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ESTIMATING CARBON STOCK OF ZAFNIGUS FOREST AND ITS IMPLICATION FOR CLIMATE CHANGE MITIGATION IN EBINAT DISTRICT, SOUTH GONDAR ZONE, ETHIOPIA

Workinesh, Asradew

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ENVIRONMENT AND CLIMATE CHANGE (M.Sc. Program)

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MSc. Thesis

By

Workinesh Asradew

October, 2019

Bahir Dar, Ethiopia

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Workinesh Asradew

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (MSc.) in “Environment and Climate Change”

Main supervisor: Dr. Dessie Assefa (PHD)

Co-Supervisor: Mr. Workineh Ejigu

October, 2019

Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Ms. Workinesh Asradew** entitled on: "**Estimating Carbon Stock of Zafnigus Forest and its Implication for Climate Change Mitigation in Ebinat District"**. We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **Environment and Climate Change**.

APPROVED BY BOARD OF EXAMINERS

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DECLARATION

This is to certify that this thesis entitled "**Estimating carbon stock of Zafnigus forest and its implication for climate change mitigation in Ebinat district, South Gondar Zone, Ethiopia"** is submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "**Environment and Climate Change**" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Ms. **Workinesh Asradew** (ID. No. BDU 1018360 PR) is an authentic work carried out by her under our guidance. The matter embodied in this project work has not been submitted earlier for the award of any degree or diploma to the best of our knowledge and belief.

Name of the Student

Ms. Workinesh Asradew Signature _____________ & Date ____________

Name of the Supervisors

1) Dessie Assefa (PhD) (Main supervisors) Signature ____________& Date ____________

2) Mr. Workineh Ejigu (Co-supervisors) Signature ____________ &Date ______________

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DEDICATION

I dedicate this thesis to my almighty God for giving me a precious breath to my family to inspire them the spirit of learning hard as a weapon of survival of the fittest, especially my beloved mother Ms Kassanesh Admassie and father Mr. Asradew Berhanu.

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LIST OF ACRONYM/ABBREVIATIONS

AGB	Aboveground biomass
M.a.s.l	Meter above sea level
BA	Basal area
BCEF	Biomass conversion and expansion actors
BEF	Biomass expansion factors
BGB	Belowground biomass
BGC	Below ground carbon
CO_2 equ	Carbon dioxide equivalent
CRGE	Climate-Resilient Green Economy
DBH	Diameter at breast height
EDAO	Ebinat district agricultural offices
FAO	United nation Food and Agricultural Organization
GHGs	Greenhouse Gasses
GPS	Global Positioning System
IPCC	Intergovernmental Panel for Climate Change
IVI	Important value index
LB	Litter biomass
LC	Litter carbon
LHGs	litter, herbs and grasses
MEFCC	Ministry of environment, forest and climate change
RD	Relative density
RDo	Relative dominances
RF	Relative frequency
SEM	Standard error of mean
SOC	Soil organic carbon
SIV	Species important value index
TCp	Total carbon pool
UNEP	United nation environmental program
ZF	Zafnigus forest

ABSTRACT

Forests play an enormous role in combating climate change, the most pressing global issue currently, by sequestering and storing carbon from the atmosphere through photosynthesis. This study was conducted to estimate total carbon stock of the dry Afromontane forest type of Zafnigus Forest and its implication for climate change mitigation. A grid method was used to identify each sampling point through Global Positioning System (GPS) and nested circular plots having 11.3m radius (401m^2*) and 8m radius (201m*^{2}*) were employed for this study. All trees within a plot which have diameter at breast height (DBH) ≥5cm were recorded and its biomass was calculated by allometric equation. Walkley Black method was used to estimate soil carbon stock and data analyzed by SPSS version 20. Results revealed that the total carbon stock of the forest was 325.48 tha*$^{-1}$* whereas trees store 194.85 t/ha, litter, herbs and grasses (LHGs) 2.01 tha*$^{-1}$* and soil 128.62 t/ha (up to 30cm depth). Soil organic carbon was different in land use type of which 128.62, 94.72 and 38.42 tha*$^{-1}$* forest, cultivated land and grazing land respectively. Altitude was affect the carbon stock distribution in all carbon pool which was determined in this study. The lower parts of altitude had high carbon stocks in all carbon pool while the upper and middle parts of altitude due to the absence of tallest trees with maximum DBH, density, age, size, branches, management activities at the edge of the forest and decomposition rate. The result of study showed a significant variation in carbon stock in all carbon pool except litter carbon pool along altitudinal range at 95% confidence interval for the case of tree carbon stock (P=0.045); SOC (P=0.021, P=0.038 and P=0.016) comprised at 0_10cm, 10_20cm and 20_30 cm depth respectively and LHGs (P=0.194). Based on the result of this study the distribution of carbon was highly affected by forest density, height and DBH of tree in all carbon pools and the variation of altitude have an impact. The study revealed that tree biomass was the major reservoir of carbon followed by soil organic carbon and litter biomass. However, further research on the rate of carbon storage estimation and develop species specific allometric equation model should be done.*

Keywords: *Zafnigus forest, Carbon stock, land use comparison, altitude and Climate change mitigation.*

Chapter 1. INTRODUCTION

1.1 Background and Justification

Forests cover just over four billion hectares, 31% of the world's total land area and the world's forests store 289 Giga tone of carbon in their biomass alone (United Nation Environmental Program (UNEP, 2012). African forest constitutes 21% of the global total of carbon stock in forest biomass and has the ability to sequester up to 630 kg of carbon ha^{-1} yr^{-1}, thereby providing critical shock absorber against global climate change (Katerere *et al.*, 2009). According to Food and Agricultural Organization (FAO, 2015), the forest cover of Ethiopia declines from 13.78 in 1990 to 11.40% in 2015 of having widespread deforestation.

The forest and woody vegetation of Ethiopia play an important environmental role in sequestering anthropogenic atmospheric carbon. According to Yitebitu Moges et al. (2010), the forest resources of Ethiopia store an estimated 2.76 billion tons of carbon, playing a significant role in the global carbon balance. Carbon sequestration from the atmosphere can be advantageous from both environmental and socioeconomic perspectives. The largest C store is found in the woodlands (45.7%) and the shrublands (34.4%).

The main factors for the destruction of natural forests are the expansion of agricultural land and human settlement, a rise in land grabbing by global investors, and over-exploitation of resources for various purposes such as firewood, coal, construction materials, and timber (Zegeye Hileab *et al.*, 2011). These factors are mainly caused by rapid population growth, weak government policy on forest management and policy, and lack of knowledge of forest management. Accordingly, the Amhara Region has become one of the severely environmentally degraded parts of Ethiopia (Zegeye Hileab *et al.*, 2011). Currently, the remaining forest is mainly limited to areas around churches and other protected or inaccessible areas (Watson, 2005).

In Ethiopia, different factors like deforestation, overgrazing, expansion of agricultural land and permanent conversion to other forms of land use are leading to shrinkage of forest resources. In addition to human activities, the forest can be affected by different environmental factors such as altitude, slope, and aspect by affecting the patterns of tree species distribution (Valencia et al, 2009).

Forests play an important role in global climate change regulation. The potential of forests in naturally sequestering carbon out of the atmosphere which is important for climate change mitigation was recognized by international climate agreements (IPCC, 2007). Currently, there is great interest in assessing forest carbon stock (Gibbs *et al.*, 2007 and Djomo *et al.*, 2016). Since forests are cleared, the carbon is converted to carbon dioxide in the atmosphere (Condit, 2008) which is the cause of global climate change at one hand and reduction of forest cover on the other hand.

The above ground carbon pools of tropical forests in their natural condition contain more carbon per unit area than any other land cover type. The main carbon pools in tropical forest ecosystems are the living biomass of trees and the mass of litter, and soil organic matter, but aboveground carbon storage in natural forest is higher than that in any other vegetation (Genene Assefa *et al.,* 2013).

The forests of Ebinat district have been cleared within the last 10 years as the demand for energy, construction wood, food, fodder, and feed has increased as a result of the increase both in human and in livestock population. The main causes of deforestation and forest degradation at Ebinat are tree cutting for fuelwood, construction materials, and selective cutting for sale Ebinat District Agricultural Offices (EDAO, 2018).

Zafnigus forest is one of the natural and dry Afromontane forest type found in Ebinat District of Amhara Region which is victimized by these anthropogenic activities as well as environmental factors. Due to the existences of living people close to the forest and deforestation for the purpose of illegal charcoal and firewood production, agricultural land expansion and free grazing are the main challenges of Zafnigus forest. Awareness and knowledge of carbon stock potential on the forest, sustainable use and management are less known to local communities.

Therefore local communities incorporating the existing forest management strategies with climate change through the sequestration of carbon is more than anything in building awareness to overcome the problem. However, few researches have been conducted to measure the potentiality of forests of Ethiopia in carbon storage. Therefore, the study was aimed to measure the carbon stock potential of Zafnigus while to contribute and give some relevant information for local and regional administration, policy makers and other conservation organization on the status of the forest.

Estimating to carbon stock potential of forests is crucial since it provides economic and ecological benefits to the local people. Thus, this study was aimed to determine carbon stock potential of the forest and its role of climate change mitigation in Ebinat district, North West (NW) Ethiopia.

1.2 Statement of the Problem

The challenge of environmental degradation primarily results from the day to day increment of atmospheric CO_2. Fossil fuel combustion, industrial processes, and unprecedented land use conversion have led to rising levels of Carbon Dioxide Equivalent (CO_2) and other Green House Gases (GHGs) in the atmosphere (Admit Wondifraw, 2007).

The role of the forest now is impaired by human-induced actions like deforestation and forest degradation which results in loss of forest cover, reduces soil productivity, rise in global temperature, erratic rainfall, sea level rise, landslides and severe environmental disturbance more than ever before (FAO, 2010).

Ethiopia is also the most climate change vulnerable country. The government of Ethiopia has ratified Climate-Resilient Green Economy (CRGE) in 2011 to achieve sustainable development by means of reconciling the environment, economic and social aspects. Unlike in the developed countries, Ethiopia does not have well organized and efficient carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests.

Therefore, it is considered a global issue that large-scale CO_2 emission reductions are required with strict limits on the country to what level of carbon is absorbed to mitigate climate change. According to the IPCC (2000) report, forests are a current focus for action since they play an important role in mitigating climate change by naturally taking carbon out of the atmosphere through photosynthesis. Hence, estimating carbon stock potential of the forest from different organic carbon pools is essential for sustainable forest management to achieve climate change mitigation.

So far no study has been conducted in Zafnigus forest that aimed at carbon sequestration potential of this forest and it is one of the forests victimized by these anthropogenic activities as well as environmental factors. Awareness and knowledge of carbon stock potential on the forest, sustainable use and management are less known to local communities. This forest is under pressure of human being and mostly depilation due to agricultural expansion, illegal cutting of tree for charcoal, house wood harvesting, free grazing, fuelwood collection and timber which aggravates carbon emission. As a result, the most important and valuable indigenous tree species which were very important for carbon sequestration are being severely depleted in the area. Up to date, there was no sufficient data about carbon stocks and the influence of environmental gradients on carbon stock in Zafnigus forest.

So, this study focuses on the influence of environmental factors on forest carbon stocks and to estimate the carbon stocks potential of Zafnigus forest by quantifying the major carbon pools.

1.3 Objectives

1.3.1 General objective

- ❖ The general objective of this study was to estimate the total carbon stock potential of Zafnigus forest and its implication for climate change mitigation.

1.3.2 Specific objectives:

The specific objective includes the following

- ➢ To assess the species composition diversity of Zafnigus forest
- ➢ To estimate the amount of carbon stock in aboveground, belowground biomass, litter biomass and soil organic carbon of Zafnigus forest
- ➢ To investigate the effect of altitude on carbon stock potential of different carbon pools

1.4 Research Questions

1. How many plant species were found in Zafnigus forest
2. How much carbon is presently being stocked in above- and below-ground biomass, dead wood, litters biomass, and soil organic carbon of Zafnigus forest land?
3. How does altitude affect carbon stock potential of Zafnigus forest?

1.5 Significance of the Study

Climate change affects the environmental conditions to which forest trees are adapted and climate is also shaped and strongly influenced by vegetation cover. Therefore, knowledge on the status of these forests, their potential as a carbon sink and overall ecosystem services will contribute a lot to the conservation and sustainable utilization of the resources and have a knowledge based conservation plan.

Currently, the importance of forest ecosystems is a consideration in the context of climate change mitigation because they can act as the sinks of CO_2. Forests are relevant to climate change mitigation through their potentials in mitigation GHGs, particularly carbon sequestration. The carbon sequestration benefits of forest can be perceived to be more important at the global than at national, regional or local levels (Sharma, 2000). Estimation of total plant biomass and soil carbon sequestered in any forest system is very important as it gives ecological and economic benefits to the local people. Therefore, this study aims to establish the baseline information for the surrounding communities and for any stakeholders on the current status of the study forest.

1.6 Scope of the Study

The scope of this study was to address the role of Zafnigus forest in South Gondar zone, Ethiopia and its carbon stock potential in role of climate change mitigation. It is impossible to cover the whole carbon stock potential of Ethiopian forest with available time and resource; since this study covered only small area from the total forest coverage of Ethiopia. The study included carbon stock of the forest in the carbon pools of above ground biomass (AGB), below ground biomass (BGB), litter, herbs and grass biomass (LHGB) and soil organic carbon (SOC) at a depth of 30cm. It also included both the carbon stock potential of different plant species and the influence of environmental factors like altitude on the carbon pool of Zafnigus forest were examined.

1.7 Limitation of the Study

Although the research was properly designed and carefully conducted, there were some limitations as follows:

- The study carbon stock of forest, i.e. the researcher had studied carbon stock potential of the forest only during the dry season.
- There is no species specific allometric equation in Ethiopia and no allometric equations developed for Ethiopian forest ecosystem. In this allometric equation the minimum diameter used is DBH ≥5cm. Those tree species which have <5cm DBH are ignored.

Chapter 2. LITERATURE REVIEW

2.1 The Role of Forest Carbon Stock on Climate Change Mitigation

Forest ecosystems play an important role in climate change mitigation because they store a large amount of carbon in vegetation biomass and soil and they are also a critical component of the global carbon cycle, storing over 80% of global terrestrial aboveground carbon (FAO, 2014a). Hence, the forest ecosystem is known to be cost effective ways of reducing global CO2 emissions which is the major GHG causing climate change (Anup *et al*., 2013) so forests serve as long term sink if forest fire and forest degradation is strictly controlled. They have also tremendous potential to contribute to sustainable development and to a greener economy (FAO, 2014b).

This is why international governments specifically, the current government of Ethiopia is relaying on enhancing forest carbon stock for the Climate Resilience Green Economy development (CRGED) strategy for reducing Green House Gas (GHG) emissions enables to sell its abatement services to developed countries by which forest carbon credit is generated (Busch and Engelmann, 2015).

Forest ecosystems store carbon through the photosynthetic assimilation of atmospheric CO2 and the subsequent storage in the form of biomass (trunks, branches, foliage, and roots, etc.) litter, woody debris (Malhi *et al*., 2002 and Houghton, 2005), soil organic matter. As Yitebitu Moges *et al*. (2010) pointed out that the forest resources of Ethiopia can store about 2.76 billion tons of carbon, playing a significant role in the global carbon balance provided that the nightmare scenario on forests is critically managed. In such a way, forests being protected and more carbon in the atmosphere sequestered and enhanced carbon stock in the biomass of forests, consequently climate change mitigation through forests can be achieved and enabled to generate forest carbon credit, positive impact to the economy and environment (FAO, 2010 and Busch and Engelmann, 2015).

2.2 Forest Resources and Carbon Sequestration

Forest in Ethiopia is defined in different ways that could be used for the National Forest Inventory purpose or for international reporting to the Global Forest Resources Assessment (FAO). Accordingly, in 2015 Ethiopia adopted a new forest definition as follows: Land spanning at least 0.5 ha covered by trees and bamboo, attaining a height of at least 2 m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course‟ Ministry of Environment, Forest and Climate Change (MEFCC, 2016).

The reason to use this definition is better capture dry and low land moist vegetation resources. The forest cover of Ethiopia since 1990-2015 ranges 13.78 up to11.40% of having widespread deforestation trend (FAO, 2015) with reduction trend of deforestation that could be due to improvement in forest resource conservation activities of afforestation and reforestation works in the country since 2015. The average annual deforestation rate is 1% which is higher compared to other Sub-Saharan African countries (0.8%) (FAO, 2010) whereas the global rate of annual net loss of forest has slowed from 0.18% in the 1990s to 0.08% in the period 2010−2015 (Table1).

Table 1: Forest cover and its trend from 1990–2015.

No	Year	Forest cover		Remark
		1000ha	%(land)	
1	1990	15114	13.78	No activity data
2	2000	13705	12.5	No activity data
3	2005	3000	11.86	Afforestation and reforestation
4	2010	122996	11.21	Natural expansion
5	2015	12499	11.4	Natural regeneration

2.3 Carbon Stock Pools

2.3.1 Aboveground biomass (AGB) carbon stock

The AGB carbon pool consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The most comprehensive method to establish the biomass of this carbon pool is destructive sampling, whereby vegetation is harvested, dried to a constant mass and the dry-to-wet biomass ratio established. Destructive sampling of trees, however, is both expensive and somewhat counter-productive in the context of promoting carbon sequestration (Tulu Tolla, 2013).

Two further approaches for estimating the biomass density of tree and biomass exist are more commonly applied. The first directly estimates biomass density through biomass regression equations. The second convert's wood volume estimates to biomass density using biomass expansion factors (Brown, 1997); where stand tables of all trees in a particular diameter class are available; the biomass per average tree of each diameter class of the stand table can be estimated through biomass regression equations, also called allometric equations. Alternatively, the results of direct sampling of tree diameter in the area of interest can be used in these regression equations. The total biomass of the forest stand is then derived from the average tree biomass multiplied by the number of trees in the class, summed across all classes. In both tropical and temperate forests, such diameter measurements explain more than 95% of the variation in tree biomass (Brown, 2002).

There are a number of databases and publications that present default regression equations, stratified by rainfall regime and region (Brown, 1997; Luckman, 1997 and Chamshama *et al.*, 2004*)*. These default equations, based on a large sample of trees, are commonly applied as the generation of local allometric equations is often not feasible. However, the application of default equations will tend to reduce the accuracy of the biomass estimate. For instance, rainfall guides generally apply to lowland conditions. However, as elevation increases potential Evapotranspiration decreases and the forest is wetter at a given rainfall: thus a regression equation applied to highland forest may give in accurate biomass estimates (Brown, 1997 and IPCC, 2003).

Where information on the volume of wood stock exists: such as from commercial inventories, biomass density can be estimated by expanding the merchantable volume of stock, net annual increment or wood removals, to account for biomass of the other above-ground components. To do this, either Biomass Expansion Factors (BEFs) or Biomass Conversion and Expansion Factors (BCEFs) are applied. BEFs expand dry wood stock volume to account for other, nonmerchantable, components of the tree. To establish biomass the volume must also be converted to a weight by multiplication of the wood density as well as the BEF. In contrast, BCEFs used only a single multiplication to transform volume into biomass; this is useful where wood densities are not available. Default BEFs and BCEFs reported in the literature can be applied in forest carbon accounting. However, unless locally-specific equations exist to convert direct measurements of tree height and diameter to volume, regression equations to directly estimate biomass from tree diameter are preferable (IPCC, 2003).

2.3.2 Belowground biomass (BGB) carbon stock

The BGB carbon pool consists of the biomass contained within live roots. As with AGB, although fewer data exists, regression equations from root biomass data have been formulated which predict root biomass based on aboveground biomass carbon (Cairns *et al*., 1997; Brown, 2002). Cairns *et al*. (1997) review 160 studies covering tropical, temperate and boreal forests and find a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30. However, according to MacDicken (1997), for cases in which more accurate estimates of BGB are economically feasible using locally established.

Although roots are believed to depend on climate and soil characteristics (Brown and Lugo, 1982), Cairns *et al*. (1997) found that root to shoot ratios were constant between latitude (tropical, temperate and boreal), soil texture (fine, medium and coarse), and the tree type (angiosperm and gymnosperm). As with AGB, the application of default root-to-shoot ratios represents a trade-off between costs of time, resources and accuracy. BGB can also be assessed locally by taking soil cores from which roots are extracted; the oven dry weight of these roots can be related to the cross-sectional area of the sample, and so to the BGB on a per area basis (MacDicken, 1997 and Tulu Tolla, 2013).

2.3.3 Dead wood tree biomass carbon stock

Dead organic matter is composed of litter and dead-wood and generally divided into course and fine with the breakpoint set at 10 cm diameter (Harmon and Sexton, 1996).

Although logged dead wood, standing and lie down on the ground, is often a significant component of forest ecosystems, often accounting for 10-20% of the aboveground biomass in mature forests but it tends to be ignored in many forest carbon budgets (Delaney *et al*., 1998). The quantity of dead wood does not generally correlate with any index of stand structure (Harmon and Sexton, 1996). The primary method for assessing carbon stock in the dead wood pool is to sample and assess the wet-to-dry weight ratio, with the large pieces of dead wood measured volumetrically as cylinders and converted to biomass on the basis of wood density, and standing trees measured as live trees but adjusted for losses in branches <20% and leaves <2_3% (MacDickens, 1997).

2.3.4 Litter carbon stock

Watson (2008) defined litter as dead surface plant material that is still recognizable and is not decomposed to the point that identification is impossible to define and includes dead leaves, twigs, dead grasses, small branches (less than the minimum diameter used to define coarse woody debris-normally 10 cm). Similarly, MacDicken (1997) indicated that the dead litter carbon pool consists of all non-living biomass with greater than the limit for soil organic matter (SOM) i.e. 2mm to 10cm diameter and contains the biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM.

As a result, litter is generally distinguished from SOM by its low degree of decomposition or fragmentation. Litter at least occasionally accumulates on top of the soil, but litter may also include newly dead roots in the soil (Watson, 2008). Many estimates of the dead litter pool in forests use quadrants to assess the litter mass per unit area at a given 19 point in time (Ordonez *et al*., 2008). However, this method needs distinguishing between the litter and SOM so that ambiguity can be avoided.

According to IPCC (2006), the dead litter carbon pool relies on the establishment of wet-to-dry mass ratio. However, where this is no possible default values are available by forest type and climate regime from IPCC ranging from 2.1 t C ha^{-1} in tropical forests to 39 t C ha^{-1} in the moist boreal broadleaf forest (IPCC, 2006).

2.3.5 Soil organic carbon stock

Soil organic carbon (SOC) is the largest terrestrial carbon (C) sink, and management of this pool is a critical component of efforts to mitigate atmospheric C concentrations (Jobbagy and Jackson 2000, Lal, 2004, 2005 and Tian *et al*. 2015). Much of this SOC is found in forest ecosystems (Lal 2005) and is thought to be relatively stable. However, there is growing evidence that SOC is sensitive to global change effects, particularly land use histories, resource management, and climate (Jobbagy and Jackson 2000, Heiman and Reichstein 2008, Nave et al. 2010, Nave et al. 2013, Tian et al. 2015).

SOM includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal and Bruce, 1999). Inorganic forms of carbon are also found in soil, however, forest management has a greater impact on organic carbon and so inorganic carbon impact is largely unaccounted. SOM is influenced through land use and management activities that affect the litter input, for example, how much-harvested biomass is left as residue, and SOM output rates, for example, tillage intensity affecting microbial survival. In SOM accounting, factors affecting the estimates include the depth to which carbon is accounted, commonly 30cm, and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years (Watson, 2008).

2.4 Tree Species Diversity

Biodiversity is defined as the kinds and numbers of organism and their patterns of distribution (Eshaghi *et al*., 2009). Moreover, diversity has become an increasingly popular topic within the discussion of sustainability in the last decade, though the maintenance of diversity of forest ecosystems is required since many years (Schuler, 1998).

Generally, biodiversity measurement typically focuses on the species level and species diversity is one of the most important indices which are used for the evaluation of ecosystems at different scales (Ardakani, 2004). The term diversity is clearer defined. Eshaghi *et al*., 2009 gave a rather narrow definition that diversity covers species richness and dominance in a system. Nagel (1976) described the demands on a diversity measure by the example of species diversity. If a system contains only one species, the species diversity equals zero. The maximum species diversity in a system occurs, if by given number of species in all species are equally frequent.

Species diversity is one of the most important indices used for evaluating the sustainability of forest communities.

Importance value indices indicates the relative ecological importance of a given woody species at a particular site (Sudi Dawud *et al*., 2018). High species importance value index is attributed to their high basal area, high relative frequency and high relative density. It is also used for setting priority/ranking species management and conservation practices and helps to identify species as dominant or rare species (Kent and Coker, 1992 and Sudi Dawud *et al*., 2018). A species having value of IVI greater than 5.00 can be considered dominant because of the relative ecological role it plays in the ecosystem (Fekadu Gurmessa, 2013 and Sudi Dawud *et al*., 2018).

2.5 Impacts of Climate Change

Climate change has posed challenges discerned from local, national to international levels. The climate change impacts are most observed in developing countries where agriculture is the primary source of food like Ethiopia. The impact impedes the socio-economic and environmental developments, relying on rain-fed agricultural systems, sensitive to climate change (FAO, 2016). It is highly affecting the development of Africa due to erratic weather patterns and climate extremes threaten agricultural production and food security, health, water and energy security. Specifically, Ethiopia in 2015 faced one of the worst droughts in thirty years caused by the El Niño climate conditions, leading to failed harvests and shortages of livestock forage (Admit Wondifraw *et al*., 2016). So such catastrophe, threaten human security and that triggers competition in basic need resources, results in instabilities among nations.

2.6 Forest Carbon Stock Measurement

Forest inventories provide vital information for well informed decision making on the management and conservation of forest resources for policy makers, governments, ecologists and environmentalists. To facilitate the works on forest carbon stock measurement, forest carbon is identified in three major pools that is, above and below ground living vegetation, dead organic matter and soil organic carbon (IPCC, 2006). To use reliable allometric models for forest biomass carbon estimation is important for the successful implementation of climate change mitigation policies (Chave *et al*., 2014). Hence, different allometric equations have been developed by many researchers to estimate the aboveground biomass.

These equations are different depending on type of species, geographical locations, forest stand types, climate and others (Baker *et al.*, 2004; Brown *et al.*, 1989). By considering these factors, different authors provided different carbon estimation models according to the ecological zone of the forest to be found (Table2).

Table 2: Different Allometric Equations for Estimation of Biomass

Allometric Equation	Ecological zone to be applied	Author	Remark
$Y=0.0673\times(\rho*D^2*H)^{0.976}$	Tropical dry forest	Chave *et al*., 2014	D:5-212 cm
$Y=\exp.\{-2.187+0.916\ \mathrm{Ln.}(\rho*D^2*H)\}$	Tropical rain forest	Chave *et al*., 2005	D: ≥ 5 cm
$Y=\exp.\{2.977+\ln(\rho*D^2*H)\}$	Tropical rain forest	Chave *et al*., 2005	D: ≥ 5 cm
$Y=\exp.\{-2.4090+0.9522\ \mathrm{Ln.}(\rho D^2H)$	Tropical rain forest	Brown *et al*., 1989	D: >5cm
$Y=34.4703-8.0671*D+0.6589*D^2$	Tropical scrubland	Brown *et al*., 1989	D: ≥ 5 cm
Y =exp.{-3.1268+0.9885ln(D2*H)}	Tropical moist	Djomo *et al*., 2010	D:5–138 cm
Y=10.0899((D2)0.9522)*(S0.9522)*(H0.9522)	General	Luckman *et al*., 1997	D: General

2.7 Factors Affecting Forest Carbon Stock

Deforestation and conversion of forest to non-forestland use is typically associated with large immediate reductions in forest carbon stock through land clearing. Forest degradation reduction in forest biomass through no sustainable harvest or land-use practices can also result in substantial reductions of forest carbon stocks from selective logging, fire and other anthropogenic disturbances, and fuelwood collection (Asner *et al.*, 2005). All of these factors have also carbon balance implications. Such disturbances affect roughly 100 million ha of forests annually (FAO, 2006).

according to the Millennium Ecosystem Assessment (2005) scenarios, degradation defined as a decrease of density or increase of disturbance in forest class, affected tropical regions at a rate of 2.4 million ha/yr in the 1990s. At the same time, the forest area in the developing regions will decrease by about 200 to 490 million ha. The lack of consensus on factors that control the carbon balance is an obstacle to the development of effective mitigations strategies. However, forests are also affected by climate change and their contribution to mitigation strategies may be influenced by stresses possibly resulting from it. Socioeconomically, global forests are important because many citizens depend on the goods, services, and financial values provided by forests. Within this context, mitigation options have to be sought (Giessen, 2011).

Chapter 3. MATERIAL AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Zafnigus forest is one of the forests found in Ebinat district, South Gondar Zone in Amhara National Regional State, Ethiopia. Geographically, it is located between 1158’ N latitude and 37° 34’E longitudes (Figure1).

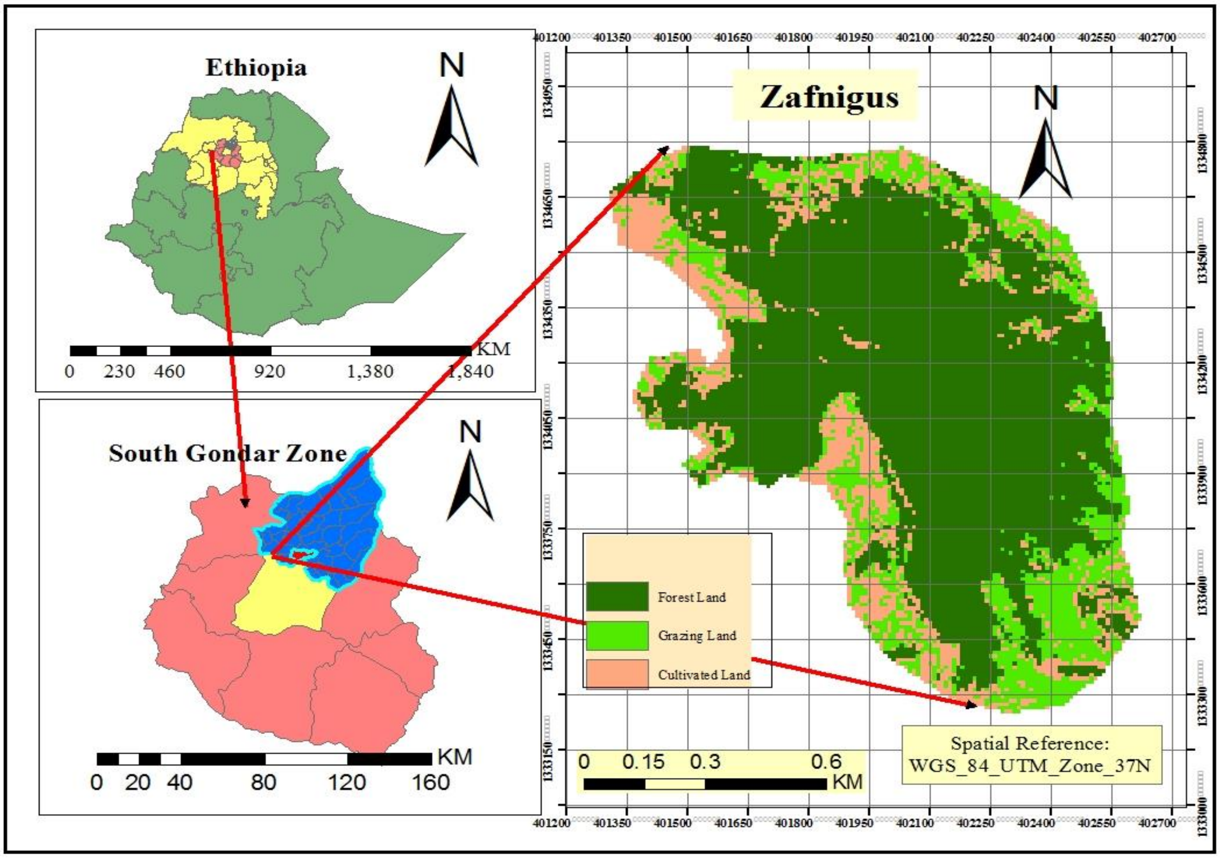


Figure 1: Location map of the study area

3.1.2 Climate

According to Ebinat district agricultural offices (EDAO, 2018) the mean maximum and minimum temperature of the district is 30°C and 15°C respectively. The mean maximum and minimum annual rainfall is 1502 mm and 665 mm with a main rainy season from June to September.

3.1.3 Soil and topography

The soil texture of the study area belongs to sandy to sandy loam texture types, whereas the soil type of the study area is characterized by liptosols and nitosols soil types Ebinat district agricultural offices (EDAO, 2018).The topography of the study area is 45% mountainous and others undulate plateau, cliffs, gorges/valley and flat are 27%, 5%, 10% 10% 4% respectively.

3.1.4 Description of study forest

Zafnigus forest is one of the dry Afromontane forests in Ethiopia, which is composed of both natural and human plantation trees. The forest area covered 258 hectares and its elevation ranges from 2333 to 2872 m above sea level (a.s.l). It comprises many plant species, which dominated mainly by *Prunus africana, Teclea nobilis*, *Olea europaea, pterolobium stellatum*, *Calpurnia aurea*, *Albizia schimperiana*, *Dodonaea angustifolia* and *Pittosporum abyssinicum*. It is also the home of different animal species such as leopard, hyena, antelope, ape, monkey, gorilla, fox, rabbit, and different types of bird species Ebinat district agricultural offices (EDAO, 2018).

3.2. Materials

The sampling points were identified by using GPS. The soil samples from the selected plots were collected in plastic bags that are taken by soil core in the field. The diameter of all trees in the sample plot were measured by calliper (<30 cm) and diameter tape (>30 cm). Tree height was also measured using hypsometer. The measured sampled trees with in the sample plot are marked by chalk to avoid double counting of the trees. Plot boundaries were marked by using rope and pegs. The indication of the sample points during sampling was done by GPS through feeding the coordinate (northing and easting) values to GPS and soil samples for bulk density determination were taken by core sampler at each recommended soil depth and placed to plastic bags.

3.3 Methods and Procedures of Data Collection

3.3.1 Area estimation and forest stratification

The boundary of the study area was delineated by using arc GIS software from satellite image. Once the study area was delineated, field survey was held to check species diversity, land use, altitude. After this, the study area was classified in to tree forest and altitude (Figure 2). These stratifications help to increase the accuracy of the forest carbon accounting. The grid points that indicate each sample plots were established 150 m by 150 m distance. A total of 30 plots were established based on the grid system and sample points were distribute proportionally in the study forest.

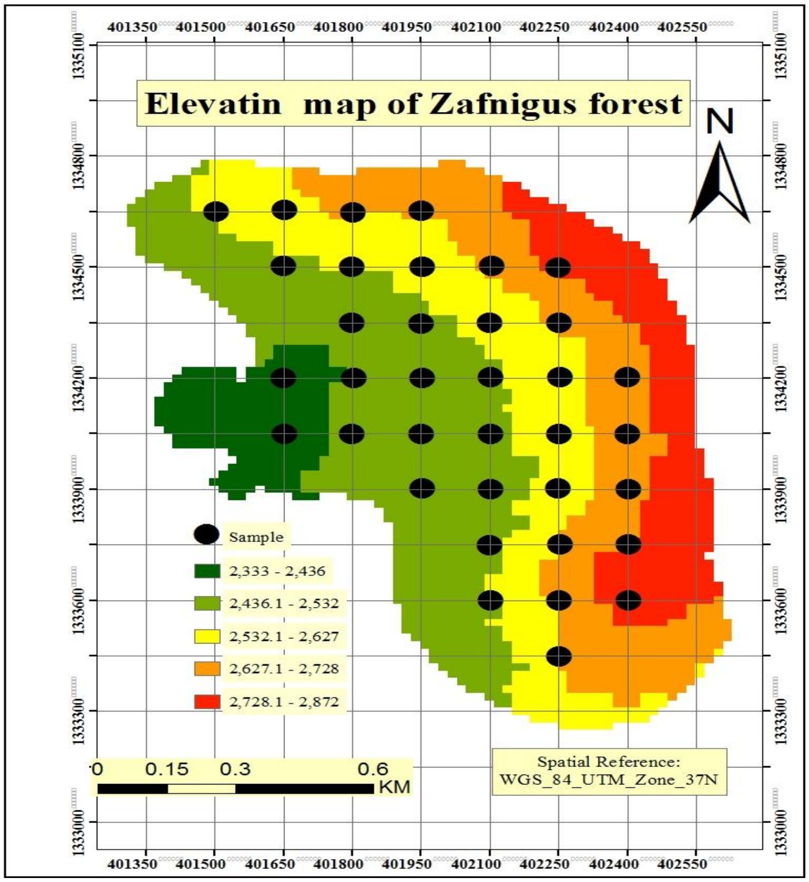


Figure 2. Distribution of sampling points by elevation at Zafnigus forest

3.3.2 Sampling technique and sample size

The total area of the study site was 257.8 ha and a total of 30 sample plots (intersection points) were determined. A grid method was used for identification of each intersection point in the field at a regular interval (Figure 3).

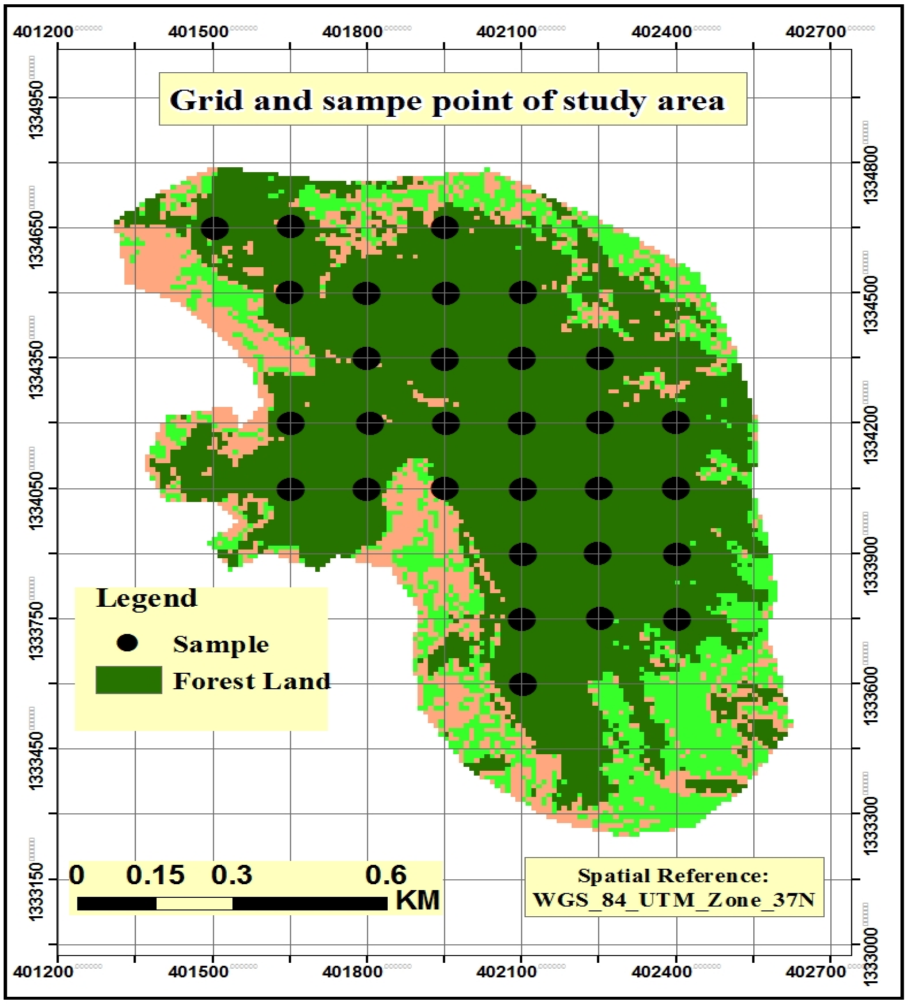


Figure 3. Distribution of sampling points with in grid technique at Zafnigus forest

The size and shape of the sample plots is a tradeoff among accuracy, precision, and time (cost) of measurement. Forest carbon measurement can be carried out in both rectangular and circular plots. Nevertheless, circular plots are recommended for this study because they are relatively easy to establish, and has less edge effect (Maleki and Kiviste., 2015).

A circular concentric plots of 401 m^2 area of main sample plot and 201 m^2 of sub sample were employed for sampling to incorporate the heterogeneity and thus be more representative with less boundary error than the other shape and size of sample plots. Trees that have large diameter (≥10cm diameter) were measured in the larger sample plot (the main plot), trees that have diameters between 5–10 cm were measured from the small plot whereas data on non-tree vegetation, litter and soil were collected in a smaller sub-plot (Figure 4).

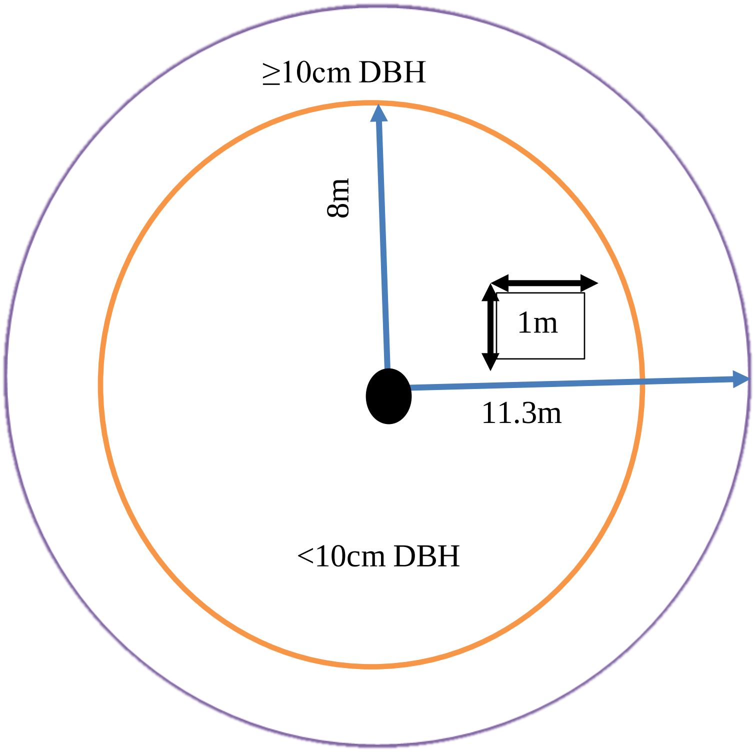


Figure 4: Size and shape of the sample plot

3.4 Determination of tree species distribution and importance value index

DBH and Height distribution of tree species

According to Sherri Jackson, (2009) the data set even easier to read (especially desirable with large data sets) by grouping the scores and creating a class interval of diameter and height distribution categorized. In a frequency distribution that are combined into categories or class intervals and then listed along with the frequency of scores in each interval from 5 to 124 cm a 119 point range. A rule of this author when creating class intervals is to have between 10 and 20 categories. The diameter and height data are grouped into class intervals according to Sherri Jackson, 2009 and determined by using the following formula.

$$\text{Class Interval} = \frac{\text{maximium}-\text{minimium}}{\text{No of class}} \qquad \text{(eq.1)}$$

Importance Value Index (IVI)

According to Kent and Coker, 1992, it often reflects the extent of the dominance occurrences and abundances of a given species in relation to other associated species in an area. Importance value index (IVI) was computed by summing up relative frequency (RF), relative density (RD), and relative dominance (RDO) values. It is described using the following formula.

Basal area was calculated for all trees with a diameter at breast height ≥5cm by using the formula sited by Yitebitu Moges *et al*. (2010).

$$BA = \left(\frac{\pi}{4} * (DBH)2\right) \qquad \text{(eq.1)}$$

$$Relative\ density = \frac{\text{Number of aboveground stems of a species}}{\text{Total number of aboveground stems in the sample area}} * 100 \qquad \text{(eq.2)}$$

$$Relative\ frequency = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ tree\ species} * 100 \qquad \text{(eq.3)}$$

$$Relative\ dominance = \frac{Total\ BA\ of\ a\ specis}{sum\ of\ BA\ in\ all\ species} * 100 \qquad \text{(eq.4)}$$

IVI= RF+ RD+ RDO (eq.5)

Where, IVI, importance value index (IVI) of the species; BA, the basal area in m^2; RF, relative frequency; RD, relative density; RDO, relative dominance and DBH, diameter at breast height.

3.5 Field Measurements and Estimation of forest carbon stock

3.5.1 Aboveground carbon stock (AGC)

According to Pearson *et al.* (2005), all tree and shrub species having ≥10cm DBH was measured from 401 m^2 and 201 m^2 (≥5cm DBH) area of sample plots using diameter tape and the height of those trees are also measured by using hypsometer. During measurement, woody plants having multiple stems at 1.3 m are considered as a single tree while woody plants forked below 1.3 m are treated as a single individual as indicated by Pearson *et al.* (2005 and 2007). According to Bhishma *et al* (2010), woody plants having ≥50% of basal area fall within the border of sample plot are include and woody plants which had more than 50% of the basal area falls outside the border line are exclude. Also, trees which have trunks inside the sample plot and branches outside the sample plot are included, but trees overhanging into the plot are excluding. Species descriptions is done in the field using their local names and scientific name by using flora of Ethiopia, Eritrea and useful trees and shrubs for Ethiopia (Azene Bekele, 1993).

After measurement of DBH and height, the aboveground biomass (AGB) of trees and shrubs existed in Zafnigus forest was calculated using the general allometric model of Chave *et al.*, 2014) as follows.

$$AGB = 0.0673*(\rho DBH^{2\,*} H)^{0.976} \qquad \text{(eq.1)}$$

Where, AGB, aboveground biomass (tha^{-1}); DBH, Diameter of trees at breast height (cm); H, Height of tree (m); ρ, Wood density of specific tree species (gcm^{-3}).

The aboveground carbon and CO_2 equivalent sequestrated in aboveground biomass of trees and shrubs found in Zafnigus forest was calculated according to Person *et al*. (2005 and 2007) respectively as follows.

$$\text{Aboveground carbon (AGC)} = \text{aboveground biomass} \times 0.47 \qquad \text{(eq.2)}$$

$$\text{The } CO_2 \text{ equivalent sequestered in the aboveground biomass} = AGC \times 3.67 \qquad \text{(eq.3)}$$

Belowground biomass (BGB) of trees and shrubs found in Zafnigus forest was estimated by using root-shoot ratio factor (Cairns *et al*. 1997 and MacDickens, 1997). According to Mac Dickens (1997) and Pearson *et al.* (2005), standard methods of estimating BGB and BGC can be obtained as 27% and 47% of aboveground tree biomass respectively.

$$BGB = AGB \times 0.27 \qquad \text{(eq. 4)}$$

$$BGC = BGB \times 0.47 \qquad \text{(eq. 5)}$$

Where, BGB, belowground biomass (tha^{-1}); BGC, carbon content of belowground biomass (tha^{-1}) and 0.27 is the conversion factor (or root-shoot ratio), which is 27% of the aboveground biomass. The amount of CO_2 equivalent sequestrated in below ground biomass of Zafnigus forest was calculated by multiplying BGC by the molecular mass ratio of carbon dioxide to Carbon (44/12) which is 3.67 as indicated by Pearson *et al.* (2007).

3.5.2 Litter, herbs and grasses (LHGs) sampling

The LHGs samples were collect from 1 m × 1m quadrat sub-plots in each plot. LHGs within 1 m^2 quadrat sub-plots of each main plot were collected, weighed and recorded as field wet weight on the field, and taken to laboratory to determine the litter biomass. Then it was placed in a plastic bag and labelled to which sample plot it belongs. Then after, about 30 labelled samples were taken to the Biotechnology laboratory of the College of Agricultural and Environmental Sciences at Bahir Dar University.

Finally, the litter samples was oven dry to a constant weight at 105°C for 12 hours and the carbon fraction of litter samples was determined in the laboratory according to Walker *et al*, (2012).

The litter biomass (LB) found in Zafnigus forest was calculated by the formula of Pearson *et al.,* (2005) as follows.

$$LB = \frac{W_{field}}{A} * \frac{W_{subsample(dry)}}{W_{subsample(fresh)}} * 0.0001 \qquad \text{(eq.6)}$$

Where, LB, Biomass of litter (tha^{-1}); W_{field}, weight of wet field sample of litter in gram from an area of $1m^2$; A, size of the area in which litter samples was collected; $W_{sub\text{-}sample\ (dry)}$, weight (g) of the oven dry subsample of litter taken to the laboratory; $W_{sub\text{-}sample\ (fresh)}$, weight of the fresh subsample of litter (g) taken to the laboratory (g)

Schlesinger (1991) noted that carbon content of biomass is almost always found to be between 45 and 50% (by oven dry mass). In many applications, the carbon content of vegetation is estimated by simply taking a fraction of the biomass by multiplying 0.5 (Mohammed Gedefaw *et al.*, 2014)

$$LBC = 0.5 * LB \qquad \text{(eq. 7)}$$

Where, LBC, carbon stocks in the litter biomass (tha^{-1}) and LB, biomass of litter (tha^{-1})

3.5.3 Soil sampling and estimation of soil organic carbon (SOC)

Soil samples from the forested areas were systematically taken on the same forest biomass sampling grid points. The litter layer was removed and soil probes were taken with a soil corer (inner diameter 6.6 cm). The soil samples were taken at 0 - 10 cm, 10 - 20 cm, 20 - 30 cm soil depth 2 m far away from the center of each plot and stored in plastic bags. The probes were sieved to 2 mm sieve and dried to a constant weight in an oven at 105°C at Bahir Dar University soil laboratory and the percentage of organic carbon was determined in the Adet Research Center institute of soil laboratory.

Bulk density determination

Bulk density of soil samples were taken from 30 sampling points in forest area. The samples were taken during the onset of wet season when the soil had no drying cracks. At the edge of each sampling plot, a profile was dug to 30 cm. using a trowel, the ring was removed from the horizon and the soil trimmed to the tops and bottoms of the ring using a sharp knife. Any stones were sieved out and weighed separately. The volume of stones was quantified by displacement in a water bath. Bulk density (soil particle <2 mm) was determined after oven dry at 105°C as a stone free dry weights according to Dessie Assefa *et al*. (2017). Therefore, bulk density of fine soil sample was calculated as follows.

$$BD\ of\ fine\ soil = \frac{mass\ sample - mass\ rock\ fragment}{volume\ of\ sample - \frac{rock\ fragment}{\rho\ rock\ fragment}} \quad \text{(eq.8)}$$

Where, BD, soil bulk density fine soil (g/cm^3); and V, the volume of soil sample in core sampler (cm^3).

The percentage of organic carbon, were analyzed by the Walkley and Black, 1934 method to be estimated. The Walkley Black (WB) method used for determining Soil Organic Matter (OM) utilizes a specified volume of acidic dichromate solution reacting with a determined amount of soil in order to oxidize the OM. The oxidation step is then followed by titration of the excess dichromate solution with ferrous sulfate which gives a volume of ferrous sulfate in ml. Then the OM is calculated using the difference between the total volumes of dichromate added and the volume titrated after reaction. The carbon stock density of soil organic carbon found in the study area was calculated using the volume and bulk density of soil as it recommended by (Don *et al.,* 2007).

SOC stock = C% *BD*D (eq.9)

Where**,** SOC, soil organic carbon stock per unit area (tha^{-1}); C%, carbon fraction of soil samples (%) determined in the laboratory; BD, fine soil bulk density (g/cm^3); D, the total depth at which the samples was taken (10cm). While, gram was converted to ton, 1ton=1000000g and cm was converted to hectare, 1ha=10000m$^{2.}$

3.5.4 Estimation of total carbon stock density (TC)

The total carbon stock density of Zafnigus forest was calculated by using the equation of (Subuied *et al.,* 2010), by summing the individual carbon pools of the study area.

$$TC = AGC + BGC + LC + SOC + DTWC \quad \text{(eq.10)}$$

Where, CT, Carbon stock for all carbon pools (tha^{-1}); AGC, Carbon stock in above ground tree and shrub biomass (tha^{-1}); BGC, Carbon stock in below-ground tree and shrub biomass (tha^{-1}); LC, Carbon stock in litter biomass (tha^{-1}); SOC, Soil organic carbon (tha^{-1}) and DTWC, carbon stock in dead tree wood

3.6 Data Analysis

The collected data like DBH and height of live trees, dry weight & carbon fraction of litter samples and soil samples was recorded on the Microsoft excel data sheet of 2013 and analyzed by using Statistical Package for Social Science (SPSS) software version 21. The relationship between different dependent variables (AGC, BGC, LC and SOC) and independent variable (altitude) was tested by descriptive statistics and one-way analysis of variance (ANOVA) at 95% of confidence interval. Descriptive statistics was used to summarize the data, including the mean, maximum, minimum and standard error of carbon stock of each carbon pool of the study area, while one way ANOVA was used to determine the statistical significance difference of carbon stocks of each carbon pool along altitudinal gradient of the study area. The mean comparison of each carbon stock along altitudinal range of the study area was processed using Duncan post-hocsignificant testing.

Chapter 4. RESULT AND DISSCSSION

4.1 Composition of Zafnigus forest

The total number of woody tree species individual having diameter at breast height (DBH) ≥5cm and height 3m of 1227 trees were collected from 43 species of plants in the study area.

Among these *Teclea nobilis* (214 stems/ha), *Olea europaea* (131 stem/ha), *Rhus glutinosa* (70 stem/ha) and *Albizia schimperiana* (51 stems/ha) and *Pittosporum abyssinicum* (51 stem/ha) were the most dominant species whereas the least dominant tree species were *Schefflera abyssinica* (3 stems/ha), *Pterolobium stellatum* (3 stems/ha), and *Clematis hirsute*, *Cupressus lusitanica* and *Hypericum revoltum* (2 stems/ha) (Table 3 and Appendix1).

*Olea europaea (*83%), *Rhus glutinosa* (60%) *and Teclea nobilis* (53%) were the most species frequently occurred while the least frequently occurred species are *Clematis hirsuta*, *Cupressus lusitanica* and *Hypericum revoltum*(3%) shows detail (Table 3 and Appendix 1).

The number of species found in Zafnigus Forest (43) was lower than the number of species found in Guangua Ellala Forest (48; Alves, 2010) and higher than Forest of north-western lowlands of Ethiopia (24; Biniam Alemu, 2012) and Danaba Community Forest (16; Muluken Nega, 2014))

Based on the data indicated the study found by Mesfin Woldearegay *et al*. (2018) noted that variation in species composition over different forests could be attributed to topographic differences among the forests and woodlands compared, as well as the degree of availability and suitable environmental conditions in the respective forests. Another finding by Muluken Nega (2014) states that the study forest are highly impaired by illegal cutting of trees for charcoal and fuel wood production which resulted less number of tree species in the study area.

This could be due to the presence of illegal selective cutting, topographic variation (like altitude factor), the diameter, height of sampled trees considered, forest type and degree of anthropogenic influences on forest areas.

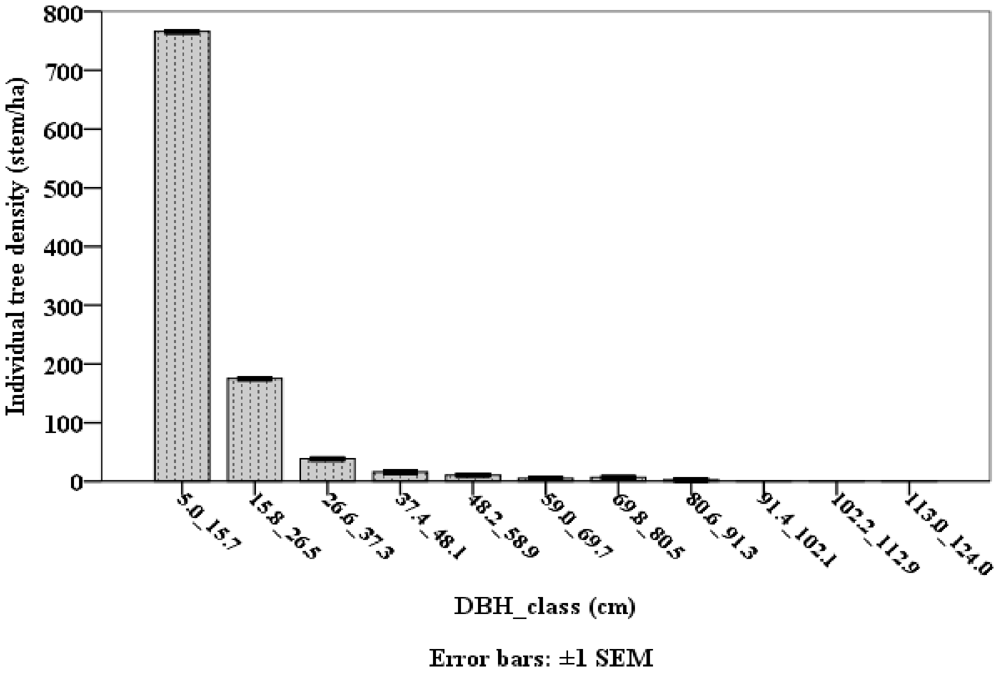
Table 3 : Tree density in stem/ha and frequency in the study

Scientific name	No spp. sampled	No. of plots spp occurred	D stem / ha	RD (%)	F (%)	RF (%)
Teclea nobilis	257	16	214	21.0	53.3	6.3
Olea europaea	157	25	131	12.8	83.3	9.9
Rhus glutinosa	84	18	70	6.9	60.0	7.1
Albizia schimperiana	61	12	51	5.0	40.0	4.8
Pittosporum abyssinicum	61	11	51	5.0	36.7	4.4
Calpurnia aurea	58	16	48	4.7	53.3	6.3
Dodonaea angustifolia	56	14	47	4.6	46.7	5.6
Croton macrostachyus	51	6	43	4.2	20.0	2.4
Carissa edulis	36	12	30	2.9	40.0	4.8
Buddleja polystachya	32	9	27	2.6	30.0	3.6
Ficus sur	32	10	27	2.6	33.3	4.0
Dombeya torrida	27	5	23	2.2	16.7	2.0
Maytenus arbutifolia	25	9	21	2.0	30.0	3.6
Eucalyptus camaldulensis	22	3	18	1.8	10.0	1.2
Myrica salicifolia	22	2	18	1.8	6.7	0.8
Strychnos innocua	22	2	18	1.8	6.7	0.8
Podocarpus falcatus	19	10	16	1.6	33.3	4.0
Phytolacca dodecandra	18	5	15	1.5	16.7	2.0
Coffea arebica	16	6	13	1.3	20.0	2.4
Gina	16	7	13	1.3	23.3	2.8
Acacia decurrens	15	2	13	1.2	6.7	0.8
Acanthus senni	15	5	13	1.2	16.7	2.0
Bersama abyssinica	15	5	13	1.2	16.7	2.0
Rosa abyssinica	13	5	11	1.1	16.7	2.0
Clematis hirsuta	2	1	2	0.2	3.3	0.4

4.2 DBH and Height Distribution of Tree Species

The distribution of tree in different DBH class was analyzed. According to Sherri L. Jackson 2009, each tree species DBH was measured starting from ≥5 cm and categorized into eleven classes of DBH (5.0-15.7; 15.8-26.5; 26.6-37.3; 37.4-48.1; 48.2-58.9; 59.0-69.7; 69.8-80.5; 80.6-91.3; 91.4-102.1; 102.2-112.9 and 1130.0-124.0 cm). Among these DBH class of (5.0-15.7) had the highest tree density with 765 stem/ha or 75 % and the remaining ten classes together accounted for 25% of total standing tree individuals (Figure 5).

As DBH class size increases, the number of individuals gradually decreases toward the higher DBH classes. Similar results were reported by Gebrehiwot and Hundra, 2014 from Belete forest and Tesfaye Bogale *et al.*, 2017 from Berbere forest. The general pattern of DBH class distribution of Zafnigus tree species was showed an inverted J-shaped distribution showed a pattern where species frequently had the highest frequency in low diameter classes and a gradual decrease towards the higher class (Figure 5). This could be due to selective harvesting of individuals in the particular size classes, which is important for timber, agricultural apparatus construction and firewood.

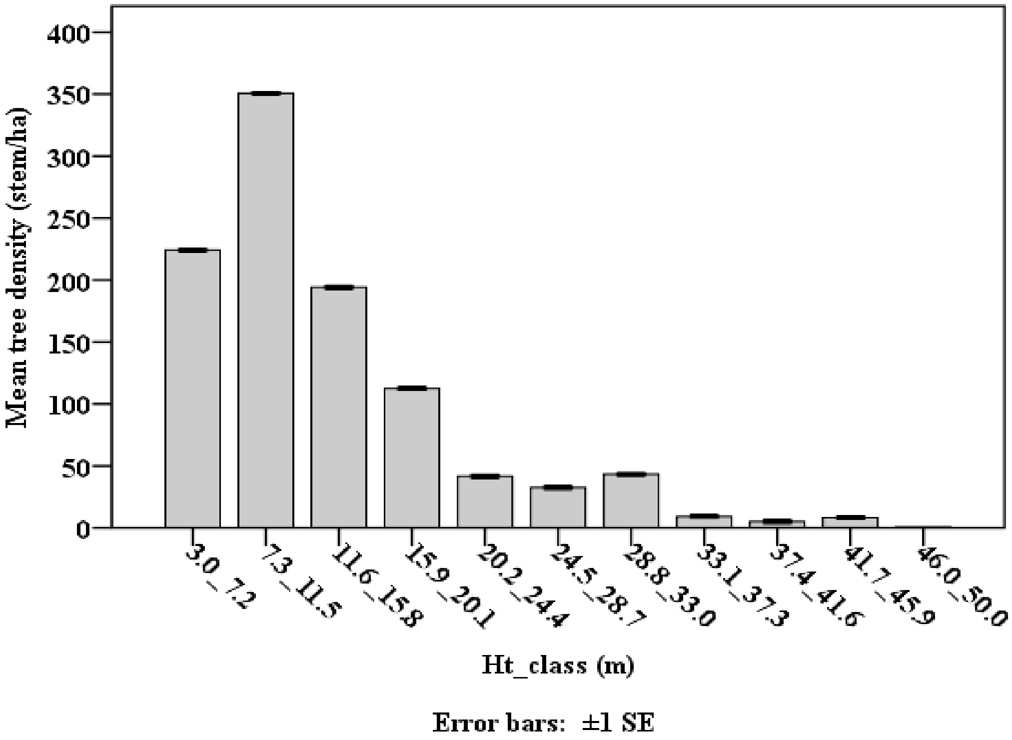


Where, SE, standard error and DBH, diameter at breast height in cm

Figure 5: DBH class distribution of existed trees in Zafnigus Forest

Like DBH, each tree height (H) was measured and categorized in eleven classes (Sherri Jackson 2009). The number of trees regarding the height distribution of the Zafnigus forest was seen a decreasing tendency with increasing height. H class of 7.3-11.5 m (350 stem/ha or 34.3%) and 3.0-7.2m (224 stem/ha or 21.9%) had the highest density with 574 stem/ha or 56.2% while the remaining nine classes together accounted for 43.8% of total standing tree individuals show detail (Figure 6).

This arrangement suggests that a high number of individuals counted for the lower height classes while the middle and higher height classes showed a decreasing density. This condition indicates that, the dominance of small-sized individuals in the forest and greater potential of the regeneration capacity for young trees which have much more growing rate and carbon accumulating capacity than older trees (Getachew Tesfaye, 2007, Sultan Mohammed and Berhanu Abraha, 2013 and Muluken Nega, 2014). The reason of finding could be due to the presence of illegal selective cutting for the purpose of charcoal and timber production.



Where, SE, standard error and H, height in cm

Figure 6: H class distribution of existed trees in Zafnigus Forest

4.3 Importance value index (IVI) dominant species

Importance value index (IVI) was calculated for all 43 tree and shrub species of DBH ≥5 cm (Table 4 and Appendix 2). It indicates the relative ecological importance of a given woody species at a particular site (Sudi Dawud *et al*., 2018). High species importance value index is attributed to their high basal area, high relative frequency and high relative density. It is also used for setting priority/ranking species management and conservation practices and helps to identify species as dominant or rare species (Kent and Coker, 1992 and Sudi Dawud *et al*., 2018). A species having value of IVI greater than 5.00 can be considered dominant because of the relative ecological role it plays in the ecosystem (Fekadu Gurmessa, 2013 and Sudi Dawud *et al*., 2018).

The dominant and ecologically most significant tree species in Zafnigus forest on the base of their IVI values were among them *Prunus africana* was found to have the highest (32.50) followed by *Teclea nobilis* (28.28), *Olea europaea* (27.61) and *Pterolobium stellatum* (14.56). Relatively, the higher IVI these species is due to their high value basal area. This suggests that these species are dominant species of Zafnigus forest and play crucial role for the ecological function of the area. On the other hand least IVI result was found from *Clematis hirsuta* species (0.84).

The study by (Feyera Senbeta *et al*., 2007 and Sudi Dawud *et al*., 2018) noted that such low abundances may be due to either adverse environmental conditions (temperature and climate) or the distribution of available resources in the forest area. The reasons to low IVI in the finding due to sparsely distributed available resources and adversely affected by environmental condition which is slowly adapted in that area.

Table 4: Importance value indices of woody species for Zafnigus forest.

Species	RDo (%)	RD (%)	RF (%)	IVI	IVI Rank
Prunus africana	31.38	0.33	0.79	32.50	1
Teclea nobilis	0.90	21.03	6.35	28.28	2
Olea europaea	4.84	12.85	9.92	27.61	3
pterolobium stellatum	0.54	6.87	7.14	14.56	4
Calpurnia aurea	0.64	4.75	6.35	11.74	5
Albizia schimperiana	1.79	4.99	4.76	11.54	6
Dodonaea angustifolia	0.49	4.58	5.56	10.63	7
Pittosporum abyssinicum	0.93	4.99	4.37	10.28	8
Ficus sur	3.33	2.62	3.97	9.91	9
Podocarpus falcatus	3.73	1.55	3.97	9.26	10
Clematis hirsuta	0.28	0.16	0.40	0.84	43

Where RDo, Relative dominances (%); RD, Relative density (%); RF, Relative frequency (%) and IVI, Important vale index)

4.4 Carbon Stock in Different Carbon Pools of Zafnigus forest (ZF)

4.4.1 Estimation of aboveground and belowground carbon stock

By using allometric equation the biomass and the carbon stock of the tree was used to determine in the study site. The result revealed that mean aboveground biomass and carbon stock stored in tree species were 326.40±65.97 and 153.40±31.02 tha^{-1} respectively. The aboveground carbon stock ranged from 8.15 to 616.93 tha^{-1} (Table 5 and Appendix3).

The report of Muluken Nega, 2014 the average carbon stock of Sub-Saharan Africa and Tropical Asia forests were 143 and 151 t/ha respectively. Hence, the current study was higher than those continental assessments.

However, the result of mean aboveground and belowground tree carbon stock was almost less than to the previous Ethiopian studies of tree biomass carbon stocks of Egdu forest (278.08±34.61 tha^{-1}Adugna Feyissa et al., 2013)$^{;}$ Danaba Community forest (277.78 Muluken Nega *et al*., 2014);Tara Gedam forest (306.37 tha^{-1} Mohammed Gedefaw et al., 2014) and

Woody Plants of Arba Minch Ground Water Forest (414.70±78.3tha^{-1} Belay Melese *et al.*, 2014). But greater than Menagasha Suba state forest (133±99tha^{-1} Mesfin Sahlie, 2011) aboveground carbon.

The reasons to the finding are stated that according to the result of Adugna Feyissa *et al.* (2013) the higher carbon stock in aboveground biomass in the study site could be related to the higher tree carbon stock in forest area. The present study was difference might be due to variations in age, densities and existing species height and diameter range of the trees. Topological feature, anthropogenic factors (fire wood collection and selling purpose) may be also the other reason of the finding.

Belowground tree biomass (roots) measuring is difficult as compared to the aboveground biomass. It is more complex, time consuming and almost never measured, but instead it is included through a relationship to aboveground biomass (usually a root-to-shoot ratio of 0.27) The result of the present study revealed that mean belowground biomass and carbon stock stored in tree species were 88.13±17.82 and 41.42± 8.13tha^{-1}, respectively. The comparison with other study shows a similar tendency with aboveground carbon stock (Table 5).

Table 5: The minimum, maximum, mean and standard error of above ground biomass and carbon stock

No	Carbon pool	N	Minimum tha^{-1}	Maximum tha^{-1}	Mean tha^{-1}	SEM
1	AGB	30	17.33	1312.62	326.40	±65.97
2	AGC	30	8.15	616.93	153.40	±31.02
3	BGB	30	4.68	354.41	88.13	±17.82
4	BGC	30	2.20	166.57	41.42	±8.38

4.4.2 Trees species biomass carbon stock contribution in Zafnigus forest

The biomass carbon stock contained in each tree species of Zafnigus forest varied from one tree species to the other. The mean result showed that the largest aboveground carbon stock was estimated in the tree species of *Olea europaea* (78.3 t/ha) whereas the least carbon stock was reserved in *Pterolobium stellatum* (0.03 t/ha) and *Celmatis hiruta (*0.03 t/ha).

The variation in carbon stock of the species may come from the difference in the size of diameter and height class that results high biomass of the species when it tends to increasing the DBH and height of the species. Variation in tree density also another reason (Figure 7 and Appendix 1).

This result was in consistent with a study by Bhatta *et al*. (2018) which states that among the determined tree species during study (*Cinnamomum camphora, Pinus roxburghii, Sambucus javanica, and Alangium chinense*), *Cinnamomum camphora* was stored high carbon stock than the rest tree species.

This variation with the species could be due to the variation in the actual age of the species (young trees have less carbon stock than aged tree species), growth rate and productivity potential, the density of tree and habit of the species that was observed during the study.

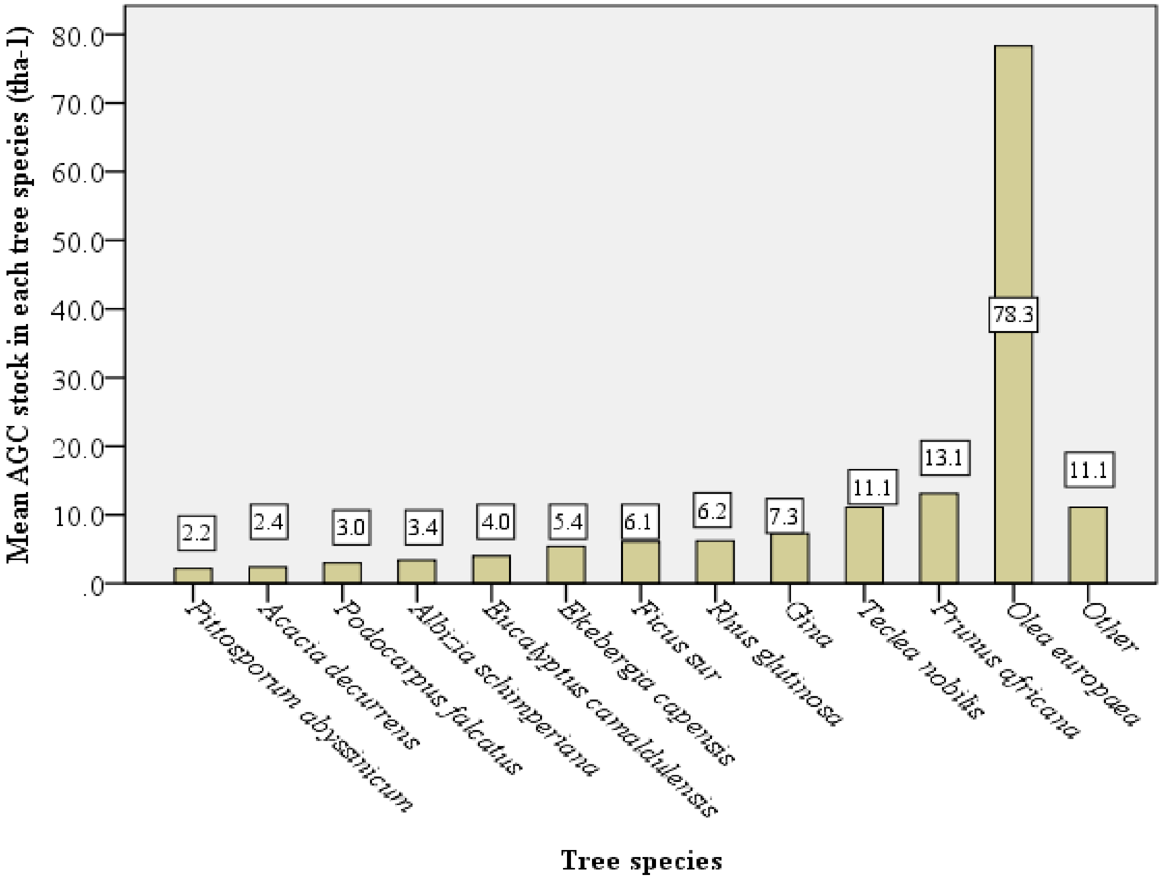


Figure 7: The biomass carbon stock found within each tree species.

4.3.3 Estimation of carbon stock in litter, herb, and grass (LHG)

The result showed that mean LHGs carbon stock contained were 2.01±0.08 tha^{-1}. The minimum and maximum LHGs carbon stocks with value of 0.50 and 2.65 tha^{-1}were estimated in the region of plots seven and fifteen) respectively (Table 6 and Appendix 5).

The mean biomass carbon stock in LHGs for tropical dry forests was 2.01tha^{-1} as reported by IPCC (2006) and similar result was found by the present study which was 2.01tha^{-1}. Hence, litter biomass of the study could be considered good reservoir of carbon as compared to other study sites in Ethiopia.

It is similar within Yeka Forest which was 2.01 t/ha (Getnet Abate, 2015) the findings was higher than Danba community forest (1.06t/ha; Muluken Nega *et al*., 2014) and Tara Gedam forest (0.9 tha^{-1}, Mohammed Gedefaw *et al*., 2014) the amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species age and density) The difference with the present study could be due to forested area is covered by dense tree species like *Teclea nobilis* which contributes a lot in intense litter fall amount within the forested patch and due to the presence of old aged trees that are responsible for shedding their leafs frequently. But it was lower than Egdu forest (3.47 tha^{-1} Adugna Feyissa *et al.*,2013); Selected Church Forest (4.95tha^{-1} Tulu Tolla *et al.*, 2013) and Woody Plants of Mount Zequalla Monastery of Ethiopia (6.49tha^{-1} Abel Girma *et al.*, 2014).

The reason to their findings are stated in according to Adugna Feyissa *et al.*, (2013) stated that the tree stands in the forest area were relatively still young and the result could be low amount of litter fall.

In addition Mohamed Gedefaw *et al.*, (2014) noted that the relatively low amount of carbon stored in litter carbon stock in the studied forest area due to high rate of decomposition which is governed by climatic factor like temperature and moisture. The difference with the present study could be due to the presence of decomposition rate the top soil profile.

Table 6: The minimum, maximum, mean and standard error of Litter Biomass and Carbon.

No	Carbon Pool	Minimum tha^{-1}	Maximum tha^{-1}	Mean tha^{-1}	SEM
1	LB	1.01	5.31	4.02	±0.17
2	LC	0.50	2.65	2.01	±0.08

Where, LB, litter biomass and LC, litter Carbon

4.4.4 Estimation of soil organic carbon in Zafnigus forest (ZF)

Like other carbon pools, the result showed that mean soil organic carbon stock was 128.62±6.67 tha^{-1}. The minimum and maximum soil organic carbon stock with 100.10 tha^{-1} and 159.81.2 tha^{-1} respectively (Table 7 and Appendix 6). Soil organic carbon estimates of Afromontane rain forests varies between 252 and 581 tha^{-1} (Munishi and Shear, 2004).

When the study was compared with other findings, it was also lower than Egdu Forest (277.56 tha^{-1}, Adugna Feyissa *et al*., 2013) and Ades Forest (271.69 tha^{-1}, Kidanemariam Kassahun *et al*., 2015) but, it was higher than with the value of Selected Church Forest (135.94 tha^{-1}, Tulu Tolla et al., 2013); Menagasha Suba State Forest (121.8 tha^{-1}) (Mesfin Sahile, 2011).

According to Anup *et al*., 2013 in the community forest of Nepal with a total area of 92 ha indicates that since the forest is dominated by scattered type of trees and small area coverage, low SOC was recorded in the study area. A study by Kidanemariam Kassahun *et al*. (2015) in Ades forest revealed that there was better SOC accumulation due to the presence of good vegetation density and moisture. Because vegetation density enhances liter fall accumulation whereas moisture favors the decomposition process.

The percentage of SOC decreased with increasing depth and significantly lower C% was found at 20-30cm as compared to 0-10 cm depth due to the presences of litter, leaf, grass, crop residue and organic matter reached in the top soil. Decomposition rate should be fast in the first soil profile in the case of microbes.

This result was in agreement with the finding of (Sahoo UK *et al.*, 2019, Singh SL., 2018 and Yifru Abera and Taye Belachew, 2011).

Table 7: Mean SOC within forest soil depth

No	Soil Carbon Pool	Minimum	Maximum	Mean	SEM
1	0-10 cm	41.63	68.34	55.25	±1.42
2	10-20 cm	31.45	51.58	41.03	±0.90
3	20-30 cm	27.02	39.89	32.34	±0.60
	Total	100.10	159.81	128.62	±6.67

Where, SEM = Standard error of the mean.

4.5 Total carbon stock of Zafnigus forest

The carbon stock distribution of all carbon pools within sample plots is ranged from a minimum of 119.6 tha^{-1} to maximum of 922.1 $tha^{-1}$with the average value of 325.48 while corresponding minimum and maximum CO_2 equivalents were 438.9 and 3384.1 tha^{-1} with the average value of 1194.5 respectively (Table 8 and Appendix 7).

The total mean carbon stock of Zafnigus forest was obtained by summing up the carbon stock found in each carbon pool namely, aboveground carbon stock (AGC), belowground carbon stock (BGC), carbon in LHGs (LC) and carbon in organic soil (SOC). Accordingly, the carbon stock distribution and the percent share of each carbon pool was examined to be maximum in the trees (47% of AGC and 13% of BGC) and the soil with 39% while the minimum carbon stock was contained in the litter, herbs and grasses (1%).

The variation in carbon stock between different forest types could be attributed to imprecise measurements of tree variables, inefficiency of allometric models, and presence of bigger sized trees with a higher basal area, higher density of woody species, anthropogenic disturbance and environmental conditions.

Table 8: Carbon pools with total carbon stock and it's CO_2 equ of Zafnigus forest.

Carbon pool	Mean carbon(tha^{-1})	CO_2 equ. (tha^{-1})
AGC	153.43	563.09
BGC	41.42	152.01
LC	2.01	7.38
SOC (up to 30 cm)	128.62	472.04
Over all	325.48	1194.52

Where, TAGB and TBGB, Total aboveground, belowground biomass respectively; TB, total biomass; TCp, total carbon pools ; LC, litter carbon for LHGs (litter, herbs and grasses); SOC, soil organic carbon, and CO_2equ, carbon dioxide equivalent.

Table 9: Comparisons of carbon stocks of Zafnigus Forest with other studies in Ethiopia

Study site	Carbon stocks in (tha^{-1})					Sources
	TAGC	TBGC	LC(LHG)	SOC	TC	
Danaba Community Forest	277.78	41.65	1.06	186.4	506.89	Muluken Nega *et al.*, 2014
Tara Gedam forest	306.37	61.52	0.90	274.32	643.11	Mohammed Gedefaw et al., 2014
Egdu forest	278.08	55.62	3.47	277.56	614.73	Adugna Feyissa *et al.*,2013
Zafnigus forest	153.9	41.42	2.01	128.5	325.31	Present study

Where, TAGC, total aboveground carbon; TBGC, total belowground carbon; LC, litter carbon; SOC, soil organic carbon and TC, total carbon

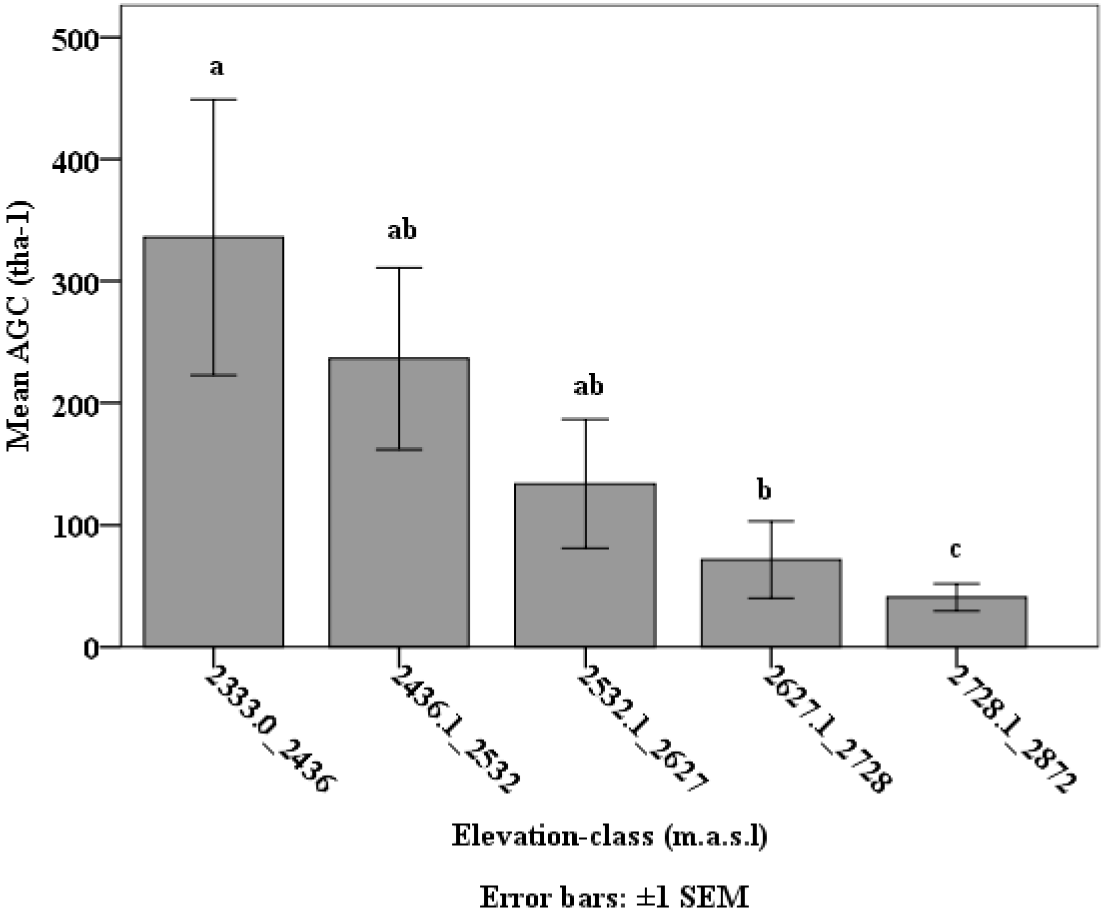
4.6 Factors Affecting Carbon Stocks of Zafnigus forest

4.6.1 Aboveground and belowground carbon stock along altitudinal gradient

Forests are one of the crucial ecosystem component that plays a great role for temporary and long term carbon storage but, the forest biomass and carbon is highly disturbed by environmental factors like altitude (Luo *et al.*, 2005, Alves *et al.*, 2010, Asner *et al.*, 2014 and Fentahun Abere *et al.*, 2017). The presence of variation in altitudinal range affects the carbon stock of different pools in the forest. The results of the present study showed that the mean carbon stock was varied in altitude class. The lower parts of altitude was high in aboveground carbon stocks while the upper and middle parts of altitude have low to moderate carbon stocks in above ground biomass (Figures 8).

Since the mean total belowground biomass carbon stock was derived from the aboveground biomass; the trend showed similar within each altitudinal class. The result of one way ANOVA indicates that the study is significant variation in carbon stock in aboveground and belowground carbon pools along altitudinal range at 95% confidence interval for the case of AGC (F=2.84, P=0.045); BGC, (F=2.84, P=0.045) (Table 10). It had been reported in many studies in other parts of the world that the result of aboveground and belowground biomass and its carbon stock decline with an increase in altitude (Zhu *et al.*, 2011).

Similarly, in other studies it had been reported that biomass carbon storage has decreases as altitude increases (Moser *et al*., 2007 and Sheikh *et al.*, 2012). On the other hand, it had been reported by many studies as live biomass carbon increase with altitude increases (Adugna Feyissa *et al*., 2013). This may be due to the absence of tallest trees with maximum DBH and due to the density of the forest, age and size of the forest in the upper part and also due to the presence of less security and management activities at the edge of the forest.



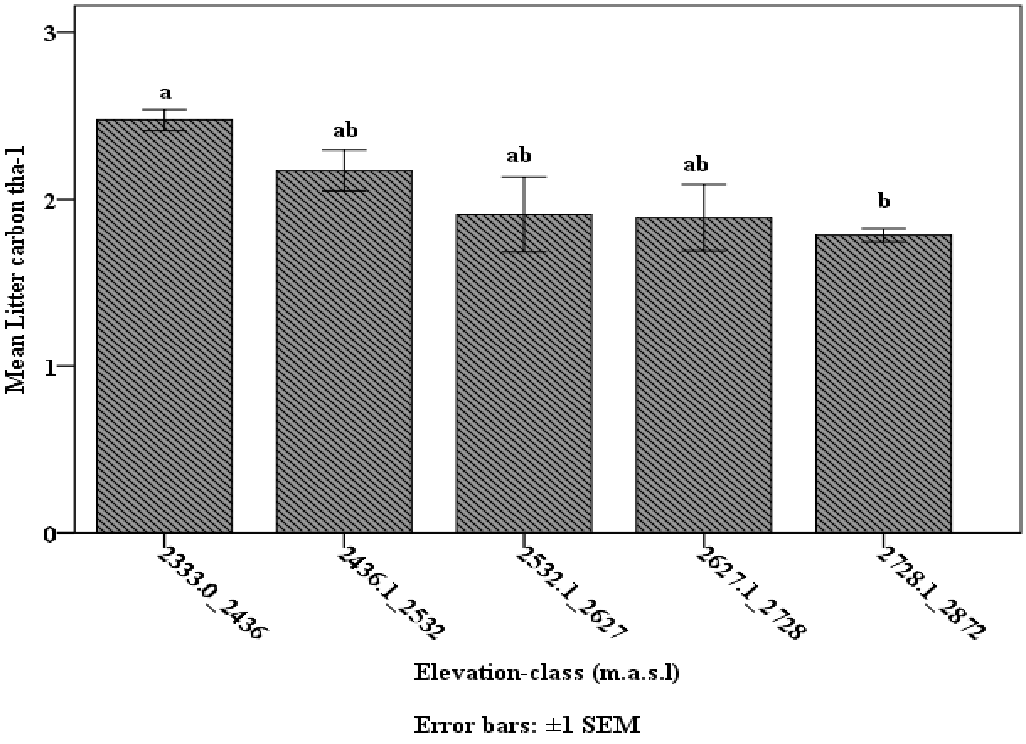
Where, m.a.s.l, meter above sea level; AGC, aboveground carbon and SE, standard error

Figure 8: Mean AGC stocks (tha^{-1}) with altitudinal range.

4.6.2 Litter carbon stock along altitudinal gradient

In the same way, the mean total carbon stock of LHGs varied in altitudinal range. Hence, LHG followed a similar trend with that of aboveground and belowground biomass higher carbon stock in litter was estimated as lower altitudinal range of mean (2.47±0.06 tha^{-1}) and lower amount was in higher altitude (1.78±0.04 tha^{-1}). It was observed that Litter biomass means decreases as altitude increases. The result of this study is not significant variation in litter carbon pool along altitudinal range at 95% confidence interval for the case of F=1.65, P=0.194.

This result was consistent with (Sheikh *et al*., 2009, Mwakisunga *et al*., 2012 and Hamere Yohannes *et al*., 2015). According to Sheikh *et al*., 2009 forest stand with dense canopy and higher input of litter can results in maximum storage of carbon stock in the pool. The reason is that may be due to the presences of trees having large DBH with more branches which results more crown cover that contributes for more litter and existence of broad leaved trees that sheds their leaves frequently for better accumulation of litter (Figure 9).



Where, m.a.s.l, meter above sea level and SE, standard error

Figure 9: Mean LHGs Carbon stocks (tha^{-1}) with Elevation class.

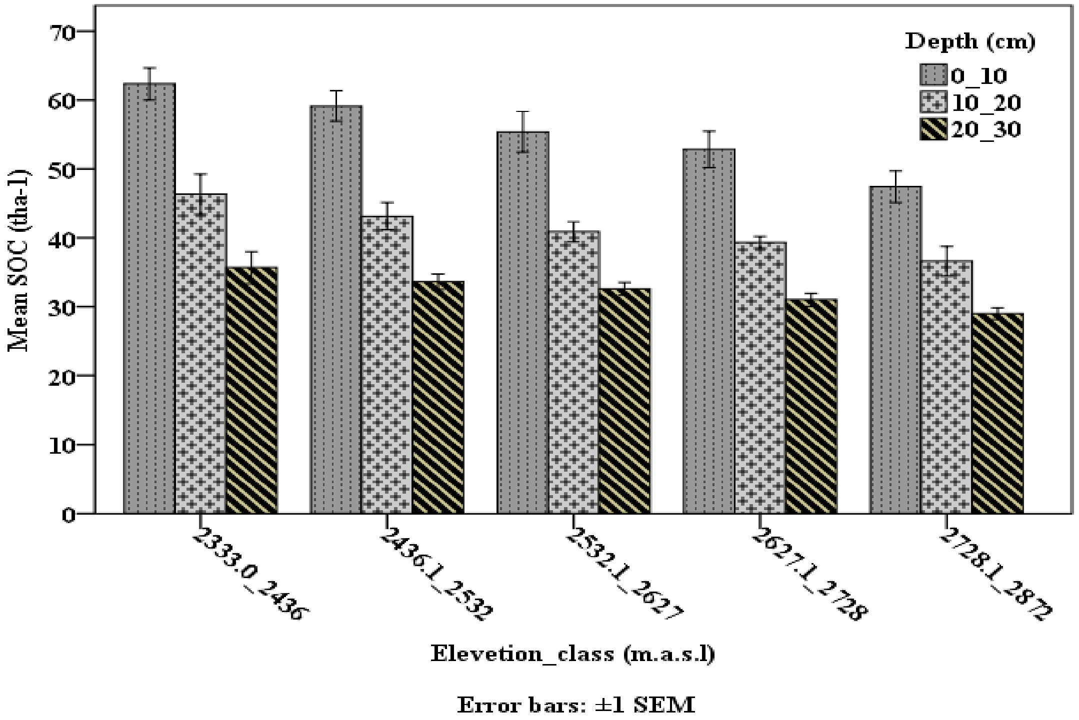
4.6.3 Soil organic carbon stock along altitudinal gradient

Similarly other carbon pool, the mean total soil carbon stock density was varied in altitude range from 2333 up to 2872m as natural image processing classification divided by five class were 62.33±2.33 tha^{-1} (2333.0-2436m); 59.13±2.2tha^{-1} (2436.1-2532m); 55.38±2.97tha^{-1} (2532-2627m); 52.83±2.65 tha^{-1} (2627.1-2728m) and 47.4±2.29 tha^{-1} (2728.1-2872m) in 0-10 depth of soil and similar trend by other soil depth (Figure 10). Therefore, the mean total maximum soil carbon stock was stored in the first altitude range followed by those five altitude range respectively.

The result of SOC showed that variation along elevation classes SOC density increased with precipitation and decreased with temperature (Jobbagy and Jackson, 2000). In the present study, relatively, an overall decreasing trend in mean SOC density with increasing altitude was observed (Figure 10). The result of this study is significant variation in soil organic carbon pool in three depth class along altitudinal range at 95% confidence interval for the case of 0-10 (F=3.5, P=0.021); 10-20 (F=3.0, P=0.038) and 20-30 (F=3.72; P= 0.016).

The result of study was consistent with Hamere Yohannes *et al*., 2015. But it was less carbon density as compared with other studies of altitudinal variation effect on SOC Arba Minch ground water forest (Belay Melese *et al.*, 2014) and Tara Gedam Forest (Mohammed Gedefaw *et al*., 2014) of Ethiopia.

The result of study decreasing trend in SOC stock along elevation might be due to the decline in temperature accompanied with an increase in elevation in case of microorganism died the decomposition rate could be decrease and the precipitation is high as elevation increase then organic matter reduces through leaching. The canopy cover, litter biomass accumulation and species diversity were another reason to decrease soil organic carbon stock.



Where, SE, standard error; m.a.s.l, meter above sea level and SOC, soil organic carbon in ton per hectare.

Figure 10: Mean SOC stocks (tha-1) with elevation class.

Table 10: Summarized results of one-way ANOVA different carbon pools with altitude at ($P<0.05$) significance level.

Parameter	Carbon pools	P-Value
Altitudinal Gradient	AGC	0.045*
	BGC	0.045*
	LC	0.194ns
	SOC 0-10cm	0.021*
	SOC 10-20cm	0.038*
	SOC 20-30cm	0.016*

Where, ns, non-significances AGC, aboveground carbon; BGC, belowground carbon; LHGs, litter, herbs and grasses carbon and SOC, soil organic carbon

Chapter 5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the result, that concluded the vegetation structure of the Zafnigus Forest indicates in total of common families with 43 tree species were recorded, of which, *Teclea nobilis, Olea europaea*, and *Prunus africana* were the most dominant species and *Clematis hirsuta, Cupressus lusitanica* and *Hypericum revoltum were* the least dominant species in the study site. Densities of tree species decrease as the DBH and height classes increases in the forest. This implies that, the predominance of small sized tree species in the lower classes than in the upper DBH and height classes. According to IVI *Prunus africana* was found to have high relative ecological importance of a given woody species and the least ecological importance was *Clematis hirsuta species.*

The carbon stocks of the study site show a variation among the plots due to the presence of high biomass plants in some plots and low biomass in other plots. In the present study tree biomass was stored the highest carbon stock of all carbon pools and *Olea europaea* species was sequestered the largest portion of the forest carbon whereas *Celmatis hiruta* had accounted the least biomass carbon stock reserves due to the presences of DBH size and tree height.

Forest soil was also found to have the first reservoir of carbon stock as compared to other land use covers. The other important carbon pool was the LHGs that contributed for carbon sink in this forest with comparable carbon density as compared to other Ethiopian and tropical forests.

The lower parts of altitude was high carbon stocks in all carbon pool while the upper and middle parts of altitude due to the absence of tallest trees with maximum DBH, density, age, size, branches, management activities at the edge of the forest and decomposition rate. The result of ANOVA indicates that the study was significant variation in carbon stock in all carbon pool except litter carbon along altitudinal range at 95% confidence interval for the case of tree carbon stock (P=0.045); SOC (P=0.021, P=0.038 and P=0.016) comprised at 0-10cm, 10-20cm and 20-30 cm depth and LHGs (P=0.194).

Currently, Zafnigus Forest had the capacity to store 325.48 tha^{-1} of carbon. Consequently, this forest could sequester 1194.5 tha^{-1} of CO_2_equ which indicates the potential of the forest. The result of the present study revealed that tree biomass was the major reservoir carbon followed by soil organic carbon whereas litter biomass was the least carbon reservoir among the determined carbon pools.

Therefore to reduce atmospheric carbon dioxide through sequester up to1194.5 tha^{-1} on the current carbon stock of forest and should be mitigate climate change.

5.2 Recommendation

According to the conclusion the following recommendations have been forwarded.

- There was high human interference observed in the study site such as deforestation, overgrazing and farming as well, so the regional government should have to give attention and creating awareness to the local people regarding with forest management of natural resources.
- Further research should focus on developing and applying the country specific (species specific) allometric equations. This will increase the reliability and acceptance of the existing data on forest carbon stocks.

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APPENDICES

Appendix table 1: The names of tree species with their density and frequency of ZF

Spp. No	*scientific name*	local name	family name	No of trees	No. plot spp occurred	D (stem / ha)	RD (%)	F (%)
1	*Teclea nobilis*	Sehel	Rutaceae	257	16	214	21.0	53.3
2	*Olea europaea*	Woira	Oleaceae	157	25	131	12.8	83.3
3	*Rhus glutinosa*	Embus	Anacardiaceae	84	18	70	6.9	60.0
4	*Albizia schimperiana*	Kachena		61	12	51	5.0	40.0
5	*Pittosporum abyssinicum*	Dingay seber	Rubiaceae	61	11	51	5.0	36.7
6	*Calpurnia aurea*	Dgita	Fabaceae_papilonoidea	58	16	48	4.7	53.3
7	*Dodonaea angustifolia*	Kitkita	Sapindaceae	56	14	47	4.6	46.7
8	*Croton macrostachyus*	bisana	Euphorbiaceae	51	6	43	4.2	20.0
9	*Carissa edulis*	Agam	Apocynaceae	36	12	30	2.9	40.0
10	*Buddleja polystachya*	Atkuar	Loganiaceae	32	9	27	2.6	30.0
11	*Ficus sur*	Shola	Moraceae	32	10	27	2.6	33.3
12	*Dombeya torrida*	Wulikifa	Sterculiaceae	27	5	23	2.2	16.7
13	*Maytenus arbutifolia*	Atat	Celastraceae	25	9	21	2.0	30.0
14	*Myrica salicifolia*	shinet	Myricacea	22	2	18	1.8	6.7

15	*Strychnos innocua*	Mernz		22	2	18	1.8	6.7
16	*Podocarpus falcatus*	Zigiba	Podocarpaceae	19	10	16	1.6	33.3
17	*Phytolacca dodecandra*	Indod	Phytolacaceae	18	5	15	1.5	16.7
18	*Coffea arebica*	Buna ayinet	Rubiaceae	16	6	13	1.3	20.0
19	*Eucalyptus camaldulensis*	bahir zaf	Myrtaceae	22	3	18	1.8	10.0
20	*Gina*	Gina		16	7	13	1.3	23.3
21	*Acacia decurrens*	akacha	fabaceae_mimosoideae	15	2	13	1.2	6.7
22	*Acanthus senni*	kusheshila		15	5	13	1.2	16.7
23	*Bersama abyssinica*	Azamr	Melianthaceae	15	5	13	1.2	16.7
24	*Rosa abyssinica*	Kega	Rosaceae	13	5	11	1.1	16.7
25	*Ekebergia capensis*	Lol	Meliaceae	12	5	10	1.0	16.7
26	*Urera hypselodendron*	Lankuso	Urticaceae	10	4	8	0.8	13.3
27	*Erythrina brucei*	Kermo ayiderk	Fabaceae _Papilionoideae	9	3	8	0.7	10.0
28	*Psydrax schimperiana*	seged		8	4	7	0.7	13.3
29	*Rhus vulgaris*	kamo	Anacardiaceae	7	3	6	0.6	10.0
30	*Euphorbium candelabrum*	kulkual	Euphorbiaceae	6	2	5	0.5	6.7

31	*Galineria saxifraga*	Tota kolet		6	1	5	0.5	3.3
32	*Terminalia brownii*	abalo	Combretaceae	6	3	5	0.5	10.0
33	*Dovyalis abyssinica*	Koshim	Flacourtiaceae	5	2	4	0.4	6.7
34	*Olea capensis*	Senf woira	Oleaceae	4	1	3	0.3	3.3
35	*Prunus africana*	Ahoma	Rosaceae	4	2	3	0.3	6.7
36	*Schefflera abyssinica*	Getem		4	1	3	0.3	3.3
37	*Buddleia polystachya*	Anfar	Loganiaceae	3	1	3	0.2	3.3
38	*Maytenus obscura*	Kumbel	Celastraceae	3	1	3	0.2	3.3
39	*pterolobium stellatum*	Kentafa	Fabaceae Mimosoideae	3	1	3	0.2	3.3
40	*Celtis africana*	Kewot	Ulmaceae	2	1	2	0.2	3.3
41	*Clematis hirsuta*	Azo hareg	Ranunculaceae	2	1	2	0.2	3.3
42	*Cupressus lusitanica*	yeferenji tsid	Cupressaceae	2	1	2	0.2	3.3
43	*Hypericum revoltum*	amija	Hypericaceae	2	1	2	0.2	3.3

Where, D, density of tree in stem/hectare; RD, relative density (%) and F, frequency (%)

Appendix table 2: Importance value indices of woody species for Zafnigus forest

Species	Relative Dominances (%)	Relative Density (%)	Relative Frequency (%)	IVI	IVI Rank
Prunus africana	31.38	0.33	0.79	32.50	1
Teclea nobilis	0.90	21.03	6.35	28.28	2
Olea europaea	4.84	12.85	9.92	27.61	3
pterolobium stellatum	0.54	6.87	7.14	14.56	4
Calpurnia aurea	0.64	4.75	6.35	11.74	5
Albizia schimperiana	1.79	4.99	4.76	11.54	6
Dodonaea angustifolia	0.49	4.58	5.56	10.63	7
Pittosporum abyssinicum	0.93	4.99	4.37	10.28	8
Ficus sur	3.33	2.62	3.97	9.91	9
Podocarpus falcatus	3.73	1.55	3.97	9.26	10
Gina	4.14	1.31	2.78	8.23	11
Carissa edulis	0.51	2.95	4.76	8.22	12
Croton macrostachyus	1.24	4.17	2.38	7.80	13
Buddleja polystachya	1.25	2.62	3.57	7.44	14
Ekebergia capensis	4.15	0.98	1.98	7.12	15
Maytenus arbutifolia	0.57	2.05	3.57	6.19	16
Eucalyptus camaldulensis	3.10	1.80	1.19	6.09	17
Terminalia brownii	3.26	0.49	1.19	4.94	18
coffea arebica	1.15	1.31	2.38	4.84	19
Acacia decurrens	2.76	1.23	0.79	4.78	20
Dombeya torrida	0.56	2.21	1.98	4.76	21
galineria saxifraga	3.52	0.49	0.40	4.41	22

Phytolacca dodecandra	0.77	1.47	1.98	4.22	23
Rosa abyssinica	1.06	1.06	1.98	4.11	24
Bersama abyssinica	0.68	1.23	1.98	3.89	25
Myrica salicifolia	1.12	1.80	0.79	3.71	26
Acanthus senni	0.34	1.23	1.98	3.56	27
Rhus glutinosa	1.77	0.57	1.19	3.54	28
Maytenus obscura	2.70	0.25	0.40	3.34	29
Strychnos innocua	0.65	1.80	0.79	3.25	30
Erythrina brucei	1.08	0.74	1.19	3.00	31
Dovyalis abyssinica	1.79	0.41	0.79	2.99	32
Olea capensis	2.24	0.33	0.40	2.96	33
Urera hypselodendron	0.52	0.82	1.59	2.93	34
Prunus africana (Hook.f.) Kalkm.	0.55	0.65	1.59	2.79	35
Euphorbium candelabrum	1.38	0.49	0.79	2.66	36
Schefflera abyssinica	1.86	0.33	0.40	2.59	37
Celtis africana	1.98	0.16	0.40	2.54	38
Buddleia polystachya	1.38	0.25	0.40	2.02	39
Cupressus lusitanica	1.21	0.16	0.40	1.77	40
Psydrax schimperiana	0.90	0.25	0.40	1.54	41
Hypericum revoltum	0.94	0.16	0.40	1.50	42
Clematis hirsuta	0.28	0.16	0.40	0.84	43
	100	100	100	300	

Where, IVI, importance value index

Appendix table 3: Total tree biomass and carbon in present study

			DBH(cm)		Ht(m)		Tree biomass and carbon(tha^{-1})						
scientific name	WD	N. tree	Mean	class	mean	class	AGB	BGB	TB	AGC	BGC	TC	CO2
Acacia decurrens	0.816	15	21.3	16_28	19.0	11_28	5.15	1.39	6.54	2.42	0.65	3.07	11.28
Acanthus senni	0.592	15	7.9	5_11	6.1	3_9	0.19	0.05	0.24	0.09	0.02	0.11	0.42
Albizia schimperiana	0.525	61	15.2	6_28	15.9	4_33	7.14	1.93	9.06	3.35	0.91	4.26	15.64
Bersama abyssinica	0.671	15	9.3	7_14	8.2	6_12	0.35	0.09	0.44	0.16	0.04	0.21	0.77
Buddleia polystachya	0.4	3	13.3	8_22	9.0	8_10	0.12	0.03	0.15	0.06	0.01	0.07	0.26
Buddleja polystachya	0.52	32	12.7	6_35	11.7	5_28	2.55	0.69	3.24	1.20	0.32	1.53	5.60
Calpurnia aurea	0.612	58	9.1	5_15	9.9	3_30	1.61	0.43	2.04	0.76	0.20	0.96	3.52
Carissa edulis	0.65	36	8.3	6_11	7.5	4_15	0.62	0.17	0.79	0.29	0.08	0.37	1.37
Celtis africana	0.76	2	16.0	10_22	21.0	13_29	0.53	0.14	0.67	0.25	0.07	0.31	1.15
Clematis hirsuta	0.612	2	6.0	6.0	20.0	20.00	0.04	0.01	0.05	0.02	0.01	0.03	0.09
coffea arebica	0.62	16	12.2	5_25	13.1	7_25	1.35	0.36	1.71	0.63	0.17	0.81	2.96
Croton macrostachyus	0.56	51	12.7	5_23	10.5	4.5_23	2.83	0.76	3.59	1.33	0.36	1.69	6.19
Cupressus lusitanica	0.43	2	12.5	10_15	9.5	9_10	0.06	0.02	0.08	0.03	0.01	0.04	0.14
Dodonaea angustifolia	1.04	56	8.3	5_16	7.3	3.5_18	1.69	0.46	2.15	0.79	0.21	1.01	3.70
Dombeya torrida	0.451	27	8.9	5_12	9.1	6_13	0.47	0.13	0.60	0.22	0.06	0.28	1.03
Dovyalis abyssinica	0.579	5	15.2	10_24	18.8	12_13	0.68	0.18	0.86	0.32	0.09	0.40	1.48

Ekebergia capensis	0.58	12	23.2	7_117.8	16.6	10_31	11.58	3.13	14.70	5.44	1.47	6.91	25.36
Erythrina brucei	0.314	9	11.8	9_15	9.6	8_12	0.19	0.05	0.24	0.09	0.02	0.11	0.42
Eucalyptus camaldulensis	0.853	22	19.6	8_50	18.9	7_30	8.46	2.28	10.74	3.97	1.07	5.05	18.52
Euphorbium candelabrum	0.471	6	13.3	6_18	14.5	3_28	0.43	0.12	0.55	0.20	0.05	0.26	0.95
Ficus sur	0.441	32	20.7	6_77	17.3	5_40	12.92	3.49	16.41	6.07	1.64	7.71	28.30
galineria saxifraga	0.612	6	21.3	10_31.9	18.7	11_30	1.56	0.42	1.98	0.73	0.20	0.93	3.42
Gina	0.612	16	23.1	6_79.6	17.9	5_45	15.51	4.19	19.70	7.29	1.97	9.26	33.99
Hypericum revoltum	0.726	2	11.0	8_14	7.0	4_10	0.08	0.02	0.10	0.04	0.01	0.05	0.17
Maytenus arbutifolia	0.713	25	8.6	5_15	9.0	4_15	0.66	0.18	0.84	0.31	0.08	0.40	1.45
Maytenus obscura	0.75	3	18.7	15_21	12.7	11_14	0.48	0.13	0.61	0.22	0.06	0.29	1.05
Myrica salicifolia	0.618	22	12.0	6_20	9.5	4_25	1.25	0.34	1.59	0.59	0.16	0.75	2.75
Olea capensis	0.7	4	17.0	10_23	17.3	8_30	0.83	0.22	1.05	0.39	0.11	0.50	1.82
Olea europaea	0.807	157	25.1	6_124	17.7	4_50	166.62	44.99	211.60	###	21.14	99.45	364.99
Phytolacca dodecandra	0.612	18	9.9	7_20	16.4	7_35	1.18	0.32	1.49	0.55	0.15	0.70	2.58
Pittosporum abyssinicum	0.645	61	11.1	6_50	11.1	5_31	4.61	1.25	5.86	2.17	0.59	2.75	10.11
Podocarpus falcatus	0.523	19	21.9	6_50	16.4	4_36	6.41	1.73	8.14	3.01	0.81	3.83	14.04
Prunus africana	0.938	4	63.6	23_101.9	31.3	23_42	27.84	7.52	35.35	###	3.53	16.62	60.98

Prunus africana (Hook.f.) Kalkm.	0.693	7	8.4	6_10	9.6	4_20	0.18	0.05	0.23	0.08	0.02	0.11	0.39
Psydrax schimperiana	0.743	8	10.8	6_17	9.6	4_14	0.41	0.11	0.52	0.19	0.05	0.24	0.90
pterolobium stellatum	0.612	3	8.3	8_9	8.7	7_10	0.05	0.01	0.07	0.02	0.01	0.03	0.12
Rhus glutinosa	0.612	84	15.2	6_43.9	12.7	4_43	13.16	3.55	16.71	6.18	1.67	7.85	28.83
Rosa abyssinica	0.612	13	11.7	6_16	10.4	6_15	0.57	0.15	0.73	0.27	0.07	0.34	1.25
Schefflera abyssinica	0.491	4	15.5	7_25	10.5	4_15	0.35	0.09	0.44	0.16	0.04	0.21	0.76
Strychnos innocua	0.87	22	9.2	6_18	8.8	5_15	0.78	0.21	0.99	0.37	0.10	0.47	1.72
Teclea nobilis	0.798	257	10.8	5.5_54.1	13.2	4_45	23.53	6.35	29.89	###	2.99	14.05	51.55
Terminalia brownii	0.495	6	20.5	13_24	19.3	15_25	1.21	0.33	1.53	0.57	0.15	0.72	2.64
Urera hypselodendron	0.324	10	8.2	6_12	12.9	5_32	0.17	0.05	0.22	0.08	0.02	0.10	0.38

Where, WD, wood density; DBH, diameter at breast height; H, height; AGB, aboveground biomass; AGC, aboveground carbon; BGB, belowground biomass; BGC, belowground carbon; TC, total carbon and CO2, carbon dioxide equivalent

Appendix table 4: Share of biomass carbon stock in each tree species

Tree species	TAGB (t/ha)	BGB (t/ha)	TB (t/ha)	AGC (t/ha)	BGC (t/ha)	TC (t/ha)	CO2equ-
Olea europaea	166.62	44.99	211.60	78.31	21.14	99.45	364.99
Prunus africana	27.84	7.52	35.35	13.08	3.53	16.62	60.98
Teclea nobilis	23.53	6.35	29.89	11.06	2.99	14.05	51.55
Gina	15.51	4.19	19.70	7.29	1.97	9.26	33.99
Rhus glutinosa	13.16	3.55	16.71	6.18	1.67	7.85	28.83
Ficus sur	12.92	3.49	16.41	6.07	1.64	7.71	28.30
Ekebergia capensis	11.58	3.13	14.70	5.44	1.47	6.91	25.36
Eucalyptus camaldulensis	8.46	2.28	10.74	3.97	1.07	5.05	18.52
Albizia schimperiana	7.14	1.93	9.06	3.35	0.91	4.26	15.64
Podocarpus falcatus	6.41	1.73	8.14	3.01	0.81	3.83	14.04
Acacia decurrens	5.15	1.39	6.54	2.42	0.65	3.07	11.28
Pittosporum abyssinicum	4.61	1.25	5.86	2.17	0.59	2.75	10.11
Croton macrostachyus	2.83	0.76	3.59	1.33	0.36	1.69	6.19
Buddleja polystachya	2.55	0.69	3.24	1.20	0.32	1.53	5.60
Dodonaea angustifolia	1.69	0.46	2.15	0.79	0.21	1.01	3.70
Calpurnia aurea	1.61	0.43	2.04	0.76	0.20	0.96	3.52
Galineria saxifraga	1.56	0.42	1.98	0.73	0.20	0.93	3.42
Coffea arebica	1.35	0.36	1.71	0.63	0.17	0.81	2.96
Myrica salicifolia	1.25	0.34	1.59	0.59	0.16	0.75	2.75
Terminalia brownii	1.21	0.33	1.53	0.57	0.15	0.72	2.64
Phytolacca	1.18	0.32	1.49	0.55	0.15	0.70	2.58

dodecandra							
Olea capensis	0.83	0.22	1.05	0.39	0.11	0.50	1.82
Strychnos innocua	0.78	0.21	0.99	0.37	0.10	0.47	1.72
Dovyalis abyssinica	0.68	0.18	0.86	0.32	0.09	0.40	1.48
Maytenus arbutifolia	0.66	0.18	0.84	0.31	0.08	0.40	1.45
Carissa edulis	0.62	0.17	0.79	0.29	0.08	0.37	1.37
Rosa abyssinica	0.57	0.15	0.73	0.27	0.07	0.34	1.25
Celtis africana	0.53	0.14	0.67	0.25	0.07	0.31	1.15
Maytenus obscura	0.48	0.13	0.61	0.22	0.06	0.29	1.05
Dombeya torrida	0.47	0.13	0.60	0.22	0.06	0.28	1.03
Euphorbium candelabrum	0.43	0.12	0.55	0.20	0.05	0.26	0.95
Psydrax schimperiana	0.41	0.11	0.52	0.19	0.05	0.24	0.90
Bersama abyssinica	0.35	0.09	0.44	0.16	0.04	0.21	0.77
Schefflera abyssinica	0.35	0.09	0.44	0.16	0.04	0.21	0.76
Erythrina brucei	0.19	0.05	0.24	0.09	0.02	0.11	0.42
Acanthus senni	0.19	0.05	0.24	0.09	0.02	0.11	0.42
Prunus africana	0.18	0.05	0.23	0.08	0.02	0.11	0.39
Urera hypselodendron	0.17	0.05	0.22	0.08	0.02	0.10	0.38
Buddleia polystachya	0.12	0.03	0.15	0.06	0.01	0.07	0.26
Hypericum revoltum	0.08	0.02	0.10	0.04	0.01	0.05	0.17
Cupressus lusitanica	0.06	0.02	0.08	0.03	0.01	0.04	0.14
pterolobium stellatum	0.05	0.01	0.07	0.02	0.01	0.03	0.12
Clematis hirsuta	0.04	0.01	0.05	0.02	0.01	0.03	0.09
Total	326.4	88.1	414.5	153.4	41.4	194.8	715.0

Where, AGC. Aboveground carbon; BGC, belowground carbon; TC, total carbon and CO_2, corbon dioxide equivalent.

Appendix table 5: Biomass and carbon stock of Litter, herbs and grasses (LHGs)

Plot No	field wt (g)	Sf wt (g)	OD wt (g)	LB tha^{-1}	%c	LC tha^{-1}	CO2 equ._ tha^{-1}
1.00	393.45	100.00	79.81	3.14	0.50	1.57	5.76
2.00	482.21	100.00	91.82	4.43	0.50	2.21	8.12
3.00	484.50	100.00	93.82	4.55	0.50	2.27	8.34
4.00	398.51	100.00	79.82	3.18	0.50	1.59	5.84
5.00	391.20	100.00	85.82	3.36	0.50	1.68	6.16
6.00	630.69	100.00	75.82	4.78	0.50	2.39	8.77
7.00	128.16	100.00	78.72	1.01	0.50	0.50	1.85
8.00	457.70	100.00	86.38	3.95	0.50	1.98	7.26
9.00	409.40	100.00	77.83	3.19	0.50	1.59	5.85
10.00	580.40	100.00	89.65	5.20	0.50	1.77	9.55
11.00	284.50	100.00	87.83	2.50	0.50	1.25	4.59
12.00	589.60	100.00	85.75	5.06	0.50	2.53	9.28
13.00	425.50	100.00	91.38	3.89	0.50	1.94	7.14
14.00	580.80	100.00	90.43	5.25	0.50	2.63	9.64
15.00	409.30	100.00	84.98	3.48	0.50	1.74	6.38
16.00	450.74	100.00	91.38	4.12	0.50	2.06	7.56
17.00	520.70	100.00	87.82	4.57	0.50	2.29	8.39
18.00	545.80	100.00	88.82	4.85	0.50	2.42	8.90
19.00	590.29	100.00	89.89	5.31	0.50	2.65	9.74
20.00	533.20	100.00	89.82	4.79	0.50	2.39	8.79
21.00	523.30	100.00	91.62	4.79	0.50	2.40	8.80
22.00	434.40	100.00	90.72	3.94	0.50	1.97	7.23
23.00	389.23	100.00	90.82	3.54	0.50	2.60	6.49
24.00	375.60	100.00	92.57	3.48	0.50	1.74	6.38
25.00	435.40	100.00	88.72	3.86	0.50	1.93	7.09
26.00	431.35	100.00	87.12	3.76	0.50	1.88	6.90
27.00	453.26	100.00	91.78	4.16	0.50	2.08	7.63
28.00	565.67	100.00	78.88	4.46	0.50	2.23	8.19
29.00	514.24	100.00	89.25	4.59	0.50	2.29	8.42
30.00	388.31	100.00	88.96	3.45	0.50	1.73	6.34
Over all				4.02		2.01	7.38

Where, Field Wt, field weight of litter sample; Sf Wt, sample fresh weight, OD Wt, oven dry weight of sample; LB, litter biomass; C, carbon fraction ; LC, litter carbon and CO2, carbon dioxide equivalent

Appendix table 6: Soil organic carbon (SOC).

P N	Depth cm	TDs g	MRs g	MFs g	TSV ml	RV ml	ρR gcm^{-3}	BD gcm^{-3}	**%C**	D cm	SOC gcm-2	Soc kgm-^{2}	SOC Tha^{-1}	TC (depth)	SOC mean
F1	0_10	340.34	110.71	229.63	341.95	95	1.17	0.93	7.07	10	0.66	6.57	65.74	148.16	128.6
	10_20	424.28	228.67	195.62	341.95	115	1.99	0.86	5.91	10	0.51	5.10	50.98		
	20_30	608.80	386.91	221.89	341.95	190	2.04	1.46	2.15	10	0.31	3.14	31.44		
F2	0_10	410.34	130.71	279.63	341.95	105	1.24	1.18	5.07	10	0.60	5.98	59.83	137.62	
	10_20	424.28	258.67	165.62	341.95	160	1.62	0.91	4.91	10	0.45	4.47	44.73		
	20_30	558.80	386.91	171.89	341.95	165	2.34	0.97	3.40	10	0.33	3.31	33.06		
F3	0_10	374.82	203.88	170.94	341.95	100	2.04	0.71	6.78	10	0.48	4.79	47.90	127.71	
	10_20	363.04	167.71	195.33	341.95	95	1.77	0.79	5.90	10	0.47	4.67	46.67		
	20_30	296.81	139.87	156.94	341.95	90	1.55	0.62	5.32	10	0.33	3.31	33.14		
F4	0_10	371.10	180.81	190.29	341.95	103	1.76	0.80	7.71	10	0.61	6.14	61.41	132.12	
	10_20	314.14	171.14	143.00	341.95	90	1.90	0.57	7.22	10	0.41	4.10	41.00		
	20_30	391.10	235.67	155.43	341.95	135	1.75	0.75	3.96	10	0.30	2.97	29.71		
F5	0_10	369.40	129.77	239.63	341.95	100	1.30	0.99	6.90	10	0.68	6.83	68.34	147.84	
	10_20	343.04	167.71	175.33	341.95	90	1.86	0.70	5.92	10	0.41	4.12	41.20		
	20_30	388.80	206.91	181.89	341.95	105	1.97	0.77	4.99	10	0.38	3.83	38.31		
F6	0_10	407.82	203.88	203.94	341.95	110	1.85	0.88	6.87	10	0.60	6.04	60.41	136.21	
	10_20	343.04	167.71	175.33	341.95	95	1.77	0.71	5.83	10	0.41	4.14	41.39		
	20_30	324.81	137.87	186.94	341.95	85	1.62	0.73	4.73	10	0.34	3.44	34.41		
F7	0_10	462.81	235.87	226.94	341.95	135	1.75	1.10	5.61	10	0.62	6.16	61.55	130.43	
	10_20	443.35	215.85	227.50	341.95	135	1.60	1.10	3.45	10	0.38	3.80	37.97		
	20_30	427.04	278.01	149.03	341.95	165	1.68	0.84	3.67	10	0.31	3.09	30.90		
	0_10	441.82	190.88	250.94	341.95	105	1.82	1.06	5.53	10	0.59	5.86	58.58	131.48	
	10_20	455.55	236.53	219.02	341.95	125	1.89	1.01	4.21	10	0.43	4.25	42.51		

F8	20_30	411.41	195.95	215.46	341.95	123	1.59	0.98	3.09	10	0.30	3.04	30.39		
F9	0_10	416.60	209.05	207.55	341.95	100	2.09	0.86	5.86	10	0.50	5.02	50.24	118.28	
	10_20	467.48	282.36	185.13	341.95	130	2.17	0.87	4.70	10	0.41	4.10	41.03		
	20_30	410.32	282.00	128.32	341.95	155	1.82	0.69	3.94	10	0.27	2.70	27.02		
F10	0_10	416.82	213.88	202.94	341.95	120	1.78	0.91	5.53	10	0.51	5.06	50.57	109.31	
	10_20	446.55	246.53	200.02	341.95	125	1.97	0.92	3.41	10	0.31	3.14	31.45		
	20_30	420.32	252.00	168.32	341.95	130	1.94	0.79	3.44	10	0.27	2.73	27.29		
F11	0_10	423.60	210.05	213.55	341.95	105	2.00	0.90	5.91	10	0.53	5.32	53.24	125.72	
	10_20	437.48	262.36	175.13	341.95	130	2.02	0.83	4.96	10	0.41	4.10	40.96		
	20_30	415.89	235.95	179.94	341.95	120	1.97	0.81	3.89	10	0.32	3.15	31.52		
F12	0_10	390.00	190.05	199.95	341.95	100	1.90	0.83	7.31	10	0.60	6.04	60.41	129.83	
	10_20	352.48	222.36	130.13	341.95	130	1.71	0.61	6.26	10	0.38	3.84	38.42		
	20_30	371.19	235.95	135.24	341.95	120	1.97	0.61	5.09	10	0.31	3.10	31.00		
F13	0_10	440.48	190.78	249.70	341.95	125	1.53	1.15	4.25	10	0.49	4.89	48.87	111.46	
	10_20	423.04	207.71	215.33	341.95	115	1.81	0.95	3.52	10	0.33	3.34	33.36		
	20_30	478.80	292.03	186.77	341.95	165	1.77	1.06	2.77	10	0.29	2.92	29.23		
F14	0_10	381.23	204.62	176.61	341.95	109	1.88	0.76	6.81	10	0.52	5.16	51.62	122.29	
	10_20	344.77	204.00	140.77	341.95	120	1.70	0.63	6.33	10	0.40	4.02	40.17		
	20_30	327.28	216.85	110.43	341.95	125	1.73	0.51	5.99	10	0.30	3.05	30.50		
F15	0_10	414.23	187.62	226.61	341.95	110	1.71	0.98	5.39	10	0.53	5.27	52.65	123.06	
	10_20	384.77	174.00	210.77	341.95	105	1.66	0.89	4.73	10	0.42	4.21	42.07		
	20_30	336.43	226.00	110.43	341.95	195	1.16	0.75	3.77	10	0.28	2.83	28.34		
F16	0_10	408.64	151.17	257.47	341.95	70	2.16	0.95	5.53	10	0.52	5.24	52.37	119.46	
	10_20	308.13	107.76	200.37	341.95	71	1.52	0.74	4.60	10	0.34	3.40	34.03		
	20_30	429.05	261.96	167.09	341.95	140	1.87	0.83	4.00	10	0.33	3.31	33.06		
F17	0_10	388.64	171.17	217.47	341.95	120	1.43	0.98	6.31	10	0.62	6.18	61.83	136.53	
	10_20	338.13	117.76	220.37	341.95	60	1.96	0.78	5.60	10	0.44	4.38	43.79		

	20_30	422.05	261.96	160.09	341.95	135	1.94	0.77	4.00	10	0.31	3.09	30.91		
F18	0_10	378.64	151.17	227.47	341.95	70	2.16	0.84	7.53	10	0.63	6.30	62.99	141.28	
	10_20	328.13	97.76	230.37	341.95	51	1.92	0.79	5.90	10	0.47	4.67	46.73		
	20_30	389.05	201.96	187.09	341.95	105	1.92	0.79	4.00	10	0.32	3.16	31.55		
F19	0_10	406.60	209.05	197.55	341.95	110	1.90	0.85	7.41	10	0.63	6.31	63.08	136.50	
	10_20	427.48	302.36	125.13	341.95	130	2.33	0.59	6.96	10	0.41	4.11	41.07		
	20_30	371.19	235.95	135.24	341.95	125	1.89	0.62	5.19	10	0.32	3.23	32.34		
F20	0_10	398.64	181.17	217.47	341.95	120	1.51	0.98	6.53	10	0.64	6.40	63.99	130.16	
	10_20	288.13	107.76	180.37	341.95	60	1.80	0.64	5.60	10	0.36	3.58	35.84		
	20_30	419.05	261.96	157.09	341.95	135	1.94	0.76	4.00	10	0.30	3.03	30.33		
F21	0_10	388.64	181.17	207.47	341.95	110	1.65	0.89	7.43	10	0.66	6.65	66.47	152.57	
	10_20	358.13	177.76	180.37	341.95	100	1.78	0.75	6.90	10	0.51	5.15	51.45		
	20_30	389.05	231.96	157.09	341.95	115	2.02	0.69	5.01	10	0.35	3.47	34.65		
F22	0_10	373.22	174.53	198.70	341.95	80	2.18	0.76	7.57	10	0.57	5.74	57.38	134.17	
	10_20	202.61	27.11	175.50	341.95	15	1.81	0.54	7.51	10	0.40	4.03	40.31		
	20_30	270.16	116.61	153.56	341.95	50	2.33	0.53	6.94	10	0.36	3.65	36.48		
F23	0_10	318.22	89.53	228.70	341.95	40	2.24	0.76	7.65	10	0.58	5.79	57.94	138.77	
	10_20	222.61	47.11	175.50	341.95	20	2.36	0.55	7.51	10	0.41	4.09	40.94		
	20_30	280.16	126.61	153.56	341.95	75	1.69	0.58	6.94	10	0.40	3.99	39.89		
F24	0_10	252.73	100.63	152.10	341.95	75	1.34	0.57	7.31	10	0.42	4.16	41.63	113.89	
	10_20	265.48	101.38	164.09	341.95	70	1.45	0.60	6.73	10	0.41	4.06	40.62		
	20_30	495.35	304.30	191.05	341.95	120	2.54	0.86	3.68	10	0.32	3.16	31.64		
F25	0_10	323.73	171.63	152.10	341.95	75	2.29	0.57	7.31	10	0.42	4.16	41.63	113.37	
	10_20	265.48	101.38	164.09	341.95	60	1.69	0.58	6.73	10	0.39	3.92	39.17		
	20_30	385.35	184.30	201.05	341.95	115	1.60	0.89	3.68	10	0.33	3.26	32.57		
F26	0_10	284.22	85.53	198.70	341.95	20	4.28	0.62	7.57	10	0.47	4.67	46.69	123.48	
	10_20	202.61	27.11	175.50	341.95	15	1.81	0.54	7.51	10	0.40	4.03	40.31		

	20_30	270.16	116.61	153.56	341.95	50	2.33	0.53	6.94	10	0.36	3.65	36.48		
27	0_10	277.22	88.53	188.70	341.95	38	2.33	0.62	7.77	10	0.48	4.82	48.21	119.11	
	10_20	247.61	77.11	170.50	341.95	15	5.14	0.52	7.51	10	0.39	3.92	39.16		
	20_30	270.16	116.61	153.56	341.95	50	2.33	0.53	6.04	10	0.32	3.17	31.74		
28	0_10	375.23	178.62	196.61	341.95	89	2.01	0.78	6.99	10	0.54	5.43	54.32	145.32	
	10_20	454.77	274.00	180.77	341.95	120	2.28	0.81	6.33	10	0.52	5.16	51.58		
	20_30	414.43	306.00	108.43	341.95	195	1.57	0.74	5.34	10	0.39	3.94	39.41		
29	0_10	325.23	158.62	166.61	341.95	85	1.87	0.65	6.99	10	0.45	4.53	45.32	115.45	
	10_20	409.77	284.00	125.77	341.95	120	2.37	0.57	6.33	10	0.36	3.59	35.89		
	20_30	486.43	386.00	100.43	341.95	195	1.98	0.68	5.01	10	0.34	3.42	34.25		
30	0_10	415.23	208.62	206.61	341.95	99	2.11	0.85	4.99	10	0.42	4.24	42.43	107.55	
	10_20	420.77	254.00	166.77	341.95	124	2.05	0.77	4.73	10	0.36	3.62	36.22		
	20_30	418.43	296.00	122.43	341.95	175	1.69	0.73	3.94	10	0.29	2.89	28.90		
G1	0_10	522.40	193.50	328.90	341.95	105	1.84	1.39	2.33	10	0.32	3.23	32.33	95.97	94.72
	10_20	456.15	190.06	266.09	341.95	103	1.85	1.11	2.98	10	0.33	3.32	33.23		
	20_30	506.63	197.73	308.90	341.95	100	1.98	1.28	2.38	10	0.30	3.04	30.41		
G2	0_10	506.45	208.00	298.45	341.95	105	1.98	1.26	3.13	10	0.39	3.94	39.39	103.89	
	10_20	491.24	208.00	283.24	341.95	95	2.19	1.15	2.98	10	0.34	3.42	34.18		
	20_30	470.33	175.00	295.33	341.95	90	1.94	1.17	2.59	10	0.30	3.03	30.32		
G3	0_10	517.00	232.00	285.00	341.95	112	2.07	1.24	2.34	10	0.29	2.90	29.00	84.29	
	10_20	506.00	194.00	312.00	341.95	110	1.76	1.35	2.30	10	0.31	3.09	30.94		
	20_30	486.30	189.00	297.30	341.95	110	1.72	1.28	1.90	10	0.24	2.44	24.35		
C1	0_10	458.04	205.23	252.81	341.95	95	2.16	1.02	1.64	10	0.17	1.68	16.81	37.63	38.42
	10_20	545.55	249.40	296.15	341.95	110	2.27	1.28	1.00	10	0.13	1.28	12.81		
	20_30	572.34	246.97	325.38	341.95	110	2.25	1.40	0.57	10	0.08	0.80	8.01		
C2	0_10	559.44	226.61	332.83	341.95	125	1.81	1.53	0.80	10	0.12	1.23	12.26	26.92	
	10_20	573.01	257.56	315.46	341.95	110	2.34	1.36	0.56	10	0.08	0.77	7.67		

	20_30	540.53	245.49	295.04	341.95	101	2.43	1.22	0.57	10	0.07	0.70	6.99		
C3	0_10	514.00	213.00	301.00	341.95	103	2.07	1.26	1.57	10	0.20	1.98	19.75	50.71	
	10_20	517.00	220.00	297.00	341.95	114	1.93	1.30	1.39	10	0.18	1.81	18.11		
	20_30	583.00	280.00	303.00	341.95	125	2.24	1.40	0.92	10	0.13	1.28	12.85		

Where, TDs_total dry soil, MRs_mass of rock fragment, MFs_mass of fine soil, TSV_total volume of soil, RV_ rock volume, and ρR_densty of rock and BD_bulk density of fine soil, SOC _soil organic carbon, C1_cultivated land, G1_grazing land and CO2eq_ corbon dioxide equivalent.

Appendix table 7: Total carbon stock density and altitude of Zafnigus Forest

		Carbon pool in t/ha							
plot	**Elv(m.a.s.l)**	**AGB(t/ha)**	**AGC(t/ha)**	**BGB(t/ha)**	**BGC(t/ha)**	**LC(t/ha)**	**SOC**	**TC**	**CO2 equ.**
1	2436.1_2532	833.14	391.57	224.95	105.73	1.57	148.16	647.03	2374.6
2	2532.1_2627	300.65	141.30	81.17	38.15	2.21	137.62	319.29	1171.79
3	2532.1_2627	55.27	25.98	14.92	7.01	2.27	127.71	162.97	598.118
4	2627.1_2728	477.68	224.51	128.97	60.62	1.59	132.12	418.84	1537.13
5	2532.1_2627	1028.85	483.56	277.79	130.56	1.68	147.84	763.64	2802.57
6	2436.1_2532	1312.62	616.93	354.41	166.57	2.39	136.21	922.10	3384.12
7	2532.1_2627	155.10	72.90	41.88	19.68	0.50	130.43	223.51	820.276
8	2532.1_2627	314.90	148.00	85.02	39.96	1.98	131.48	321.42	1179.6
9	2627.1_2728	161.76	76.03	43.68	20.53	1.59	118.28	216.43	794.306
10	2728.1_2872	61.61	28.95	16.63	7.82	1.77	109.31	147.85	542.611
11	2627.1_2728	44.50	20.92	12.02	5.65	1.25	125.72	153.53	563.448
12	2627.1_2728	78.73	37.00	21.26	9.99	2.53	129.83	179.35	658.217
13	2728.1_2872	74.41	34.97	20.09	9.44	1.94	111.46	157.82	579.191

14	2532.1_2627	137.71	64.73	37.18	17.48	2.63	122.29	207.11	760.107
15	2728.1_2872	146.34	68.78	39.51	18.57	1.74	123.06	212.16	778.615
16	2532.1_2627	233.43	109.71	63.03	29.62	2.06	119.46	260.86	957.345
17	2436.1_2532	180.99	85.07	48.87	22.97	2.29	136.53	246.85	905.93
18	2333.0_2436	295.01	138.66	79.65	37.44	2.42	141.28	319.79	1173.64
19	2436.1_2532	244.70	115.01	66.07	31.05	2.65	136.50	285.21	1046.73
20	2436.1_2532	386.45	181.63	104.34	49.04	2.39	130.16	363.23	1333.06
21	2333.0_2436	719.13	337.99	194.17	91.26	2.40	152.57	584.22	2144.09
22	2436.1_2532	864.60	406.36	233.44	109.72	1.97	134.17	652.22	2393.66
23	2333.0_2436	1129.47	530.85	304.96	143.33	2.60	138.77	815.55	2993.08
24	2728.1_2872	134.08	63.02	36.20	17.01	1.74	113.89	195.66	718.057
25	2532.1_2627	51.42	24.17	13.88	6.53	1.93	113.37	146.00	535.802
26	2436.1_2532	55.53	26.10	14.99	7.05	1.88	123.48	158.50	581.699
27	2627.1_2728	91.01	42.77	24.57	11.55	2.08	119.11	175.52	644.147
28	2436.1_2532	145.56	68.41	39.30	18.47	2.23	145.32	234.43	860.359
29	2627.1_2728	60.01	28.20	16.20	7.61	2.29	115.45	153.57	563.586
30	2728.1_2872	17.33	8.15	4.68	2.20	1.73	107.55	119.62	439.001
Over all								325.48	1194.5

Where, AGB, aboveground biomass; AGC, aboveground carbon; BGB, belowground biomass; BGC, belowground carbon; LC, litter carbon; SOC, soil organic carbon; TC, total carbon and CO2, carbon dioxide equivalent

Appendix table 8: Result of one-way ANOVA all carbon pools with respect to elevation

ONEWAY AGC, BGC, LC and SOC (0-10cm) SOC (10-20cm) SOC (20-30cm) by elevation
/missing analysis
/POSTHOC=DUNCUN ALPHA (0.05).
ONE WAY ANOVA

Carbon pool in t/ha			SS	DF	MS	F	Sig
AGC	Between Groups		261611	4	65402.7	2.841	0.045
	within groups		575441	25	23017.6		
	total		837052	29			
BGC	Between Groups		19071.4	4	4767.84	2.841	0.045
	within groups		41951.2	25	1678.05		
	total		61022.6	29			
LC	Between Groups		1.284	4	0.321	1.645	0.194
	within groups		4.88	25	0.195		
	total		6.165	29			
SOC 0_10	Between Groups		628.286	4	157.072	3.486	0.021
	within groups		1126.51	25	45.06		
	total		1754.8	29			
SOC10_20	Between Groups		230	4	57.5	3	0.038
	within groups		479.159	25	19.166		
	total		709.159	29			
SOC20_30	Between Groups		116.187	4	29.047	3.743	0.016
	within groups		194.032	25	7.761		
	total		310.219	29			

Where, SS, sum of square; DF, degree of freedom; MS, mean square; F, f-value; sig, significances value; AGC, aboveground carbon; BGC, belowground carbon; LC, litter carbon and SOC, soil organic carbon

Appendix photo 1 : Zafnigus forest through data collection

Appendix photo 2: Soil sample through data collection

AUTHOR'S BIOGRAPHY

The author was born on January 11, 1994 G.C in Amhara National Regional State (ANRS), South Gonder Zone, and Ebinat District from her father Asradew Berhanu and her mother Kassanesh Adimassie. She attended her elementary education (1-8 grades) at Gunaguna Elementary School & she attended her secondary and preparatory school education (9_12) at Ebinat Secondary Preparatory School. Then she joined DebreTabor University College of Agriculture and Environmental Sciences in 2015 G.C and graduated with Degree in Natural Resources Management in 2017G.C. Soon after graduation, she employed at Debre Tabor University as an assistant lecturer since July 2017 G.C. Starting from /September 2017, she joined Bahir Dar University to pursue her graduate studies in MSc. with Environment and Climate Change.