123.33 | 452.63 | 52.48 | 24.67 | 148 | 24.67 | 72.69 | 0.64 | 0.75 | 0.64 | 247.39 |
| 18 | 974666.2 | 974.67 | 458.09 | 1681.2 | 194.93 | 91.62 | 549.71 | 91.62 | 111.87 | 0.27 | 0.44 | 0.27 | 754.18 |

| Plot No. | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | $CO_2$(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC | BGC | SOC | LC | HC | ShC | Total carbon stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 688215.27 | 688.22 | 323.46 | 1187.1 | 137.64 | 64.69 | 388.15 | 64.69 | 131.48 | 0.3 | 0.18 | 0.3 | 585.11 |
| 20 | 184766.2 | 184.77 | 86.84 | 318.7 | 36.95 | 17.37 | 104.21 | 17.37 | 184.18 | 0.35 | 0.76 | 0.35 | 307.21 |
| 21 | 741070.69 | 741.07 | 348.3 | 1278.27 | 148.21 | 69.66 | 417.96 | 69.66 | 124.89 | 0.14 | 0.25 | 0.14 | 613.03 |
| 22 | 76450.61 | 76.45 | 35.93 | 131.87 | 15.29 | 7.19 | 43.12 | 7.19 | 209.52 | 0.25 | 0.52 | 0.25 | 260.84 |
| 23 | 1371.84 | 1.37 | 0.64 | 2.37 | 0.27 | 0.13 | 0.77 | 0.13 | 131.4 | 0.2 | 0.4 | 0.26 | 133.32 |
| 24 | 244742.86 | 244.74 | 115.03 | 422.16 | 48.95 | 23.01 | 138.03 | 23.01 | 177.26 | 0.23 | 0.52 | 0.23 | 339.28 |
| 25 | 138536.33 | 138.54 | 65.11 | 238.96 | 27.71 | 13.02 | 78.13 | 13.02 | 125.34 | 0.45 | 0.79 | 0.45 | 218.18 |
| 26 | 132834.69 | 132.83 | 62.43 | 229.13 | 26.57 | 12.49 | 74.92 | 12.49 | 116.61 | 1.73 | 4.2 | 1.73 | 211.67 |
| 27 | 203704.49 | 203.7 | 95.74 | 351.37 | 40.74 | 19.15 | 114.89 | 19.15 | 152.91 | 0.9 | 0 | 0.9 | 288.74 |
| 28 | 292672.73 | 292.67 | 137.56 | 504.83 | 58.53 | 27.51 | 165.07 | 27.51 | 90.49 | 0.62 | 1.97 | 0.62 | 286.28 |
| 29 | 249288.33 | 249.29 | 117.17 | 430 | 49.86 | 23.43 | 140.6 | 23.43 | 102.35 | 0.68 | 2.1 | 0.68 | 269.84 |
| 30 | 97993.96 | 97.99 | 46.06 | 169.03 | 19.6 | 9.21 | 55.27 | 9.21 | 134.96 | 0.93 | 0 | 0.93 | 201.3 |
| 31 | 358093.88 | 358.09 | 168.3 | 617.68 | 71.62 | 33.66 | 201.96 | 33.66 | 122.3 | 0.14 | 1.8 | 0.14 | 360.1 |
| 32 | 783779.59 | 783.78 | 368.38 | 1351.94 | 156.76 | 73.68 | 442.05 | 73.68 | 174.3 | 1.33 | 1.33 | 0.53 | 692.72 |
| 33 | 1314849.1 | 1314.85 | 617.98 | 2267.98 | 262.97 | 123.6 | 741.57 | 123.6 | 147.09 | 1.72 | 0 | 1.72 | 1015.71 |
| 34 | 597532.08 | 597.53 | 280.84 | 1030.68 | 119.51 | 56.17 | 337.01 | 56.17 | 149.33 | 1.21 | 0 | 1.21 | 544.92 |
| 35 | 555137.88 | 555.14 | 260.91 | 957.56 | 111.03 | 52.18 | 313.1 | 52.18 | 229.5 | 0.93 | 0 | 0.93 | 596.64 |
| 36 | 736791.84 | 736.79 | 346.29 | 1270.89 | 147.36 | 69.26 | 415.55 | 69.26 | 126.86 | 2.48 | 4.39 | 2.48 | 621.03 |
| 37 | 85044.26 | 85.04 | 39.97 | 146.69 | 17.01 | 7.99 | 47.96 | 7.9 | 179.22 | 0.46 | 0 | 0.46 | 236.1 |

| Plot No. | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | $CO_2$(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC | BGC | SOC | LC | HC | ShC | Total carbon stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 9 | | | | | |
| 38 | 177329.8 | 177.33 | 83.35 | 305.88 | 35.47 | 16.67 | 100.01 | 16.67 | 107.48 | 1.25 | 0 | 1.25 | 226.67 |
| 39 | 471803.27 | 471.8 | 221.75 | 813.81 | 94.36 | 44.35 | 266.1 | 44.35 | 93.91 | 0.85 | 0 | 0.85 | 406.05 |
| 40 | 1205.71 | 1.21 | 0.57 | 2.08 | 0.24 | 0.11 | 0.68 | 0.11 | 82.1 | 0.64 | 0 | 0.64 | 84.18 |
| 41 | 935.92 | 0.94 | 0.44 | 1.61 | 0.19 | 0.09 | 0.53 | 0.09 | 104.43 | 0.38 | 0 | 0.38 | 105.81 |
| 42 | 2817.96 | 2.82 | 1.32 | 4.86 | 0.56 | 0.26 | 1.59 | 0.26 | 78.54 | 0.16 | 0 | 0.16 | 80.71 |
| 43 | 39007.33 | 39.01 | 18.33 | 67.28 | 7.8 | 3.67 | 22 | 3.67 | 77.57 | 0.34 | 0 | 0.34 | 103.93 |
| 44 | 36371.02 | 36.37 | 17.09 | 62.74 | 7.27 | 3.42 | 20.51 | 3.42 | 44.17 | 0.45 | 0 | 0.45 | 69 |
| 45 | 217213.39 | 217.21 | 102.09 | 374.67 | 43.44 | 20.42 | 122.51 | 20.42 | 58.67 | 0.96 | 0 | 0.96 | 203.51 |
| 46 | 112789.39 | 112.79 | 53.01 | 194.55 | 22.56 | 10.6 | 63.61 | 10.6 | 103.82 | 0.64 | 3.3 | 0.64 | 182.61 |
| 47 | 226840.82 | 226.84 | 106.62 | 391.28 | 45.37 | 21.32 | 127.94 | 21.32 | 70.86 | 0.67 | 0 | 0.67 | 221.47 |
| 48 | 156096.33 | 156.1 | 73.37 | 269.25 | 31.22 | 14.67 | 88.04 | 14.67 | 100.62 | 2.05 | 0 | 2.05 | 207.42 |
| 49 | 259112.41 | 259.11 | 121.78 | 446.94 | 51.82 | 24.36 | 146.14 | 24.36 | 94.65 | 1.18 | 1.78 | 1.18 | 269.29 |
| 50 | 451706.45 | 451.71 | 212.3 | 779.15 | 90.34 | 42.46 | 254.76 | 42.46 | 64.76 | 1.33 | 0 | 1.33 | 364.65 |
| 51 | 542058.78 | 542.06 | 254.77 | 935 | 108.41 | 50.95 | 305.72 | 50.95 | 81.16 | 1.28 | 0 | 1.28 | 440.4 |
| 52 | 589832.65 | 589.83 | 277.22 | 1017.4 | 117.97 | 55.44 | 332.67 | 55.44 | 147.29 | 1.55 | 0 | 1.55 | 538.5 |
| 53 | 284156.49 | 284.16 | 133.55 | 490.14 | 56.83 | 26.71 | 160.26 | 26.71 | 133.2 | 0.37 | 0 | 0.37 | 320.91 |
| 54 | 60993.31 | 60.99 | 28.67 | 105.21 | 12.2 | 5.73 | 34.4 | 5.73 | 115.16 | 0.49 | 0 | 0.49 | 156.27 |
| 55 | 69265.06 | 69.27 | 32.55 | 119.48 | 13.85 | 6.51 | 39.07 | 6.51 | 158.68 | 0.61 | 1.76 | 0.61 | 207.22 |

| Plot No. | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | $CO_2$(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC | BGC | SOC | LC | HC | ShC | Total carbon stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | 527960.57 | 527.96 | 248.14 | 910.68 | 105.59 | 49.63 | 297.77 | 49.63 | 122.95 | 0.53 | 1.62 | 0.53 | 473.03 |
| 57 | 690022.86 | 690.02 | 324.31 | 1190.22 | 138 | 64.86 | 389.17 | 64.86 | 140.35 | 0.59 | 0 | 0.59 | 595.57 |
| 58 | 88697.96 | 88.7 | 41.69 | 153 | 17.74 | 8.34 | 50.03 | 8.34 | 180.99 | 0.47 | 0 | 0.47 | 240.29 |
| 59 | 230580.41 | 230.58 | 108.37 | 397.73 | 46.12 | 21.67 | 130.05 | 21.67 | 113.85 | 0.48 | 0 | 0.48 | 266.52 |
| 60 | 266367.35 | 266.37 | 125.19 | 459.46 | 53.27 | 25.04 | 150.23 | 25.04 | 140.68 | 1.07 | 1.32 | 1.07 | 319.4 |
| 61 | 239043.27 | 239.04 | 112.35 | 412.33 | 47.81 | 22.47 | 134.82 | 22.47 | 101.19 | 0.37 | 0.15 | 0.37 | 259.36 |
| 62 | 1251559.2 | 1251.56 | 588.23 | 2158.81 | 250.31 | 117.65 | 705.88 | 117.65 | 128.24 | 0.49 | 0 | 0.49 | 952.74 |
| 63 | 2266318 | 2266.32 | 1065.17 | 3909.17 | 453.26 | 213.03 | 1278.2 | 213.03 | 173.78 | 0.34 | 0 | 0.34 | 1665.69 |
| 64 | 248635.27 | 248.64 | 116.86 | 428.87 | 49.73 | 23.37 | 140.23 | 23.37 | 137.04 | 0.31 | 0 | 0.31 | 301.27 |
| 65 | 122046.94 | 122.05 | 57.36 | 210.52 | 24.41 | 11.47 | 68.83 | 11.47 | 127.54 | 0.31 | 0 | 0.31 | 208.46 |
| 66 | 738516.81 | 738.52 | 347.1 | 1273.87 | 147.7 | 69.42 | 416.52 | 69.42 | 189.14 | 0.63 | 0 | 0.63 | 676.34 |
| 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 146.94 | 0.77 | 0 | 0.77 | 148.47 |
| 68 | 368846.72 | 368.85 | 173.36 | 636.22 | 73.77 | 34.67 | 208.03 | 34.67 | 136.36 | 0.26 | 0 | 0.26 | 379.58 |
| 69 | 823839.43 | 823.84 | 387.2 | 1421.04 | 164.77 | 77.44 | 464.65 | 77.44 | 74.55 | 0.34 | 0 | 0.34 | 617.31 |
| 70 | 350839.59 | 350.84 | 164.89 | 605.16 | 70.17 | 32.98 | 197.87 | 32.98 | 112.16 | 1.06 | 1.79 | 1.06 | 346.93 |
| 71 | 725923.84 | 725.92 | 341.18 | 1252.15 | 145.18 | 68.24 | 409.42 | 68.24 | 168.62 | 1.44 | 0 | 1.44 | 649.16 |
| 72 | 868817.96 | 868.82 | 408.34 | 1498.62 | 173.76 | 81.67 | 490.01 | 81.67 | 112.82 | 1.15 | 0 | 1.15 | 686.8 |
| 73 | 222113.47 | 222.11 | 104.39 | 383.12 | 44.42 | 20.88 | 125.27 | 20.88 | 139.99 | 0.67 | 0 | 0.67 | 287.48 |
| 74 | 156563.76 | 156.56 | 73.58 | 270.06 | 31.31 | 14.72 | 88.3 | 14.72 | 123.01 | 0.74 | 0 | 0.74 | 227.52 |

| Plot No. | AGB(Kg/ ha) | AGB (ton/ha) | AGC(ton/ ha) | $CO_2$(ton/ ha) | BGB(ton/ ha) | BGC(ton/ ha) | Total AGC | BGC | SOC | LC | HC | ShC | Total carbon stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 75 | 114673.31 | 114.67 | 53.9 | 197.8 | 22.93 | 10.78 | 64.68 | 10.78 | 101.77 | 0.92 | 0 | 0.92 | 179.07 |
| 76 | 251111.02 | 251.11 | 118.02 | 433.14 | 50.22 | 23.6 | 141.63 | 23.6 | 207.3 | 0.96 | 0 | 0.96 | 374.45 |
| 77 | 16623.67 | 16.62 | 7.81 | 28.67 | 3.32 | 1.56 | 9.38 | 1.56 | 93.45 | 0.62 | 0 | 0.62 | 105.62 |
| 78 | 155040.82 | 155.04 | 72.87 | 267.43 | 31.01 | 14.57 | 87.44 | 14.57 | 137.81 | 0.57 | 0 | 0.57 | 240.97 |
| 79 | 2386.12 | 2.39 | 1.12 | 4.12 | 0.48 | 0.22 | 1.35 | 0.22 | 140.32 | 0.62 | 0 | 0.62 | 143.12 |
| 80 | 300315.43 | 300.32 | 141.15 | 518.01 | 60.06 | 28.23 | 169.38 | 28.23 | 278.16 | 0.21 | 0 | 0.21 | 476.18 |
| 81 | 445934.45 | 445.93 | 209.59 | 769.19 | 89.19 | 41.92 | 251.51 | 41.92 | 107.99 | 0.76 | 0 | 0.76 | 402.94 |
| 82 | 560792.24 | 560.79 | 263.57 | 967.31 | 112.16 | 52.71 | 316.29 | 52.71 | 95.1 | 0.3 | 0 | 0.3 | 464.71 |
| 83 | 476598.37 | 476.6 | 224 | 822.08 | 95.32 | 44.8 | 268.8 | 44.8 | 59.88 | 0.61 | 0 | 0.61 | 374.71 |
| 84 | 450641.63 | 450.64 | 211.8 | 777.31 | 90.13 | 42.36 | 254.16 | 42.36 | 176.07 | 0.12 | 0 | 0.12 | 472.84 |
| 85 | 11841.63 | 11.84 | 5.57 | 20.43 | 2.37 | 1.11 | 6.68 | 1.11 | 100.54 | 0.2 | 0 | 0.2 | 108.74 |
| 86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 83.76 | 0.09 | 0 | 0.09 | 83.93 |
| 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 103.53 | 0.06 | 0 | 0.06 | 103.65 |
| 88 | 10014.69 | 10.01 | 4.71 | 17.27 | 2 | 0.94 | 5.65 | 0.94 | 108 | 0.18 | 0 | 0.18 | 114.94 |
| 89 | 9869.39 | 9.87 | 4.64 | 17.02 | 1.97 | 0.93 | 5.57 | 0.93 | 107 | 0.61 | 0 | 0.61 | 114.72 |
| 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 120 | 0.61 | 0 | 0.61 | 121.23 |
| | | | | | | | | | | | | Mean | 362.4 |

**Appendix 12. List of selected models for studied species with their parameter estimates and model performance**

| *Species* | *Model for total AGB* | **Parameter Estimates** | | | | **Model Performance metrics** | |
|---|---|---|---|---|---|---|---|
| | | $\widehat{\beta}_0$**(std.error)** | $\widehat{\beta}_1$**(std.error)** | $\widehat{\beta}_2$**(std.error)** | $\widehat{\beta}_3$**(std.error)** | **AIC** | $Adj.R^2$ |
| *Apodytes dimiidata* | $AGB = \beta_0 + log\beta_1 DBH + \varepsilon$ | 0.31(0.55) | 0.74 (0.1506) *** | - | - | 48 | 0.81 |
| | $\log(AGB) = \beta_1 \log(Height) + \varepsilon$ | 2.44(0.59) *** | 1.67(0.23)*** | - | - | 70 | 0.62 |
| | $\mathrm{Log}(AGB) = \beta_0 + \beta_1 \log(WD) + \varepsilon$ | 8.34 (0.36)*** | 2.88(0.5490)*** | - | - | 81 | 0.46 |
| | $\log(AGB) = \beta_0 + \beta_1 logDBH + \beta_2 log(height) + \varepsilon$ | 0.32 (0.51) | 1.35(0.212)* | - | - | 44 | 0.837 |
| | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(WD) + \varepsilon$ | 1.91 (0.76)* | 1.46 (0.1691) *** | 1.00 (0.36)* | - | 42 | 0.847 |
| | $\log(AGB) = \beta\_1 \ \log(Height) + \beta 2 \log(WD) + \varepsilon$ | 4.47(0.67) | 1.28(0.2)*** | 1.74 (0.4*** | - | 56 | 0.75 |
| | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 log(Height) + \beta_3 \log(Height) + \varepsilon$ | 1.91(0.69)* | 1.0767 (0.2)*** | 0.55 (0.2)** | 0.0040 (0.33) | 37 | 0.87 |

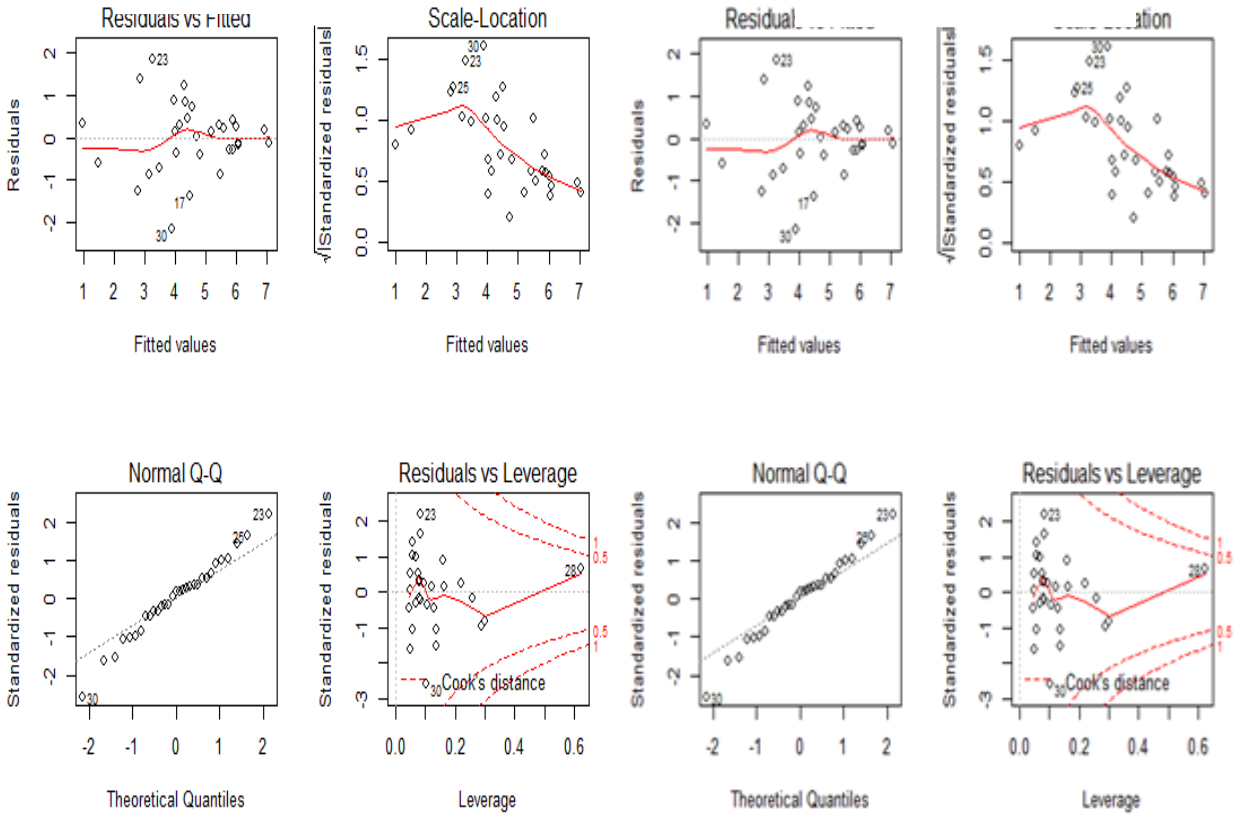
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Gallinaria saxifraga* | $\log(AGB) = \beta_1 \log(DBH) + \varepsilon$ | -3.26(0.89)** | 1.66 (0.269) | - | - | 0.48 | 0.56 |
| | $\log(AGB) = \beta_1 \log(\ height\ ) + \varepsilon$ | -0.109(0.45) | 1.67(0.33)*** | - | - | 52.6 | 0.49 |
| | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \log(height) + \varepsilon$ | -3.29(0.77) | 1.21 (0.23)*** | 1.09(0.225) | - | 34 | 0.49 |
| | $\text{Log}(AGB) = \beta_1 log\,\text{l}(DBH) + \beta_2 \log(CA) + \beta_3 \log(DBH) : \log(CA) + \varepsilon$ | | 2.56(0.076)*** | 2.15(0.682)** | -0.54(0.208)* | 47.376 | 0.90 |
| | Log(AGB) = $\beta_1$log(DBH)+$\beta_2$(WD) | -1316.17(336.23)*** | 60.25(7.854)*** | - | - | 440.9 | 80.66 |
| | Log(AGB)= $\beta_1$log(DBH)+$\beta_2$log(Height)+$\beta_3 log(CRA)$ | -3.32(0.72)*** | 1.2125(0.241)*** | 1.0663(0.30)** | 0.027 (0.13) | 36.2 | 0.72 |
| | Log(AGB) = $\beta_1$log(Height)+$\beta_2$(CRA) | -0.12(0.46) | 1.75(0.38)** | -0.059(0.18) | - | 54.6 | 0.47 |

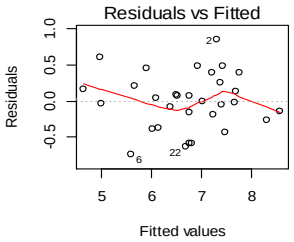
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Illex mitis* | $logAGB = \beta_0 + \beta_1 \log(DBH) + \varepsilon$ | --1.4655 (0,56) * | 2.2035 (0.15)*** | - | - | 46.7 | 0.86 |
| | $\log(AGB) = \beta_0 + \beta_1 \log(Height) + \varepsilon$ | -1.24 (0.93) | 2.20(0.35) *** | - | - | 72.6 | 0.68 |
| | $\log(AGB) = \beta_0 + \beta_1 \log(WD) + \varepsilon$ | 7.57 (0.60)*** | 1.6156 (0.7329)* | - | - | 104 | 0.114 |
| | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 \log(\text{Heigh}) + \varepsilon$ | -1.35(0.62) * | 2.35(0.38)*** | -0.25 (0.56)** | - | 48 | 0.86 |
| | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 \log(WD) + \varepsilon$ | -1.69 (0.62)* | 2.23 (0.17)*** | 0.32(-0.44) | - | 48 | 0.86 |
| | $\log(AGB) = \beta_1(Height) + \beta_2 \log(WD) + \varepsilon$ | -1.06 (1.26) | 2.85 (0.39) *** | 0.105(0.49) | - | 74 | 0.67 |
| | $\log(AGB) = \beta_1 \log(DBH) + \beta_2 \log(\text{Height}) + \beta_{3 \log(WD))} + \varepsilon$ | -1.57(0.84) | 2.37 (0.39)*** | -0.23 (0.57) | - 0.13(0.34) | 49.9 | 0.85 |
| *Sapium ellipticum* | $Log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$ | -0.1391(0.71)** | 1.8 (0.18) *** | - | - | 46 | 0.75 |
| | $\log(AGB) = \beta_1 \log(Height) + \varepsilon$ | 1.40 (0.65) * | 1.87(0.23) *** | - | - | 53 | 0.69 |
| | $\ln(AGB) = \beta_0 + \beta_1 \log(WD) + \varepsilon$ | 7.64 (0.55)*** | 1.10(0.64) | - | - | 88 | 0.062 |
| | $\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(\text{Height})) + \varepsilon$ | -0.2172(0.62) | 1.16(0.26)*** | 0.88(0.28) ** | - | 39.2 | 0.81 |

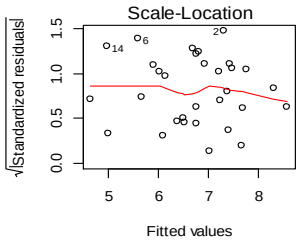
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Sapium ellipticum* | log(AGB) =$\beta_0 + \beta_1$log(DBH)+$\beta_2$log(WD)+ $\varepsilon$ | -0.4408 (0.94) | 1.8517(0.2057)*** | -0.1792(0.360) | - | 48 | 0.75 |
| | log(AGB)= $\beta_0 + \beta_1$log(Height)+$\beta_2$log(WD) | 2.03 (0.77)* | 0.2262(7.992 )*** | 0.5395 (0.3672) | - | 53 | 0.70 |
| | Log (AGB) =$\beta_0 + \beta_1 \log(DBH) + \beta_2 \log(Height) + \beta_{3\log(WD)}$ | -0.18 (0.83) | 1.16(0.29)*** | 0.88732(0.29)** | 0.022(0.32) | 41.2 | 0.80 |
| *Vernonia auriculifera* | Log$(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$ | 6(0.29)*** | 1.51(0.18)*** | - | - | 58.9 | 0.69 |
| | log$(AGB) = \beta_0 + \beta_1 \log(height) + \varepsilon$ | 6.2(0.58) | 1.6245(0.43) | - | - | 84.7 | 0.30 |
| | log$(AGB) = \beta_1 \log(CRA) + \varepsilon$ | 7.9 (0.22)*** | 0.41(0.15)* | - | - | 90.0 | 0.17 |
| | log$(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta 2 \log(Height) + \varepsilon$ | 6.05 (0.39028))*** | 1.55 (0.25)*** | -0.09006(0.404) | - | 60.9 | 0.68 |
| | log$(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_1 \log(CRA) + \varepsilon$ | 6.01784(0.307)*** | 1.48579(0.21309)*** | 0.02917(0.10) | - | 60.8 | 0.68 |
| | Log(AGB) = $\beta$1og(Height)+ $\beta$2 log(CRA)+ $\varepsilon$ | 6.4(0.65)*** | 1.36(0.55)* | 0.1386(0.18) | - | 86.0 | 0.29 |
| | Log(AGB)= $\beta_0$ +$\beta_{2\ \log(DBH)+}$ $\beta_3$ log(Height)+ $\beta$3 log(CRA) | 6.1342(0.44) | 1.5420(0.26) | 0.4570 (-0.372) | 0.0492 (0.12) | 62.7 | 0.67 |

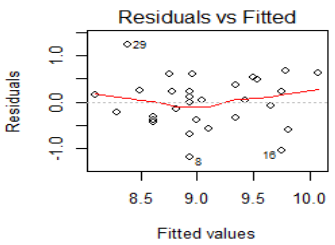
Modelling total AGB (Sign. code: * significant at 5%, ** significant at 1% and *** significant at 0.1%)

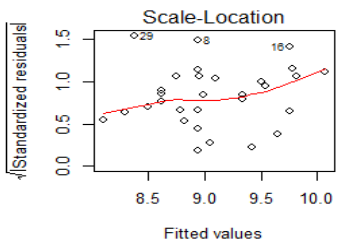
**Appendix 13. Graphical presenation of Model validation for the study species**

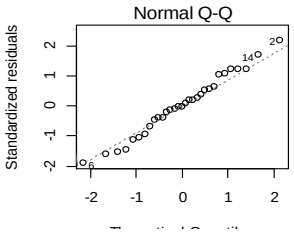


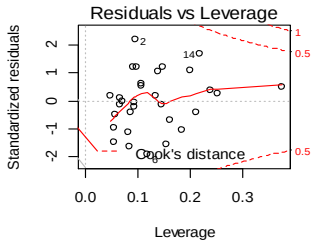

Residuals vs Fitted
Residuals
Fitted values

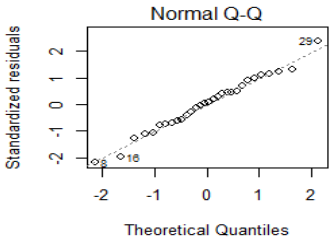

Scale-Location
√|Standardized residuals|
Fitted values

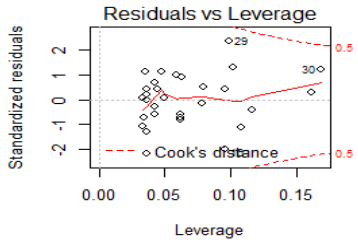

Residuals vs Fitted
Residuals
Fitted values

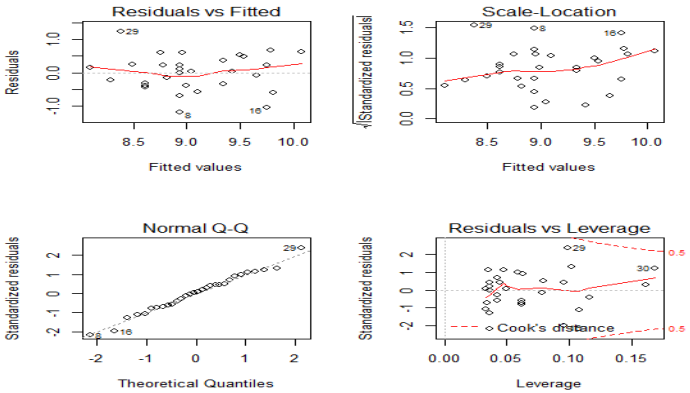

Scale-Location
√|Standardized residuals|
Fitted values


Normal Q-Q
Standardized residuals


Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage


Normal Q-Q
Standardized residuals
Theoretical Quantiles


Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage


Residuals vs Fitted
Residuals
Fitted values
29
8
16
Scale-Location
√|Standardized residuals|
Fitted values
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Residuals vs Leverage
Standardized residuals
Cook's distance
Leverage
30

**ppendix 14. Wood density of the trees and shrubs of Ethiopia**

| Plant species | Wood density | Source |
|---|---|---|
| *Allohylus abysinicus* | 0.58 | Getachew Desalegn *et al*.(2012) |
| *Phonix reclinata* | 0.5 | IPCC(2006) |
| *Dracaena afromontana* | 0.418 | |
| *Dracaena fragrans* | 0.418 | *Genus average (http://db.worldagroforestry.org* |
| *Dracaena steudneri* | 0.418 | *Genus average(http://db.worldagroforestry.org* |
| *Galiniera saxifraga* | 0.399 | Vreugdenhil *et al*.(2012) |
| *Pouteria adolfi-friederici* | 0.6 | Getachew Desalegn *et al*.,(2012) |
| *Syzygium guineense* | 0.712 | http://db.worldagroforestry.org// |
| *Schefflera abyssinica* | 0.491 | Vreugdenhil *et al*.(2012) |
| *Rytigynia neglecta* | 0.5 | IPCC(2006) |
| *Ilex mitis* | 0.466 | Vreugdenhil *et al*.,(2012) |
| *Solanecio gigas* | 0.5 | IPCC (2006) |
| *Psychotria orophila* | 0.5 | IPCC (2006) |
| *Vepris dainellii* | *0.7* | http://db.worldagroforestry.org// |
| *Macaranga capensis* | 0.416 | global data base |
| *Apodytes dimidiata* | 0.61 | http://db.worldagroforestry.org//wd/genus/A |
| *Cyathea manniana* | 0.5 | IPCC(2006) |
| *Maytenus gracilipes sub sp. gracilipes* | 0.713 | Average Genus, Africa |
| *Cassipourea malosana* | 0.673 | Genus average |
| *Landolphia buchananii* | 0.5 | IPCC(2006) |
| *Lepidotrichilia volkensii* | 0.58 | Average of tropical Africa |
| *Vangueria madagascariensis* | 0.67 | Average of tropical Africa |
| *Urera hypselodendron* | 0.324 | (http://db.worldagroforestry.org//wd/genus/ |
| *Solanecio mannii* | 0.5 | IPCC(2006) |
| *Ocotea kenyensis* | 0.56 | Getachew Desalegn *et al*.,(2012) |
| *Deinbollia kilimandscharica* | 0.5 | IPCC(2006) |
| *Croton macrostachyus* | 0.56 | Getachew Desalegn *et al*.,(2012) |
| *Brucea antidysenterica* . | 0.64 | Wood density of Trees of Uganda |
| *Bersama abyssinica* | 0.671 | http://db.worldagroforestry.org//wd/ |
| *Ekebergia capensis* | 0.58 | Getachew Desalegn *et al*.,(2012) |
| *Pavetta abyssinica* | 0.5 | IPCC(2006) |
| *Embelia schimperi* | 0.775 | Average of tropical Africa |
| *Oxyanthus speciosus* | *0.525* | http://db.worldagroforestry.org//wd/ |
| *Vernonia auriculifera* | 0.413 | (http://db.worldagroforestry.org//wd/genus/ |
| *Arundinaria alpina* | 0.63 | Getachew Desalegn *et al*.,(2012) |
| *Prunus africana* | 0.85 | Getachew Desalegn *et al*.,(2012) |

| **Plant species** | **Wood density** | **Source** |
|---|---|---|
| *Alangium chinense* | 0.408 | http://db.worldagroforestry.org//wd/ |
| *Vernonia amygdalina* | 0.413 | http://db.worldagroforestry.org//wd/ |
| *Brillantaisia grotanellii* | 0.5 | IPCC(2006) |
| *Millettia ferruginea* | 0.738 | Average Millettia, Africa |
| *Clausena anisata* | 0.482 | http://db.worldagroforestry.org//wd/species/ |
| *Tiliacora troupinii* | 0.5 | IPCC(2006) |
| *Albizia gummifera* | 0.58 | Getachew Desalegn *et al*.,(2012) |
| *Albizia schimperiana* | 0.53 | Getachew Desalegn *et al*.,(2013) |
| *Clematis longicauda* | 0.526 | Genus average |
| *Sericostachys scandens* | 0.5 | IPCC(2006) |
| *Celtis africana* | 0.76 | Getachew Desalegn *et al.*,(2012) |
| *Canthium oligocarpum* | 0.643 | Genus average |
| *Combretum paniculatum*. | 0.59 | Vreugdenhil *et al.*,(2012) |
| *Elaeodendron buchananii* | 0.5 | IPCC(2006) |
| *Olea capensis* subsp. *macrocarpa* | 0.99 | Getachew Desalegn *et al.*,(2012) |
| *Ehretia cymosa* | 0.56 | http://db.worldagroforestry.org//wd/ |
| *Euphorbia ampiphyla* | 0.471 | http://db.worldagroforestry.org//wd/ |
| *Pittosporum viridiflorum* | 0.633 | http://db.worldagroforestry.org//wd/species/ |
| *Rothmannia urcelliformis* | 0.642 | Africa (extratropical): global database |
| *Olea welwitschii* | 0.814 | http://db.worldagroforestry.org//wd/species/ |
| *Gouania longispicata* | 0.5 | IPCC(2006) |
| *Maesa lanceolata* | 0.676 | (http://db.worldagroforestry.org//wd/genus |
| *Schefflera volkensii* | 0.405 | http://db.worldagroforestry.org//wd/species/ |
| *Maytenus undata* | 0.713 | G.average(http://db.worldagroforestry.org//wd/ |
| *Oncoba spinosa* | 0.5 | IPCC(2006) |
| *Teclea nobilis* | 0.798 | http://db.worldagroforestry.org//wd/genus/T |
| *Hallea rubrostipulata* | 0.5 | IPCC(2006) |
| *Polyscias fulva* | 0.44 | Getachew Desalegn *et al.*,(2012) |
| *Clematis simensis* | 0.526 | Genus average |
| *Nuxia congesta* | 0.5 | IPCC(2006) |
| *Hagenia abyssinica* | 0.56 | Getachew Desalegn *et al.*,(2012) |
| *Ficus sur* | 0.441 | http://globalspecies.org/ntaxa/869708 |
| *Jasminum abyssinicum* | 0.58 | Average of tropical Africa |
| *Diospyros abyssinica* | *0.79* | Getachew Desalegn *et al.,* (2012) |
| *Dombeya torrida* | *0.451* | Getachew Desalegn *et al*,(2012) |
| *Buddleja polystachya* | 0.4 | Getachew Desalegn *et al.*,(2012) |
| *Erythrococca trichogyne* | 0.58 | Average of tropical Africa |
| *Hypericum revolutum* | 0.726 | Genus average |
| *Sapium ellipticum* | 0.576 | http://db.worldagroforestry.org//wd/species/ |
| *Coffea arabica* | 0.62 | http://db.worldagroforestry.org//wd/ |

## Appendix 15.Checklist of bee forage identified from field observation and pollen collection

| No | Plant species | Family | Habit | Flowering period | Rewards |
|---|---|---|---|---|---|
| 1 | *Acanthopale ethio-germanica* Ensermu | Acanthaceae | Herb | Sept-Nov | N&P |
| 2 | *Acanthus eminens* C.B.Clarke | Acanthaceae | Herb | Sept-Nov | N |
| 3 | A*chyranthes aspe*ra L. | Amaranthaceae | Herb | Aug-Dec | P |
| 4 | *Achyrospermum schimperi* (Hochst. ex Briq.) Perkins | Lamiaceae | Herb | Sept-Oct | P |
| 5 | *Acmella caulirhiza* Del. | Asteraceae | Herb | Sept-Nov | P |
| 6 | *Ageratum conyzoides* L. | Asteraceae | Herb | Sept-Dec | P |
| 7 | *Allophyllus abyssinicus* (Hochst.) Radlk. | Sapindaceae | Tree | Sept-Oct | P |
| 8 | *Andropogon abyssinicus*Fresen | Poaceae | Herb | Sept-Oct | P |
| 9 | *Apodytes dimidiata* E. Mey. ex Arn. | Icaccinaceae | Tree | Sept-Nov | N&P |
| 10 | *Aspilia mossambicensis* (Oliv.) Wild | Asteraceae | Herb | Sept-Nov | P |
| 11 | *Basella alba* L. | Basellaceae | Climber | Sept-Oct | P |
| 12 | *Bersama abyssinica* Fresen. | Melianthaceae | Tree | Sept-Nov | N&P |
| 13 | *Bidens prestinaria* (Sch. Bip.) Cufod. | Asteraceae | Herb | Sept-Nov | P |
| 14 | *Bothriocline schimperi* Olivo & Hiern ex Benth. | Asteraceae | Herb | Sept-Dec | P |
| 15 | *Brassica carinata*A. Br | Brassicaceae | Herb | Sept-Oct | N&P |
| 16 | *Brucea antidysenterica* J. F. Mill. | Simaroubaceae | Shrub | Sept-Oct | P&N |
| 17 | *Buddleja polystachya* Fresen. | Loganiaceae | Shrub | Sept-Oct | N&P |
| 18 | *Celtis africana* Burm. f. | Ulmaceae | Shrub | Sept-Nov | N&P |
| 19 | *Circium schimperi(Yatke)* C. Jeffrey ex cufod | Asteraceae | Herb | Sept-Oct | P |
| 20 | *Clausena anisata* (Wild.) Benth. | Rutaceae | Shrub | Sept-Dec | N&P |
| 21 | *Clematis simensis* Fresen. | Ranunculaceae | Climber | Sept-Dec | P |
| 22 | *Datura innoxia* Mill. | Solanaceae | Shrub | Sept- march | N&P |
| 23 | *Dombeya torrida* (J.F. Gmel.) P.Bamps | Sterculiaceae | Tree | Sept-Nov | N&P |
| 24 | *Ehretia cymosa* Thonn. | Boraginaceae | Shrub | Sept-Dec | N&P |
| 25 | *Eucalyptus globulus*Labill | Myrtaceae | Tree | March-April | N&P |
| 26 | *Ekebergia capensis* Sparrm. | Meliaceae | Tree | Jan-Feb | N&P |
| 27 | *Galiniera saxifraga* (Hochst.) Bridson | Rubiaceae | Shrub | Sept-Dec | N |
| 28 | *Galinsoga quadriradiata* Ruiz & Pavon | Asteraceae | Herb | Sept-Oct | P |
| 29 | *Glycine wightii* (Wight & Am.) Verdc. | Fabaceae | Climber | Sept-Dec | P |
| 30 | *Gouania longispicata* Engl. | Rhamnaceae | Climber | Sept-Dec | P |
| 31 | *Guizotia scabra (*Vis.) Chiov. | Asteraceae | Herb | Sept-Nov | N&P |
| 32 | *Helichrysum formosissimum*Sch. Bip. ex A. Rich | Asteraceae | Herb | Sept-Oct | P |
| 33 | *Hibiscus berberidifolius* A. Rich. | Malvaceae | Shrub | Sept-Oct | N&P |
| 34 | *Hibiscus ludwigii* Eckl. & Zeyh. | Malvaceae | Shrub | Sept-Oct | N&P |
| 35 | *Hypericum revolutum* Vahl | Hypericaceae | Shrub | Sept-Oct | N |
| 36 | *Hypoestes triflora* (Forssk.) Roem & Schult | Acanthaceae | Herb | Sept-Oct | P |

| No | Plant species | Family | Habit | Flowering period | Rewards |
|---|---|---|---|---|---|
| 37 | *Ilex mitis* (L.) Radlk. | Aquifoliaceae | Tree | Sept-Oct | P |
| 38 | *Impatiens ethiopica* Grey-Wilson | Balsaminaceae | Herb | Aug-Oct | N&P |
| 39 | *Ipomea purpurea* (L.) Roth. | Convolvulaceae | Climber | Sept-Oct | N |
| 40 | *Ipomea indica* (Burm.f) Merrill | Convolvulaceae | Climber | Sept-Oct | P&N |
| 41 | *Isoglossa somalensi*s Lindau | Acanthaceae | Herb | Sept-Dec | N&P |
| 42 | *Justicia schimperiana* (Hochst. ex Nees) T. Anders. | Oleaceae | Climber | Sept-Dec | N&P |
| 43 | *Laggera crispata* Vahl Hepper & Wood | Asteraceae | Herb | Sept-Oct | P |
| 44 | *Maesa lanceolata* Forssk. | Myrsinaceae | Shrub | Sept-Oct | P |
| 45 | *Malva verticillata* L. | Malvaceae | Herb | Sept-Nov | N&P |
| 46 | *Maytenus undata* (Thunb.) Blaelock | Cleastraceae | Shrub | Sept-Nov | P |
| 47 | *Mikaniopsis clematoides* (S'ch. Bip. ex A. Rich.) Milne-Redh. | Asteraceae | Climber | Sept-Nov | P |
| 48 | *Nuxia congesta* R. Br. ex Fresen. | Loganiaceae | Shrub | Sept-Nov | P&N |
| 49 | Ocimum spp. | Lamiaceae | Herb | Sept-Nov | N&P |
| 50 | *Olea welwitschii* (Knobl.) Gilg & Schellenb. | Oleaceae | Tree | May-Jun | N &P |
| 51 | *Pentas schimperiana* (A.Rich.) Vatke | Rubiaceae | Shrub | Sept-Oct | N |
| 52 | *Periploca linearifolia* Quart.Dill & A. Rich. | Asclepiadaceae | Climber | Sept-Dec | P |
| 53 | *Phoneix reclinata* Jacq. | Arecaceae | Tree | Sept-Dec | P |
| 54 | *Phytolacca dodocandra* L 'Herit. | Phytolaccaceae | Climber | Sept-Dec | P |
| 55 | *Polyscias fulva* (Hiern) Harms | Araliaceae | Tree | Oct-Dec | N&P |
| 56 | *Pouteria adolfi-friederici* (Engl.) Baehni | Sapotaceae | Tree | May-Jun | N |
| 57 | *Premna schimperi* Engl. | Verbenaceae | Shrub | Sept-Oct | P&N |
| 58 | *Prunus africana* (Hook. f.) Kalkm. | Roseaceae | Tree | Sept-Oct | N&P |
| 59 | *Psycnostachys eminii* Gurke | Lamiaceae | Herb | Sept-Dec | N&P |
| 60 | *Ranunculus multifidus*Forssk. | Ranunculaceae | Herb | Sept-Dec | P |
| 61 | *Rhamnus prinoides* L'Herit. | Rhamnaceae | Herb | Sept-Dec | P |
| 62 | *Rothmannia urcelliformis* (Hiern) Robyns | Rubiaceae | Shrub | Sept-Dec | N |
| 63 | *Rubus steudneri* Schweinf. | Roseaceae | Climber | Sept-Dec | P&N |
| 64 | *Salix subserrata* Willd. | Salicaceae | Shrub | Sept-Dec | P |
| 65 | *Salvia nilotica* Juss. ex Jacq. | Lamiaceae | Herb | Sept-Oct | P |
| 66 | *Satureja paradoxa* (Vatke) Engl. | Lamiaceae | Herb | Sept-Oct | N&P |
| 67 | *Schefflera abyssinica* (Hochst . ex A.Rich ) Harms | Araliaceae | Tree | March-April | N |
| 68 | *Solanecio gigas* (Vatke) C. Jeffrey | Asteraceae | Herb | Sept-Dec | P |
| 69 | *Solanecio mannii* (Hook. f.) C. Jeffrey | Asteraceae | Shrub | Sept-Dec | P |
| 70 | *Sphaeranthus suaveolen*s (Forssk.) DC. | Asteraceae | Herb | Sept-Dec | P |
| 71 | Syzygium guineense (Willd.) DC. | Myrtaceae | Tree | Feb-Mar | N&P |
| 72 | *Trifolium polystachyum* Fresen. | Fabaceae | Herb | Sept-Oct | N&P |
| 73 | *Vernonia auriculifera* Hiern | Asteraceae | Shrub | Dec-Jan | N&P |
| 74 | *Vernonia hochstetteri* Sch. Bip. ex Walp. | Asteraceae | Shrub | Dec-Jan | N&P |
| 75 | *Vernonia ituriensis* Muschl. | Asteraceae | Shrub | Dec-Jan | N&P |
| 76 | *Vernonia leopoldi* (Sch. Bip. ex Walp.) Votke | Asteraceae | Shrub | Dec-Jan | N&P |

| No | Plant species | Family | Habit | Flowering period | Rewards |
|---|---|---|---|---|---|
| 77 | *Vernonia wollastonii* S'. Moore | Asteraceae | Climber | Dec-Jan | N&P |
| 78 | *Vicia faba* L. | Fabaceae | herb | Sept | P |
| 79 | *Zea mays* L. | Poaceae | Herb | Aug- Sept | P |

**Appendix 5.List of bee forages identified from pollen**

| Plant species | Family | Habit | Pollen weight | Proportion | Flowering period |
|---|---|---|---|---|---|
| *Achyranthes aspera* L | Amaranthaceae | Herb | 0.65 | 0.1 | Sep-Jan |
| *Ageratum conyzoides* L. | Asteraceae | Herb | 2.93 | 0.2 | Sep-Nov |
| *Andropogon abyssinicus* | Poaceae | Herb | 0.773 | 0.1 | Aug-Nov |
| *Bidens pilosa* | Asteraceae | Herb | 155 | 12.2 | Sept-Oct |
| *Brassica spp* | Brassicaceae | Herb | 0.34 | 0.0 | Sep-Oct |
| *Cirsium schimperi* | Asteraceae | Herb | 2.34 | 0.2 | Oct-Nov |
| *Combretum paniculatum* | Combretaceae | Climber | 27.5 | 2.2 | Jan-Mar |
| *Cordia africana* | Boraginaceae | Tree | 7.4 | 0.6 | Sept-Oct |
| *Croton macrostachyus* | Euphorbiaceae | Tree | 24.53 | 1.9 | Mar-Jun |
| *Cyperus fischerianus* | Cyperaceae | Herb | 2.89 | 0.2 | Jan |
| *Datura innoxia* | Solanaceae | Shrub | 135 | 10.6 | Sep-Jan |
| *Eucalyptus spp* | Myrtaceae | Tree | 121.9 | 9.6 | July-Aug |
| *Glycine wightii* | Fabaceae | Climber | 6.0652 | 0.5 | Oct-Jan |
| *Guizotia scabra* | Asteraceae | Herb | 287.56 | 22.7 | Nov-Jan |
| *Hibiscus spp* | Malvaceae | Shrub | 0.639 | 0.1 | Sep-Dec |
| *Hypericum revolutum* | Guttiferae | Shrub | 1.67 | 0.1 | Sept-Oct |
| *Hypoestes triflora* | Acanthaceae | Herb | 6.32 | 0.5 | Sep-Nov |
| *Ilex mitis* | Aquifoliaceae | Tree | 35 | 2.8 | Sept-Oct |
| *Maesa lanceolata* | Myrsinaceae | Shrub | 45 | 3.5 | Aug-Oct |
| *Maytenus arbutifolia* | Celestarceae | Shrub | 10.74 | 0.8 | Sept-Nov |

**Appendix continued 16**

| ***Plant species*** | **Family** | **Habit** | **Pollen weight** | **proportio** | **Flowering period** |
|---|---|---|---|---|---|
| *Ocimum spp* | Lamiaceae | Herb | 0.421 | 0.0 | Oct-nov |
| *Plantago lanceolatum* | Plantaginaceae | Herb | 24.32 | 1.9 | Sept-Jan |
| *Poaceae* | Poaceae | Herb | 1.045 | 0.1 | Sept-Jan |
| *Ranunculus multifidus* | Ranuculaceae | Herb | 0.28877 | 0.0 | Sept-Nov |
| *Rumex nervosus* | Polygonaceae | Shrub | 2.8 | 0.2 | Sept-Nov |
| *Saturja paradoxa* | Lamiaceae | Herb | 2.5 | 0.2 | Sept-Nov |
| *Schefflera abyssinica* | Araliaceae | Tree | 15.1 | 1.2 | April |
| *Syzygium guineense* | Myrteatceae | Tree | 88 | 6.9 | Jan-Feb |
| *Trifoilum spp* | Fabaceae | Herb | 5.64231 | 0.4 | Sept-oct |
| *Unknown pollen1* | Asteraceae | - | 6.3 | 0.5 | Sept-oct |
| *unknown pollen2* | Fabaceae | - | 9.14 | 0.7 | Jan |
| *Vernonia amygdalina* | Asteraceae | Shrub | 26.86 | 2.1 | Jan |
| *Vernonia spp* | Asteraceae | Shrub | 52.88 | 4.2 | Dec |
| *Vicia faba* | Fabaceae | herb | 3.946 | 0.3 | Aug-sept |
| *Zea mays* | Poaceae | Herb | 6.832 | 0.5 | Aug |

**Appendix 17. Questionnaire for the beekeeping socioeconomic survey**

**1. General**

Region name:_____ Temp_____

District name: _____ Rainfall_____

Specific locality name:_____

Geographical coordinate:_____

Name of beekeeper:_____

Years of beekeeping experience:_____

Source of experience (neighbor, parents, training):_____

Family size: _____

Age: _____

Education level: _____

2. Production related

Total number of colonies owned: _____

In box hive: _____

In traditionalhive: _____

Total honey production/annum:_____

Frequency of harvest/year:_____

What is average annual honey yield/colonies in traditional hive_____?

What is average annual honey yield/colonies in box: _____

What is your annual household income from beekeeping:_____

## 3. Related to beekeeping constraints

What are the major constraints of beekeeping in degree of importance? Give rate 1 What up to 10

| Factors | Rate | Remark |
|---|---|---|
| Honeybee disease | | |
| Honeybee enemies | | |
| Pesticide | | |
| High temperature | | |
| Shortage of bee forage | | |
| Drought | | |
| Shortage of training | | |
| absence of good market | | |

Which kebeles are potentail for beekeeping?

High potential_____

Midium potential_____

Low potential_____

Which types found in the kebele and explain interms of color and body size

Are there any difference interns of bee behavior?

Which type of tree species for production of monofloral honey

Explain roots of honey markets

When the following major activities of the bee colonies occurs in your locality

| No. | Major activities | Season(s) of occurrence | | | |
|---|---|---|---|---|---|
| | | Sept-Nov | December- February | March to May | June-August |
| 1 | Brood rearing period | | | | |
| 2 | Colony swarming | | | | |
| 3 | Colony migration | | | | |
| 4 | Colony absconding | | | | |
| 5 | Honey flow season | | | | |
| 6 | Dearth period | | | | |

List seasonal availability of bee forages in your area

| Sept- Nov | Dec- Jan | Feb -Mar | April-May | Jun-May |
|---|---|---|---|---|
| *Bidens prestinaria* | *Vernonia amygdalina* | *Syzgium guinnese* | Eucalyptus globulus | *Croton macrostachyus* |
| *Trifolium rupellianum* | *Clematis simensis* | *Schefflera abyssinica* | | |
| *Masea lanceolata* | *Guizotia scabra* | *Coffea arabica* | | |
| | | | | |
| | | | | |

List and rank constraints

| No | Types of constraints | Rank |
|---|---|---|
| 1 | Lack of organized honey market | |
| 2 | Low supply of honey due to decreasing productivity of colonies | |
| 3 | Scarcity and high cost of honey processing equipment | |
| 4 | Low quality of honey processing equipments and honey containers | |
| 5 | Limited knowledge and skill of honey processing | |
| 6 | Low quality of honey and adulteration of honey | |
| 7 | Limited knowledge of preference of target market | |
| 8 | Lack of market information | |
| 9 | Cheating on honey weight and price information by honey collectors | |
| 10 | Increasing price of honey | |
| 11 | Lack of market promotion and facilities | |

Local bee flora species and their flowering time

| No. | Local name of bee flora | Flowering month | Gps points |
|---|---|---|---|
| | | | |
| | | | |

Can you rank the above bee forage species in order of their important and to give good honey yield as well as colony performance? Yes No, if yes rank in the table below

| No. | Local name of bee flora | Rank of bee forage |
|---|---|---|
| | | |
| | | |

Do you think that there is shortage of bee forage in your local area? Yes No
If yes in which month/season is the most critical shortage of bee forage happen?

| Season | Months of the year | critical shortage | shortage | Less shortage |
|---|---|---|---|---|
| | | | | |
| | | | | |

Harvesting time of honey bee in the local area

| | Harvesting time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Most common | s | o | N | D | J | F | M | A | M | J | J | A |
| Rare | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

Is there change in honey quality in different harvesting time? Yes No, if yes classify thequality of honey /harvesting time in the table below.

Rank of honey quality in different harvesting time

| | Harvesting time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Honey quality | s | o | N | D | J | F | M | A | M | J | J | A |
| Very good | | | | | | | | | | | | |
| good | | | | | | | | | | | | |
| medium | | | | | | | | | | | | |
| Low | | | | | | | | | | | | |

What do you think the main reason for this quality difference?

_____

Have you noticed colon's performance difference in the different seasons of the year? Yes No , if yes rate them

Which types of tree species are preferred for hanging traditional hives?

_____

Does honey production affected with the height of the tree on which hive

hanging? Yes/No

What is the advantage and disadvantage of forest beekeeping?

_____

How do you often manage honeybee colonies in the forest?

_____

Are there poisonous honeybee plants? Yes / No

If yes, please list them with their side effect.

_____

_____

Sting less bees (Meliponinae) honey yield/harvest _____

Sting less bees (Trigona species) honey yield/ harvest _____

Honey harvesting periods

Major _____

Minor _____

_____ Do you think that there is shortage of bee forage in your local area? Yes or No

If yes in which month/season is the most critical shortage of bee forage happen?

| *Months of the year* | *critical shortage* | *shortage* | *Less shortage* |
|---|---|---|---|
| | | | |
| | | | |

11. Harvesting time of honey in the area

| | Harvesting time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | s | o | N | D | J | F | M | A | M | J | J | A |
| Major | | | | | | | | | | | | |
| Minor | | | | | | | | | | | | |

12. Important tree species

What are the most important tree species for honey production?

| Local name | Rank |
|---|---|
| | |
| | |

What are the most important tree species for hive production?

| Local name | Rank |
|---|---|
| | |
| | |

13. How do you often manage honeybee colonies in the forest?

_____

_____

_____

14. Are there poisonous honeybee plants? Yes / No

If yes, please list them with their side effect.

_____

_____

15 Where do you hang or put your hives?

i. Natural forest (kobo forest)

ii. Natural forest non-kobo forest

iii. Secondary forests

iv. Religious forests

v. (Coffee) plantation

vi. Home garden/crop land

15. If you have the Kobo forest and what is the size of the your Kobo in hectare_____

16. How many hives do you have in your Kobo forest _____

17. Why do you hang hives on tall trees?

i. to protect from theft

ii. To avoid from ant attack

iii. To make visible for swarming bees

iv. To ease of pollen collection for bees

18 What is advantage and disadvantage of Traditional forest beekeeping over the improved beekeeping?

Advantages of Traditional forest beekeeping in Kobo

Encourages protection of forest

For organic honey production

Less damage to bees by pesticide

19 Competition of honey production with other forms of forest use

1. What is the effect of forest coffee production on honey production?

i. No effect

ii. Slashing of undergrowth and vines decreases bee forage

iii. Coffee flowers give good honey production and stimulation of coffee flower increases bee forage supplement

iv. People cultivating forest coffee do not allow beehives on their lands

v. Anti-fungi used for coffee are poisonous for bees

vi. Coffee generates better income than beekeeping and therefore replaces it

vii. Other, specify

20. Forest and tree management practices

20.1. Have you ever undertaken any activity?

i. To preserve forests for honey production

ii. To retain specific old trees for use in honey production

iii. To protect any young trees for future use in honey production

iv. To plant trees for honey production

21. Perception on the role of forest in honey production

1. Do you think forests are important for beekeeping? 1=yes; 2= no
Yes (explain why)
No, because

22. Do you think that the disappearance of forest has a negative effect on honey production?

i. Yes, why?

ii. No, why?

30. Do you think that beekeeping does stimulate forest conservation?

i. If yes, in what way?

ii. If no, why