CARBON STOCK ESTIMATION ALONG ALTITUDINAL GRADIENT IN SEKELE-MARIAM DRY EVERGREEN MONTANE FOREST, NORTH-WESTERN ETHIOPIA

M.Sc. THESIS

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WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCE, WONDO GENET, ETHIOPIA

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A THESIS SUBMITTED TO THE SCHOOL OF FORESTRY, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCE, SCHOOL OF GRADUATE STUDIES

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IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE

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MASTER OF SCIENCES IN FOREST RESOURCE ASSESSMENT AND MONITORING

OCTOBER, 2018

Approval Sheet 1

This is to certify that the thesis entitled “Carbon Stock estimation along Altitudinal Gradient in Sekele-Mariam Dry Evergreen Montane Forest, North-Western Ethiopia’’ submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Forest Resource Assessment and Monitoring of the Graduate Program of the School of forestry, Wondo Genet College of Forestry and Natural Resources carried out by Asersie Mekonnen Aregie Id. No MSc/FRAM/R002/09, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

| | | |
|---|---|---|
| Dr. Motuma Tolera | --------------------- | ------------------------- |
| Name of Major Advisor | Signature | Date |

Approval Sheet 2

We, the undersigned, members of the Board of Examiners of the final open defense by Asersie Mekonnen have read and evaluated his thesis entitled "Carbon Stock Estimation along Altitudinal Gradient in Sekele-Mariam Dry Evergreen Montane Forest, North-Western Ethiopia' and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science.

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Dedication

To my sister, Sewnet Mekonnen and her husband Tizazu Anemaw

Acronyms and Abbreviations

| | |
|---|---|
| AGB | Above-Ground Biomass |
| asl | above sea level |
| BGB | Below-Ground Biomass |
| C | Carbon |
| $CO_2$ | Carbon Dioxide |
| CRGE | Climate Resilient Green Economy |
| DBH | Diameter at Beast Height |
| EBI | Ethiopian Biodiversity Institute |
| ENMA | Ethiopian National Meteorological Agency |
| FAO | Food and Agriculture Organization of the United Nations |
| GHGs | Greenhouse Gases |
| Gt: | Giga ton |
| ha | hectare |
| IBC | Institute of Biodiversity Conservation |
| IPCC | Intergovernmental Panel on Climate Change |
| MEFCC | Ministry of Environment Forest and Climate Change |
| MRV | Measuring Reporting and Verification |
| OFLP | Oromia Forested Landscape Program |
| REDD+ | Reducing Emission from Deforestation and Forest Degradation and Conservation of forests, Sustainable forest management, Enhancing forest carbon stocks |
| SOC | Soil Organic Carbon |
| UNFCCC | United Nation Framework Convention on Climate Change |
| WBISPP | Woody Biomass Inventory Strategic Planning Project |

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Abstract

*Nowadays carbon stock estimation has gained greater attention for environmental and economical (carbon market) perspectives. Forest play an important role in climate change mitigation through sequestering and storing carbon from the atmosphere. Carbon stock estimation enables to understand the current status of carbon stocks and to deduce its changes in the future. However, studies on carbon stock and factors that affect carbon stock have not been well studied. Hence, the aim of this study was to estimate carbon stock of Sekele-Mariam dry Afromontane forest, North Western Ethiopia. A systematic random sampling was employed to collect dendrometric data (DBH and height), litter and soil. A total of 60 plots with 50m *50m size each with nested plot (1m*1m) size for litter and soil data collection were laid on the transect line. Diameter at breast height of trees with diameter ≥ 5cm and height were measured. Carbon stock was estimated using allometric equation and soil organic carbon was analyzed in the laboratory following Walkley Black method. The result of this study revealed that Sekele-Mariam forest had stored a total of 185.71 ton carbon/ha within its aboveground, belowground, litter biomasses and soil. The higher carbon stock in all carbon pools was found at the higher altitudinal range (2395-2460 m a.s.l.). The variation of carbon pools between altitudinal gradient was not significant. Sekele-Mariam forest had smaller stock of carbon in its biomass and therefore, better forest conservation and management are the best strategy to enhance the carbon stock potential of the study area.*

**Key Words**: Biomass carbon stock, Carbon sequestration, Climate change, Soil organic Carbon, Sekele-Mariam forest

# 1. INTRODUCTION

## 1.1. Background

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change (Gibbs *et al*., 2007). The biomass and carbon stocks in forests are important indicators of forests' productive capacities, energy potential, and capacity to sequester carbon (FAO, 2015). The role of forests as terrestrial sinks and sources of carbon dioxide has received increasing attention since the adoption of the 1997 Kyoto Protocol to the United Nations Framework convention on Climate Change (FAO, 2015). The world's forests store 289 Gt of carbon in their biomass (FAO, 2010). However, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005-2010 globally, due to forest cover change (FAO, 2010). The carbon stored in the aboveground living biomass of trees is typically the largest pool and it is directly influenced by deforestation and forest degradation (Hairiah *et al*., 2011).

Ethiopia has one of the largest forest resources in the horn of Africa (Moges and Tenkir, 2014). Ethiopia's Forest resources supply most of the wood products used with in the country, as well as a large volume of diverse non-timber forest product (Moges *et al*., 2010). The forest resources play significant roles in the livelihoods of the community and the national economy at large. Their direct roles include provisions of energy, construction wood, poles, timber and non-timber forest products (NTFPs) that are highly prized for their food, medicinal and commercial values (Asfaw *et al*., 2015). Moreover, forests play a vital role in climate change mitigation through sequestering carbon dioxide from the atmosphere. Ethiopia's forest resources have store 219 million ton of carbon in their living biomass (FA0, 2010). Despite their economic and environmental value, the countries' forests resources are under threat. Deforestation and forest degradation activities are the main sources of forest carbon stock loss and GHGs emission. According to CRGE (2011), 37% of the total greenhouse gas emission in the country comes from forestry due to anthropogenic activities (deforestation and forest degradation). According to FAO recent report, Ethiopia loses more than 73,000 ha of forest on average annually. Currently the country is implementing a robust system for monitoring and measuring carbon emissions and removals to enable the country to report and verify actions on deforestation and forest degradation and other activities aiming to conserve, sustainably manage and increase forest carbon stocks (OFLP, 2017).

Forest carbon stock is highly variable due to various factors and processes operating in the systems. Forest carbon stock is affected by different environmental factors such as: altitude, aspect and slope by affecting the distribution of tree species (Feyissa *et al.*, 2013).

## 1.2. Statement of the Problem

Dry Afromontane forest stores a huge amount of aboveground carbon compared to other terrestrial ecosystems in Ethiopia (Lemenih, 2015). Despite their immense carbon sequestration potential most forests of the country lacks carbon stock data/ information. Nowadays, estimates of carbon stock in forests is critical in carbon credit programs-quantities of assimilated carbon claimed against $CO_2$ emission. Sekele-Mariam forest is one of the dry Afromontane forest in West Gojjam Zone North-Western Ethiopia and its carbon stock potential is not studied yet. Altitude is one of the key environmental factor that had significant impact on carbon pools (aboveground, belowground, litter and soil) (Girma *et al.*,2014). However, researches on the effect of altitude on carbon stocks of a forest is limited in the study area and Ethiopia at large.

### 1.3. Objectives

#### 1.3.1. General Objective

The general objective of this study was to determine the carbon stocks of Sekele-Mariam dry evergreen montane forest along altitudinal gradient in North-Western Ethiopia

#### 1.3.2. Specific Objectives

Specifically, this study aimed:

- To estimate biomass carbon stock along altitudinal gradient of Sekele-Mariam forest
- To estimate soil organic carbon along altitudinal gradient in the study area
- To compare forest carbon stocks along altitudinal gradient in the study area

### 1.4. Research Questions

- How much carbon is stored in Sekele- Mariam forest?
- Is carbon stock affected by altitude?

### 1.5. Significance of the Study

Reducing Emissions from Deforestation and Forest Degradation, and enhancing forest carbon stocks (REDD+) has become one of the global instruments to curb greenhouse gas emissions and to mitigate climate change (OFLP, 2017). As Ethiopia is participating in REDD+ activities under UNFCCC estimating forest sector GHGs emissions by sources, removal by sink and forest carbon stocks are an important issue for measuring, reporting and verifying (MRV) the forest carbon. Measuring the current state of forest carbon stocks is necessary for analysis of alternate management options and to evaluate carbon sequestration potential of forests.

Thus, this study will provide baseline information on the carbon stock potential of Sekele-Mariam forest and hence serve as to understand the carbon stock dynamics of the forest in the future. Moreover, it generates information on the relationship between carbon stock and altitudinal gradient in the study area. Forestry experts, researchers and development agents, (DAs) will be the primary users to design forest management plans and monitoring purpose. Besides the information will serve as an input for the national MRV program.

# 2. LITERATURE REVIEW

## 2.1. Terrestrial Carbon Stocks

Terrestrial carbon stock is the carbon stored in terrestrial ecosystems, as living or dead plant biomass (aboveground and belowground) and in the soil, along with usually negligible quantities as animal biomass (Hairiah *et al*., 2011). The woody vegetation builds up carbon in their woody stem and roots. The terrestrial ecosystems of the world stores 2500 Gt of carbon in its biomass, the net uptake by terrestrial ecosystems is 0.7 Gt C yr-1 is small relative to the flux; about 60 Gt C yr-1 is taken up by vegetation but almost the same amount is released by respiration and fire. There has been a drastic increase in the atmospheric concentration of $CO_2$. In the last 200 years, the burning of fossil fuels and deforestation has raised the amount of atmospheric $CO_2$ from 0.028 to 0.035% and the concentration is continuing to increasing (Hairiah *et al*., 2011). The world's forests store an estimated 296 Gt of carbon in both above- and below-ground biomass, which contains almost half of the total carbon stored in forests. The highest densities of carbon are found in forests of south America and Western and central Africa, storing about 120 tons of carbon per hectare in the living biomass alone. The global average is close to 75 tons per hectare. over the past 25 years the carbon stocks in forest biomass decreased by almost 17.4 Gt, equivalent to a reduction of 697 million tons per year or about 2.5 Gt of carbon dioxide. The reduction is mainly driven by carbon stock changes as a result of converting forest lands to agriculture, settlements and degradation of forest land (FAO, 2015).

## 2.2. The Role of Forest on Climate Change Mitigation

Forest play a crucial role in sequestering atmospheric $CO_2$ emitted from different source and maintain global carbon balance. Global forests capture and store significant amounts of $CO_2$ through photosynthesis. Forests represent a massive carbon reservoir on the planet storing over 4,500 G tons of carbon. However, GHGs emissions due to deforestation and forest degradation are the second-largest representing about 15-17% of the global GHG emissions after industry sector (Moges and Tenkir, 2014). The role of forest as carbon sink can be much more important regionally than globally (Lehtonen, 2005). The forest resources of Ethiopia sequester 44 times the amount of $CO_2$ and 478 times the $CO_2$ that is being released by burning the woody biomass stocks as fuels released from clearing for agriculture (WBISPP, 2005). The WBISPP's (2005) carbon stock assessment resulted in an estimate of 2,683,127 tons of carbon in woody biomass stock across the country. However, Moges *et al*. (2010) indicated that the WBISPP compared to other small scale studies, likely underestimate carbon density by a factor of two and suggest further classifying forest types for a more accurate estimate. For higher accuracy and increased utility at management level, finer scale of vegetation classification and make estimates at this scale. For instance, nine vegetation types are distinguished in Ethiopia: Afro-alpine and Sub-Afro Alpine, Dry Evergreen Montane Forest, Moist Evergreen Montane Forest, Acacia- Commiphora (small leaved) Woodland, Combretum-Terminalia (broad leaved) Woodland, Lowland Dry Forest, Wetland (swamps, lakes, rivers and riparian) Vegetation, Evergreen Scurb Vegetation and Lowland Semi Desert and desert Vegetation (Tilahun *et al*.,1996; CSE,1997; Woldu *et al.* ,1999; IBC, 2005).

### 2.3. Carbon pools in forest ecosystems

Forests are the largest terrestrial reservoir for atmospheric carbon because they remove $CO_2$ from the atmosphere and store it in the soil litter, trees and other organic matter. (Mwakisunga and. Majule, 2012). Forest ecosystems are generally recognized as significant stock of carbon. The carbon pools in forest ecosystems comprises of carbon stored in the living trees aboveground and belowground (roots); in dead matter including standing dead trees, down woody debris and litter; in non-tree understory vegetation and in the soil organic matter. The total carbon stock of a forest ecosystem is the sum of carbon stocks in the different pools expressed in tons or kilograms per unit area (IPCC, 2006). The selection of carbon pools depends on several factors, including expected rate of change, magnitude and direction of the change, availability and accuracy of methods to quantify change, and cost to measure. Generally, a carbon pool may be neglected if it is considered "insignificant." Insignificance of a pool is determined following test of significance procedure described in the various standards (the accounting methodologies adopted by a project). For instance, in Clean Development Mechanism (CDM) project, a pool is considered 'insignificant' when its carbon stock or emission reduction is < 5% of the total $CO_2$ e benefits expected to be generated by a project. This is also more or less the same for REDD+ project that follows the Verified Carbon Standard (VCS) methodology (Lemenih, 2015). Thus, all pools that are expected to decrease significantly due to activities must be measured and monitored (Pearson, 2007).

#### 2.3.1. Aboveground Biomass

Aboveground Biomass refers to all biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage

(IPCC, 2006). It is a critical component of the carbon cycle in forest ecosystems, providing both short- and long-term carbon sequestration (Creighton, Litton and Kauffman, 2008). The carbon stock in aboveground tree biomass is estimated from measurements conducted in sample plots. Tree measurements in sample plots are converted into tree biomass either by using allometric equations (tree biomass equations) or by using volume equations in combination with wood density and biomass expansion factors (UNFCCC, 2015). The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation. Thus, estimating aboveground forest biomass carbon is the crucial step in quantifying carbon stocks and fluxes (Hairiah *et al.*, 2011).

### 2.3.2. Belowground Biomass

The belowground biomass comprises living and dead roots, soil fauna and the microbial community. There is also a large pool of organic C in various forms of humus and other soil organic C pools. It is always derived from the AGC. Root biomass is estimated to be 20% of the aboveground forest carbon stocks for most forest types Hairiah *et al.*, 2011). Belowground biomass is estimated mostly using a suitable root-shoot ratio (also established as default for global applications). Root-shoot (R-S) ratio is a factor that expresses root biomass in relation to above ground biomass. Belowground biomass is difficult and time-consuming to measure and methods are generally not standardized. Since measurements in the field are very costly and require huge human effort, it is good practice to apply root-to-shoot ratios or allometric equations.

### 2.3.3. Deadwood Biomass

It comprises all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots down to a diameter of 2mm, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country (IPCC, 2006).

### 2.3.4. Litter Biomass

Litter includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2mm) and less than the minimum diameter chosen for dead wood (e.g., 10cm), lying dead, in various states of decomposition above or within the mineral or organic soil (IPCC, 2006). Litter carbon is dependent on forest type and stand age. It is an important carbon pool especially in older forests. Litter is collected and weighted on up to 4 small subplots and a well-mixed sub-sample of taken in order to determine the dry-to-wet matter ratio (Lackmann, 2011).

### 2.3.5. Soil Organic Carbon

Soil plays an important role in carbon sequestration by increasing soil organic carbon. Globally, the soil carbon stock is nearly three times the amount in the AGB and about twice as large as the carbon stock of the atmosphere (Mäkipää *et al.*, 2012). Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots of less than 2mm (or other value chosen by the country as diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically (UNFCCC, 2015). The largest carbon pool is found in the soil (Hairiah *et al*.,2011). The global soil carbon pool amounts to 2500 Gt (Lal, 2004). However, the content of carbon in the soil has been decreased mainly due to soil degradation, including accelerated erosion and mineralization, and land use change, and has amounted to 78+/- 12 Gt since 1850 (FAO, 2008). In order to calculate soil organic carbon three types of variables must be measured: soil depth, soil bulk density (calculated from the oven-dry weight of soil from a known volume of sampled material), and concentrations of organic carbon within the sample. Concentrations of soil chemicals generally are measured in air-dried soils, while bulk density must be measured in oven-dried soils to 105 o C (Pearson, 2007).

## 2.4. Forest Carbon Stock in Ethiopia

Ethiopia is a country with great geographic diversity with wide range of altitudinal, physiographic variations. and macro- and micro-climatic variability. The altitude ranges from 116 meters below sea level in the Danakil Depression in Afar national regional state to the highest peak of 4,620 meters above sea level on Mount Ras Dashen in Amhara national regional state. As a result, the country endowed with diverse plant species (EBI, 2014). According to Friis *et al.* (2010), there are twelve major vegetation types in Ethiopia, some of these divided into subtypes: (1) Desert and semi-desert scrubland (DSS); (2) *Acacia-Commiphora* woodland and bushland (ACB); (3) Wooded grassland of the Western Gambella Region (WG); (4) *Combretum Terminalia* woodland and wooded grassland (CTW); (5) Dry evergreen Afromontane Forest and grassland complex (DAF); (6) Moist evergreen Afromontane Forest (MAF); (7) Transitional Rain Forest (TRF); (8*)* Ericaceous Belt (EB); (9) Afro-Alpine belt (AA); (10) Riverine Vegetation (RV); (11) Freshwater Lakes, lakeshores, swamps and floodplains Vegetation (FLV); and (12) Salt-water Lakes, lake shores, salt marshes and pan Vegetation (SLV). All these vegetation types have different size, management and disturbance level and hence their carbon storage potentials also varied. There is variation among different author on estimates of carbon stock in the country. According to national level forest biomass carbon stock estimate, the carbon stock of Ethiopia is 153 million tons (Houghton,1999) and 867 million tons (Gibbs and Brown 2007a,). For consistent and higher accuracy in estimation of carbon stock, scholars have been suggested to use finer scale of aforementioned vegetation classification.

Table 1: Mean aboveground carbon stock per biomes in forests of Ethiopia

| Biomes | Aboveground biomass (ton/ha) |
|---|---|
| Moist Afromontane | 200 |
| Dry Afromontane | 113 |
| Combretum-Terminalia | 65 |
| Acacia-Commiphora | 55 |

Source: (EFRL, 2017)

### 2.5. Dry Evergreen Montane Forest and Grassland Complex Vegetation in Ethiopia

Dry evergreen montane forest is a very complex vegetation type occurring in an altitudinal range of 1500-2700 m, with average annual temperature and rainfall of 14-25° C and 700-1100 mm, respectively (Friis, 1992). It covers much of the highland areas and mountainous chains of Oromia, Amhara, Tigray and Southern Nations Nationalities and Peoples (SNNP) regions. It is mainly of two types: conifer forest and mixed forest type. This vegetation is characterized by *Olea europea* subsp. *africana, Juniperus procera, Celtis kraussiana, Euphorbia amplipylla, Dracaena spp. Carissa edulis, Rosa abyssinca, Mimusops kummel, Ekebergia capensis*, etc. These includes small to medium size trees, though some provenances *of J. procerea* can get very big and some others remain small. This vegetation type is associated with highland Bamboo (*Arundinaria alpina*) and extensive areas of grassland rich in species including many legumes. The most important genera are *Hyparhenia, Eragrotis, Panicum, Sporoblus, and Pennisetum* for the grasses and *Triflium, Eriosema, Crotalaria* for the legumes. These include a large number of endemics (Anonymous, 1992).

In terms of carbon stock, the dry afromontane forest is the largest carbon storehouse of all vegetation types in the country (Lemenih, 2015). Despite their huge storage of carbon, the dry evergreen montane forests are under severe threat to habitat conversion caused by deforestation for wood products (especially fuel wood extraction), fire, agricultural expansion and overgrazing (EBI. 2014).

### 2.6. Carbon Stock Estimation Methods

The IPCC Good Practice Guide (GPG) and Agriculture, Forestry and Other Land Use (AFOLU) guidelines present three general approaches for estimating emissions/removal of greenhouse gases, namely; Tier 1, using default values of forest biomass and forest mean annual increment from the IPCC emission factor database. Tier 2, using country specific data (i.e. collected within the national boundary), and by resolving forest biomass at finer scales through the delineation of more detailed strata. Tier 3, is a hybrid approach which uses actual inventories with repeated measurements of permanent plots to directly measure changes in forest biomass and/or uses well parameterized models in combination with plot data. Measuring the biomass of a tree is a tedious and time consuming task. Moreover, it is a destructive measurement. because of this reason, biomass equation which predicts the biomass of the tree from easily collected dendrometrical characteristics such as diameter or height have been developed (Crow ,1978; Perrsol, 1999). Quantifying the carbon stock of a forest ecosystem begins with estimating the biomass of its different species. Forest biomass can be an indicator of biological and economic productivity including the presence of wood (Brown *et al.*, 1989; Chave *et al.*, 2005). Direct and indirect methods are used to estimate the biomass of wood. Destructive methods directly measure the biomass by harvesting the tree and measuring the actual mass of each of its compartments, (e.g., roots, stem, branches and foliage). Indirect methods are attempts to estimate tree biomass by measuring variables that are more accessible and less time-consuming to assess (e.g., wood volume and gravity) (Peltier *et al*. 2007). The total amount of carbon stocks within a stratum, simply sum the carbon stocks in all measured pools. To convert tons of carbon to tons of carbon dioxide equivalence, simply multiply by the atomic weight difference between C and $CO_2$ (44/12).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Geographical and Topographic Location

Sekele-Mariam forest is located in Dembecha district, West Gojjam Zone of Amhara National Regional State, Ethiopia at about 350 km north of Addis Ababa. The forest lies between $10^0$ 35'- $10^0$37' N latitudes and $37^0$ 28' - 37 $^0$ 30 'E longitudes. The forest covers an area of 532.42 hectare. Sekele-Mariam forest is characterized by rugged terrain with an altitude ranges from 2259 m to 2460 m a.s.l. The study area is categorized under mid highlands locally known as ''Weyna Dega'' agro-climatic zone. and has unimodal rainfall distribution.

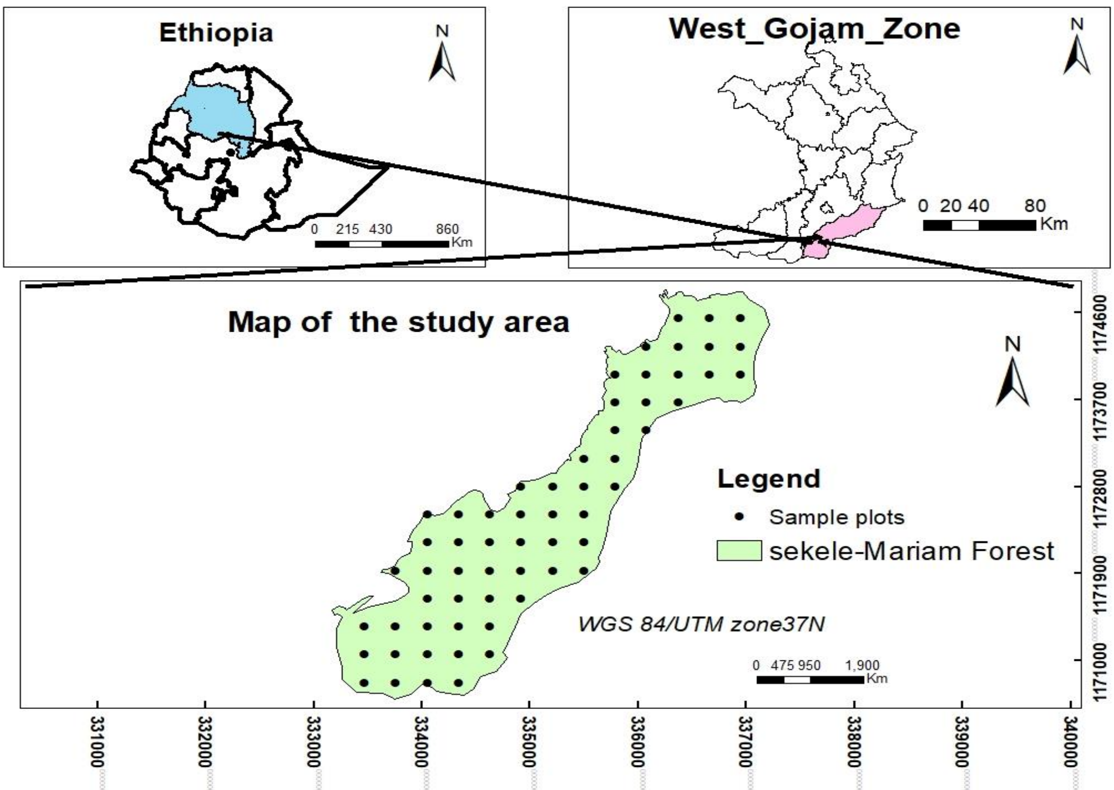


Figure 1: Map of Ethiopia showing West Gojam Zone and the study area (Sekele-Mariam forest)

### 3.1.2. Climate

Metrological data from 1986 -2016 obtained from Ethiopian National Meteorology Agency (ENMA) of Dembecha was extracted, analyzed and presented in climadiagram (Figure 2). The mean minimum and maximum temperature of the study area were 8.5 $^{0}$C and 29$^{0}$C respectively and had an average temperature of 18.5 $^{0}$C. The area received high amount of rainfall during keremt season (June, July, August and September). The average annual rainfall was 1368 mm and had unimodal rainfall distribution (ENMA, 2018).

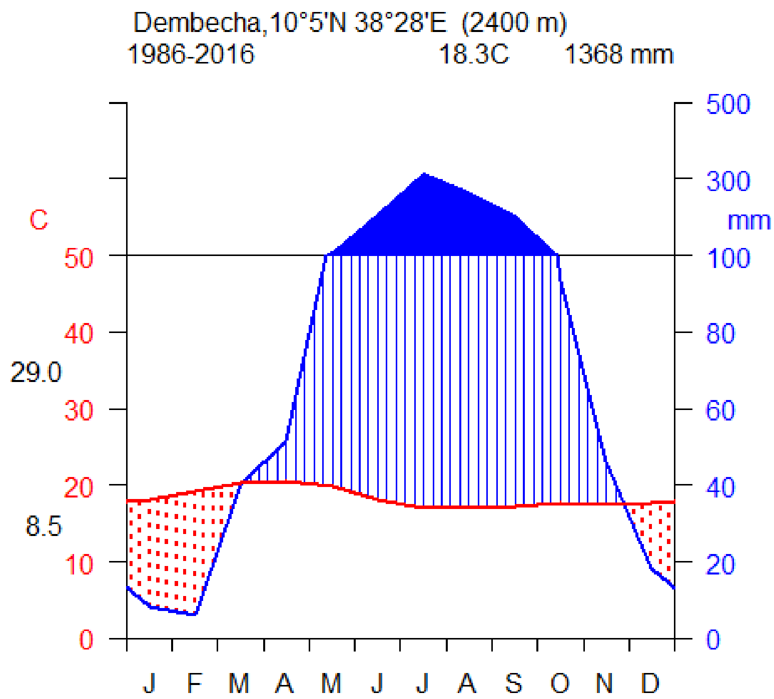


Figure 2 : Climate diagram of Dembecha (Southern part of Sekele-Mariam forest)

(Data source: ENMA, 2018)

### 3.1.3. Soil

According to Zerihun *et al*. (2018), the study area is dominated by Alisols type of soil. Moreover, Cambisols, Fluvisols, Leptosols, Vertisols and Nitisols are also found in the study area. The quaternary columnar flood basalts in the area are probably the source of the black soils as a result of intense weathering. Most of the study area is used for crop production and mixed farming.

### 3.1.4. Vegetation

Sekele-Mariam forest is categorized under dry evergreen montane forest of vegetation classification of Ethiopia (Woldu ,1999) and is characterized by *Croton, macrostachyus Albizia gummifera, Calpurnia aurea, Acacia abyssinica, Maytenus obscura Buddleia polystachy, Bersama abyssinica, Carissa spinarum, Nuxia congesta, Acacia lahai ,Clausena anisata ,Rosa abyssinica, ,Grewia ferruginea, Vernonia auriculifera , Pavetta abyssinica* among others.

## 3.2. Sampling design

### 3.2.1. Delineation and Stratification of the Study Area

The spatial boundaries of the study area were defined and geographic coordinates and elevation of the strata were taken using Geographical Positioning System (GPS) to generate the map of the study area. with the aid of GIS software (Q 2.2-GIS). Considering the topography of the forest the study area was stratified in to three different strata based on altitudinal variation as; lower altitude (2259-2326) considered as dry Weyna Dega; middle altitude (2327-2394) and higher altitude (2395-2460) a.s.l which is considered as wet Weyna Dega agro-climatic zone.

### 3.2.2. Sampling Techniques

The number of plots to be measured were determined using pragmatic approach (Woldemariam, 2015) and therefore, a total of 60 sample plots were sampled. Systematic transect sampling was employed and thus, four transect lines were laid with an interval of 200 m between each transect line and square sample plots with an area of 2500 $m^2$(50m*50m) each was designed along transect lines with 300 m gaps between each plots. Within the large plot (50m*50m) dendrometric parameters was measured. Moreover, nested plot of 1m*1m subplot for litter and soil sample were taken (Bhishma *et al*., 2010; Assaye, 2014).

## 3.3. Data Collection Methods

In each plot trees with ≥ 5 cm DBH were measured at 1.3 m above the ground since in carbon stock measurement the minimum diameter is often 5 cm DBH as recommended by IPCC; (2006) and Pearson; (2007). For inclined terrain DBH tree measurement at 1.3 m was taken on uphill position and for other anomalies such as forked trees measurement were taken following the standard methods recommended in Philip (1994) trees and forest measurement guideline. The DBH of trees/shrubs were measured using caliper and diameter tape and range finder was used for height measurement. Woody species with their vernacular name of the study was recorded in the species checklist.

### 3.3.1. Carbon Pools Considered and Measurement

#### 3.3.1.1. Aboveground Biomass Measurement

For aboveground biomass measurement, DBH at 1.3 m of each trees with ≥ 5 cm diameter in each sample plot was measured using caliper and diameter tape whereas rangefinder was used for height measurement. The biomass of each tree in all plots was calculated using allometric equations, defined as statistical relationship between key characteristic dimensions of trees that are fairly easy to measure, such as DBH or height, and other properties that are more difficult to assess (Bhishma *et al.*, 2010). In this study generalized allometric equations developed by Chave *et al*, (2014) was used hence the equation consists tree variables (trunk diameter, wood specific gravity and height) which are the most important predictors of tree biomass (Chave *et al*, 2005). This allometric equation was also used in the National Forest Inventory (NFI) of Ethiopia. The biomass was converted to units of carbon stock and carbon dioxide equivalent ($CO_2$ e) by multiplying by a carbon fraction of 0.47 and 3.67 respectively (IPCC ,2006). Species specific wood density value from World Agroforestry Centre also known as the International Centre for Research in Agroforestry (ICRAF) database and other sources were applied in this study. However, wood density value of some species did not available from the database and therefore, the average wood density of all species of Ethiopia which is 0.612 g/cm$^3$ (EFRL ,2017) was used (Appendix 2).

AGB= 0.0673*(WD*DBH^2*Ht) ^0.976 …………… … … (Equation 1)

Where,

AGB = Aboveground biomass (Kg)

WD = Wood density(g/cm$^3$)

DBH = diameter at breast height (cm)

Ht = Total height of the tree (m)

#### 3.3.1.2. Belowground Biomass Measurement

Belowground biomass was estimated using IPCC root –to- shoot ratio value of 0.26 for tropical dry forests (IPCC ,2006).

BGB = AGB × 0.26 …………………………………… (Equation 2)

Where, BGB is belowground biomass (Kg), AGB is aboveground biomass, 0.26 is conversion factor

#### 3.3.1.3. Litter Biomass Measurement

Samples of litter (dead leaves, twig) in sub-plot of 1 $m^2$ in size were established using 1m*1m sample frame and four sub- samples at the corner and one from the center of the plot were collected and fresh weight were recorded. Then after, composite sample in each plot were brought to Wondo Genet College of Forestry and Natural Resource soil laboratory. The litter sample were oven dried at 70 $^0$C for 24 hours to determine moisture content from which the total dry mass is calculated (Ullah and Al-Amin, 2012; Negash and Starr, 2015). The dried litter sample was further oven dried in the muffle furnace at a temperature of 550 $^0$C for 4 hours and then the sample was cooled in the desiccator for 10 minutes. According to Pearson *et al*., (2005), estimation of the amount of biomass in the litter is calculated as:

$$LB = \frac{Wfield}{A} * \left(\frac{Wsubsampledry}{Wsubsamplefresh}\right) * \frac{1}{10000} \quad ---- \quad Equation\ 3$$

Where: LB = Litter (biomass of litter ton/ha)

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 collected (ha);

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

$W_{(subsample}dry)$ = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g).

According to Allen *et al*. (1986), the percentage of organic carbon storage was calculated from the dry ash of the litter carbon pool

The total carbon content of litter (ton/ha) =Total dry litter biomass*Carbon fraction; mathematically;

$C_T = LB \times \% C$ ………………………………… (Equation 4)

Where, $C_T$ is total carbon stocks in the dead litter in ton/ ha, % C is carbon fraction determined in the laboratory (Pearson *et al*., 2005).

#### 3.3.1.4. Soil Organic Carbon Measurement

The soil samples were collected from the four corners and at the center of 1m$^2$ sub-sample plot of from 30 sample plots. Soil samples were taken from two depths (0-20 cm and 20-40 cm) using core sampler with 2.5 cm and 20 cm radius and height respectively. Soil samples from each depth were collected from five pits in the major plot (one at the center and four at the corners of each plot) and composite samples in their respective layers were collected. Then after, soil samples were placed in a plastic paper bags and labeled separately. Then, samples were taken to Debre Markos soil laboratory for analysis. Soil organic carbon was determined in the laboratory following Walkley-Black Method. In the laboratory, soil samples were dried at 105 $^0$C for 24 hours to remove the soil moisture and to determine the percentage of organic carbon as well as the bulk density (Pearson *et al*. ,2005). The soil organic carbon was calculated according to Pearson *et al*. (2005) as:

$BD = \frac{Wdry}{V}$ ………………………………. (Equation 5)

Where,

BD = bulk density ($g/cm^3$) of the soil sample,

Wdry = air dry weight (g) of soil sample,

V = volume ($cm^3$) of the soil sample

The volume of each soil sample in turn was calculated as;

$V = h * \pi r^2$ ………….. ..……………………… (Equation 6)

Where,

V = volume of the soil in the core sampler augur in $cm^3$,

h = the height of core sampler augur in cm, and

r = the radius of core sampler in cm.

Then, soil organic carbon was calculated as follows:

SOC = BD * D * % C ………………………………….. (Equation 7)

Where,

SOC= soil organic carbon stock per unit area (ton/ ha),

BD = soil bulk density ($g/cm^3$),

D = the total depth at which the sample was taken (40 cm i.e. 0-20 cm and 20-40 cm) and

%C = Carbon concentration (%)

#### 3.3.1.5.Estimation of Total Carbon Stock

The total carbon stock density was calculated by adding the carbon stock densities of the individual carbon pools using Pearson *et al*. (2005) formula as follows;

$C_T$= AGC+BGC+CL+SOC ……………………………… (Equation 8)

Where,

$C_T$= Carbon stock density for all pools (ton/ ha),

AGC= Carbon in above -ground tree biomass (ton C/ ha),

BGC = Carbon in below-ground biomass (ton C/ ha)

CL= Carbon in dead litter (ton C/ ha) and

SOC = Soil organic carbon (ton C/ha).

### 3.4. Data Analysis

The data analysis of various carbon pools measured (DBH, fresh weight and dry weight of litter and soil) was done in Statistical Package for Social Science (SPSS) software version 23, Analysis of Variance (ANOVA) was used to test the relationship between forest carbon stocks with altitude at 95% confidence interval.

# 4. RESULTS

## 4.1. Woody species characteristics of Sekele-Mariam forest

A total of 29 trees and shrub species belonging to 23 families were recorded in Sekele-Mariam forest. *Croton macrostachyus, Albizia gummifera, Acacia abyssinica, Buddleia polystachya and Acacia lahai* were the most frequently occurred species and accounts for 100, 80, 70, 69, 50, respectively and the dominant species in the lower altitudinal range were Acacia *abyssinica* (36.56%), *Albizia gummifera* (15.39%), *Croton macrostachyus* (12.11%) *Rhus glutinosa*, (5.94%) *Maytenus obscura*, (4.34%). In the middle altitudinal range *Croton macrostachyus* (100), *Albizia gummifera* (81.25), *Acacia abyssinica* (62.5), *Calpurnia aurea* (43.75) and *Clausena anisata* (43.75) were the most frequently occurred species and the dominant species are *Maytenus obscura*.(19.61%), *Albizia gummifera* (12.47%), *Croton macrostachyus* (12.05%), *Ficus sur* (11.02%) and *Protea gaguedi* (5.18%). In the higher altitudinal range; *Albizia gummifera* (100) *Croton macrostachyus* (94.12), *Acacia abyssinica* (82.35), *Maesa lanceolate* (58.82) and *Calpurnia aurea* (50) were the most frequently occurred species and the dominant species are *Acacia abyssinica* (15.08%), *Albizia gummifera* (12.6%), *Croton macrostachyus* (9.86%), *Maytenus obscura* (8.34%) and *Dombeya torrida* (7.11%). The average number of stems per hectare of the study area was 264 and the estimated average basal area was 12.61 $m^2$/ha. The highest number of stems were recorded in the higher altitudinal range and the smallest was recorded in the lower altitudinal range. The highest basal area was estimated in the lower altitudinal range and the smallest basal area was estimated in the middle altitudinal class (Table 2).

Table 2: Mean ± standard deviation of Stand characteristics of Sekele-Mariam forest

| Altitude class | DBH (cm) | Height (m) | Basal area ($m^2$/ha) | Stem density/ha |
|---|---|---|---|---|
| Lower | 20.11±6.5 | 12.46±5.6 | 12.70±241 | 220±105.2 |
| Middle | 18.85±5.6 | 11.33±4.8 | 11.16±175 | 264±133.3 |
| Higher | 19.46±4.4 | 13.48±5 | 11.89±136 | 276±119 |

### 4.2. Biomass of Sekele-Mariam Forest

The average aboveground biomass was 79.88 ton/ha and the minimum and maximum were 11.16 ton/ha and 203.68 ton/ ha. Similarly, the average belowground biomass was 20.77 ton/ha with the minimum and maximum biomass of 2.9 ton /ha and 52.96 ton/ ha, respectively. The mean litter biomass was 0.05 ton/ha with the minimum and maximum of 0.01 ton/ha and 0.29 ton/ha, respectively. The average total forest biomass of Sekele-Mariam forest was 96.49 ton/ha. The aboveground and belowground biomass contributed about 79.32% and 20.62%, respectively to the total biomass while the litter biomass contributed insignificant amount of biomass (0.05%) to the total biomass.

The biomass (aboveground, belowground and litter) of the forest were varied with respect to the three altitudinal gradients (lower, middle and higher). The lowest amount of aboveground biomass with 61.63 ± 12.97 ton/ha was estimated in the middle altitudinal range of the forest, moderate amount with 73.89 ± 16.86 of biomass was estimated in the lower portion of the altitude whereas the highest biomass with 90.22± 14.4 ton/ha was estimated in the higher portion of the altitude. Similar trend was shown in the litter biomass with 0.04 ± 0.005 ton/ha ,0.03 ± 0.003 ton/ha and 0.06 ± 0.01 ton/ha in the lower, middle and higher altitude respectively.

## 4.3. Carbon Stock in different Carbon Pools and Altitude

### 4.3.1. Aboveground and Belowground Carbon Stocks

The mean aboveground and belowground carbon stock of Sekele-Mariam forest was 37.54 ton/ha and 9.76 ton /ha, respectively. The minimum and maximum aboveground and the minimum and maximum belowground carbon were 5.24 ton/ha, 95.73 ton/ha and 1.36 ton/ha ,24.89 ton/ha, respectively.

There was distinct variation of mean carbon stock in each carbon pools with different altitudinal ranges. As shown in Table _3, it was noted that the higher altitudinal range constitutes the largest portion of aboveground carbon stock while the smallest stock of carbon was estimated in middle altitudinal range. But the variation of aboveground and belowground carbon stock along altitude is statistically insignificant (F- value=1.487, P- value =0.235) at 95% confidence interval.

### 4.3.2. Carbon Stock in Litter Biomass

The mean carbon concentration in the litter was 43.6 % with the minimum and maximum of 30.56 % and 47.96 %, respectively. The average litter carbon stock was 0.02 ton /ha with minimum and maximum stock of 0.005 ton/ ha and 0.14 ton/ha, respectively.

Like aboveground and below ground carbon stock, the highest litter carbon was estimated at higher altitudinal range and smallest carbon stock was estimated at the middle altitude. But, there was a significant difference (F- value=3.233, P- value =0.047) at 95% confidence interval (Table _3).

Table 3: Mean Litter carbon stock (ton/ha) along altitudinal gradient of Sekele-Mariam forest, North-Western Ethiopia

| Altitude class | No. of Plots | LC |
|---|---|---|
| Lower | 10 | 0.01 |
| Middle | 16 | 0.01 |
| Higher | 34 | 0.02 |
| F value | | 3.233 |
| P value | | 0.047 |

### 4.3.3. Soil Carbon Stock

The soil carbon stock represents the largest stocks of all carbon pools in the study area. The highest mean value of soil organic carbon (149.35 ton/ha) was observed in the middle altitudinal range whereas the lowest SOC (128.29 ton/ha) was observed in the lower altitudinal range. The higher altitude shares the mean SOC of 137.28 ton/ha (Table_4). The analysis of variance showed that the mean SOC stock was not significant (F- value = 1.049, P- value = 0.364) at 95% confidence interval.

Table 4: Mean Soil carbon stock with respect to Altitudinal class

| Soil Depth | Soil carbon stock (ton/ha) | | |
|---|---|---|---|
| | Lower | Middle | Higher |
| 0-20 cm | 84.99 | 100.3 | 86.23 |
| 20-40 cm | 43.30 | 49.05 | 51.05 |
| 0-40 cm | 128.29 | 149.35 | 137.28 |

#### 4.3.4. Total Carbon Stock of Sekele-Mariam Forest

The soil component shares the highest carbon stock (138.39 ton/ha) followed by aboveground carbon (37.54 ton/ha) of the total forest carbon stock, whereas the belowground and litter contributed the lowest carbon stock ,9.76 ton/ha and 0.02 ton/ha respectively. The result of this study indicated that the highest total carbon stock (190.72 ton /ha) was recorded in the higher altitudinal range whereas the lower altitudinal range had the lowest stock of carbon (172.03 ton /ha).

# 5. DISCUSSION

## 5.1. Woody species characteristics of the study area

Sekele-Mariam forest comprises a total of 29 plant species (Appendix 1). The DBH distribution of the trees/shrubs showed an inverted J-shaped distribution, indicating that there was high number of young individual trees and shrubs in the lowest diameter class. Whereas, smaller number of tree and shrubs were observed under the highest diameter class. It is obvious that tree with smaller DBH sequester less carbon than that of higher DBH. However, younger tree gradually increases their DBH through growth and would accumulate more carbon than the old one. The Carbon stock in an individual tree depends on the tree's size (Hairiah *et al.*, 2011).

## 5.2. Biomass and Carbon Stock in different Carbon Pools

### 5.2.1. Aboveground and Belowground Biomass and Carbon Stock

The mean aboveground carbon stock of Sekele-Mariam forest was smaller as compared to previously studied similar forest type of Ethiopia except Humbo forest. The variation of carbon in the aboveground biomass may be due to intensive forest degradation mainly fuel-wood collection. Moreover, stand structure and composition, topography, altitude and micro climate variation may have also contributed for the variation of carbon in the aboveground biomass. Besides, variation in tree dendrological parameters measured, allometric equations applied, carbon fraction used and root-shoot ratio used to estimate below ground biomass may also have resulted in the discrepancy of estimation of aboveground and belowground biomass and carbon stock. In line with allomertic equation most researchers used Brown *et al* (1989) equation to estimate forest carbon stock in Ethiopia. Moreover, they used a carbon fraction of 0.5 suggested in the IPCC 2003 Good Practice Guidance. In this study The aboveground biomass was estimated using allometric equation developed by Chave *et al*,

(2014) which consists dendrometric parameters (DBH and height) and wood density and are important predictors of biomass. The different types of models used for biomass estimation have impact on the value of carbon estimated in a given forest (Moges *et al.* (2010).

### 5.2.2. Litter Carbon Stock

The mean carbon stock in litter pool of the current study was 0.02 ton/ha which is lower than other similar forest type studied by Feyissa *et al.*, 2013; Gedefaw *et al.* ,2014; Girma *et al.*.,2014; Chinasho *et al*., 2015; Dagnachew Tefera ,2016).The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate (Fisher and Binkly, 2012). Fisher and Binkly, (2012) also indicated that the tropical area had relatively fast decomposition rate. The reason for smaller litter carbon may be due to fast decomposition rate and less amount of litter fall in the study area. The highest and lowest mean carbon stock in litter biomass was found in higher and lower altitudinal ranges, respectively. Similar result was also reported in Egdu forest in Oromia region by Feyissa *et al.* (2013).

### 5.2.3. Carbon stock in the soil

As reported in Luke (2018), the average soil organic carbon in Ethiopia ranges from 94 to 133 ton/ha which is smaller compared to the present study and the IPCC default values (31 to 130 ton/ha) for different tropical soils (IPCC, 2006). In this study, the soil carbon pool had the highest carbon stock compared to other pools in the study area. Soil is the largest carbon pools in global terrestrial ecosystems, because they can contain three times more carbon than that contained in vegetation (Schlesinger, 1990), and about 32% of global soil carbon pool is in tropical soils (Lal, 2004). The mean soil bulk density was 1.37 g/cm3 and ranges from 0.76 g/cm3 to 1.82 g/$cm^3$. Bulk density between 0.72 to 0.98 g/$cm^3$ has high organic matter content in the soil (Brady ,1974) and indicating that the study area has low soil organic matter. The mean carbon stock of soil organic pool in the study area was lower as compared with other studies except Zequala forest with an average bulk density of 0.79 g/$cm^3$ (Girma *et al.*.,2014) and Meskel Gedam forest with an average bulk density of 0.66 g/$cm^3$. This could be due to the existence of low soil organic matter, relatively higher range of bulk density. The average bulk density of the study was higher as compared to Humbo, Zequal monastery, Tara Gedam, Meskel Gedam and Egdu forests with an average bulk density of 0.55, 0.79, 0.43 ,0.66 and 0.46 g/$cm^3$, respectively. Normally, Bulk density increases with soil depth since subsurface layers are more compacted and have less organic matter, less aggregation, and less root penetration compared to surface layers, therefore contain less pore space (http:www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053260.pdf). In addition, the accumulation of soil organic carbon also depends on the quantity of litter (Lemma *et al*., 2007) and root activity such as rhizo-deposition and decomposition (Rees *et al*., 2005).

### 5.3.Relation of Carbon Stock with Altitude

The highest total carbon stock was recorded in the higher altitudinal range whereas smaller carbon stock was recorded in lower altitudinal range. The carbon stock in all carbon pools of the study area varied with altitudinal ranges. but did not show direct increment or decrement. This study showed that the mean carbon stock in all carbon pools exhibits an increasing trend with increasing altitudinal variation, the reason for this may be due to, disturbance level and species composition and density occurred in the altitudinal ranges. As noted from field observation, more wood collection for construction and fuel wood was highly pronounced in lower altitude than the higher one.  Overall, the carbon pool of Sekele-Mariam forest did not show significant variation along altitudinal gradient as aboveground carbon, belowground carbon, litter carbon and soil organic carbon. Similar finding was reported from Chinasho *et al*. (2015). The reason for such statistically insignificant result in the carbon pools may be due to the similar species composition and soil type throughout the altitudinal gradient of the forest.

# 6. CONCLUSION AND RECOMMENDATIONS

## 6.1. Conclusion

Sekele-Mariam .forest had stored a total of 185.71 ton C/ ha in its biomass. The largest carbon stock was found in the soil organic carbon followed by the aboveground biomass The carbon stock of the study area was smaller compared to other studies of similar forest type in Ethiopia. Carbon stock in different carbon pools (aboveground and belowground biomass, litter biomass and soil) has a potential to decrease the rate of improvement of atmospheric concentration of carbon dioxide. Increase in carbon stock in Dry Afromontane forest can be achieved through sustainable forest management including enrichment planting. Furthermore, attention has to be given on the conservation of the Dry Afromontane forest to enhance the carbon sequestration capacity so as to mitigate climate change. Carbon stock in all carbon pools was varied with altitude. But, the variation was not statistically significant in aboveground, belowground carbon and soil organic carbon except litter carbon at 95 % confidence interval.

## 6.2. Recommendations

- Carbon stock was estimated using generalized allometric equation for all forest types due to absence of species specific allometric equations in this study. It is recommended to develop local and species specific equation for better estimation of forest carbon stock.
- This study was not cover the carbon stock in non- woody above ground biomass and in necromass (dead plant parts) therefore comprehensive carbon stock estimation studies including these carbon pools is recommended in the study area.

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APPENDICES

Appendix 1. List of woody species, their family, local name habit, frequency and Importance Value Index (IVI)

| Scientific Name | Family | Local Name | Habit | Frequency | IVI (%) |
|---|---|---|---|---|---|
| Acacia abyssinica Hochst. ex Benth. | Fabaceae | Girar | Tree | 75 | 12.78 |
| Acacia lahai Steud & Hochst. ex Benth. | Fabaceae | Cheba | Tree | 18.33 | 2.17 |
| Acanthus sennii Chiov. | Acanthaceae | Kosheshela | Shrub | 5 | 0.55 |
| Albizia gummifera (J.F.Gmel.) C.A. | Fabaceae | Sesa | Tree | 91.67 | 14.05 |
| Bersama abyssinica Fresen | Meliantaceae | Azamira | Shrub | 35 | 3.60 |
| Buddleia polystachya Fresen. | Loganiaceae | Anfar | Shrub | 23.33 | 2.91 |
| Calpurnia aurea (Ait.) Benth | Myrtaceae | Ligita | Shrub | 41.67 | 4.89 |
| Carissa spinarum L. | Apocynaceae | Agam | Shrub | 25 | 2.16 |
| Clausena anisata (Willd.) Benth. | Rutaceae | Medeb | Shrub | 23.33 | 1.80 |
| Combretum molle R.Br.ex.G.Don. | Combretaceae | Abalo | Shrub | 6.67 | 0.64 |
| Croton macrostachyus Del. | Euphorbiaceae | Bisana | Tree | 96.67 | 19.16 |

| | | | | | |
|---|---|---|---|---|---|
| Dombeya torrida (J.F.Gmel.) P.Bamps | Sterculiaceae | Wulkefa | Tree | 1.67 | 2.27 |
| Dovyalis abyssinica (A.Rich.) Warb. | Flacourtiaceae | Koshem | Tree | 6.67 | 1.22 |
| Euclea divinorum Hiern | Ebenaceae | Elaho | Shrub | 1.67 | 2.27 |
| Ficus sur Forssk | Moraceae | Shola | Tree | 3.33 | 3.17 |
| Galiniera saxifraga | Rubiace ae | Yetota qolet | Tree | 6.67 | 1.31 |
| Grewia ferruginea Hochst.ex.A. Rich | Tiliaceae | Lenquato | Shrub | 8.33 | 1.11 |
| Hypericum revolutem Vahl | Hypericacceae | Amija | Shrub | 5 | 0.74 |
| Maesa lanceolata Forssk | Myrsinaceae | Kelaba | Shrub | 48.33 | 6.13 |
| Maytenus gracilipes Welw. ex Oliv.) | Celastraceae | Atat | Shrub | 5 | 0.60 |
| Maytenus obscura (A.Rich.) Cuf. | Celastraceae | Koba | Tree | 35 | 5.50 |
| Nuxia congesta R. Br. ex. Fresen | Loganiaceae | Atkuar | Shrub | 8.33 | 1.85 |
| Osyris quadripartita Decne. | Santaleceae | Keret | Shrub | 5 | 0.73 |
| Pavetta abyssinica Hochst. Ex A. Rich | Rubiaceae | Dengaye sebere | Shrub | 6.67 | 0.86 |
| Protea gaguedi J.F.Gmel. | Proteaceae | Awura | Shrub | 5 | 1.46 |
| Rhus glutinosa A.Rich.subsp.glutinosa | Anacardiaceae | Kamo | Tree | 15 | 1.70 |

| | | | | | |
|---|---|---|---|---|---|
| Rosa abyssinica Lindley | Rosaceae | Kega | Shrub | 18.33 | 1.70 |
| Vernonia amygdalina Del. | Asteraceae | Grawa | Shrub | 6.67 | 1.51 |
| Vernonia auriculifera Hiern. | Asteraceae | Gengerita | Shrub | 11.67 | 1.16 |

Appendix 2: Basic wood density of woody species

| Scientific Name | WD ($g/cm^3$) | Reference |
|---|---|---|
| Acacia abyssinica Hochst. ex Benth. | 0.826 | Average of genus (ICRAF database) |
| Acacia lahai Steud & Hochst. ex Benth. | 0.769 | Average of genus (ICRAF database) |
| Acanthus sennii Chiov. | 0.592 | Global database (Zanne et al., 2009) |
| Albizia gummifera (J.F.Gmel.) C.A. | 0.58 | Getachew Desalegn et al., 2012 |
| Bersama abyssinica Fresen | 0.671 | http://db.worldagroforestry.org//wd/genus/Bersama<br>& also global database |
| Buddleia polystachya Fresen. | 0.4 | Vreugdenhil et al., 2012 |
| Calpurnia aurea (Ait.) Benth | 0.612 | Average wood density of all species of Ethiopia (EFRL (2017) |
| Carissa spinarum L. | 0.834 | http://db.worldagroforestry.org//wd/genus/Carissa |
| Clausena anisata (Willd.) Benth. | 0.482 | http://db.worldagroforestry.org//wd/species/Clausena_anisata |
| Combretum molle R.Br.ex.G.Don. | 0.482 | Vreugdenhil et al., 2012 |
| Croton macrostachyus Del. | 0.56 | Getachew Desalegn et al., 2012 |
| Dombeya torrida (J.F.Gmel.) P.Bamps | 0.588 | *http://db.worldagroforestry.org//wd/species* |
| Dovyalis abyssinica (A.Rich.) Warb. | 0.579 | *http://db.worldagroforestry.org//wd/species* |
| Euclea divinorum Hiern | 0.775 | *http://db.worldagroforestry.org//wd/species* |
| Ficus sur Forssk | 0.441 | http://globalspecies.org/ntaxa/869708 |
| Galiniera saxifraga | 0.399 | Vreugdenhil et al., 2012 |
| Grewia ferruginea Hochst.ex.A. Rich | 0.583 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Hypericum revolutem Vahl | 0.726 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Maesa lanceolata Forssk | 0.676 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Maytenus gracilipes Welw. ex Oliv.) | 0.713 | Average Genus, Africa |
| Maytenus obscura (A.Rich.) Cuf. | 0.713 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Nuxia congesta R. Br. ex. Fresen | 0.676 | Genus average (http://db.worldagroforestry.org//wd/species) |

| | | |
|---|---|---|
| Osyris quadripartita Decne. | 0.854 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Pavetta abyssinica Hochst. Ex A. Rich | 0.612 | Average wood density of all species of Ethiopia (EFRL (2017) |
| Protea gaguedi J.F.Gmel. | 0.663 | *Protea angolensis* |
| Rhus glutinosa A.Rich.subsp.glutinosa | 0.62 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Rosa abyssinica Lindley | 0.612 | Average wood density of all species of Ethiopia (EFRL (2017) |
| Vernonia amygdalina Del. | 0.413 | Genus average (http://db.worldagroforestry.org//wd/genus) |
| Vernonia auriculifera Hiern. | 0.413 | Genus average (http://db.worldagroforestry.org//wd/genus) |

Appendix 3. Plot wise aboveground and belowground biomass and carbon stock of Sekele-Mariam forest

| Plot No. | AGB (Kg/plot) | AGB (ton/ha) | AGC (ton/ha) | CO2 e (ton/ha) | BGB (ton/ha) | BGC (ton/ha) | CO2e (ton/ha) |
|---|---|---|---|---|---|---|---|
| 1 | 11030.98 | 44.12 | 20.74 | 76.11 | 11.47 | 5.39 | 19.79 |
| 2 | 17965.24 | 71.86 | 33.77 | 123.95 | 18.68 | 8.78 | 32.23 |
| 3 | 8777.59 | 35.11 | 16.50 | 60.56 | 9.13 | 4.29 | 15.75 |
| 4 | 22091.67 | 88.37 | 41.53 | 152.42 | 22.98 | 10.80 | 39.63 |
| 5 | 6317.99 | 25.27 | 11.88 | 43.59 | 6.57 | 3.09 | 11.33 |
| 6 | 6297.43 | 25.19 | 11.84 | 43.45 | 6.55 | 3.08 | 11.30 |
| 7 | 10690.48 | 42.76 | 20.10 | 73.76 | 11.12 | 5.23 | 19.18 |
| 8 | 4995.53 | 19.98 | 9.39 | 34.47 | 5.20 | 2.44 | 8.96 |
| 9 | 9493.94 | 37.98 | 17.85 | 65.50 | 9.87 | 4.64 | 17.03 |
| 10 | 7965.89 | 31.86 | 14.98 | 54.96 | 8.28 | 3.89 | 14.29 |
| 11 | 10052.51 | 40.21 | 18.90 | 69.36 | 10.45 | 4.91 | 18.03 |
| 12 | 6435.69 | 25.74 | 12.10 | 44.40 | 6.69 | 3.15 | 11.54 |
| 13 | 8094.30 | 32.38 | 15.22 | 55.85 | 8.42 | 3.96 | 14.52 |
| 14 | 3251.28 | 13.01 | 6.11 | 22.43 | 3.38 | 1.59 | 5.83 |
| 15 | 3293.66 | 13.17 | 6.19 | 22.72 | 3.43 | 1.61 | 5.91 |
| 16 | 7494.87 | 29.98 | 14.09 | 51.71 | 7.79 | 3.66 | 13.45 |
| 17 | 33665.37 | 134.66 | 63.29 | 232.28 | 35.01 | 16.46 | 60.39 |
| 18 | 29913.25 | 119.65 | 56.24 | 206.39 | 31.11 | 14.62 | 53.66 |
| 19 | 42023.44 | 168.09 | 79.00 | 289.94 | 43.70 | 20.54 | 75.39 |
| 20 | 47251.31 | 189.01 | 88.83 | 326.02 | 49.14 | 23.10 | 84.76 |
| 21 | 50919.83 | 203.68 | 95.73 | 351.33 | 52.96 | 24.89 | 91.34 |
| 22 | 18521.43 | 74.09 | 34.82 | 127.79 | 19.26 | 9.05 | 33.23 |
| 23 | 29977.69 | 119.91 | 56.36 | 206.83 | 31.18 | 14.65 | 53.78 |
| 24 | 31961.08 | 127.84 | 60.09 | 220.52 | 33.24 | 15.62 | 57.33 |
| 25 | 37964.07 | 151.86 | 71.37 | 261.94 | 39.48 | 18.56 | 68.10 |
| 26 | 25806.69 | 103.23 | 48.52 | 178.06 | 26.84 | 12.61 | 46.29 |
| 27 | 49115.84 | 196.46 | 92.34 | 338.88 | 51.08 | 24.01 | 88.11 |
| 28 | 28941.89 | 115.77 | 54.41 | 199.69 | 30.10 | 14.15 | 51.92 |
| 29 | 15472.59 | 61.89 | 29.09 | 106.75 | 16.09 | 7.56 | 27.76 |
| 30 | 16894.38 | 67.58 | 31.76 | 116.56 | 17.57 | 8.26 | 30.31 |
| 31 | 6163.12 | 24.65 | 11.59 | 42.52 | 6.41 | 3.01 | 11.06 |
| 32 | 9409.65 | 37.64 | 17.69 | 64.92 | 9.79 | 4.60 | 16.88 |
| 33 | 28466.77 | 113.87 | 53.52 | 196.41 | 29.61 | 13.91 | 51.07 |
| 34 | 40160.70 | 160.64 | 75.50 | 277.09 | 41.77 | 19.63 | 72.04 |
| 35 | 42566.51 | 170.27 | 80.03 | 293.69 | 44.27 | 20.81 | 76.36 |
| 36 | 26336.83 | 105.35 | 49.51 | 181.71 | 27.39 | 12.87 | 47.25 |
| 37 | 11470.31 | 45.88 | 21.56 | 79.14 | 11.93 | 5.61 | 20.58 |
| 38 | 42276.55 | 169.11 | 79.48 | 291.69 | 43.97 | 20.66 | 75.84 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 39 | 11046.97 | 44.19 | 20.77 | 76.22 | 11.49 | 5.40 | 19.82 |
| 40 | 31257.68 | 125.03 | 58.76 | 215.67 | 32.51 | 15.28 | 56.07 |
| 41 | 42403.91 | 169.62 | 79.72 | 292.57 | 44.10 | 20.73 | 76.07 |
| 42 | 35097.41 | 140.39 | 65.98 | 242.16 | 36.50 | 17.16 | 62.96 |
| 43 | 5099.97 | 20.40 | 9.59 | 35.19 | 5.30 | 2.49 | 9.15 |
| 44 | 21226.63 | 84.91 | 39.91 | 146.46 | 22.08 | 10.38 | 38.08 |
| 45 | 7326.06 | 29.30 | 13.77 | 50.55 | 7.62 | 3.58 | 13.14 |
| 46 | 13784.59 | 55.14 | 25.92 | 95.11 | 14.34 | 6.74 | 24.73 |
| 47 | 11940.89 | 47.76 | 22.45 | 82.39 | 12.42 | 5.84 | 21.42 |
| 48 | 13050.56 | 52.20 | 24.54 | 90.04 | 13.57 | 6.38 | 23.41 |
| 49 | 12265.54 | 49.06 | 23.06 | 84.63 | 12.76 | 6.00 | 22.00 |
| 50 | 15245.21 | 60.98 | 28.66 | 105.19 | 15.86 | 7.45 | 27.35 |
| 51 | 15350.55 | 61.40 | 28.86 | 105.91 | 15.96 | 7.50 | 27.54 |
| 52 | 3447.23 | 13.79 | 6.48 | 23.78 | 3.59 | 1.69 | 6.18 |
| 53 | 24845.10 | 99.38 | 46.71 | 171.42 | 25.84 | 12.14 | 44.57 |
| 54 | 2790.97 | 11.16 | 5.25 | 19.26 | 2.90 | 1.36 | 5.01 |
| 55 | 11748.46 | 46.99 | 22.09 | 81.06 | 12.22 | 5.74 | 21.08 |
| 56 | 4461.72 | 17.85 | 8.39 | 30.78 | 4.64 | 2.18 | 8.00 |
| 57 | 5112.30 | 20.45 | 9.61 | 35.27 | 5.32 | 2.50 | 9.17 |
| 58 | 27948.05 | 111.79 | 52.54 | 192.83 | 29.07 | 13.66 | 50.14 |
| 59 | 46900.81 | 187.60 | 88.17 | 323.60 | 48.78 | 22.93 | 84.14 |
| 60 | 26258.77 | 105.04 | 49.37 | 181.17 | 27.31 | 12.84 | 47.11 |
| **Mean** | **19968.96** | **79.88** | **37.54** | **137.78** | **20.77** | **9.76** | **35.82** |

Appendix 4. Litter biomass and carbon stock

| Plot No. | **A** | B | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 800 | 100 | 69.78 | 0.06 | 7.20 | 92.80 | 46.40 | 0.03 | 0.10 |
| 2 | 300 | 100 | 92.6 | 0.03 | 11.82 | 88.18 | 44.09 | 0.01 | 0.04 |
| 3 | 800 | 100 | 90.98 | 0.07 | 9.67 | 90.33 | 45.17 | 0.03 | 0.12 |
| 4 | 200 | 100 | 97.78 | 0.02 | 14.06 | 85.94 | 42.97 | 0.01 | 0.03 |
| 5 | 700 | 100 | 92.91 | 0.07 | 13.85 | 86.15 | 43.08 | 0.03 | 0.10 |
| 6 | 400 | 100 | 90.25 | 0.04 | 30.19 | 69.81 | 34.91 | 0.01 | 0.05 |
| 7 | 450 | 100 | 92.51 | 0.04 | 29.80 | 70.20 | 35.10 | 0.01 | 0.05 |
| 8 | 400 | 100 | 91.58 | 0.04 | 13.27 | 86.73 | 43.37 | 0.02 | 0.06 |
| 9 | 400 | 100 | 77.01 | 0.03 | 5.74 | 94.26 | 47.13 | 0.01 | 0.05 |
| 10 | 400 | 100 | 93.07 | 0.04 | 16.68 | 83.32 | 41.66 | 0.02 | 0.06 |
| 11 | 200 | 100 | 90.12 | 0.02 | 14.83 | 85.17 | 42.59 | 0.01 | 0.03 |
| 12 | 500 | 100 | 88.51 | 0.04 | 22.06 | 77.94 | 38.97 | 0.02 | 0.06 |
| 13 | 600 | 100 | 91.64 | 0.05 | 24.99 | 75.01 | 37.50 | 0.02 | 0.08 |
| 14 | 300 | 100 | 95.33 | 0.03 | 38.88 | 61.12 | 30.56 | 0.01 | 0.03 |
| 15 | 500 | 100 | 321.4 | 0.16 | 18.98 | 81.02 | 40.51 | 0.07 | 0.24 |
| 16 | 300 | 100 | 88.21 | 0.03 | 15.60 | 84.40 | 42.20 | 0.01 | 0.04 |
| 17 | 500 | 100 | 93.12 | 0.05 | 8.54 | 91.46 | 45.73 | 0.02 | 0.08 |
| 18 | 700 | 100 | 93.33 | 0.07 | 10.94 | 89.06 | 44.53 | 0.03 | 0.11 |
| 19 | 600 | 100 | 97.73 | 0.06 | 5.61 | 94.39 | 47.19 | 0.03 | 0.10 |
| 20 | 1000 | 100 | 94.73 | 0.09 | 6.60 | 93.40 | 46.70 | 0.04 | 0.16 |
| 21 | 900 | 100 | 92.26 | 0.08 | 5.60 | 94.40 | 47.20 | 0.04 | 0.14 |
| 22 | 600 | 100 | 88.08 | 0.05 | 13.01 | 86.99 | 43.49 | 0.02 | 0.08 |
| 23 | 300 | 100 | 87.21 | 0.03 | 11.95 | 88.05 | 44.03 | 0.01 | 0.04 |
| 24 | 700 | 100 | 86.09 | 0.06 | 17.18 | 82.82 | 41.41 | 0.02 | 0.09 |
| 25 | 500 | 100 | 86.48 | 0.04 | 4.07 | 95.93 | 47.96 | 0.02 | 0.08 |
| 26 | 300 | 100 | 88.18 | 0.03 | 13.79 | 86.21 | 43.10 | 0.01 | 0.04 |
| 27 | 900 | 100 | 92.1 | 0.08 | 7.49 | 92.51 | 46.26 | 0.04 | 0.14 |
| 28 | 900 | 100 | 90.8 | 0.08 | 11.18 | 88.82 | 44.41 | 0.04 | 0.13 |
| 29 | 950 | 100 | 84.25 | 0.08 | 6.29 | 93.71 | 46.86 | 0.04 | 0.14 |
| 30 | 200 | 100 | 83.3 | 0.02 | 11.66 | 88.34 | 44.17 | 0.01 | 0.03 |
| 31 | 900 | 100 | 89.7 | 0.08 | 11.78 | 88.22 | 44.11 | 0.04 | 0.13 |
| 32 | 200 | 100 | 86.15 | 0.02 | 12.30 | 87.70 | 43.85 | 0.01 | 0.03 |
| 33 | 500 | 100 | 72.82 | 0.04 | 6.91 | 93.09 | 46.55 | 0.02 | 0.06 |
| 34 | 300 | 100 | 88.68 | 0.03 | 18.91 | 81.09 | 40.54 | 0.01 | 0.04 |
| 35 | 300 | 100 | 249.37 | 0.07 | 7.66 | 92.34 | 46.17 | 0.03 | 0.13 |
| 36 | 950 | 100 | 97.2 | 0.09 | 15.52 | 84.48 | 42.24 | 0.04 | 0.14 |
| 37 | 300 | 100 | 220.01 | 0.07 | 14.08 | 85.92 | 42.96 | 0.03 | 0.10 |
| 38 | 200 | 100 | 26.15 | 0.01 | 14.26 | 85.74 | 42.87 | 0.00 | 0.01 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 39 | 200 | 100 | 91.3 | 0.02 | 6.40 | 93.60 | 46.80 | 0.01 | 0.03 |
| 40 | 900 | 100 | 320.67 | 0.29 | 6.45 | 93.55 | 46.78 | 0.14 | 0.50 |
| 41 | 800 | 100 | 84.2 | 0.07 | 14.96 | 85.04 | 42.52 | 0.03 | 0.11 |
| 42 | 900 | 100 | 91.4 | 0.08 | 11.15 | 88.85 | 44.42 | 0.04 | 0.13 |
| 43 | 300 | 100 | 92.15 | 0.03 | 7.56 | 92.44 | 46.22 | 0.01 | 0.05 |
| 44 | 600 | 100 | 91.8 | 0.06 | 5.68 | 94.32 | 47.16 | 0.03 | 0.10 |
| 45 | 700 | 100 | 90.68 | 0.06 | 6.98 | 93.02 | 46.51 | 0.03 | 0.11 |
| 46 | 700 | 100 | 94.07 | 0.07 | 4.99 | 95.01 | 47.50 | 0.03 | 0.11 |
| 47 | 500 | 100 | 92.66 | 0.05 | 9.64 | 90.36 | 45.18 | 0.02 | 0.08 |
| 48 | 400 | 100 | 93.07 | 0.04 | 5.95 | 94.05 | 47.03 | 0.02 | 0.06 |
| 49 | 500 | 100 | 92.4 | 0.05 | 9.62 | 86.63 | 43.31 | 0.02 | 0.07 |
| 50 | 400 | 100 | 173.22 | 0.07 | 16.28 | 83.72 | 41.86 | 0.03 | 0.11 |
| 51 | 300 | 100 | 91.03 | 0.03 | 13.63 | 86.37 | 43.19 | 0.01 | 0.04 |
| 52 | 500 | 100 | 93.03 | 0.05 | 16.45 | 83.55 | 41.78 | 0.02 | 0.07 |
| 53 | 200 | 100 | 91.23 | 0.02 | 12.62 | 87.38 | 43.69 | 0.01 | 0.03 |
| 54 | 300 | 100 | 92.83 | 0.03 | 19.85 | 80.15 | 40.07 | 0.01 | 0.04 |
| 55 | 600 | 100 | 89.4 | 0.05 | 12.52 | 87.48 | 43.74 | 0.02 | 0.09 |
| 56 | 300 | 100 | 93.22 | 0.03 | 13.22 | 86.78 | 43.39 | 0.01 | 0.04 |
| 57 | 300 | 100 | 93.3 | 0.03 | 19.18 | 80.82 | 40.41 | 0.01 | 0.04 |
| 58 | 400 | 100 | 92.94 | 0.04 | 8.75 | 91.25 | 45.62 | 0.02 | 0.06 |
| 59 | 300 | 100 | 91.2 | 0.03 | 14.04 | 85.96 | 42.98 | 0.01 | 0.04 |
| 60 | 800 | 100 | 92.83 | 0.07 | 5.26 | 94.74 | 47.37 | 0.04 | 0.13 |
| **Mean** | | | | **0.05** | **12.74** | **87.20** | **43.60** | **0.02** | **0.09** |

A = Weight of wet field sample of litter (gm)

B = Weight of fresh sub-sample (gm)

C = Weight of oven dry sub-sample of litter (gm)

D = Litter biomass (ton/ha)

E = % Ash

F = % Organic matter

G = % Organic carbon in litter fall

H = Litter carbon stock (ton/ha)

I = $CO_2$ e (ton/ha)

Appendix 5. Carbon stock in soil carbon pool

| Plot No. | SOC 0-20 cm | | | | SOC 20-40 cm | | | | SOC 0-40 cm |
|---|---|---|---|---|---|---|---|---|---|
| | BD | Depth | %C | SOC | BD | Depth | %C | SOC | |
| 1 | 1.35 | 20 | 3.31 | 89.37 | 1.51 | 20 | 1.97 | 59.49 | 148.86 |
| 3 | 1.6 | 20 | 5.42 | 173.44 | 1.82 | 20 | 3.1 | 112.84 | 286.28 |
| 5 | 1.34 | 20 | 2.74 | 73.43 | 1.5 | 20 | 1.45 | 43.5 | 116.93 |
| 7 | 0.94 | 20 | 3.19 | 59.97 | 1.39 | 20 | 1.5 | 41.7 | 101.67 |
| 9 | 1.29 | 20 | 3.91 | 100.88 | 1.7 | 20 | 1.1 | 37.4 | 138.28 |
| 11 | 1.4 | 20 | 3.35 | 93.80 | 1.68 | 20 | 1.76 | 59.13 | 152.94 |
| 13 | 1.23 | 20 | 2.83 | 69.62 | 1.31 | 20 | 0.99 | 25.93 | 95.56 |
| 15 | 1.32 | 20 | 4.44 | 117.22 | 1.45 | 20 | 2.38 | 69.02 | 186.24 |
| 17 | 1.27 | 20 | 3.21 | 81.53 | 1.47 | 20 | 2.1 | 61.74 | 143.27 |
| 19 | 1.13 | 20 | 2.56 | 57.86 | 1.69 | 20 | 0.87 | 29.40 | 87.26 |
| 21 | 1.2 | 20 | 3.23 | 77.52 | 1.31 | 20 | 1.72 | 45.06 | 122.58 |
| 23 | 1 | 20 | 2.82 | 56.40 | 1.22 | 20 | 1.94 | 47.336 | 103.74 |
| 25 | 1.33 | 20 | 2.93 | 77.94 | 1.45 | 20 | 1 | 29 | 106.94 |
| 27 | 1.17 | 20 | 2.82 | 65.99 | 1.46 | 20 | 1.47 | 42.92 | 108.91 |
| 29 | 1.41 | 20 | 3.3 | 93.06 | 1.48 | 20 | 1.96 | 58.01 | 151.08 |
| 31 | 1.64 | 20 | 3.49 | 114.47 | 1.73 | 20 | 1.64 | 56.74 | 171.22 |
| 33 | 1.51 | 20 | 4.31 | 130.16 | 1.62 | 20 | 2 | 64.8 | 194.96 |
| 35 | 1.47 | 20 | 4.32 | 127.01 | 1.53 | 20 | 1.96 | 59.97 | 186.98 |
| 37 | 1.29 | 20 | 4.73 | 122.03 | 1.34 | 20 | 2.16 | 57.88 | 179.92 |
| 39 | 0.97 | 20 | 4.64 | 90.02 | 1.3 | 20 | 2.51 | 65.26 | 155.28 |
| 41 | 0.81 | 20 | 4.8 | 77.76 | 1.13 | 20 | 2.47 | 55.82 | 133.58 |
| 43 | 0.76 | 20 | 4.81 | 73.11 | 0.82 | 20 | 2.48 | 40.67 | 113.78 |
| 45 | 0.98 | 20 | 2.96 | 58.02 | 1.26 | 20 | 0.98 | 24.69 | 82.71 |
| 47 | 1.37 | 20 | 2.47 | 67.68 | 1.43 | 20 | 0.88 | 25.16 | 92.85 |
| 49 | 1.37 | 20 | 2.26 | 61.92 | 1.57 | 20 | 0.85 | 26.69 | 88.61 |
| 51 | 1.63 | 20 | 3.64 | 118.66 | 1.73 | 20 | 1.26 | 43.59 | 162.26 |
| 53 | 1.38 | 20 | 3.98 | 109.85 | 1.43 | 20 | 1.47 | 42.04 | 151.89 |
| 55 | 1.54 | 20 | 2.6 | 80.08 | 1.57 | 20 | 0.79 | 24.80 | 104.89 |
| 57 | 1.43 | 20 | 3.26 | 93.24 | 1.49 | 20 | 1.56 | 46.48 | 139.72 |
| 59 | 1.33 | 20 | 3.65 | 97.09 | 1.36 | 20 | 1.67 | 45.42 | 142.51 |
| Mean | | | | 90.30 | | | | 48.08 | 138.39 |

Appendix 6. Woody species inventory data collection format

Plot Number :----------------------------------- Land use type:-------------------------------

Latitude :--------------------------------------- Recorder: -------------------------------------

Longitude :------------------------------------- Date: ------------------------------------------

Altitude: ---------------------------------------

| Scientific Name | Local Name | DBH (cm) | Height (m) | Remark |
|---|---|---|---|---|
| | | | | |
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Appendix 7. Litter and soil sample date collection format

Latitude :---------------------------------------- Recorder: --------------------------------------

Longitude :-------------------------------------- Date: --------------------------------------------

Altitude: ---------------------------------------- Land use type: ---------------------------------

| Plot No. | Sample field fresh weight of litter (g) | Soil bulk density (g/cm$^3$ ) | % organic carbon |
|---|---|---|---|
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Appendix 8. List of instruments and equipments used for forest inventory

| Instruments and equipments | Purpose |
|---|---|
| GPS | Plot location |
| Meter | Locating plot boundary and distance measurement |
| Tissue paper | For marking the tree in the four corner of the plot |
| Plastic bag | For collecting litter and soil samples |
| Caliper and diameter tape | For measuring diameter of a tree at breast height |
| Range finder | For tree height measurement |
| Spring scale | For weighting samples |

## BIOGRAPHICAL SKETCH

Asersie Mekonnen was born on February 15, 1989 in Gojjam, Ethiopia. He attended his elementary and junior secondary school education at Dembecha from 1996 to 2005. He pursued preparatory program at Dembecha secondary and preparatory school from 2006 to 2007. He joined Addis Ababa University in 2008 and earned his B.Sc. degree in Biology on July 2010.

The author was employed by Institute of Biodiversity Conservation (now Ethiopian Biodiversity Institute) on October 2012 as biologist at Addis Ababa until 2016. He joined the School of Graduate Studies at Wondo Genet College of Forestry and Natural Resources, Hawassa University for Master of Science study in Forest Resource Assessment and Monitoring.