ESTIMATION OF ABOVE AND BELOW GROUND CARBON STOCK ALONG ALTITUDINAL GRADIENT OF MONTANE MOIST FOREST: -THE CASE OF BELETE NATURAL FOREST, SOUTHWEST ETHIOPIA.

M.Sc. THESIS

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,JUNE,2018

APPROVAL SHEET I

This is to certify that the thesis entitled "Estimation of Above and Below- ground Carbon stock along Altitudinal gradient of Montane moist forest,–:_the case of Belete Natural forest, Southwest Ethiopia**"** submitted in partial fulfillment of the requirement for the degree of master's with specialization in Forest Resource Assessment And Monitoring, the graduate program of school of forestry, and has been carried out by Soressa Tore Fufa Id.No MSc/FRAM/R0016/09, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Yemiru Tesfaye (PhD)	________________	________________
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APPROVAL SHEET II

We the undersigned members of the board of examiners of the final open defense by Soressa Tore have read and evaluated his thesis entitled **"**Estimation of Above and Below- ground Carbon stock along Altitudinal gradient of Montane moist forest:- the case of Belete Natural forest, Southwest Ethiopia**"**and examined the candidate. Accordingly, this is to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree of Masters of Science.

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DECLARATION

I hereby declare that this thesis entitled ***"Estimation of Above and Below- ground Carbon stock along Altitudinal gradient of Montane moist forest:- the case of Belete Natural forest, Southwest Ethiopia"***submitted to the school of forestry is my original work and any work taken from other authors is duly acknowledged within the text and references chapter. It is my own responsibility to declare that it has not been previously submitted or accepted for the award of any degree of the university or institutions.

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ABSTRACT

Forests play a significant role in climate change mitigation by sequestering and storing more carbon from the atmosphere which is released by anthropogenic causes mainly through fossil fuel burning and deforestation. Ethiopia is one of tropical country which has significant forest resource but the studies on carbon stock variation along altitudinal gradient have not been well studied. This study was done with the aim of estimating above and below ground carbon stock amount variation along altitudinal gradient in the Moist Afromontane of the belete natural forest The total forest area of Belete natural forest were stratified in to three forest strata(lower, middle and higher) using Digital elevation model with GIS. The data was collected through systematic stratified and grid random sampling. Each plot of 15mx20m was lied across transect line with a distance of 500m between plot and 2.5km between transect to collect data. Within each main plot a quadrant of 1mx1m with four at corners and one at center were used to collect litter sample data .The results shown that, there were forty two species with individual of 2053 trees and shrubs in the study sites which had DBH ≥5 cm. The total mean above ground and below ground carbon stock were 232.44 and 67.1 t ha-1 respectively. The deadwood biomass was only found in lower and middle altitude. The total mean carbon in dead wood and litter Were 0.66 and 0.18 t ha-1 respectively. The total mean carbon stock for all measured carbon pools were 300.38 ton ha^{-1} .The total mean Carbon stock variation along altitudinal gradient was 251.79, 294.52 and 358.25 t ha-1 for lower, middle and higher altitude respectively of which higher amount of carbon stored in higher altitude. The difference of carbon stock and biomass in lower ,middle and higher altitude were statistically insignificant except in dead wood carbon.

Key words*: Forest strata , Climate change mitigation, Carbon stock, Altitude, Belete Natural Forest.*

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LIST OF ACRONYMS

AGB	Above Ground Biomass
BGB	Below-Ground Biomass
C	Carbon
CDM	Clean Development Mechanism
CIFOR	Center for International Forestry Research
CRGE	Climate Resilience Green Economy
CO_2	Carbon dioxide
DBH	Diameter at Breast Height
DOM	Dead Organic Matter
FAO	World Food and Agricultural Organization
GDP	Gross Domestic Product
Gt	Giga tones
GHGs	Green House Gases
GIS	Geographical Information System
GPS	Global Positioning System
H	Height of the tree
HST	Higher Strata Tree
IPCC	Intergovernmental Panel on Climate Change

LST	Lower strata Tree
M	Meter
MST	Medium Strata Tree
Mt	Mega tone
OFWE	Oromia Forest and Wild Life Enterprise
PFM	Participatory Forest Management
Pg	Petagram
PPM	Parts Per Million
REDD+	Reduction Emissions from Deforestation and Degradation
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SPSS	Statistical Package for the Social Sciences
UNFCCC	United Nations Framework Convention on Climate Change
UN	The United Nation

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1. INTRODUCTION

1.1. Background of the Study

Forests are the most diverse ecosystems and are often considered as the reservoirs of biodiversity. Forests are globally important in the conservation of the environment, biodiversity, water, and soil resources. However, In Developing Country like Ethiopia the population grows rapidly; the demand exceeded the replacing rate and aggravated deforestation due to different diverse need and plan of the people. On the other hand destruction of the natural forests of Ethiopia results directly in the loss of unaccounted plant and animal species as well as in a shortage of fuel wood, timber, and other forest products.

To reduce this problem, the 1992 UN Forest Principles identified the multifunctional and multiservice purpose of the world's forests and consequences of its loss: Forest resources and forest lands shall be managed and used sustainably to fulfill social, economic, ecological, cultural and spiritual needs of present and future generations. In today's modern world the global climate change becomes an environmental problem which, mainly caused by anthropogenic greenhouse gas emissions of carbon dioxide mainly from the burning of fossil fuels for both domestic and industrial purposes, deforestation and emission of other greenhouse gas (Freestone and Streck, 2009). However, within the portfolio of climate change mitigations options, carbon capture and storage has emerged as one of the most promising greenhouse gas reduction technologies with the enormous potential to achieve significant cuts in CO_2 emissions from fossil fuels (Bielicki and Kalinowski, 2007).REDD+ activities have been developed as part of international climate change mitigation efforts. Removing carbon from the atmosphere and storing it in the terrestrial biosphere is one of the methods proposed to reduce greenhouse gas emissions (Albrecht and

Kandji 2003). Forests are known in contributing to greenhouse gas reductions through carbon sequestration (Brand, 1998; Metz et al., 2001).

The main Carbon pools in the tropical forest ecosystem are the living biomass of tree and understory vegetation, the dead mass of litter and woody debris, and soil organic matter. Carbon stored in the aboveground biomass constitutes the largest pool of all the carbon pools in tropical forest ecosystems (Baccini et al. 2008). From 99% of the world's forest area, 432 billion tons of dry matter is aboveground woody biomass of live trees and dead trees with DBH > 10 cm size (Shvidenko *et al.*, 2005).

In Ethiopia, assessment of carbon stock potential of forest begun in recent years. However, the contribution of forest to climate change mitigation is currently the most front issue globally including Ethiopia. Ethiopia has limited information about carbon stocks of the forest (Feyissa et al., 2013). Similarly, Melese et al., (2013) described that although carbon is varying from forest to forest and soil to soil, Ethiopia has only limited number of studies regarding carbon stock. Therefore, all mentioned above invite research works regarding carbon stock estimation at regional and local level of the forest resources of the country. The amount of carbon stored in forests of Ethiopia is about 2.76 billion tons of C (Moges et al .,2010). Carbon stocks in a forest vary depending upon various factors and processes operating in the systems. Bhat et al. (2013) indicated that from these factors, the most significant ones are land use, land use changes, soil erosion and deforestation.

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1.2. Statement of the Problem

The role of forest in providing environmental services is significant but in some area including Belete natural forests not supported by studies. Therefore, the potential capacity of forest in storing carbon and contribution of the forest in climate change mitigation in the study area needs to be explored. Today, because of climatic concerns and interest in global Carbon trade, estimating aboveground biomass to establish increments or decrements of Carbon stored in forests is increasingly important (IPCC, 2006). And the demand of reliable information regarding forest carbon stock at both country and global levels is growing (Asseffa et al., 2013)

However, Sahile. (2011) explain that unlike the developed nations, Ethiopia`s carbon inventory and data storage to monitor and enhance carbon sequestration capacity of different forests is inadequate to assess the biomass carbon sequestration at micro-level. In addition, in Ethiopia as one of the country in the tropics, little is known about inter site of forest biomass when compared to the large amount of information available in other continents (Chave et al., 2001; Abel et al., 2014). Similarly, Belete forest is one of the few remnant moist evergreen montane forests of southwest Ethiopia, for which biomass carbon inventory is not conducted. Belete natural forest is one of high forest in southwest Ethiopia which contributes to climate change mitigation by sequestering GHGs from the atmosphere. However, in the forest area there is no scientific study conducted with aiming estimation of AG biomass carbon of the forest area and its dynamics along altitudinal gradient and potential of the forest in climate change mitigation is not addressed. Therefore, this study was aimed to fill all this gaps.

Fang *et al*., (2004) and Korner, (2007) indicate that altitudinal gradients are the most powerful ‘natural experiments for testing ecological and evolutionary responses of biota to environmental changes. Forest carbon is affected by different environmental factors such as: altitude, aspect and slope by affecting the distribution of tree species (Feyissa *et al.*,2013)

Therefore, this study was designed to estimate above and below ground potential capacity of carbon stock of Belete natural forest and its carbon stock change along altitudinal gradient.

1.3. Objectives of the Study

1.3.1. General Objective

- The general objective of this study was to estimate Carbon stock along altitudinal gradients in above and below ground carbon pools of Belete Montane Moist forest, southwest Ethiopia.

1.3.2. Specific Objectives

- To identify woody plant species found in the natural forest in the study area.
- To estimate total carbon stock of the above and below ground biomass of the natural forest in the study area along altitudinal gradient.
- To estimate litter carbon stock of the natural forest in the study area along atitudinal gradient.
- To estimate Dead wood carbon stock of the natural forest in the study area along atitudinal gradient.
- To estimate total carbon stock of the above ground biomass of litter and dead wood of the natural forest in the study area.

1.4.Research Questions

To accomplish objectives of the study the following questions are formulated:-

Do above and below ground biomass and - carbon storage potential of the natural forest in Belete forest area varies along altitudinal gradient?

1.5. Significance of the Study

. This study provides information in addressing the role of the forest in contribution of climate change mitigation by reducing GHGs from the atmosphere through sequestration which helps for the sustainable management of forest resource. The study provides insights about the forest's potential to sequester and store carbon in the forest ecosystem considering altitudinal variation. This study benefited decision makers, researcher, government and nongovernmental organization for different purpose. for instance, the information provided from this study benefit in REDD+ activities through estimating the amount of carbon emitted when this forest area is deforested or degraded, for decision makers and forest managers in the plan of climate change mitigation activities like enhancing forest carbon through forest management and replacing deforested area through Afforestation /Reforestation/ to increase carbon sequestration and reduce the amount of carbon in the atmosphere and for scientific communities for further studies.

1.6. Scope and Limitations of the study

. The study area of the forest is large and it is known that it requires more samples to represent the total forest area to increase accuracy. Because of budget and time constraint, this study was not include all forest carbon pools to explore total carbon density(carbon stock) of major carbon pools of the forest ecosystem, specifically estimation of soil organic carbon of the forest was not included in this study.

2. LITERATURE REVIEW

2.1 Global carbon cycle and Forest

Carbon is an element found in all forms of life. It isa major component of trees and plants and also exists in the environment in non-living things like rocks, oil, natural gas, coal, and air. Naturally, the amount of carbon as any other system in the environment retains its balance. But, natural exchange of C compounds between the atmosphere, the oceans and terrestrial ecosystems is now being modified by human activities that release CO2 from fossilized organic compounds ('fossil fuel') and through land use changes. Moreover, according to FAO, (2004) in the last 200 years, fossil burning in combination with deforestation have increased CO2 concentration in atmosphere from 0.028 to 0.035% and the concentration is continuing to increase.

Globally, the carbon cycle plays a key role in regulating the Earth's climate by controlling the concentration of CO2 in the atmosphere. But if the concentration of CO2 is high it has negative consequences, and an unnatural buildup of GHGs can lead to a planet that gets unnaturally hot.However, Forest play a major role in balancing this CO2 concentration in the atmosphere in the global climate changes of the century to come as far as these are managed sustainably (Shvidenko *et al.,* 2005).Forest plays an important role in the carbon cycle as they dominate the terrestrial vegetation, which exchanges CO_2 with the atmosphere through photosynthesis and respiration (Dixon *et al*., 1994) .Feyissa *et al., (2013*) indicate that, trees in a forest have important contribution to the global carbon cycle, because of their large biomass per unit area of land. As much of the flux is above the ground, estimation of forest structural attributes such as aboveground biomass is therefore an important step in identifying the amount of carbon in terrestrial vegetation pools and is central to global carbon cycle studies (Drake *et al*., 2002).

The different components of AGB constitute different amounts of carbon. According to Hairiah et al. (2001), trunk diameter contain the highest and forest type contain the least carbon stock from the following consecutive order; trunk diameter, wood specific gravity, total height, and forest type (dry, moist or wet). When trees in a forest grow, the amount of CO_2 absorbed by the trees is increased while the concentration of CO_2 in the atmosphere can be reduced. Globally, forests act as a natural storage for carbon, contributing approximately 80% of terrestrial above ground, and 40% of terrestrial below ground biomass carbon storage (Kirschbaum 1996).

Since forests play an important role in carbon cycle it is important to achieve reduction of GHG emissions and increase sequestration in forestry sector through reducing demand for fuel wood with using fuel wood efficient stoves and other advanced cooking technologies (electric, biogas, and stoves) .In addition, afforestation, reforestation, and forest management of forests and wood land can help to increase sequestration that makes forest carbon sinker rather than source.

2.2 . Global climate change and its impacts

According to UNFCCC, climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

The earth’s average temperature has slowly increased over the last 100 years. Changes are also happening much faster than they have in the past. Greenhouse gases including water vapor, carbon dioxide, methane, nitrous oxide, and ozone, are believed to have played an important role in the global climate change (Patenaude et al., 2005; UNFCCC, 1997). The Earth’s atmosphere contains carbon dioxide and other GHGs that act as a protective layer, causing the planet to be warmer than it would in the long past.

Changes in the global climate are primarily caused by changes in the composition of the atmosphere. Increasing GHGs in the atmosphere causes climate change (Global Warming).This increase in GHGs caused by Burning of fossil fuels (80%) and deforestation (20%) which both are human activity release 49 GtCO2e (billion tons of CO_2) annually (IPCC 2007). As a result GHGS have emitted and increasing quantities of GHGs into the earth's atmosphere causing rise in the amount of heat from the sun withheld in the earth's atmosphere. This increase in heat has led to the greenhouse effect, resulting in climate change. The IPCC report (2007) indicates that most of the observed increase in global average temperatures since the mid-20th Century is very likely due to observed increases in anthropogenic greenhouse gas concentrations. And Over the last century, atmospheric concentrations of carbon dioxide increased from a pre-industrial value of 278 parts per million to 379 parts per million in 2005, and the average global temperature rise by 0.74° C.

Climate change has impact on many natural and human systems. For instance, it is being observed that snow and ice are melting and frozen ground is thawing, hydrological and biological systems are changing, migrations are starting earlier, and species geographic ranges are shifting towards the poles. It also has on human health, environment (soil erosion), effects on agriculture, livestock and the economy, water resources etc**.**To overcome these wide effects, the mechanism for the response or solution of climate change is adaptation and mitigation. mitigation to climate change is done in two ways- reducing further emission (stabilizing climate change) and/or sequestering back the already emitted GHGs .Mitigation measures that aim to reduce greenhouse gas emissions can help to avoid reduce or delay impacts of climate change (Green Facts, 2007).

.The current contribution of Ethiopia to the global increase in GHG emission is overall total emissions of around 150 Mt CO2e from different sectors(agriculture, forestry and others) which represent less than 0.3% of global emissions(CRGE Ethiopia, 2011).

The forest cover of Ethiopia has been diminishing overtimes due to an ever-increasing demand for farmlands, fire wood, charcoal and the increasing livestock population(Senbeta and Teketay 2003; Soromessa *et al.,* 2004).Even though, there are remnants' of forest in some parts of Ethiopia like south west Ethiopia which stores many biodiversity and contributes to climate change mitigation and needs continuous management.

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2.3. The role of forest in climate change mitigation

Climate change mitigation is the process of reducing greenhouse gas (GHG) emissions that come from forestry and agricultural activities and industrial activities. Forests play an important role in keeping greenhouse effect and carbon cycle working naturally by reducing CO_2 emissions and increasing the CO_2 pulled out of the atmosphere and stored as carbon that helps for climate change mitigation. About 45% of the earth's terrestrial carbon is stored in forests, in 2005,forests covered 4 billion ha of the earth's surface (30%), of this, African forests covered 635 million and accounted for around 16% of the world's forests (Pearson,et al, 2005)

Forests are net sinks that absorb more carbon out of the atmosphere than they emit globally. However, from 2.6 billion tons of carbon that forests annually absorb, about 60% is emitted back into the atmosphere through deforestation. It is estimated that about 86% of the terrestrial above ground carbon and 73% of the earth's soil carbon are stored in the forests (Vashum and Jayakumar 2012).

Properly designed and implemented forestry mitigation options have substantial co-benefits in terms of employment opportunities, watershed and biodiversity conservation, provision of timber and fiber, as well as aesthetic and recreational services (IPCC 2007).Therefore, if deforestation and forest degradation is decreased and sustainable forest management practiced the amount of carbon in a forest and sequestration of carbon from the atmosphere increased which helps for climate change mitigation.

2.4 . Afromontane Moist forest of Ethiopia

Schmitt et al., (2010) indicate that, Afromontane forests are the most species-rich ecosystems on earth. The montane moist forest ecosystem comprises high forests of the country mainly the southwest forests, which are the wettest, and also the humid forest on the southeastern plateau known as the Harenna forest. The forest vegetation was stratified into four different layers, namely, upper canopy, sub-canopy, shrub layer and the ground layer (Tadesse, 1986, Friis 1986 and 1992).In Ethiopia, montane moist forest ecosystem found mostly in the southwestern plateau, with altitudinal range between 800 m-2500 m a.s. l. and the southeastern plateau, on the southern portion of the Bale Mountains at an altitude between 1450 -2700 m.

In southwest part of Ethiopia forests are a major sources of coffee production and timber for saw log, plywood, chip wood and paper industries during the last century.(Tesfaye, 2001).Moreover, forests of the country particularly the montane moist forests are important components of the planet to sequester CO2 gases in the Atmosphere. The Current estimate has shown that our forests sequester nearly 27,579 Gg of CO_2 per annum from the atmosphere (Bekele 2001). And at present Ethiopia is a net sinker of GHG owing to her natural forest resources. However, the destruction of natural forests as well as degradation of the various habitat types caused by different human activities in montane moist forests made the most vulnerable and threatened ecosystem. Therefore, appropriate and effective laws that is applied should be formulated to safeguard the protection and sustainable utilization of the remaining forest resources, otherwise the country losses one of its major 'Carbon Sink'

2.5 Forest Carbon Pool

Carbon pool: is system or a reservoir which has the capacity to accumulate or release carbon. According to the IPCC, The terrestrial ecosystem comprises five carbon pools which include the above-ground biomass, below-ground biomass, the dead mass of litter, woody debris and soil organic matter.

2.5.1 Aboveground Biomass

The AGB of woody vegetation comprises all woody stems, leaves of living trees, branches, creepers, climbers, and epiphytes as well as plants and herbaceous growth. The aboveground living biomass of trees is mainly the largest pool and the most directly impacted by deforestation and degradation. In the forest ecosystem, estimation of the accumulated biomass is important for the purpose of assessing the productivity and sustainability of the forest.

Estimating the amount of carbon stored in the biomass has increased and gained attention as a result of the UNFCCC and its Kyoto Protocol deciding on agreements that, countries are required to estimate and report CO2 emissions and removals by forests .Forest biomass assessment is important for national development planning as well as for scientific studies (Zianis and Mencuccini, 2004).

The approaches that have been used to estimate forest biomass and forest carbon stocks in different pools are field measurement of forest stand characters such as height, diameter and basal area and remote sensing-based estimates of AGB (Wulder *et al.* 2008) The field measurement is direct way of estimating carbon stored in AGB includes destructive and non-destructive method.

The destructive method involves harvesting all trees in a known area and weighing different components of harvested tree biomass and measuring component of these weight after oven dried. This method is accurate for a particular location. However, it is limited to small area, time and resource consuming, expensive and impractical for country level. This method is applied to develop allometric equation for assessing larger-scale biomass.

The non-destructive method to estimate carbon stored in AGB involves estimating of biomass without tree felling. One way of estimating AGB by non –destructive method is with applying sampling method and measuring diameter at breast height, height of the tree, volume of the tree and wood density and calculates the biomass using allometric equations (Pearson *et al*, (2005).The inclusion of H to biomass model lead to negligible changes in biomass prediction (Nelson et al., 1999,(Basuki et al., 2009) and (Kuyah et al., (2012). Diameter at 1.3 alone explains more than 95% of the variation in aboveground tropical forest carbon stocks (Gibbs et al. 2007).

The minimum diameter often is 5cm in DBH but it can vary depending on the expected size of trees. For arid environments in which trees grow slowly, the minimum DBH may be as small as 2.5cm; for humid environments in which trees grow rapidly, the minimum DBH may be up to10 cm. Pearson *et al*, (2005) indicated that, the DBH biomass is estimated using appropriate allometric equations applied to the tree measurements. All plant materials from their dry weight contain 50% carbon (Gibbs *et al*., 2007; Pearson *et al.,* 2005 and Hairiah *et al.,* 2001).To estimate forest carbon stock, measurements of diameter at breast height (DBH) alone or with combination tree height can be converted to estimates of its carbon stocks using linear relationships derived from various allometeric equation, volume tables and yield tables (Wulder et al., 2008).

2.5.2 Below- ground biomass

BGB carbon pool consists of the biomass contained within live roots. It can be assessed either by taking soil cores from which roots are extracted or quantified by using ratios with AGB. The measurement of belowground biomass is more difficult due to the mass of soil that needs to be excavated and the difficulty in separating fine roots from soil particles and measuring root biomass is time consuming and expensive due to the way that roots are distributed in the soil. Due to this reason, mostly BGB is derived from measurements of AGB by root to shoot ratio. Brown (2002) found that the root to shoot ratio were not significantly vary with soil texture (fine, medium and coarse), latitudinal zone (tropical, temperate, and boreal) and tree type (angiosperm and gymnosperm). According to Gibbs et al. (2007), root biomass is estimated as 20% of the aboveground tree biomass. Similarly, as AGB, although less data exists, regression equations from root biomass data have been formulated which predict root biomass based on above-ground biomass carbon (Brown, 2002).

2.5.3 Dead wood biomass

The dead wood carbon pool includes all non-living standing and fallen trees, roots and stumps that has a diameter of greater or equal to 10cm. it can contains 10-20% of that in the AGB pool in mature forest. But, the dead wood carbon pool in immature forests and plantations of fallen and standing dead wood are likely to be insignificant in the first 30-60 years of establishment (Delaney *et al*., 1998). The carbon stock in the dead wood pool can be done with method of sample and assessment of the wet-to-dry weight ratio, and converted to biomass on the basis of wood density. The methods to establish the ratio of living to dead biomass are under investigation, but data are limited on the decline of wood density as a result of decay (Brown, 2002).

2.5.4 Dead organic matter (Litter)

The DOM litter includes the layer of organic debris, dead plant material fallen or removed, and plant parts not attached to plants. The diameter of dead organic matter (litter) with less than 5 cm is included in the litter layer (Subuied *et al.,* 2010).

Local estimation of the litter pool can be done with the establishment of the wet-to-dry mass ratio. Where this method of estimation is not possible, default values are available by forest type and climate regime ranging from 2.1 tons of carbon per hectare in tropical forests to 39 tons of carbon per hectare in moist boreal broadleaf forest (IPCC, 2006). Biomass always is oven dried and generally is converted to units of carbon by multiplying biomass by 0.5 (Pearson *et al.*, 2005).

2.5.5 Soil Organic Matter

Soil organic carbon (SOC) is larger one part of global carbon cycle that involves the cycling of carbon through the soil, vegetation, ocean and the atmosphere. SOM constitutes various tissues from dead plants and animals, materials less than 2mm in size, and soil organisms.SOM compromises carbon in mineral and organic soils and is a major reserve of terrestrial carbon (Lal and Bruce, 1999).

Kane, (2015) indicated that, around the world, the majority of soils are far from their saturation thresholds, as a result there is great potential for increased carbon inputs and management that protects existing stocks to maximize soil carbon sequestration.when adding new C sources to sub soils care should be taken because of the risk of enhanced mineralization of existing SOC. The solutions to sustain soil functions, the balanced cycling of nutrients in soils must be maintained (FAO and ITPS, 2015)

2.5.6 The Effect of Elevation on Carbon stocks.

Carbon stocks in a forest vary depending upon various factors and processes operating in the systems. Bhat et al. (2013) indicated that from these factors, the most significant ones are land use, land use changes, soil erosion and deforestation. According to Feyissa *et al.* (2013), forest carbon is affected by altitude by affecting the distribution of tree species. The decrease in size with elevation indicates a reduction of the biomass C pool towards higher altitudes, (Grubb et al. 1963; Tanner 1981; Schawe et al. 2007). In many mountain forests, tropical and temperate, tree size tends to decrease with altitude less continuously (Liebermann et al. 1996; Raich et al. 1997). Variation in elevation is one of the major determinant factors for both carbon stocks aboveground and below- ground. This is because with elevation tree species and composition tends vary and they affects carbon stock contents. (Mwakisunga and Majule,2012).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location and Climate

The study area is located in Jimma zone, which is found in Oromia Regional State to the Southwest of the Addis Ababa at a distance of 375km. Its location lies at longitudes between 36°15´ E and 36°45´ E and latitude 7°30´ N and 7°45´N and Altitude between 1365m.a.s.l and 2642m.a.s.l. The area is characterized by a humid tropical climate of heavy annual rainfall that ranges between 1800 and 2300 mm with maximum rainfall between the months of June and September. The mean monthly Temperature of the area is between about15°c – 22°c (source-Shabe sombo District Agricultural office).

3.1.2. . Vegetation

This study was conducted in Belete forest area which is located in Shabe-Sombo districts of Jimma zone. Belete forest is located 50km West of Jimma town (Figure 1). The forest area borders Gera districts in the west, Goma district in the north, Southern Peoples' Regional State in the south and Seka-Chekorsa districts in the east. There are 14 kebeles in Shabe-Sombo district living in the forest area. The total population living in the forest area is 76, 571 individuals living in 17,473 households (Cheng *et al.*, 1998). Belete Forest is part of the Belete-Gera National Forest Priority Area. The forest is administrated and managed by OFWE through PFM strategy and known as part of Belete-Gera PFM project. In Ethiopia, the initiative to establish participatory forest management for Belete-Gera forest has begun since September 2003.The total area of the forest is 22,058ha (source OFWE Jimma Branch).

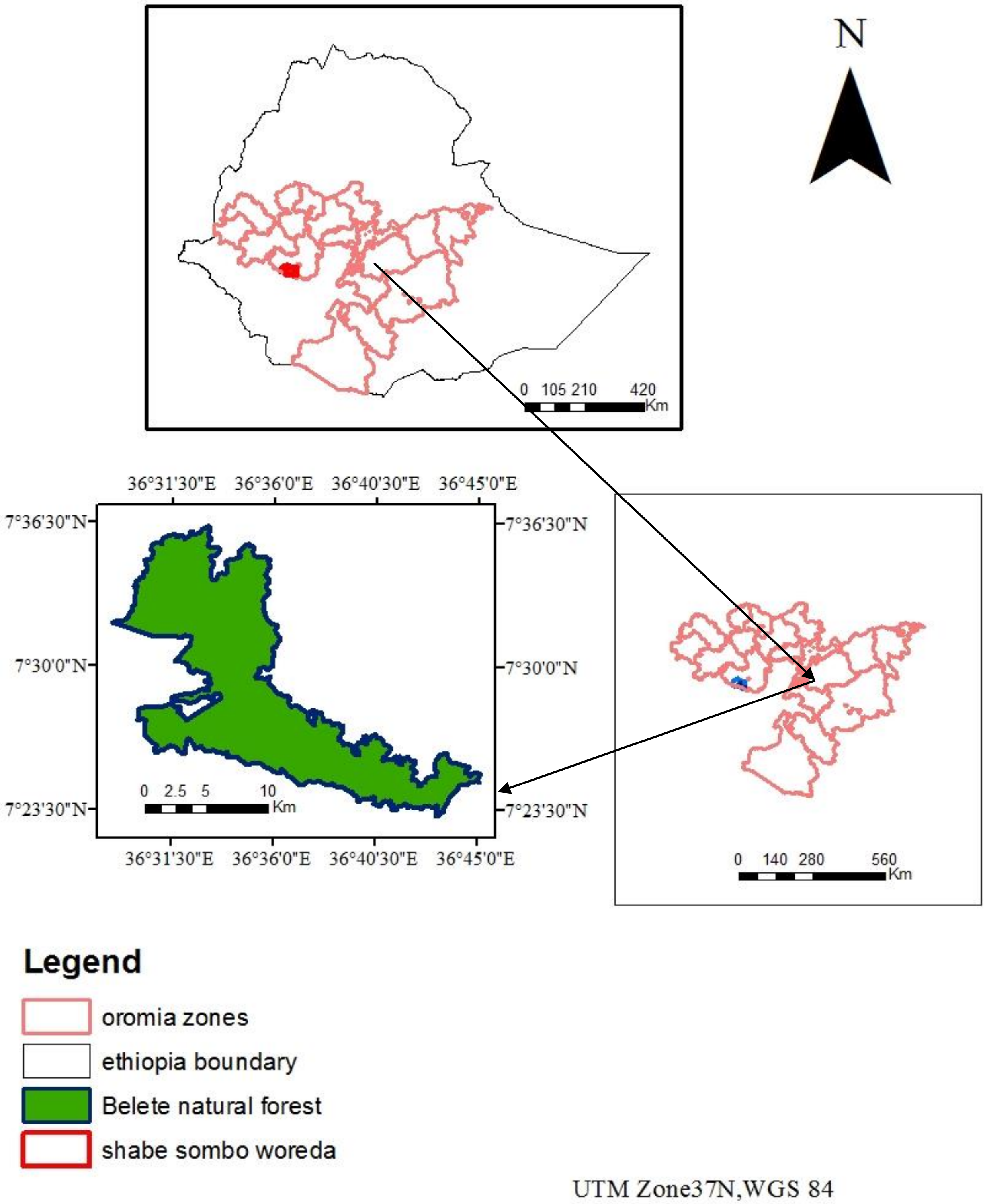

Figure 1, Map of the study area

The area is known for its coffee production. The occurrence of Coffee in this area is in a wild state which as sparsely distributed shrubs in the forest that are harvested without any management and in semi forest coffee system. The stands with high coffee cover are managed with enrichment planting, removal of competing shrubs, and felling of some larger trees to get a higher yield (Hylander *et al.* 2013).

3.1.3. Soils

The soils of Belete Forest are generally fine-textured. Soil types of Nitisols and Cambisols occurs in areas with gentle slopes and forest cover. Leptosols are found on mountain peaks, steep slopes and stream banks where soil is shallow (less than 30cm deep). Luvisols dominate in depressions such as lowlands along rivers and marshes (Cheng et al., 1998).

3.2. Methodology

3.2.1. Delineation of the Study Site

The boundaries of the forest area and stratification of the forest was done by using digital Elevation Model, Google Earth, remote sensing images and QGIS application with ground survey verification way points from OFWE jimma branch office or ground way points of Belete Natural forest demarcation, 2005.

3.2.2. Stratification of the Study Area

Stratification was done in the forest area in order to increase the accuracy and precision of collecting data from the field and as well as to form relatively homogenous forest units. Stratification of the forest area was carried out on the basis of altitude. Based on altitudinal variation, the study site was stratified into three purposely and the major strata namely: lower (1365m-1887m), middle (1887m-2186m) and higher (2186m-2642m) with an area (ha) of 6825,8731 and 6502 ha respectively.

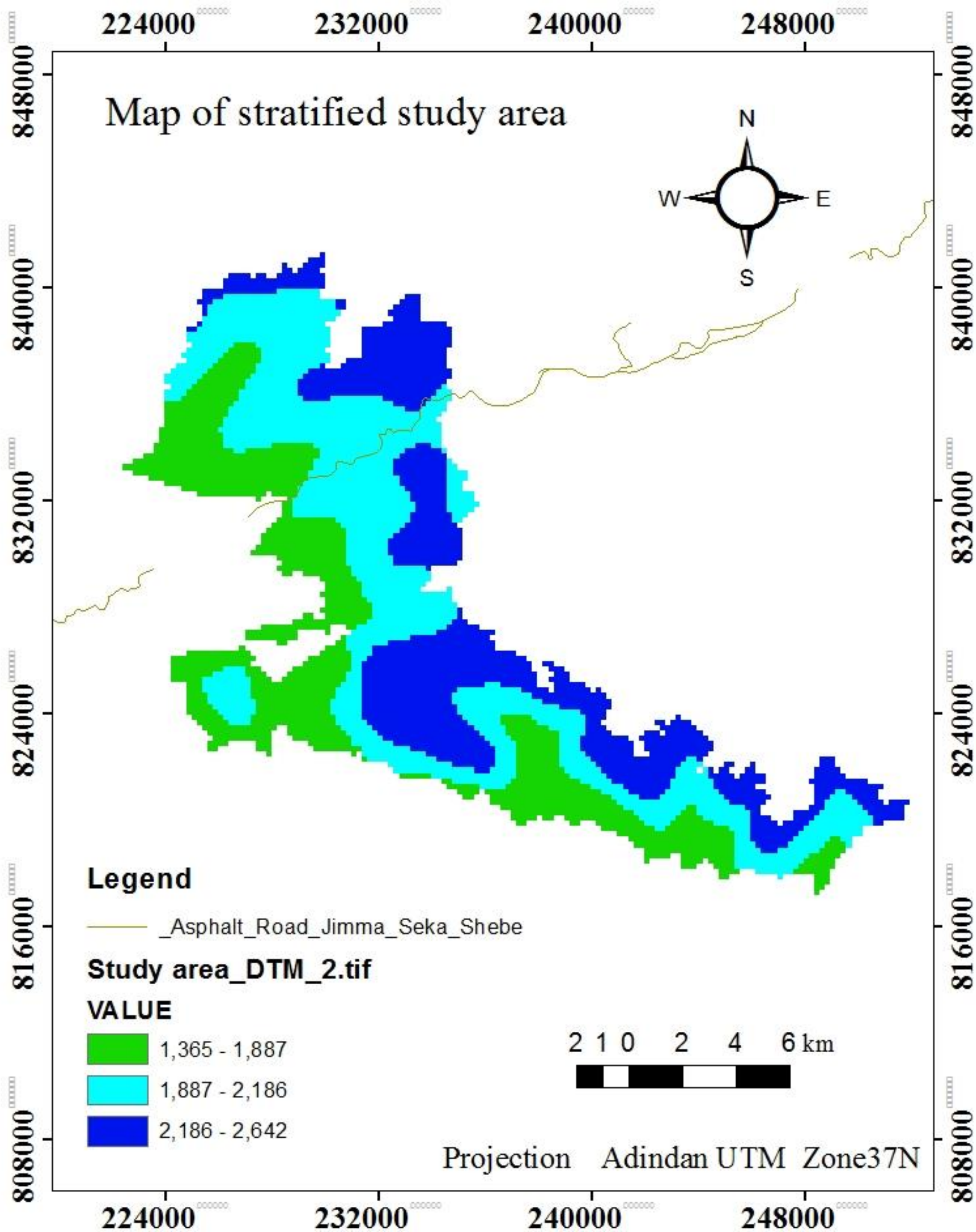

Figure 2. Map shows stratification of study area

3.2.3. Sampling techniques and Intensity

In forest inventory, different literature suggest that the decision on plot size and number of plots depends on logistics, manpower, cost and time required. Therefore, for this study, Nested plot type with sub-plots in the main plot was used to sample and record different size classes of trees. Nested plots are composed of several plots (typically two to four, depending upon forest structure), each of which should be viewed as separate (Pearson *et al*, 2005).According to Genene et al. (2013) and Hairiah *et al*., (2001), the square or rectangular plot shape is the most cost-efficient and it includes more heterogeneity within-plot, and it is more representative than the circular plots of the same area. Due to resource and time constraints, rectangular sample plot size of 15m x 20m (300m2 equivalent to 0.03 ha) was used in this study. Systematic transect sampling technique was used in this study for tree sampling and measurement.

Rectangular sample plots of 15m x 20m were laid through systematic random sampling method at distance 500m from each other. Using Arc GIS a total of 9 transect lines was lied across the forest area with 2.5km apart, and was established across altitudinal gradients. Along each transects, Plots of 15m x 20 m size was placed systematically at 500m interval resulting in a total of 151 sample plots within total forest area .The area and proportion of lower, middle and higher forest strata were 6825 ha (30.9%),8731 ha (39.6%) and 6502 ha (29.5%) respectively. Number of sample plots for each stratum proportional to its size is- lower, middle and higher are 47, 59 and 45 plots respectively. To avoid boarder effect the first plot was laid 150 meters from the boarder to inside the forest. Sampling plot direction was laid down across the forest area. To make the transects to be parallel with one another, a compass bearing was used.

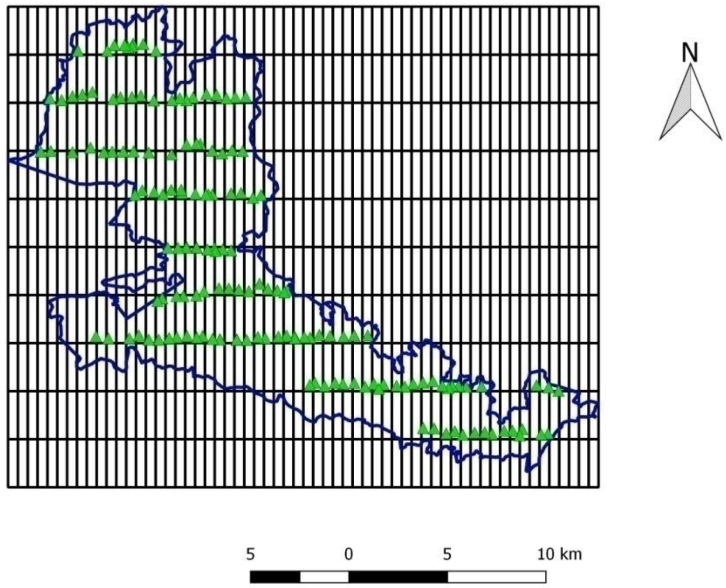

Figure 3 Map shows plot distribution

The location of each plot (latitude and longitude) including altitude was recorded by using GPS. Trees/Shrubs with DBH ≥ 5 cm except for coffee at diameter 40cm from the ground (≥ 2.5cm)was measured at each plot. Pearson et al., (2005) indicate that, to reveal the tree composition and biomass, all live trees and shrubs with a diameter ≥ 5 cm recorded. To estimate the biomass of agroforestery based coffee, all live coffees with DBH ≥2.5cm measured at 40cm from the ground and recorded (Negash et al.,2010). The rectangular plot size with 15m x 20m was laid along transects to measure trees/shrubs with DBH ≥ 5 cm and some sample height and sub-plots of four at corner and one at center with size 1mx1m was laid within main plot to collect litter samples. The diameter was measured at breast height (DBH, 1.3 m height from the ground) by using tree Caliper and Diameter tape to estimate biomass. Tree diameter at breast height (DBH) was measured by using caliper for those trees which have a circular trunk and by diameter tape for those trees which have buttressed trunks and large sized diameter. Trees with multiple stems near the ground were considered as single individuals and their bole circumference measured separately.

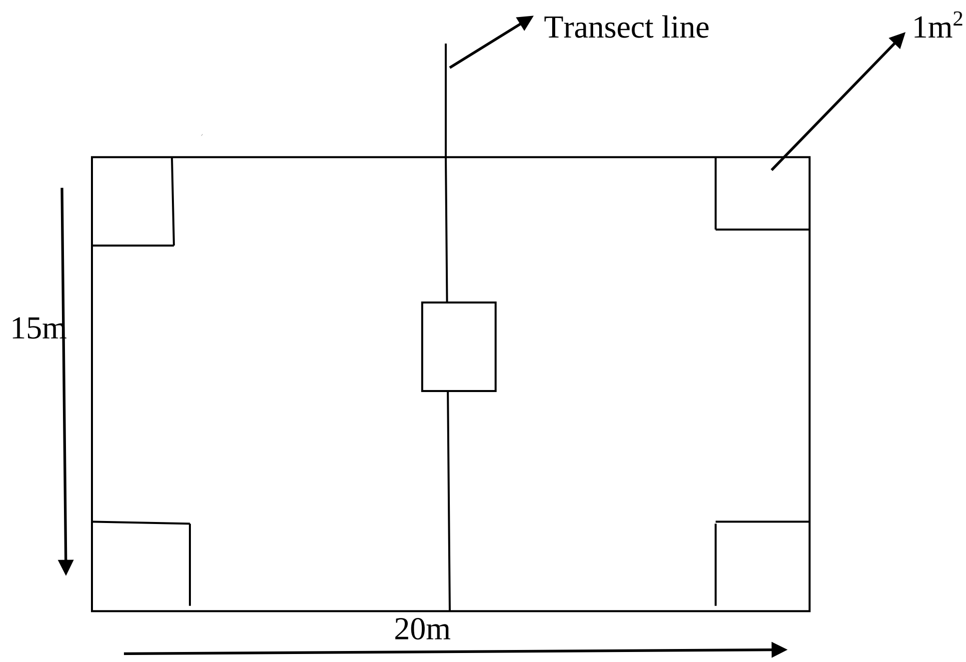

Figure 4. Sampling plot design of the study area

Note:Trees/shrubs with DBH≥5cm and for coffee 2.5cm were measured within 15mx20m plot size and Litter samples were collected within 1mx1m four at corners and one at center with in main plot.

3.2.4. Methods of data Collection

All trees and shrubs species with DBH $\geq$ 5cm and coffee with DBH $\geq$ 2.5cm were identified and recorded within established sample plots designed for data collection in the field for estimation of above ground biomass. For identification and recording, trees and shrubs within the plot were marked to prevent the probability of counting twice and recorded individually with their species name. Species which were easily identifiable recorded in the field. For species which were difficult to identify in the field, the local name were recorded and identified from Flora of Ethiopia and Eritrea and Tree and Shrubs of Ethiopia (Azene, 2007).

3.3. Field Carbon Stock Measurement

The biomass inventory of the major carbon pools like aboveground live biomass, below ground biomass, aboveground dead tree biomass, litter were the estimated forest carbon storage in this study.

3.3.1. Above Ground Biomass (AGB)

Aboveground biomass comprises all living vegetation including stems, stumps, branches, bark, seeds and foliage. According to Gibbs et al., (2007), methods of estimating forest carbon stock is from measurements at breast (DBH) alone or in combination with tree height can be converted to estimates of forest carbon stocks using linear relationships.

. In the tropics measuring H is difficult and expensive (Sawadogo etl.2010).However, to increase the cost-efficiency of the field work, it is common procedure to measure D for every tree and H for a subset of trees, called sample tree for the purpose of H-D model developed for the rest of tree height (Lappi et al, 2006).

Therefore, the height of some sample trees and shrub with DBH $\geq$ 5cm within each plot were measured and D – H Regression equation established to determine the height of the rest trees for biomass estimation.

3.3.2. Litter Biomass (LB)

The forest leaf litter includes dead leaves, twigs, dead grasses and small branches which are all dead organic surface material on top of the mineral soil. The diameter of dead organic matter (litter) with less than 5 cm is included in the litter layer (Subuied *et al.*, 2010).

The litter samples were collected by establishing a quadrate with a size of 1 m × 1 m within main plot. To collect litter sample, a total of four small quadrates at corner and one at center were laid within large or main plot. The litter samples with size less than 5cm within in each sub plots (1mx1m) were taken and then the leaf litters will be collected and weighed on the field. The litter collected from subsamples was mixed and 100g taken to laboratory and oven dried at a temperature of 70^{o}c for 24 hours.

3.3.3. Deadwood Biomass

The dead wood includes standing dead trees, fallen stems and fallen branches. The standing individual dead trees with DBH greater equal to 10cm of its height and DBH (at 1.3m) was measured and recorded within main plot. To estimate dead standing wood biomass, the parameters measured are similar with standing live trees. The dead wood may be standing or down and the measurement method can be varies depending on the position and category of the dead wood.

3.4. Estimation of Carbon stock in Carbon pools

3.4.1. Estimation of carbon in aboveground carbon pool

According to Bhishma et al. (2010),Allometric equation is defined as statistical relationship between key characteristic dimensions of trees that are fairly easy to measure, such as DBH or height, and other properties difficult to assess, such as above ground biomass. Clark and Kellner, (2012) indicate that, diameter measurements and/or estimates of height of tree can be converted into biomass units using allometric equations.

Nelson et al., (1999), Basuki et al., (2009) and Kuyah et al., (2012) authors found that inclusion of H to biomass model (allometeric equation) lead to negligible changes in biomass prediction. According to Gibbs et al. (2007), diameter at 1.3 alone explains more than 95% of the variation in aboveground tropical forest carbon stocks.

Therefore ,to see the difference in estimation of aboveground biomass using allometeric equation that include DBH only and H and DBH the following two equations were used.

(i). The aboveground biomass was estimated by using general allometric equation that include WD,DBH and H recommended by Chave et al., (2014) for all forest type, which is given below.

AGB (kg) = $0.0673*(WD*D^2*H)$ ^0.976……………………………………(equ.1)

Where, AGB is aboveground tree biomass (kg/tree),DBH is diameter at breast height (cm), WD is wood density (g/cm^3) and H is total height (m)

(ii) The aboveground biomass was estimated by using general allometeric equation that includes only DBH recommended by Brown (1997) tropical moist forest, which is given below:

AGB **(kg) =42.69-12.800*(DBH) +1.242*(DBH) ^2……………………………(equ.2)**

Where AGB is aboveground tree biomass (kg/tree),DBH is diameter at breast height (cm).

The carbon stock in above ground standing live trees can be estimated by multiplying the biomass of standing live trees by 0.5 (IPCC, 2006).

In the Belete natural forest especially at lower and middle forest strata there is coffee plantation which is managed by local community for the purpose of coffee production. Therefore the above ground biomass of coffee in the forest was estimated using allometeric equation developed by Negash,et al,(2013) which is given below.

been applied which is the default value for wood in the tropical and subtropical domain)

Coffee AGB **(kg) =**$0.147*d_{40}2$**……………………………(equ.3)**

Where d_{40} =the diameter of coffee at 40cm from the ground.

The above ground biomass carbon stock for coffee was estimated by multiplying AGB with 0.49(Negash.et al.2013)

3.4.2. Below Ground Biomass (BGB)

Since the estimation of BGB by direct measurement is more expensive and time consuming, it is derived from AGB (shoot root ratio). Singh et al.,(1994) indicate that ,the root-to shoot ratio for tropical mountain system is 27%. i.e.

BGB = AGB × 0.27 ………………………………………………… (equ.4)

Where, BGB is below ground biomass, AGB is above ground biomass

3.4.3. Estimation of carbon in Litter carbon pool

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

$$LB = \frac{W_{field}}{A} * \frac{W_{sub\ sample\ (dry)}}{W_{sub\ sample\ (fresh)}} * \frac{1}{10,000} \quad \text{…………………………. (equ.5)}$$

Where: LB = Litter dry biomass (t ha-1); W field = Weight of wet field sample of litter sampled within an area of size 1 m^2 (g); A = Size of the area in which litter were collected (ha);

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

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

CL = LB * % C... (equ.6)

Where, CL is total carbon stocks in the dead litter in t ha-1, % C is carbon fraction determined in the laboratory **(**Pearson et al., 2005).The carbon fraction used in the laboratory was 37% (0.37).

3.4.4. Estimation of Carbon in above ground Dead Wood

The dead wood carbon pool can be standing and downed or fallen dead wood. To estimate the biomass standing and fallen, volume of this dead wood was calculated as follows.

The volume of downed (fallen) dead wood was estimated as (CSEMF, 2011):

$$\mathbf{Volume = 0.25\pi \left(\frac{D_{base}+D_{tip}}{2*100}\right)^2 * H} \text{ ………………………………….. (equ.7)}$$

The volume of standing dead wood was calculated as standing live trees as :

Volume=Basal area*height*form factor…………………………………..(8)

According to EFRL, (2016) there are two decomposition classes recorded for deadwood particles: sound and rotten. If the decomposition class was missing in the data, it was assumed that deadwood piece was sound. Because, a rotten wood contains less biomass than a sound dead wood and can be calculated as:

Sound deadwood biomass: Volume * 90% * Default WD,

Rotten deadwood biomass: Volume * 50% * Default WD.

In this study there is no decomposition class data and for standing and downed (fallen) dead wood was taken as sound dead wood and its biomass was calculated as:

Sound deadwood biomass: Volume * 90% * Default WD……………………………..(equ.9)

Where, WD is wood density

The specific density of wood is estimated as 0 .612 g/cm3 as default value (EFRL,2016)

The total biomass of dead wood was estimated by adding the biomass of standing dead wood and dead downed wood.

TBDW=SBDWB+BDDW…………………………………………………(equ.10)

Where, TBDW is Total Biomass Dead Wood, SBDWB is standing biomass dead wood Branched and BDDW is biomass dead downed (fallen) wood.

The total carbon stock in dead wood can be estimated by multiplying the total biomass of dead wood by 0.47 **(**IPPC, 2006)

3.4.5. Estimation of total carbon stock

According to Subuied et al., (2010),the total carbon stock for measured carbon pool were calculated by summing the carbon stock densities of the individual carbon pools of that stratum. Carbon storage of AG and BG of the study area was calculated by the following formula.

CT = AGC +BGC+ LC +DWC……………………………………………….. (equ.11)

Where, CT = Total Carbon stock for all pools (ton/ha); AGC=above ground carbon stock (ton/ha); LC=litter carbon stock (ton/ha); DWC= dead wood carbon (ton/ha) and BGC= below ground carbon stock (ton/ha)

The carbon stock for each carbon pool was added to get the total C stock at the plot level and then converted to the C stock (tons) per unit area (hectare).According to Pearson *et al*., (2007), the total carbon stock were then converted to tons of CO2 equivalent by multiplying it by 44/12, or 3.67

3.5.Statistical Data Analysis

The different carbon pools data measured in the forest was organized by recording on the excel sheet data. Descriptive statistics was used to illustrate mean and standard deviation of measured values. The effect of altitudinal variation on carbon storage was tested by using one way ANOVA. The data collected in the field such as DBH, Height, wet weight, fresh weight and dry weight of litter were analyzed using SPSS software version 20. The finalized data were presented in the form of tables, charts, and graphs.

4. RESULTS AND DISCUSSIONS

4.1. Forest Structure

Forest structure is the horizontal and vertical distribution of layers in a forest which includes the trees, shrubs, and ground cover including vegetation and dead and down wood and Structure at the proportion of small, medium, and large trees.

In the Belete Natural forest, a total of forty two different woody plant species were identified within all stratum. In the study area, during data collection a total number of 2053 individual with 69.3% trees and 30.7% shrub were recorded from forty two plant species, of which 759, 778 and 516 individual were collected from lower, Middle and Higher stratum respectively.

Millettia ferruginea,*Dra*caena *afromontana*.*Olea capensis and Cordia Africana* were the most frequent tree species recorded in the lower forest stratum with relative coverage of 9.7%, 8.2, 6.7 and 6.3 respectively.*Olea capensis,Syzygium guineense Dracaena afromontana and Trema orientalis were* the most frequent tree species in the middle forest stratum with relative coverage of 12.3%, 10.9, 10.7 and 5.9% respectively and *Syzygium guineense,Dracaena afromontana,Olea capensis* and*Canthium oligocarpum* were the most frequent tree species in the higher forest stratum with relative coverage of 12.3%,10.9%,10.7% and 5.9% respectively. While Euphorbia abyssinica,Ficusvasta,*Pouteria adolfi-friederici* and *Vepris dainellii,* were the least frequent species in the lower forest strata with coverage of each 0.3%,*Calpurina aurea* and *Ficus thoningi Blume* were the least frequent species in the middle forest strata with coverage of each 0.1% and *Allophylus abyssinicus* ,*Fagaropsis angloensis* ,*Ehretia cymosa* and *Cordia Africana* were the least frequent species in the higher forest strata with coverage of each 0.1%.(Appendices 7,8 and 9)

The frequencies of wood plant was higher at middle than at lower and higher forest strata in the increasing order. This result showed different with strata and this may be because of at higher forest strata the stand is old aged and low regeneration was appear due to canopy effect which leads to limited sunlight for photosynthesis and also there was deforestation problem. But at the lower forest strata there was majority of illegal thinning trees and slashing of seedling by the community for coffee plantation for the purpose of coffee production. Fast growing tree species are expected to have higher growth rates, and may accumulate large amounts of carbon in the first stage of their lifespan (Thomas, 1996).

Table 1, Stand structure of the forest in the lower, middle and higher forest strata

Altitude	DBH(cm)	Ht.(m)	BA(m2)/ha	stem/ha
Lower	0.30	19.1	61.28	473
Middle	0.33	20.5	67.31	485
Higher	0.35	22.2	72.32	314

4.1.1.Distribution of DBH and Height within strata

The distribution of DBH of plant species collected in the Belete forest was classified in to seven classes in each strata. In the lower forest strata, middle forest strata and higher forest the largest number of plant species fall in the DBH class between5-15cm and the DBH class ranged between 16-25cm was the second largest number of plant species in the lower, middle and higher forest strata .Especially in the lower forest strata this condition was due to there were coffee plantation potential in the natural forest which falls in this DBH class. Others the least number of trees were fall with DBH class greater than 65cm in each forest strata. The highest frequency of plant species showed at the lowest DBH class size than middle and higher class in all forest strata and this result showed that as the size of DBH class increase, inversely the frequency of plant species decrease. This is due to deforestation and human interference in the forest for different purpose. In other way in the higher forest strata the number of plant species is larger at higher DBH class than in the middle and lower forest strata in increasing order. The appearance of more tree species at higher DBH class distribution resulted in more amount of biomass and carbon accumulation in the tree species. The diameter class distribution of woody plant species collected in the lower, middle and higher forest strata were illustrated in the following figures (Fig. 4)

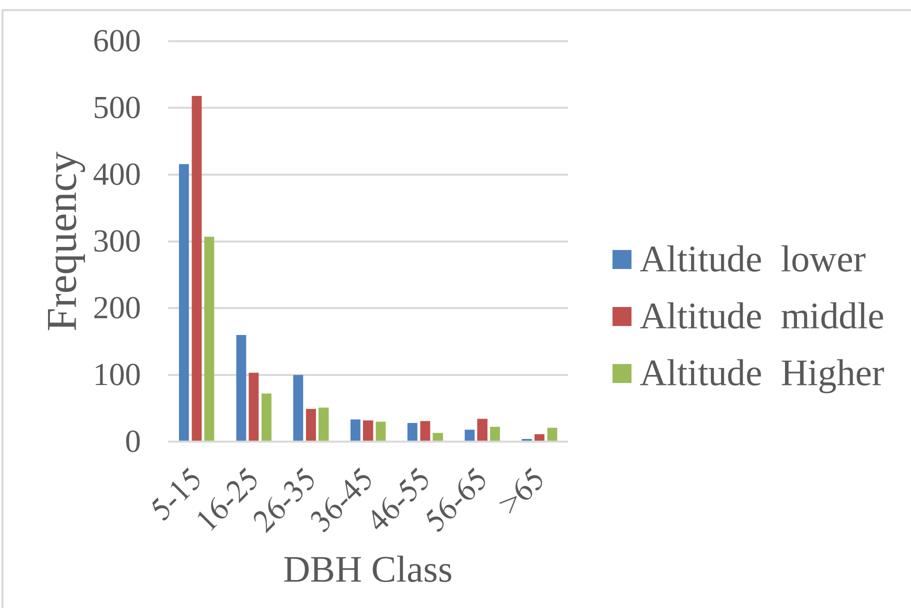

Figure 5 DBH class size distribution and frequency of woody plant species at lower ,middle and higher forest strata of Belete natural forest.

Plant species in Belete natural forest had varies height class like their DBH value within each forest strata. The height of trees in all strata were classified in to six classes.The distribution of height also showed variation among classes and forest stratum. The largest number of plant species fall in the range of first height class in the lower, middle and higher strata with different frequency. Whereas the least number of trees species found in the fifth height class in the all forest strata with varies frequencies. According to Silvertown& Doust (1993), In the forest area analysis of plant structures using frequency distribution of the height and diameter classes of woody plant species provide an insight into their regeneration status which leads to show plant densities.

The height class distribution of woody plant species collected in each strata were showed in the following table (Table 4)

Table 2 Height class size distribution and frequency of woody plant species at all forest strata

Height Class	Frequency of woody plant species for height class within Strata (%)		
	Lower	Middle	Higher
5-10	42.0	46.0	46.0
11-15	24.6	28.4	28.4
16-20	15.9	8.7	8.7
21-25	6.7	4.5	4.5
26-30	5.0	4.1	4.1
>30	5.7	8.2	8.2
Total	100.0	100.0	100.0

4.1.2. Important Value Index

According to Kent and Coker, (1992), Importance Value Index combines data from three parameters which include Relative frequency, Relative density and Relative dominance (Basal area).It is important to compare the ecological significance of species and species with high density and high frequency coupled with high BA indicate the overall dominant species of the forest(Lamprecht, 1989). High IVI value is the most dominant of specified vegetation (Simon Shibru and Girma Balcha, 2004). And those species which receive lower IVI values need high conservation efforts while those with higher IVI values need monitoring management which helps for climate change mitigation through sequestration. The Importance Value Index (IVI) of woody plant species in the lower forest strata(41),middle(38) and higher forest strata(32) was calculated .Based on their IVI value ,the five most dominant and ecologically significant trees and shrubs in the lower forest strata were *Dracaena steudneri, Millettia ferruginea, Cordia africana , Trema orientalis* and *Coffea arabica L,*in decreasing order , In the middle forest strata *Pouteria adolfi-friederici, Syzygium guineense, Trema orientalis , Dracaena afromontana* and *Teclea nobilis* in decreasing order and in the higher forest strata *Syzygium guineense,Dracaena afromontana , Apodytes dimidiata , Teclea nobilis and Olea capensis* in decreasing order *were* the most dominant trees and shrubs species.(table 3.4.and 5). The most dominant and ecologically significant species may be due to successful species in regeneration, pathogen resistance, grow in the shade and in competition with other trees and the reverse for least dominant species.

Table 3 Tree species IVI in the lower forest strata

.(Rd=Relative density,RDO=Relative dominance, RF=Relative frequency)

No.	Species Name	RD	RDO	RF	IVI
1	Dracaena steudneri Engl	4.61	15.50	4.49	24.60
2	*Millettia ferruginea* Bak.	9.75	4.48	9.29	23.52
3	*Cordia africana L.*	6.32	10.75	4.17	21.24
4	*Trema orientalis Bl.*	5.80	8.47	6.09	20.35
5	*Coffea arabica L.*	9.62	0.91	7.69	18.22
6	*Ehretia cymosa* Thonn.	3.69	8.88	5.45	18.01
7	*Syzygium guineense DC.*	2.77	8.01	5.13	15.90
8	*Dracaena afromontana Mildbr.*	8.17	3.11	4.17	15.45
9	Phoenix reclinata Jacq.	5.67	5.78	3.21	14.65
10	*Croton macrostachyus* Del.	5.14	3.16	5.77	14.07
11	*Olea capensis L.*	6.72	0.53	4.81	12.06
12	*Galiniera saxifraga* Bridson	2.11	6.70	2.88	11.70
13	*Ficus sur* Forssk.	3.82	2.01	3.85	9.68
14	*Teclea nobilis Del.*	1.98	3.69	2.24	7.91
15	*Canthium oligocarpum* Hiern	2.11	2.34	2.88	7.33
16	*Polyscias fulva* Harms	1.71	1.89	2.56	6.17
17	*Bersama abyssinica* Fresen	2.24	0.68	2.88	5.80

No.	Species Name	RD	RDO	RF	IVI
18	Byttneria catalpitiolata Jacq.	1.98	1.37	1.60	4.95
19	Calpurina aurea (Ait.) Benth	2.11	0.94	1.28	4.33
20	Pittosporum viridiflorum Sims	0.66	1.46	1.60	3.72
21	*Apodytes dimidiata* E. Mey. Ex Am.	0.66	1.44	1.28	3.38
22	Albizia gummifera (J.F.Gumel.) C.A.Sm	0.79	0.67	1.60	3.07
23	*Maesa lanceolata* Forssk.	1.19	0.10	1.60	2.89
24	Ficus thoningi Blume	1.58	0.22	0.96	2.76
25	*Ekebergia capensis* Sparrm	0.53	1.88	0.32	2.73
26	*Fagaropsis angloensis* Dale.	0.79	1.18	0.64	2.61
27	*Schefflera abyssinica Harms*	0.92	0.49	0.96	2.37
28	*Vernonia amygdalina Del.*	1.19	0.06	0.96	2.21
29	Brucea antidysenterica J.F. Mill.	0.53	0.26	1.28	2.07
30	*Maytenus gracilipes* Exell	0.53	0.17	1.28	1.98
31	*Prunus africana* Kalkm.	0.40	0.63	0.64	1.66
32	*Sapium ellipticum Pax*	0.53	0.11	0.96	1.60
33	*Cluasena anisata* Benth.	0.40	0.15	0.96	1.51
34	Ficus vasta Forssk.	0.26	0.51	0.64	1.42
35	*Diospyros abyssinica* F. White	0.40	0.34	0.64	1.38
36	*Vernonia auriculifera* Hiern.	0.66	0.04	0.64	1.34

No.	Species Name	RD	RDO	RF	IVI
37	*Allophylus abyssinicus* (Hochst.) Radikofer	0.66	0.24	0.32	1.22
38	*Olea welwitschii* Gilg & Schellenb.	0.40	0.10	0.64	1.14
39	*Pouteria adolfi-friederici* Baehni	0.13	0.67	0.32	1.12
40	*Vepris dainellii* Kokwaro	0.26	0.05	0.64	0.95
41	Euphorbia abyssinica Gmel.	0.26	0.03	0.64	0.93
	Total	100.00	100.00	100.00	300.00

Table 4 Tree species IVI in the Middle forest strata.

No.	Spps Name	RD	RDO	RF	IVI
1	*Pouteria adolfi-friederici* Baehni	10.93	3.20	9.44	23.56
2	*Syzygium guineense DC.*	4.24	13.63	5.36	23.23
3	*Trema orientalis Bl.*	5.91	8.80	6.12	20.84
4	*Dracaena afromontana Mildbr.*	10.67	2.52	7.65	20.84
5	*Teclea nobilis Del.*	5.40	7.86	6.38	19.64
6	*Olea capensis L.*	12.34	0.47	6.63	19.44
7	*Canthium oligocarpum* Hiern	5.14	4.94	6.63	16.71
8	Pittosporum viridiflorum Sims	2.44	7.45	3.57	13.46
9	*Croton macrostachyus* Del.	4.37	3.34	5.10	12.81
10	*Apodytes dimidiata* E. Mey. Ex Am.	1.54	8.91	2.30	12.75

No.	Spps Name	RD	RDO	RF	IVI
11	*Ehretia cymosa* Thonn.	2.06	7.11	3.06	12.23
12	*Cordia africana L.*	2.70	5.55	2.55	10.80
13	*Schefflera abyssinica Harms*	1.80	4.14	3.32	9.26
14	*Ficus sur* Forssk.	3.60	1.54	3.06	8.20
15	*Millettia ferruginea* Bak.	3.73	0.45	3.32	7.49
16	*Polyscias fulva* Harms	2.44	1.94	2.81	7.19
17	*Olea welwitschii* Gilg & Schellenb.	2.96	0.56	3.57	7.09
18	*Coffea arabica L.*	3.34	0.91	2.30	6.55
19	*Allophylus abyssinicus* (Hochst.) Radikofer	1.29	3.76	1.28	6.32
20	*Maytenus gracilipes* Exell	2.06	1.96	1.53	5.55
21	Dracaena steudneri Engl	0.90	2.96	1.02	4.88
22	*Bersama abyssinica* Fresen	0.77	1.97	1.28	4.02
23	*Maesa lanceolata* Forssk.	1.67	0.19	1.79	3.65
24	Albizia gummifera (J.F.Gumel.) C.A.Sm	1.41	0.87	1.28	3.56
25	*Galiniera saxifraga* Bridson	0.39	1.74	0.77	2.89
26	Ficus vasta Forssk.	0.26	1.40	0.26	1.92
27	Byttneria catalpitiolata Jacq.	0.64	0.11	1.02	1.77
28	*Prunus africana* Kalkm.	0.39	0.55	0.77	1.70
29	*Vernonia auriculifera* Hiern.	0.51	0.41	0.77	1.69

No.	Spps Name	RD	RDO	RF	IVI
30	Euphorbia abyssinica Gmel.	0.64	0.02	0.77	1.43
31	Phoenix reclinata Jacq.	0.77	0.15	0.51	1.43
32	Simaroubiaceae	0.39	0.16	0.77	1.31
33	*Diospyros abyssinica* F. White	0.51	0.17	0.51	1.19
34	*Cluasena anisata* Benth.	0.39	0.02	0.77	1.17
35	*Vernonia amygdalina Del.*	0.77	0.05	0.26	1.08
36	*Vepris dainellii* Kokwaro	0.39	0.08	0.51	0.97
37	Ficus thoningi Blume	0.13	0.08	0.51	0.72
38	Calpurina aurea (Ait.) Benth	0.13	0.02	0.51	0.66
	Total	100.00	100.00	100.00	300.00

Table 5 Tree species IVI in the Higher forest strata.

No.	Species Name	RD	RDO	RF	IVI
1	*Syzygium guineense DC.*	21.90	9.13	11.66	42.69
2	*Dracaena afromontana Mildbr.*	19.19	5.86	8.97	34.02
3	*Apodytes dimidiata* E. Mey. Ex Am.	5.04	20.77	5.38	31.19
4	*Teclea nobilis Del.*	4.26	12.60	6.73	23.59
5	*Olea capensis L.*	9.69	3.66	7.62	20.97
6	*Trema orientalis Bl.*	4.46	9.36	5.38	19.20

No.	Species Name	RD	RDO	RF	IVI
7	*Canthium oligocarpum* Hiern	5.62	5.49	7.62	18.73
8	*Pouteria adolfi-friederici* Baehni	3.49	8.97	4.93	17.39
9	*Prunus africana* Kalkm.	3.10	6.73	4.48	14.32
10	*Croton macrostachyus* Del.	4.65	2.21	6.28	13.13
11	*Ficus sur* Forssk.	1.74	3.13	3.59	8.47
12	*Maesa lanceolata* Forssk.	2.71	0.53	3.14	6.38
13	*Olea welwitschii* Gilg & Schellenb.	2.13	0.24	3.59	5.96
14	*Bersama abyssinica* Fresen	1.36	1.20	2.69	5.25
15	Byttneria catalpitiolata Jacq.	0.97	1.64	1.79	4.41
16	*Millettia ferruginea* Bak.	1.16	0.44	2.24	3.84
17	*Polyscias fulva* Harms	0.39	2.48	0.90	3.77
18	*Maytenus gracilipes* Exell	0.97	0.52	2.24	3.73
19	*Schefflera abyssinica Harms*	0.78	0.85	1.35	2.97
20	Simaroubiaceae	0.58	0.81	1.35	2.74
21	*Vernonia amygdalina Del.*	1.55	0.21	0.90	2.66
22	Flacourtia indica (Brm.f.) Merr	0.58	0.25	1.35	2.18
23	Albizia gummifera (J.F.Gumel.) C.A.Sm	0.39	1.29	0.45	2.12
24	Pittosporum viridiflorum Sims	0.58	0.10	1.35	2.02
25	*Vernonia auriculifera* Hiern.	0.78	0.08	0.90	1.75

No.	Species Name	RD	RDO	RF	IVI
26	*Allophylus abyssinicus* (Hochst.) Radikofer	0.19	0.55	0.45	1.19
27	Ficus thoningi Blume	0.39	0.16	0.45	0.99
28	Calpurina aurea (Ait.) Benth	0.39	0.13	0.45	0.97
29	*Diospyros abyssinica* F. White	0.39	0.08	0.45	0.91
30	*Fagaropsis angloensis* Dale.	0.19	0.25	0.45	0.90
31	*Ehretia cymosa* Thonn.	0.19	0.14	0.45	0.79
32	*Cordia africana L.*	0.19	0.14	0.45	0.78
	Total	100.00	100.00	100.00	300.00

Where, RD,RDO and RF were calculated as:

RD=the number of all individuals of a species/the total number of all individuals X 100;(DBH $\geq$ 5cm for tree/shrub and DBH $\geq$ 2.5cm for coffee).

RF = the number of plots where a species occurs/ the total occurrence of all species in all of the plots X 100

RDO=Total BA of a species/sum of BA of all tree species X 100

BA = π d2/4, where, π= 3.14; d = DBH (m).

4.2. Comparison of above ground biomass estimation using two allometeric equation

The present study was used for the comparison of biomass estimation with two allometeric equation that include DBH only and DBH, Height and wood density which is developed by (chave et., al(2014) and Brown(1997) respectively. Based on result inclusion of DBH only to allometeric equation when compared with inclusion of DBH and H it overestimates the above ground biomass which recorded total mean of 507.25 ton/ha and 497.08 t/ha respectively (table 3.). This result indicates likewise additional further study needed in different forest area.

Table 6 .Comparison of Biomass (t ha -1) using chave et al.,(2014)and Brown,(1997) in above and below ground carbon pool along altitudinal range.

	Altitudinal range				
carbon pools	Lower	Middle	Higher	Total mean	Allometeric equation used
AGB	456.91	478.32	563.65	497.08	(Chave et al.,2014)
BGB	123.37	129.15	152.19	134.21	
AGB	467.08	488.49	573.82	507.25	(Brown,1997)
BGB	126.11	131.89	154.93	136.96	

Statistically the inclusion of more variables leads to more accurate than less variable. Due to this in this study biomass result obtained from allometeric equation developed by chave,et., al (2014) was used to estimate and analysis above and below ground carbon stock.

On the other hand the specific species wood density of some species was not found. And in this study it was used wood density for those species which their wood density accessed from different source like wood density of tropical tree species (Gisel et.,al, 1992)and Global wood density (Zanne, et., al 2009) and unlike for species no specific species wood density used, according to EFRL,(2016), it is 0.612g/cm3 as default value.

4.3. Carbon stock in different carbon pools along altitudinal variation

4.3.1 Above Ground Carbon stock

The amount of AGC of the present study was estimated along altitudinal gradient. the presence of altitudinal variation affects carbon stock of AG carbon stock of the forest. Altitudinal variation has an impact on AGC, BGC and SOC stock because of its influence on soil water regime (system) (Powers and Schlesinger, 2002). Based on result, the AGC recorded the highest at higher part of altitude with the mean value of 281.82 $tonha^{-1}$and moderate to lower at middle and lower part of altitude with mean value of 229.45 $tonha^{-1}$ and 188.90 $tonha^{-1}$ respectively. The total mean was 232.44 ton ha^{-1} with an equivalent CO_2 of 852.28 ton ha^{-1} . Brown, (1997) indicate that the difference in carbon accumulation among plots could be due to difference in growth rate of plants. At strata level in increasing altitude it showed distinct variation in which higher altitude store the highest carbon stock and lower altitude store the least carbon stock..Based on one way ANOVA analysis, the difference of AGC with altitude was not statistically significant (P–value>0.05)(Table 5)

4.3.2.Below ground carbon stock

The below ground biomass and carbon stock was estimated from AGB and AGC and its value was depend on the result of AGB and AGC, which was 27% of it. Similarly, the result of below ground biomass was shown at higher part of the altitude the largest BGC was recorded followed by at middle altitude and at the lower part of the altitude the lowest value was recorded. The mean value of BGC in the lower, middle and higher forest strata(altitude) was 61.68 ton ha^{-1}, 64.57 ton ha^{-1} and 76.03 ton ha^{-1} respectively in increasing order. But similarly the difference of BGB and BGC with altitude statistically is not significant at 95% confidence interval ($P>0.05$)(Table 5)

4.3.3..Litter Carbon stock

Like other forest carbon pool,. litter carbon pools also showed with altitude variation within each forest stratum. The result was showed litter carbon stock of the forest varies with altitude. The higher part of altitude had the largest carbon stock than lower and medium altitude which was recorded moderate to lower respectively. The carbon stock of the litter carbon pool in the lower, middle and higher altitude were 0.08 ton ha^{-1}, 0.10 ton ha^{-1} and 0.40 ton ha^{-1} respectively with increasing order with a total mean of 0.18 ton ha^{-1}. This condition indicates at strata level highest litter carbon stock recorded at higher altitude and lowest at lower altitude. This is may be due to at lower altitude leaf litter utilized for coffee management and more decomposition rate because of more temperature than at higher altitude .And also there was forest disturbance for coffee plantation which resulted in low litter accumulation or production in the study area. The important physical environment for litter decomposition are soil moisture, temperature and relative humidity which regulates the biological activity in the soil (Sayer, 2006). And Feyissa, (2013) indicate that the lowest carbon stock in litter pool could due to small amount of litter fall. Also the variation in mean carbon stock of litter pool with altitude was not statistically significance (P-valu 0.23 and F-value 1.48)

4.3.4..Dead wood Carbon stock

Dead wood carbon stock was occurred in the present only in the lower and middle forest strata .The mean carbon stock was recorded in the lower and middle forest strata were 1.13 ton ha^{-1} and

0.40 ton ha^{-1} respectively with total mean of 0.66 ton ha^{-1}. This result showed greater carbon stock recorded in the lower part of the altitude compared to middle altitude. This is due to may be in the study area at lower forest strata there was more clearing and girdling standing of plant species for coffee plantation and canopy opening for productivity of coffee this resulted in more dead wood occurred there than in middle forest strata. And as suggested by Sakai *et al*. (2008) the warm and humid climate induces quick decomposition of dead-wood which leads to low accumulation of dead wood and in the present study the reverse result were recorded because of mentioned above. But the variation of Carbon stock with altitude was statistically significant at 95% confidence interval (P-value 0.008 and F- value 9.31)(table 6)

Table 7 Mean carbon stock (t ha -1) in different carbon pools along altitudinal range of Belete Natural forest

carbon pools	Lower	Middle	Higher	One way ANOVA results	
				P-value	F-value
AGC	188.90±159.94	229.45 ± 201.3	281.82±251.82	0.15	0.19
BGC	61.68± 44.56	64.57±56.79	76.03 ± 58.15	0.68	0.50
LC	0.08± 0.02	0.10± 0.02	0.40 ±0.05	1.48	0.23
DWC	1.13 ± 0.65	0.40 ± 0.0.35	-	9.31	0.008

The present study of total mean carbon stock for all measured carbon pools were 300.38 ton ha^{-1} with the carbon stock of above ground carbon pool was recorded the largest carbon and it had 281.82 ton ha^{-1} .As reported by Murphy and Lugo, (1986), the global above ground carbon stock in tropical dry and wet forests ranged between 13.5-122.85 ton/ha and 95-527.85 ton/ha, respectively and the present result is with the range of global carbon stock reported above.

Usuga *et al.*, (2010) explain that the majority of carbon in the terrestrial carbon pool is stored in soils and above ground forest biomes. When compared the carbon stock of the present study with previous studies such as Menagesha suba state forest (sahile,2012) and Adest forest(Kasahun, 2014) the carbon stock of the present study was slightly higher with 135.13 ton/ha and less with 13.33 ton/ha with Menagesha suba state forest and Adest forest respectively with recorded different values in different carbon pools .This is may be due to the difference in forest ecosystem covering different species composition and species density, study sites,forest disturbance through deforestation and forest degradation for different purpose and the use of different allometric equation in biomass estimation. Yitebitu Moges *et al.* (2010), stated that the different types of models used for biomass estimation have impact on the value of carbon estimated in a given forest. When compared the total mean of litter carbon of the present study with previous study such as Adest forest and Menagesha suba forest higher and lower respectively with different values.(Table 6).

This is due to decomposition rate of the forest area which is affected by different factors like temperature, relative humidity and soil moisture as cited above under litter biomass and carbon stock.

In the present study the carbon stock in AG and BG carbon pools recorded greater in higher altitude and this is in line with the study conducted by Abel Girma *et al.* (2014).The reason that AGC and BGC were greater at higher forest stratum was in the above ground plant species density with higher DBH class recorded at this forest stratum. In other way the AGC at lower forest strata were lower due to anthropogenic disturbance occurred. Forest degradation from selective logging, fire and other anthropogenic disturbances, and fuel wood collection can also result in reductions of forest carbon stocks (Asner et al.,2005)

The carbon stock of litter carbon pool at strata level was higher at higher altitude and less at lower altitude and this is similar with the study reported by (Tsegaye, 2015, and Feyissa *et al.*, 2013).

This is may be due to litter carbon in the lower forest strata there is forest disturbance for coffee management others may be due to more rate of decomposition related to environmental condition and lower litter production than at higher forest stratum. Gallardo and Merino,(1993) indicate that, litter decomposition rates are regulated by soil organisms, environmental conditions and chemical nature of the litter. The greater Dead wood carbon stock recorded in the lower part of the altitude compared to middle altitude and this is similar pattern with the study conducted by (Tibebu andTeshome,2015)

5. CONCLUSIONS

The present study shows, the carbon stock within plot varies due to varies accumulation of biomass in different plot in which in some plot higher biomass and in other plots lower biomass. At strata level the biomass and carbon stock in the lower, middle and higher altitude recorded in increasing order respectively. But, the difference of carbon stock and biomass in lower middle and higher altitude were statistically insignificant except in dead wood.

The mean total carbon stock of Belete forest was 300.38 ton/ha with an equivalent C02 0f 1101.39 ton/ha and it has a high potential for absorbing carbon dioxide from the atmosphere which contributes in the climate change mitigation. Even though, it was observed in the field at the time of data collection there was forest degradation and deforestation especially at lower forest strata for lumber production .charcoal production and coffee plantation and at higher altitude majorly for agricultural expansion and settlement. Unless, the management and protection of Belete natural forest improved, the forest degraded and destructed continuously for above mentioned major purpose and others and this resulted in continues emission of CO_2 to the atmosphere which contributes to climate change.

6. RECOMMENDATIONS

The present study excludes soil organic carbon pool and Belete plantation forest due to resource limitation. Therefore to have more information potential carbon stock of soil carbon pool and plantation forest further research should consider this carbon pool and vegetation.

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APPENDICES

APPENDICES 1.Analyzed data for each sample plots with lower strata

plot no	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/h)	BGC/ha(ton)	Altitude(m)
1	730.50	365.25	146.10	73.05	1805
2	428.68	214.34	85.74	42.87	1756
3	177.18	88.59	35.44	17.72	1754
4	194.73	56.34	38.95	19.47	1844
5	501.28	145.04	100.26	50.13	1835
6	218.81	109.40	43.76	21.88	1803
7	510.96	255.48	102.19	51.10	1761
8	147.94	73.97	29.59	14.79	1754
9	148.04	74.02	29.61	14.80	1781
10	239.06	119.53	47.81	23.91	1832
11	661.39	56.34	132.28	66.14	1787
12	175.12	50.67	35.02	17.51	1624
13	369.62	184.81	73.92	36.96	1598
14	254.12	73.53	50.82	25.41	1886
15	573.86	286.93	114.77	57.39	1856
16	324.36	93.85	64.87	32.44	1871
17	1631.49	815.75	326.30	163.15	1842
18	523.94	261.97	104.79	52.39	1882
19	260.03	75.24	52.01	26.00	1872
20	428.71	214.35	85.74	42.87	1801
21	222.89	111.45	44.58	22.29	1835
22	502.67	251.34	100.53	50.27	1701
23	239.44	119.72	47.89	23.94	1666
24	710.66	205.63	142.13	71.07	1823
25	321.31	160.65	64.26	32.13	1775
26	781.20	390.60	156.24	78.12	1739
27	1042.70	301.70	208.54	104.27	1761
28	610.95	305.47	122.19	61.09	1807
29	772.35	223.48	154.47	77.23	1687
30	138.60	40.10	27.72	13.86	1686
31	461.48	133.53	92.30	46.15	1608
32	935.40	270.66	187.08	93.54	1523
33	285.04	82.48	57.01	28.50	1645
34	80.85	40.42	16.17	8.08	1885
35	252.97	126.48	50.59	25.30	1883

plot no	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/h)	BGC/ha(ton)	Altitude(m)
36	363.70	105.24	72.74	36.37	1754
37	610.12	305.06	122.02	61.01	1735
38	454.34	131.46	90.87	45.43	1851
39	11.80	5.90	2.36	1.18	1651
40	221.90	110.95	44.38	22.19	1514
41	662.23	331.11	132.45	66.22	1648
42	585.23	292.62	117.05	58.52	1815
43	1504.53	752.27	300.91	150.45	1846
44	179.53	89.77	35.91	17.95	1686
45	284.61	82.35	56.92	28.46	1589
46	375.57	187.78	75.11	37.56	1541
47	363.04	105.05	72.61	36.30	1740

APPENDICE 2.Analyzed data for each sample plots with Medium strata

plot no	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/h)	BGC/ha(ton)	Altitude
1	452.69	226.35	90.54	45.27	2091
2	632.30	316.15	126.46	63.23	2027
3	330.61	165.30	66.12	33.06	2011
4	562.26	281.13	112.45	56.23	2009
5	806.53	403.26	161.31	80.65	1993
6	2374.21	1187.10	474.84	237.42	2036
7	1333.72	666.86	266.74	133.37	2079
8	810.94	405.47	162.19	81.09	2062
9	506.96	253.48	101.39	50.70	2100
10	604.57	302.29	120.91	60.46	2154
11	127.18	63.59	25.44	12.72	2130
12	337.51	168.75	67.50	33.75	2067
13	198.37	99.18	39.67	19.84	1990
14	1252.89	345.26	250.58	125.29	1925
15	189.02	94.51	37.80	18.90	2181
16	401.51	200.76	80.30	40.15	2086
17	293.77	146.88	58.75	29.38	2079
18	67.57	33.78	13.51	6.76	2068
19	810.96	405.48	162.19	81.10	2105
20	91.65	45.82	18.33	9.16	2122
21	147.52	73.76	29.50	14.75	2064
22	59.13	29.57	11.83	5.91	2098

plot no	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/h)	BGC/ha(ton)	Altitude
23	627.91	313.95	125.58	62.79	1973
24	107.49	53.74	21.50	10.75	1928
25	379.93	189.97	75.99	37.99	1904
26	536.88	268.44	107.38	53.69	1922
27	79.30	39.65	15.86	7.93	2086
28	499.78	249.89	99.96	49.98	2140
29	69.83	34.92	13.97	6.98	2008
30	903.57	451.79	180.71	90.36	1902
31	497.57	248.79	99.51	49.76	1908
32	35.56	17.78	7.11	3.56	2164
33	123.35	61.68	24.67	12.34	2087
34	888.37	444.19	177.67	88.84	2014
35	454.58	227.29	90.92	45.46	2007
36	389.56	194.78	77.91	38.96	2150
37	241.62	70.55	48.32	24.16	1927
38	164.94	82.47	32.99	16.49	2143
39	195.65	97.83	39.13	19.57	2124
40	485.86	242.93	97.17	48.59	2052
41	390.90	195.45	78.18	39.09	2003
42	588.61	294.30	117.72	58.86	1926
43	307.45	153.72	61.49	30.74	1981
44	471.99	236.00	94.40	47.20	1996
45	773.47	386.74	154.69	77.35	1909
46	328.96	164.48	65.79	32.90	2153
47	441.93	220.97	88.39	44.19	2139
48	33.15	16.58	6.63	3.32	2055
49	586.97	293.49	117.39	58.70	1975
50	1545.40	772.70	309.08	154.54	2095
51	47.49	23.74	9.50	4.75	2014
52	141.94	70.97	28.39	14.19	2072
53	766.11	383.06	153.22	76.61	2004
54	79.53	39.77	15.91	7.95	2044
55	1075.21	296.30	215.04	107.52	1991
56	619.77	309.89	123.95	61.98	2035
57	462.13	231.07	92.43	46.21	2129
58	386.28	193.14	77.26	38.63	2141
59	99.97	49.98	19.99	10.00	1936

APPENDICE 3.Analyzed data for each sample plots with higher strata.

plot no	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/h)	BGC/ha(ton)	Altitude
1	922.35	461.17	184.47	92.23	2219
2	254.12	127.06	50.82	25.41	2252
3	426.29	213.14	85.26	42.63	2323
4	42.28	21.14	8.46	4.23	2306
5	436.83	218.42	87.37	43.68	2238
6	216.10	108.05	43.22	21.61	2226
7	500.52	250.26	100.10	50.05	2236
8	166.01	83.00	33.20	16.60	2251
9	63.59	31.79	12.72	6.36	2206
10	248.65	124.32	49.73	24.86	2224
11	2276.43	1138.22	455.29	227.64	2321
12	466.58	233.29	93.32	46.66	2344
13	2110.45	1055.22	422.09	211.04	2379
14	294.44	147.22	58.89	29.44	2189
15	1098.84	549.42	219.77	109.88	2231
16	567.53	283.77	113.51	56.75	2290
17	552.15	276.07	110.43	55.21	2227
18	1288.76	644.38	257.75	128.88	2253
19	431.09	215.55	86.22	43.11	2208
20	358.51	179.26	71.70	35.85	2554
21	150.63	75.32	30.13	15.06	2531
22	486.36	243.18	97.27	48.64	2486
23	233.21	116.60	46.64	23.32	2477
24	343.53	171.77	68.71	34.35	2373
25	395.24	197.62	79.05	39.52	2273
26	60.42	30.21	12.08	6.04	2287
27	2394.07	1197.04	478.81	239.41	2227
28	203.27	101.64	40.65	20.33	2253
29	2249.38	1124.69	449.88	224.94	2457
30	847.88	423.94	169.58	84.79	2461
31	80.60	40.30	16.12	8.06	2391
32	131.41	65.71	26.28	13.14	2312

plot no	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/h)	BGC/ha(ton)	Altitude
33	233.88	116.94	46.78	23.39	2236
34	65.67	32.84	13.13	6.57	2226
35	486.36	243.18	97.27	48.64	2504
36	167.09	83.55	33.42	16.71	2470
37	454.31	227.16	90.86	45.43	2237
38	298.40	149.20	59.68	29.84	2270
39	1020.25	510.13	204.05	102.03	2274
40	486.90	243.45	97.38	48.69	2293
41	54.47	27.23	10.89	5.45	2210
42	91.55	45.78	18.31	9.16	2212
43	65.67	32.84	13.13	6.57	2224
44	1080.02	540.01	216.00	108.00	2311
45	562.32	281.16	112.46	56.23	2327

APPENDICE 4. Woody plant species frequency at lower forest strata (1365-1887 m.a.s.l).

Tree Code	Species Name	Family	Local name	Frequency	Wood density (g/cm^3)
LST1	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayii	9	0.676
LST2	Euphorbia abyssinica Gmel.	Euphorbiaceae	Adaamii	2	0.612
LST3	*Millettia ferruginea* Bak.	Fabaceae	Askraa	74	0.667
LST4	*Syzygium guineense DC.*	Myrtaceae	Baddeessa	21	0.61
LST5	*Olea welwitschii* Gilg & Schellenb.	Oleaceae	Bayaa	3	0.65
LST6	*Sapium ellipticum Pax*	Euphorbiaceae	Bosoqa	4	0.612
LST7	*Schefflera abyssinica Harms*	Araliaceae	Bottoo	7	0.276
LST8	*Coffea arabica L.*	Rubiaceae	Buna	73	0.62
LST9	Calpurina aurea (Ait.) Benth	Fabaceae	Ceekaa	16	0.612
LST10	Ficus thoningi Blume	Moraceae	Dambii	12	0.612
LST11	*Vernonia amygdalina Del.*	Asteraceae	Eebicha	9	0.413
LST12	*Dracaena afromontanaMildbr.*	Dracaenaceae	Eemoo	62	0.413
LST13	*Olea capensis L.*	Oleaceae	Gajaa	51	0.612
LST14	*Vepris dainellii* Kokwaro	Rutaceae	Hadheessa	2	0.612
LST15	Byttneria catalpitiolata Jacq.	Sterculiacea	Halalee	15	0.55
LST16	Albizia gummifera (J.F.Gumel.)	Fabacea	Hambabes a	6	0.51
LST17	*Ficus sur* Forssk.	Moraceae	Harbuu	29	0.428

Tree Code	Species Name	Family	Local name	Frequency	Wood density (g/cm^3)
LST18	*Polyscias fulva* Harms	Araliaceae	Kariyoo	13	0.257
LST19	*Maytenus gracilipes* Exell	Celastraceae	Kombolcha	4	0.62
LST20	*Bersama abyssinica* Fresen	Melianthaceae	Lolchiisaa	17	0.671
LST21	*Diospyros abyssinica* F. White	Ebenaceae	Lookoo	3	0.758
LST22	*Croton macrostachyus* Del.	Euphorbiaceae	Makkanisa	39	0.479
LST23	Phoenix reclinata Jacq.	Arecaceae	Me'exii	43	0.612
LST24	*Teclea nobilis Del.*	Rutaceae	Mixirii	15	0.612
LST25	*Canthium oligocarpum* Hiern	Rubiaceae	Mixoo	16	0.715
LST26	*Prunus africana* Kalkm.	Rosaceae	Oomoo	3	0.685
LST27	*Trema orientalis Bl.*	Ulmaceae	Qahee	44	0.612
LST28	*Pouteria adolfi-friederici* Baehni	Sapotaceae	Qararoo	1	0.43
LST29	Ficus vasta Forssk.	Moraceae	Qilxuu	2	0.612
LST30	Brucea antidysenterica J.F. Mil	Simaroubiaceae	Qomonyo	4	0.612
LST31	*Vernonia auriculifera* Hiern.	Asteraceae	Reejjii	5	0.612
LST32	*Allophylus abyssinicus*	Sapindaceae	Se'oo	5	0.568
LST33	*Fagaropsis angloensis* Dale.	Rutaceae	Sigiluu	6	0.504
LST34	*Galiniera saxifraga* Bridson	Rubiaceae	Simararuu	16	0.612
LST35	*Ekebergia capensis* Sparrm	Meliaceae	Somboo	4	0.469

Tree Code	Species Name	Family	Local name	Frequency	Wood density (g/cm^3)
LST36	Pittosporum viridiflorum Sims	Pittosporaceae	Soolee	5	0.612
LST37	*Ehretia cymosa* Thonn.	Boraginaceae	Ulaagaa	85	0.612
LST38	*Cluasena anisata* Benth.	Rutaceae	Ulmaayee	3	0.612
LST39	*Cordia africana L.*	Boragnaceae	Waddessa	848	0.493
LST40	*Apodytes dimidiata* E. Mey. Ex Am	Icacinaceae	Wandabyo	5	0.61
LST41	Dracana steudneri Engl	Dracaenaceae	Yuddoo	35	0.612
Total				**759**	

APPENDICE 5. Woody plant species frequency at middle forest strata (1887-2186 m.a.s.l)

Tree Code	Species Name	Family	Local name (Afan oromo)	Frequency
MST1	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayii	13
MST2	Euphorbia abyssinica Gmel.	Euphorbiaceae	Adaamii	5
MST3	*Millettia ferruginea* Bak.	Fabaceae	Askraa	29
MST4	*Syzygium guineense DC.*	Myrtaceae	Baddeessa	85
MST5	*Olea welwitschii* Gilg & Schellenb.	Oleaceae	Bayaa	23
MST6	*Schefflera abyssinicaHarms*	Araliaceae	Bottoo	14
MST7	*Cffea arabica .*	Rubiaceae	Buna	26

Tree Code	Species Name	Family	Local name (Afan oromo)	Frequency
MST8	Calpurina aura (Ait.)Bent	Fabaceae	Ceekaa	1
MST9	Ficus thoingi Blume	Moraceae	Dambii	1
MST10	*Vernonia amygdalinaDel.*	Asteraceae	Eebicha	6
MST11	*Dracaena afromontana Mildbr.*	Dracaenaceae	Eemoo	83
MST12	*Olea capensis L.*	Dracaenaceae	Gajaa	96
MST13	*Vepris dainellii*Kokwaro	Rutaceae	Hadheessa	3
MST14	Byttneria catalpitiolata Jacq.	Sterculiacea	Halalee	5
MST15	Albizia gummifera (J.F.Gumel.) C.A.Sm	Fabacea	Hambabessa	11
MST16	*Ficus sur* Forssk.	Moraceae	Harbuu	28
MST17	*Polyscias fulva* Harms	Araliaceae	Kariyoo	19
MST18	*Maytenus gracilipes*Exell	Celastraceae	Kombolcha	16
MST19	*Bersama abyssinica* Fresen	Melianthaceae	Lolchiisaa	6
MST20	*Diospyros abyssinica* F. White	Ebenaceae	Lookoo	4
MST21	*Croton macrostachyus* Del.	Euphorbiaceae	Makkanniisa	34
MST22	Phoenix reclinata Jacq.	Arecaceae	Me'exii	6
MST23	*Teclea nobilis Del.*	Rutaceae	Mixirii	42
MST24	*Canthium oligocarpum* Hiern	Rubiaceae	Mixoo	40
MST25	*Prunus africana* Kalkm.	Rosaceae	Oomoo	3

Tree Code	Species Name	Family	Local name (Afan oromo)	Frequency
MST26	*Trema orientalis Bl.*	Ulmaceae	Qahee	46
MST27	*Pouteria adolfi-friederici* Baehni	Sapotaceae	Qararoo	33
MST28	Ficus vasta Forssk.	Moraceae	Qilxuu	2
MST29	Simaroubiaceae	Qomonyoo	Qomonyoo	3
MST30	*Vernonia auriculifera* Hiern.	Asteraceae	Reejjii	4
MST31	*Allophylus abyssinicus* (Hochst.) Radikofer	Sapindaceae	Se'oo	10
MST32	*Galiniera saxifraga* Bridson	Rubiaceae	Simararuu	3
MST33	Pittosporum viridiflorum Sims	Pittosporaceae	Soolee	19
MST34	*Ehretia cymosa* Thonn.	Boraginaceae	Ulaagaa	16
MST35	*Cluasena anisata* Benth.	Rutaceae	Ulmaayee	3
MST36	*Cordia africana L.*	Boragnaceae	Waddeessa	21
MST37	*Apodytes dimidiata* E. Mey. Ex Am.	Icacinaceae	Wandabiyoo	12
MST38	Dracaena steudneri Engl	Dracaenaceae	Yuddoo	7
Total				**778**

APPENDICE 6. Woody plant species frequency at higher forest strata (2681-2642 m.a.s.l)

Tree Code	Species Name	Family	Local name	Frequency
HST1	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayii	14
HST2	Flacourtia indica (Brm.f.) Merr	Flacourtiaceae	Akuukuu	3
HST3	*Millettia ferruginea* Bak.	Fabaceae	Askraa	6
HST4	*Syzygium guineense DC.*	Myrtaceae	Baddeessa	113
HST5	*Olea welwitschii* Gilg & Schellenb.	Oleaceae	Bayaa	11
HST6	*Schefflera abyssinica Harms*	Araliaceae	Bottoo	4
HST7	Calpurina aurea (Ait.) Benth	Fabaceae	Ceekaa	2
HST8	Ficus thoningi Blume	Moraceae	Dambii	2
HST9	*Vernonia amygdalina Del.*	Asteraceae	Eebicha	8
HST10	*Dracaena afromontana Mildbr.*	Dracaenaceae	Eemoo	99
HST11	*Olea capensis L.*	Oleaceae	Gajaa	50
HST12	Byttneria catalpitiolata Jacq.	Sterculiacea	Halalee	5
HST13	Albizia gummifera (J.F.Gumel.)	Fabacea	Hambabessa	2
HST14	*Ficus sur* Forssk.	Moraceae	Harbuu	9
HST15	*Polyscias fulva* Harms	Araliaceae	Kariyoo	2
HST16	*Maytenus gracilipes* Exell	Celastraceae	Kombolcha	5
HST17	*Bersama abyssinica* Fresen	Melianthaceae	Lolchiisaa	7
HST18	*Diospyros abyssinica* F. White	Ebenaceae	Lookoo	2
HST19	*Croton macrostachyus* Del.	Euphorbiaceae	Makkanniisa	24
HST20	*Teclea nobilis Del.*	Rutaceae	Mixirii	22

Tree Code	Species Name	Family	Local name	Frequency
HST21	*Canthium oligocarpum* Hiern	Rubiaceae	Mixoo	29
HST22	*Prunus africana* Kalkm.	Rosaceae	Oomoo	16
HST23	*Trema orientalis Bl.*	Ulmaceae	Qahee	23
HST24	*Pouteria adolfi-friederici* Baehni	Sapotaceae	Qararoo	18
HST25	Simaroubiaceae	Qomonyoo	Qomonyoo	3
HST26	*Vernonia auriculifera* Hiern.	Asteraceae	Reejjii	4
HST27	*Allophylus abyssinicus* (Hochst.)	Sapindaceae	Se'oo	1
HST28	*Fagaropsis angloensis* Dale.	Rutaceae	Sigluu	1
HST29	Pittosporum viridiflorum Sims	Pittosporaceae	Soolee	3
HST30	*Ehretia cymosa* Thonn.	Boraginaceae	Ulaagaa	1
HST31	*Cordia africana L.*	Boragnaceae	Waddeessa	1
HST32	*Apodytes dimidiata* E. Mey.	Icacinaceae	Wandabiyo	26
Total				**516**

APPENDICE 7. Woody plant species frequency at lower forest strata (1365-1887 m).

Tree Code	Family	Local name (Afan oromo)	Frequency(no.)
LST1	Myrsinaceae	Abbayii	9
LST2	Euphorbiaceae	Adaamii	2
LST3	Fabaceae	Askraa	74

Tree Code	Family	Local name (Afan oromo)	Frequency(no.)
LST4	Myrtaceae	Baddeessa	21
LST5	Oleaceae	Bayaa	3
LST6	Euphorbiaceae	Bosoqa	4
LST7	Araliaceae	Bottoo	7
LST8	Rubiaceae	Buna	73
LST9	Fabaceae	Ceekaa	16
LST10	Moraceae	Dambii	12
LST11	Asteraceae	Eebicha	9
LST12	Dracaenaceae	Eemoo	62
LST13	Oleaceae	Gajaa	51
LST14	Rutaceae	Hadheessa	2
LST15	Sterculiacea	Halalee	15
LST16	Fabacea	Hambabessa	6
LST17	Moraceae	Harbuu	29
LST18	Araliaceae	Kariyoo	13
LST19	Celastraceae	Kombolcha	4
LST20	Melianthaceae	Lolchiisaa	17
LST21	Ebenaceae	Lookoo	3
LST22	Euphorbiaceae	Makkanniisa	39
LST23	Arecaceae	Me'exii	43
LST24	Rutaceae	Mixirii	15

Tree Code	Family	Local name (Afan oromo)	Frequency(no.)
LST25	Rubiaceae	Mixoo	16
LST26	Rosaceae	Oomoo	3
LST27	Ulmaceae	Qahee	44
LST28	Sapotaceae	Qararoo	1
LST29	Moraceae	Qilxuu	2
LST30	Simaroubiaceae	Qomonyoo	4
LST31	Asteraceae	Reejjii	5
LST32	Sapindaceae	Se'oo	5
LST33	Rutaceae	Sigiluu	6
LST34	Rubiaceae	Simararuu	16
LST35	Meliaceae	Somboo	4
LST36	Pittosporaceae	Soolee	5
LST37	Boraginaceae	Ulaagaa	28
LST38	Rutaceae	Ulmaayee	3
LST39	Boragnaceae	Waddeessa	48
LST40	Icacinaceae	Wandabiyo	5
LST41	Dracaenaceae	Yuddoo	35
Total			**759**

APPENDICE 8. Woody plant species frequency at middle forest strata(1887-2186 m.a.s.l)

Tree Code	Family	Local name	Frequency(no.)
MST1	Myrsinaceae	Abbayii	13
MST2	Euphorbiaceae	Adaamii	5
MST3	Fabaceae	Askraa	29
MST4	Myrtaceae	Baddeessa	85
MST5	Oleaceae	Bayaa	23
MST6	Araliaceae	Bottoo	14
MST7	Rubiaceae	Buna	26
MST8	Fabaceae	Ceekaa	1
MST9	Moraceae	Dambii	1
MST10	Asteraceae	Eebicha	6
MST11	Dracaenaceae	Eemoo	83
MST12	Dracaenaceae	Gajaa	96
MST13	Rutaceae	Hadheessa	3
MST14	Sterculiacea	Halalee	5
MST15	Fabacea	Hambabessa	11
MST16	Moraceae	Harbuu	28
MST17	Araliaceae	Kariyoo	19
MST18	Celastraceae	Kombolcha	16
MST19	Melianthaceae	Lolchiisaa	6

Tree Code	Family	Local name	Frequency(no.)
MST20	Ebenaceae	Lookoo	4
MST21	Euphorbiaceae	Makkanniisa	34
MST22	Arecaceae	Me'exii	6
MST23	Rutaceae	Mixirii	42
MST24	Rubiaceae	Mixoo	40
MST25	Rosaceae	Oomoo	3
MST26	Ulmaceae	Qahee	46
MST27	Sapotaceae	Qararoo	33
MST28	Moraceae	Qilxuu	2
MST29	Qomonyoo	Qomonyoo	3
MST30	Asteraceae	Reejjii	4
MST31	Sapindaceae	Se'oo	10
MST32	Rubiaceae	Simararuu	3
MST33	Pittosporaceae	Soolee	19
MST34	Boraginaceae	Ulaagaa	16
MST35	Rutaceae	Ulmaayee	3
MST36	Boragnaceae	Waddeessa	21
MST37	Icacinaceae	Wandabiyoo	12
MST38	Dracaenaceae	Yuddoo	7
Total			**778**

APPENDICE 9. Woody plant species frequency at higher forest strata (2681-2642 m.a.s.l)

Tree Code	Family	Local name	Frequency(no.)
HST1	Myrsinaceae	Abbayii	14
HST2	Flacourtiaceae	Akuukuu	3
HST3	Fabaceae	Askraa	6
HST4	Myrtaceae	Baddeessa	113
HST5	Oleaceae	Bayaa	11
HST6	Araliaceae	Bottoo	4
HST7	Fabaceae	Ceekaa	2
HST8	Moraceae	Dambii	2
HST9	Asteraceae	Eebicha	8
HST10	Dracaenaceae	Eemoo	99
HST11	Oleaceae	Gajaa	50
HST12	Sterculiacea	Halalee	5
HST13	Fabacea	Hambabessa	2
HST14	Moraceae	Harbuu	9
HST15	Araliaceae	Kariyoo	2
HST16	Celastraceae	Kombolcha	5
HST17	Melianthaceae	Lolchiisaa	7
HST18	Ebenaceae	Lookoo	2
HST19	Euphorbiaceae	Makkanniisa	24
HST20	Rutaceae	Mixirii	22
HST21	Rubiaceae	Mixoo	29

Tree Code	Family	Local name	Frequency(no.)
HST22	Rosaceae	Oomoo	16
HST23	Ulmaceae	Qahee	23
HST24	Sapotaceae	Qararoo	18
HST25	Qomonyoo	Qomonyoo	3
HST26	Asteraceae	Reejjii	4
HST27	Sapindaceae	Se'oo	1
HST28	Rutaceae	Sigluu	1
HST29	Pittosporaceae	Soolee	3
HST30	Boraginaceae	Ulaagaa	1
HST31	Boragnaceae	Waddeessa	1
HST32	Icacinaceae	Wandabiyo	26
Total			**516**