ESTIMATION OF CARBON STOCK POTENTIAL ALONG AN ALTITUDINAL GRADIENT OF ZONBA NATURAL FOREST IN SOUTH ARI DISTRICT, SOUTHERN ETHIOPIA

MSC THESIS

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THESIS SUBMITTED TO HAWASSA UNIVERSITY DEPARTMENT OF GENERAL FORESTRY WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCES SUBMITTED TO SCHOOL OF GRATUATE STUDIES, HAWASSA UNIVERSITY, ETHIOPIA

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ADVISOR: MOTUMA TOLERA (PhD)

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APPROVAL SHEET 1

This is to certify that the thesis entitled *‘‘Estimating the carbon stock potential along altitudinal gradient of Zonba natural forest, South Ari Wereda, South omo zone, south Ethiopia’’* is submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in ‘‘Forest resource assessment and monitoring’’, Wondo Genet College of Forestry and Natural Resource, and is a record of original research carried out by **Melaku Anteneh** Id. No. **MSc/FRAM/R0014/11**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistances and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

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Name of Major Advisor	Signature	Date

APPROVAL SHEET II

We, the undersigned, members of the board of examiners of the final open defense by Melaku Anteneh have read and evaluated his thesis entitled *‘‘Estimating the carbon stock potential along altitudinal gradient of Zonba natural forest, South Ari Wereda, South omo zone, south Ethiopia’’.* This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of masters of Science in *‘‘Forest resource assessment and monitoring’’*.

Name of the Chairperson	Signature	Date
Name of Major Advisor	Signature	Date
Name of Internal Examiner	Signature	Date
Name of External Examiner	Signature	Date
SGS approval	Signature	Date

List of Abbreviations and Acronyms

ADEME	Agency for the Environment and Energy Management
AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above Ground Biomass
AGCs	Above Ground Carbon stocks
BGB	Below Ground Biomass
BIOME-BGC	Bio-Geochemical Cycles
CDM	Clean Development Mechanism
CO2	Carbon Dioxide
COLE	Carbon On-Line Estimator
CRGE	Climate Resilient Green Economy
CSA	Central Statistical Authority
DBH	Diameter at Breast Height
DOM	Dead Organic Matter
EFI-SCEN	European Forest Information Scenario model
FAO	Food and Agricultural Organization

GHGs	Green House Gases
GORCAM	Graz/Oak Ridge Carbon Accounting Model
Gt	Giga tones
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land-Use Change and Forestry
m.a.s.l	meter above sea level
REDD+	Reducing Emissions from Deforestation +Reducing Emissions from Forest Degradation conservation of forest+ +Sustainable forest management+ Enhancing fores carbon stock
SFM	Sustainable Forest Management
SNNPR	South Nations Nationality and Peoples Region
SOC	Soil Organic Carbon
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
WBISPP	Woody Biomass Inventory Service Planning Project

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Abstract

Forest contributes 50% of climate change mitigation potential. Forest serves as natural sinker of atmospheric CO_2 *to mitigate climate change. Although a number of studies have been done on carbon stock estimations the influence of environmental factors on forest carbon stocks* have not *been properly addressed. This study was conducted in Zonba Forest, with the objectives of estimating of the carbon stock and its variation along the altitudinal gradients. Reconnaissance survey was carried out across the forest in order to obtain an impression in site conditions and physiognomy of the vegetation and collect information on accessibility. Systematic stratified sampling method was employed in two strata to collect data and altitude was the major parameter to consider. Data collection was done by field inventory and secondary data from different sources. In order to collect vegetation data a total of 62 plots (31 quadrants in each strata) each with the size of 20 m x 20 m at an interval of 100 m, were laid along the established transects at 300 m apart. For litter and soil sample collection, five sub-quadrants 1 m x 1 m were established at four corners and center of every quadrant. Data analysis of various carbon pools measured in the forests were accomplished by organizing and recording on the excel data sheet and MINITAB software version 17.Results revealed that the total mean carbon stock density of Zonba Forest was 316.48 t/ha with aboveground biomass carbon of 155.83t/ha and belowground biomass carbon 40.5158t/ha litter biomass carbon 5.157 t/ha and soil organic carbon 114.977 t/ha. 138.31t/ha and 173.35t/ha AGC, 35.961t/ha and 45.071t/ha BGC, 106.931t/ha and 123.041t/ha SOC, 5.024 t/ha and 5.291t/ha were recorded in upper and lower altitude respectively. Therefore, higher amount of carbon was recorded in lower altitude than upper altitude. The result of this study showed that altitude has no significant impact on carbon pools except soil organic carbon. Based on overall ecosystem carbon stock result of the site was on good status and it can contribute to climate change mitigation.*

Keywords: Biomass Carbon, Soil Organic Carbon, Ecosystem carbon, Dry afromontane natural forest, Carbon stock density

1. INTRODUCTION

1.1Background

Forest ecosystems play an important role in the global carbon balance. As both carbon sources and sinks, they have the potential to form an important component in efforts to combat global climate change impacts (Trexler and Haugen, 1994). In nature, forest ecosystem act as a reservoir of carbon. The world's forests store 289 Gt (1Gt = 10^9 tons) of carbon in their biomass alone (FAO, 2010). They store huge quantities of carbon and regulate the carbon cycle by exchange of carbon dioxide from the atmosphere. Forest uptakes the carbon dioxide by the process of photosynthesis and stores the carbon in the plant tissues. However, the amount of carbon sequestered and stored in forest varies greatly based on a large number of factors, including the type of forest, its net primary production, the age of the forest and its overall composition (Millard, 2007).

The carbon pools in forest ecosystem are affected by altitude, slop and land use types (Diawei *et al*. 2006).Bhat *et al.(2003)* indicated that land use, land use changes, soil erosion and deforestation are the most important factors affecting carbon stock density in the forest ecosystem. According to Feyissa *et al*. (2003), forest carbon is affected by altitude and slop. Altitude has a significant effect on temperature and precipitation. This strongly affects species composition the diversity, the quantity and turnover of forest ecosystem (Sheikh and Bussmann 2009).

Tropical forests comprise the largest proportion of the world's forests at 44 %, it also contain one of the largest carbon pools and have a significant function in the global carbon cycle (FAO, 2011). At present, the world's tropical forests are found to be a net source of carbon dioxide due to anthropogenic activities including deforestation with an emission of 1.6 Gt (1Gt = 10^9 tons), in the year 1990 alone (Salam *et al.*,1999). The impact of these changes through carbon dioxide emissions to the atmosphere needs to be assessed with more certainty, for which spatially specific data are required. As a result, of international concerns a mechanism has been discussed within the United Nations Framework Convention on Climate Change (UNFCCC), to encourage the reduction of forest clearance in the tropics REDD+ will require robust repeatable assessments of forest cover changes so as to ensure that real reductions of carbon emissions are taking place (Mollicone *et al.*, 2007). The tropical forests are subject to severe degradation due to overpopulation, shifting cultivation and extension of agriculture (Salam *et al.*, (1999), cited in Nune *et al.*, (2010)). Alamgir and Al-Amin (2007) mentioned that the natural forest of tropical rain forest is facing such a serious destructive attack that its major parts are already lost, remaining only a small percentage. With a massive pool of existing bared hills in tropics, it may be assumed that tropical forest is playing a major role in mitigating global warming and earning carbon credits.

Ethiopia is found in the tropics and a substantial proportion of the land area in highlands of Ethiopia is once believed to, have been covered by forests (Abate *et al.*, 2006). The national carbon stock of Ethiopia was estimated to be 153 teragram (Tg) of C Houghton (1998), 867Tg of C by Gibbs *et al*. (2007), and 2.5 Gt of C by Sisay (2010). Deforestation leads to CO2 emissions, and is mostly caused by the conversion of forested areas to agricultural land. Emissions are projected to grow from 25 Mt CO2e in 2010 to almost 45 Mt in 2030. Forest degradation leads to CO2 emissions, and is primarily caused by fuel wood Consumption and logging in excess of the natural yield of the forests, with the major driver being population growth.

In Ethiopia there has been very limited forest carbon stock study by considering environmental factors, which affect carbon stock. Therefore, this study was done to assess and differentiate the altitudinal variable with carbon amount. And this gives basic information for the forest to mitigate climate change.

SNNPRS is one of the nine regional states of Ethiopia, with a total land area of about 112,000 km^2. The Region accounts for 10% of the total area of the country. SNNPRS is characterized by its relatively high rainfall and has the second largest area of rain forest in the country. It hosts more than 770,000 ha of high forest, which represents 19% of the total high forests found in the country (WBISPP, 2004). The Region is also famous for the large areas of agro forestry which are practiced in farm land. However, the region is also characterizing by the highest rate of forest clearing with an annual rate of 2.35% (WBISPP, 2004).

In the same situation, Zonba forest also expected to affect by deforestation and other anthropogenic factors. So, to get considerable attention, one way could be show its role in different perspective like its potential to stock of carbon. This has a contribution to control global warming as well as it will have a benefit for the community and country through carbon trade if it is well protected. And in Zonba forest no such study has been conducted with the aim of assessing its carbon stock amount and its dynamics along altitudinal gradient. Therefore, this study aims to estimate the carbon stock potential of Zonba natural forest along altitudinal gradient in South Ari Wereda of south Ethiopia.

1.2 Statement of the Problem

The current government of Ethiopia clearly articulated the seriousness of forest destruction in the Climate Resilient Green Economy (CRGE). For this, it provided a solution, reduction of demand for fuel wood by disseminating fuel efficient stoves; increasing afforestation and reforestation schemes; and promoting area closure via rehabilitation of degraded pastoral land and farmland are forwarded as a viable strategy.

Ethiopia is experiencing the effects of climate change. Besides, the direct effects such as an increase in average temperature or a change in rainfall patterns, climate change also presents the necessity and opportunity to switch to a new, sustainable development model (CRGE, 2011).

Ethiopia's current contribution to the global increase in GHG emissions since the industrial revolution has been practically negligible. Even after years of rapid economic expansion, today's per capita emissions of less than 2 t CO_2e are modest compared with the more than 10 t per capita on average in the EU and more than 20 t per capita in the US and Australia. Overall, Ethiopia's total emissions of around 150 Mt CO_2e represent less than 0.3 % of global emissions. Of the 150 Mt CO_2e in 2010, more than 85 % of GHG emissions came from the agricultural and forestry sectors. They are followed by power, transport, industry and buildings, which contributed 3 % each (CRGE, 2011).

Deforestation and forest degradation must be reversed to support the continued provision of economic and ecosystem services and growth in GDP. Fuel wood accounts for more than 80 % of households' energy supply today particularly in rural areas. Despite their economic and environmental value, Ethiopian forests are under threat. The growing population requires more fuel wood and more agricultural production, in turn creating needs for new farmland; both of which accelerate deforestation and forest degradation (CRGE, 2011).

The Zonba forest is located in the South Omo Zone, Debub Ari Woreda specifically in Zonba kebele and the majority of the inhabitants are Ari communities. As the forest is laid on a wide altitudinal range and the upper side from the village, it plays cultural, economical and environmental role and has been a lifeline for the local community for many decades. Ecologically, the forest gives important environmental benefits by providing carbon sink/ carbon storage service; watershed protection. In addition, the forest serves as a source of food and fodder, household energy, construction and agricultural material and medicines for local community (Bizuayehu Ayele et.al, 2016). Now it is a time to constitute the existing forest management strategies with the climate change through the stock of carbon. However, such study in the area was not done and this study is the first of its kind for the area and forest.

Therefore, this study aims to estimate the carbon stock potential of Zonba natural forest along altitudinal gradient. For that, Biomass production in different forms plays important role in carbon stock in the forest ecosystem. Above Ground Biomass, Below Ground Biomass, Litter carbon, and Soil Organic Matter in altitudinal gradient are the major carbon pools to this study. Assessment of carbon stocks changes in the forest are relevant to deal with the united nation Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol report. For that, in this study appropriate techniques and tools were implemented. Such kinds of study were providing adequate information on carbon stock estimation. Cognizant of this fact, this study tried to address the following objective.

1.3 Objective of the study

1.3.1 General objective

The general objective of this study was to estimate the carbon stock potential and its variation along altitudinal gradients of Zonba natural forest in South Ari, South Ethiopia.

1.3.2 Specific objectives

The specific objectives of this study are to;

- Assess and compare the biomass carbon stock of Zonba natural Forest along altitudinal gradient in Zonba kebele.
- Assess and compare the soil carbon stock of Zonba natural Forest along altitudinal gradient in Zonba kebele.
- Compare ecosystem level carbon stock of Zonba natural forest along altitudinal gradient in Zonba kebele

1.4 Research questions

- Do carbon pools (biomass and soil organic) vary along altitudinal gradient?

1.5 Significance of the study

The finding of the present study will generate concrete information about the existing forest carbon stock potential of above-ground, belowground soil, and liter carbon pool of the study area.

Moreover, the outcome of this study can be used as input of information for research institutes, Governmental and Non-government Organizations (NGOs). Specifically, relevant information on carbon stock potential along altitudinal gradient and its contribution to climate change impacts on the study area will be predicted .Finally; the finding of the present study will serve as a baseline for further related studies.

This study will be strongly valuable to predict carbon stock potential of the Zonba natural forest along altitudinal gradient in South Ari wereda. The investigation will point out a clue to adjust and balance co_2 emission to the atmosphere and to design a new mitigation and adaptation strategy. It is possible to decrease deforestation and to increase wise use and conservation of natural resource. Moreover, this study will provide valuable climate information with the new carbon emission scenario to farmer communities, designers, policy and decision makers, and other respective stakeholders.

Policy and decision makers can implement their proposed ideas using the information by the Comparison of historical and future projection of carbon emission and sequestration. These carbon stock data will provide climate change impacts which are helpful for planning effective and efficient adaptation and mitigation policies and strategies. The local Government can be used this study as a baseline to create awareness for local community how much they contribute to climate change mitigations by developing their sustainable use and management of the forest resources. The research is also important and it will be distributed to different bodies, organizations, decision makers to impalement and to use its result.

1.6 Scope and Limitations of the Study

It was not possible to cover the whole aspects of the study area with the available time and resources. The study focused on estimating of carbon stock potential of Zonba natural forest that is found in South Omo Zone, Debub Ari woreda, Zonba kebele.

2. LITERATURE REVIEW

2.1 Causes and consequences of climate change

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties and that persists for extended periods, typically decades or longer (IPCC, 2007b). Climate change occurs due to natural causes or as result of human activity (IPCC, 2007a). The impacts of climate change may be physical, ecological, social or economic. Indicators of global warming include the instrumental temperature record, rising sea levels, and decreased snow cover in the Northern Hemisphere (IPCC, 2007a). According to IPCC (2007b), most of the observed increased in global average temperatures since the mid 20thcentury is a result of human activities such as fossil fuel burning and deforestation.

The impacts of climate change does distributed across the world in different ways. Some regions and sectors are expected to experience benefits while others will experience costs. With greater levels of warming (greater than 2-3°C by 2100, relative to 1990 temperature levels), it is very likely that benefits will decline and costs increase. This puts low-latitude and less-developed countries at the greatest risk (IPCC, 2007b). Climate change would likely result in reduced diversity of ecosystems and the extinction of many species. In addition to that the climate change would increase the number of people suffering from death, disease and injury from heat waves, floods, storms, fires and droughts. Floods are low-probability, high-impact events that can overwhelm physical infrastructure and human communities. Hot days, hot nights and heat waves have become more frequent. Heat-related morbidity and mortality is projected to increase. The effects of drought on health include deaths, malnutrition, infectious diseases and respiratory diseases. An argument can be made that rising ethnic conflicts may be linked to competition over natural resources that are increasingly scarce as a result of climate change. According to assessment of Smith *et al.* (2001), it was suggested that major environmentally influenced conflicts in Africa have more to do with the relative abundance of resources.

2.2 Forest carbon

2.2.1 The Role of Forest as carbon pool

The global climate change is an extensive and growing concern that has led to general international discussions and negotiations to come up with mitigation strategies to reduce the negative impact of climate change. Responses to these concerns have focused on reducing emissions of greenhouse gases (GHGs) specifically CO2 and on measuring carbon in different carbon pools. One option for slowing the rise of GHG concentrations in the atmosphere and to increase the amount of carbon removed and stored in forests (IPCC, 2007).

Forests play an important role in the global carbon balance. As both carbon sources and sinks, they have the potential to form an important component in efforts to combat global climate change. According to FRA (2010) estimation the world’s forests store 289 Gt of carbon in their biomass alone. Forest ecosystems accumulate carbon through the photosynthetic assimilation of atmospheric CO2 and the subsequent storage in the form of biomass (trunks, branches, foliage, roots, etc.) (Brown et al., 1996; Malhi et al., 2002). It is the largest terrestrial ecosystem comprised 4.1 billiont/ ha (Dixon *et al*., 1994; Brown et al., 2002) and are critical in reducing the rate of CO2 build-up in the atmosphere responsible for climate change (Streck et al 2006). Forests account for 80 %-90 % of the total global carbon reservoir in the living biomass (Dixon et al., 1994), cover 30 %-40 % of the vegetated area of the earth and exchange carbon with the atmosphere through photosynthesis and respiration (Malhi et al., 1999), thus playing an important role in the global carbon cycle. The recent IPCC report estimated that the global forestry sector represents over 50 % of global greenhouse mitigation potential (IPCC, 2007). The Global estimated total carbon stock in forests in 2010 is 652 billion tones, (Africa 98, 242 million tones, Asia 74, 453 million tones, Europe 162, 583 million tones, North and Central America 107, 747 million tones, Oceania 21 692 million tones, South America 187, 654 million tons), which equates to 161.8 tons per hectare. The total carbon stock has decreased during the period 1990–2010, mainly as a result of the loss of forest area during the period (FAO, 2010).

In Ethiopia at the national level, forest inventories, woody biomass assessments, agricultural surveys, land registry information and scientific research can prove useful data for acquisition of forest carbon accounting. More importantly the WBISPP data is relevant source of information for Ethiopian forest carbon accounting. According toWBISPP (2005) the national total carbon stock is 2,763.70 million tons, the largest store of carbon in the country is found in the woodlands 1,263.13, (45.7 %), and shrub lands 951.54 tons (34.4%). High forest 434.19 tons (15.7%), Plantation 61.52tons (2.22 %), Lowland bamboo 50.80 tons (1.8 %), Highland bamboo 2.53 tons (0.091 %).

These national carbon stocks data largely agree with 2.5 billion tons in 2005 as reported by (Sisay *et al.,* 2009) reported a carbon density of 101 tons ha for high forests in Ethiopia. Some studies show even higher carbon density values of close 200 tons ha than the estimates based on WBISPP for high forests in Bale Mountains (Temam, 2010; Tsegaye Tadesse, 2010). However Ethiopia based on biome-averaged values of 153 million tons by Houghton (1999) and 8 67million tons by Gibbs and Brown, (2007) are very low. The discrepancy is due to the different methods and tools applied, regional variability in soil, topography, and forest type and the uncertainties associated with the methods used.

As result forestry became the focus of global climate change policy and is given a key position in international climate treaties. Sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, deforestation; degradation and poor forest management reduce them. As a leading tree based system, especially in the tropics, agro forestry, afforestation and reforestation has been suggested as one of the most appropriate land management systems for mitigating the atmospheric carbon increase (Dixon, 1995; Albrecht and Kandji, 2003; Montagnini and Nair, 2004). The estimation of the total global carbon sequestration potential for afforestation and reforestation activities for the period 1995-2050 was between 1.1-1.6 Gt carbon per year and of which 70% will be in the tropics (IPCC, 2000).

2.2.2 Forest Carbon Accounting

Assessing forest carbon stocks and their changes is still a fledging art (Schoene, 2002). With approximately 50% of dry forest biomass comprised of carbon (Westlake, 1966), biomass assessments also illustrate the amount of carbon that may lost or sequestered under different forest management regimes.

There are five carbon pools of terrestrial ecosystem involving biomass, namely living above-ground biomass (AGB), living belowground biomass (BGB), dead organic matter (DOM) in wood, DOM in litter and soil organic matter (SOM) (Eggleston et al., 2006). Trees often represent the greatest fraction of total biomass of a forested area, with other carbon pools only a fraction of the total tree biomass.

The understory is estimated to be equivalent to 3% of above-ground tree biomass, dead wood 5-40%, and fine litter only 5% of that in the above-ground tree biomass. BGB is more variable, ranging between 4 - 230%, and can be more than two times greater than that in the above-ground tree biomass (Brown, 1997). AGB in trees also responds more rapidly and significantly as a result of land use change than other carbon pools. As a consequence, the majority of carbons accounting efforts are focused on tree AGB, for which there is a considerable forest science research base.

2.2.3. Carbon sequestration potential of forests

Forests can act as sink through the process of trees growth and resultant biological carbon sequestration. Thus, increasing the amount of trees can potentially slow the accumulation of atmospheric carbon (Brown, 2002; Fearnside and Laurance, 2003 and 2004; Houghton, 2005). Due to their growth dynamics trees sequester and store more carbon than any other terrestrial ecosystem and are an important natural ‘brake’ on climate change (IPCC, 2001). According to IPCC (2001), it stores about 80 % of all above-ground and 40 % of all below-ground terrestrial organic carbon. During productive season, carbon dioxide from the atmosphere is taken up by vegetation and stored as plant biomass (Losi *et al.*, 2003; Phat *et al.*, 2004). However, when forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (Malhi and Grace, 2000; Fearnside and Laurance, 2003 and 2004; Houghton 2005).

Tropical deforestation is estimated to emit about 1-2 billion tons of carbon per year during the 1990s, which is roughly equivalent to 15-25 % of annual global greenhouse gas emissions (Malhi and Grace, 2000; Fearnside and Laurance, 2003 and 2004; Houghton 2005). This indicates disturbances in the forest due to natural and human influences lead to more carbon released into the atmosphere than the amount used by vegetation during photosynthesis (Brown, 2002). To combat this circumstances sustainable management strategies are, therefore, necessary to make the forest act as a carbon sink rather than source. Currently, the biosphere constitutes carbon sink that absorbs about 2.3 giga tones of carbon per year, which represents about 30 % of fossil-fuel emissions (IPCC, 2000).

As extensive experimental research has shown; the increasing atmospheric CO_2 concentration stimulates the process of photosynthesis and consequently plant growth. The extent of this stimulation varies according to different estimates, being larger for forest (up to 60 percent) and smaller for pastures and crops (about14 percent). Current scientific evidence suggests that managed and mature old growth forests act as active carbon sinks, sequestering carbon at rates of up to 6 tha^{-1} $year^{-1}$ (for boreal and temperate forests) (Malhi and Grace, 2000; Fearnside and Laurance, 2003 and 2004; Houghton 2005). Accounting and verification of the sequestered carbon is an integral component of a Carbon sequestration project (IPCC, 2000).

2.2.4. Factors affecting forest carbon stocks and sequestration

Carbon sequestration capacity of forests is affected by different natural and anthropogenic factors. Plant tissues vary in their carbon content. Stems and fruits have more carbon per gram than do leaves, because plants generally have some carbon-rich tissues and some carbon-poor tissues, an average concentration of 45-50 % carbon is generally accepted (Chan, 1982). When we evaluate carbon storage capacity, all forests do not act at equal rate. Generally, longer-lived, higher density trees store more carbon than short-lived low density, fast-growing trees (Anderson and Spencer, 1991). According Anderson and Spencer (1991) it does not mean that carbon offsets which involve big, slow-growing trees are necessarily better than those involving plantations of fast-growing trees. What it does mean is that it is important to talk about various offset options with a time scale specified and decide whether the objective is to store carbon, prevent further carbon dioxide emissions or to actively remove carbon dioxide from the atmosphere.

The growth cycle or length of rotation defines for how long carbon will be stored in standing trees. Slow growing trees retain carbon for a long time during one growth cycle, while repeated cycles of fast growing trees are required to maintain levels of stored carbon for an equivalent length of time. For this reason, when planting fast growing trees, it is particularly important to consider the post-harvest management of the forest: whether to replant, manage it for natural regeneration, or to convert the forest land to other uses. The ultimate use of the timber defines for how long carbon remains stored in the form of wood products. Construction materials and furniture potentially retain carbon for a long period. Carbon in paper or fire-wood has the shortest post-harvest lives (Elliot, 1985; Dewar, 1990).

Different systems of tree planting offer different advantages and disadvantages; Fast growing species tend to be planted as mono-specific intensive plantations. Monocultures are a very efficient way of promoting biomass and carbon accumulation, and tend to be easier to manage than multi-species, mixed stands or natural forests. On the other hand, they have several potential disadvantages such as reduction of biodiversity; higher susceptibility to fire, pests and diseases:- high water usage, and increased erosion (Evans, 1992). Conversely, most slow growing hardwood species tend to be planted in mixed stands. This is because most hardwoods are climax vegetation species and often require shading at the early stage of their growth cycle. Therefore, these species are better suited for enrichment planting or planting in the understory of nurse trees of different species (Sawyer, 1993).

Forest growth does not accumulate biomass linearly, despite the assumption of linearity used in many accounting approaches. Young, growing forests accrue carbon more quickly than mature forests, and the use of time-averaged biomass increment does not fully capture this growth over short accounting time scales (Houghton, 2005). Biomass uptake through growth is also dependent on tree species and site conditions, whether trees are planted or naturally regenerating, and the presence, absence and frequency of disturbances (Phillips et al., 1998). Forests may continue to sequester carbon at highly variable rates for centuries without observable changes in the forest area; there is no easy way to assess whether forests are growing or have reached carbon equilibrium. Some evidence suggests that the areas of tropical forest that remain are not in equilibrium and are still acting as a carbon sink. In contrast, replanted forests can actually be net emitters of carbon for up to 20 years after planting where plantation establishment greatly disturbs soils (Phillips et al., 1998, Houghton, 2005).

Furthermore, according to different literature results, it is unclear what will happen under a changing climate and CO_2 concentration. Default growth and biomass accumulation rates are based on past observations and so do not take into account global changes in the future (Bonan, 2008; Jackson et al., 2003). However, Canadell *et al.* (2003) shows that CO_2 fertilization will increase plant growth and carbon uptakes. Nitrogen deposition can also positively interact with CO_2 fertilization effect, for example in areas where forest growth is likely to be limited by lack of nutrient availability such as temperate zones and in areas where N loss is high via leaching such as in the tropics N deposition encourage biomass production in addition climate change will increase the growing season, resulting in increased carbon sequestration but also greater losses of carbon in soils. These indirect impacts need to be factored out when carbon accounting, particularly for project emissions accounting (Canadell *et al.,* 2003).

The carbon pools in forest ecosystems are affected by altitude, slope and land use types (Diawei et al. 2006). Bhat *et al.* (2013) indicated that land use, land use change, soil erosion and deforestation are the most important factors affecting the carbon stock density in the forest ecosystem. According to Feyssa *et al.* (2013), forest carbon is affected by altitude and slope.

Altitude has a significant effect on temperature and precipitation. This strongly affects the species composition, the diversity, the turnover ecosystem (Sheikh and Bussman 2009). Hamere *et al* (2015) assessed the impact of slope in above and below ground biomass, soil organic carbon, and total ecosystem carbon, in which east slope aspect showed the highest, whereas south slope aspect showed the lowest total carbon stock. In the tropics, land use affects the global carbon cycle by increasing the rate of carbon emissions (Silver *et al*. 2000).

2.3 Carbon pools and their estimation method

Carbon pool refers a system which has the capacity to accumulate or release carbon (IPCC 2006).There appears to be some confusion about the terms stocks and sinks: they are not synonymous and should not be used interchangeably. A stock of C in soil and vegetation is the quantity present at a given time. It might be thought of as equivalent to ‘commercial stock-taking’. Such stock-taking is an audit conducted on a particular day to record the quantity of products present at that time; it provides no information on trends, or whether the stock is increasing or decreasing. To obtain this information the audit or stock-taking has to be repeated at a later date and the two results compared. For example, Smith et al. (1997) estimated that the stock of organic C in soils of the EU was 22.95 Pg; this amount was then used as the starting point to estimate the potential for increases through sequestration, but does not in itself provide information on trends.

2.3.1. Above ground biomass Carbon pool and estimation method

Aboveground biomass carbon stock is the carbon in all living biomass above the soil, including stem, stump, branches, bark, seeds, foliage, standing dead trees, down woody debris and litter; (FAO, 2010). According to Ravindranath and Ostwald (2008), the aboveground biomass is the most important and visible carbon pool of the terrestrial forest ecosystem. The dead mass of litter and woody debris are not a major carbon pool as they contribute merely a small fraction to the carbon stocks of forests (IPCC, 2006). 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; Takahashi *et al*., 2010). 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).

Aboveground biomass can be estimated through direct and indirect method. Direct measurement of carbon stock by cutting and weighing the aboveground plant material, acute and weigh approach is considered as the most accurate method for estimation of aboveground biomass and the carbon stocks stored in the forest ecosystems (Ketterings *et al*., 2001; Gibbs et al., 2007).

For aboveground biomass, trees are divided by compartments: leaves, branches and trunks, and measured in dry weight (Beer et al. 1990), because each compartment has unique C content and decomposition rate. Although this is the most accurate method, inventories are often too time-consuming and costly. Alternatively, biomass expansion factors or biomass equations are often used, because they require only stem wood information such as diameter at breast height (DBH). These equations exist for practically all forests types of the world, especially in the temperate zone (Sharrow and Ismail 2004). But, because of the very general nature of these equations, they lack accuracy; they are, at best, approximations. For an agro forestry system, Shroeder (1994) used a ratio of total aboveground biomass to stem wood biomass of 2.15 derived from many previous studies.

Indirect way of estimating the aboveground biomass is non-destructive method achieve through measuring the various parts (Aboal *et al*., 2005) or by simply measuring the diameter at breast height, height of the tree, volume of the tree and wood density (Ravindranath and Ostwald, 2008) and calculate the biomass using allometric equations (Brown,1997). Since these methods do not involve felling of tree species, it is not easy to confirm the reliability of this method.

2.3.2. Below ground carbon pool and estimation method

Belowground biomass carbon stock is the carbon pool in live root biomass and soil. The belowground biomass that comprises the entire live roots (IPCC, 2006) plays an important role in the carbon cycle by transferring and storing carbon in the soil (Vashum and Jayakumar, 2012). Roots are an important part of the carbon balance, because they transfer large amounts of carbon into the soil. More than half of the carbon assimilated by the plant is eventually transported below-ground via root growth and turnover, root exudates (of organic substances) and litter deposition. Depending on rooting depth, a considerable amount of carbon is stored below the plow layer and better protected from disturbances, which leads to longer residence times in the soil. With some trees having rooting depths of greater than 60cm, root carbon inputs can be substantial, although the amount declines sharply with soil depth (Cairns et al., 1997).

Roots make a significant contribution to SOC (Strand et al., 2008). About 50% of the carbon fixed in photosynthesis is transported belowground and partitioned among root growth, rhizosphere respiration, and assimilation to soil organic matter (Lynch and Whipps, 1990; Nguyen, 2003). Roots help in accumulation of SOC by their decomposition and supply carbon to soil through the process known as rhizoid position increased production and turnover rates of roots lead to increased SOC accumulation following root decomposition (Matamala *et al*., 2003).

Belowground biomass carbon of live roots includes fine roots of greater than 2 mm diameter (Snowdon *et al.,* 2002; IPCC, 2006; Picard *et al.,* 2012). As compared to aboveground biomass estimation, measurement of belowground biomass is more time consuming and expensive, as a result of the variability in the way that roots are distributed in the soil (Macdicken, 1997). Thus, estimation of belowground biomass carbon is more efficient by using a root to shoot ratio which predict root biomass carbon based on aboveground biomass carbon. According to Macdicken (1997), locally established method is more accurate to estimate BGB and carbon.

2.3.3. Soils organic Carbon and estimation method

Soils organic carbon is thought to be the largest component of the global carbon cycle, holding more than the atmosphere and vegetation combined (Lal, 2004). Soil carbon is found in mineral and organic soils to a specified depth chosen (FAO, 2010). Soil carbon content is the result of the net balance between carbon inputs and outputs (Vashum and Jayakumar, 2012). These biological activities depend on primary production and organic matter decomposition. Both production and decomposition are strongly regulated by climate and soil variables such as texture, nutrients and water availability, which in turn determine the organic matter fluctuation into the soil, its quality and its decomposition rates (Miller et al., 2004; Leifeld and Fuhrer, 2005). The amount of carbon present in soil depends on the rate of decomposition by microorganisms, the rate of organic matter input from plant residues, soil properties and climatic region (Grandy and Robertson, 2007; Harris et al., 2015).

Soils are the largest carbon reservoirs of the terrestrial carbon cycle, 1500–1550 Gt, of organic soil carbon and soil inorganic carbon approximately 750 Gt both to 1 m depth. About three times more carbon is contained in soils than in the global vegetation (560 Gt) and soils hold double the amount of carbon that is present in the atmosphere (720 Gt) (Post *et al*., 2001; Lal, 2004). Soils play a key role in the global carbon budget and greenhouse gas effect. Soils contain 3.5% of the earth's carbon reserves, compared with 1.7% in the atmosphere, 8.9% in fossil fuels, 1.0% in biota and 84.9% in the oceans (Lal, 2004),or according to Jastrow, 2002; Baker, 2007 about 75% of the total terrestrial carbon is stored in the global soils.

To obtain an accurate estimation of organic carbon stocks in organic soil, the types of variables should be considered: Depth, Bulk density, which is calculated from the oven-dried weight of soil from a known volume of sampled material and the concentrations of organic carbon within the sample must be measured (Pearson et al ., 2007). The default for soil depth is 30cm (IPCC, 2006).Soil C samples should be collected from each layer, dry-weighed and analyzed for its C content by recommended laboratory procedures. To calculate C stocks per unit area, the Content in the soil is multiplied by the bulk density of the respective soil layer.

2.3.4. Humus and litter carbon (DOM) and estimation method

The DOM litter carbon pool includes all non-living biomass with a size greater than the limit for soil organic matter (SOM), commonly 2mm, and smaller than that of DOM wood, 10cm diameter. This pool comprises biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM. Local estimation of the DOM litter pool again relies on the establishment of the wet-to-dry mass ratio. Where this is not possible default values are available by forest type and climate regime from IPCC ranging from 2.1 tons of carbon per hectare in tropical forests to 39 tons of carbon per hectare in moist boreal broadleaf forest (IPCC, 2006).

The litter pool includes dead organic surface materials less than10cm diameter. It often considered an insignificant source in REDD+ projects, and inclusion of the litter pool as part of the project boundary is optional, as per applicability criteria in the frame work module REDD-MF. The litter sample will be collected inside the same frames as the above ground non-woody vegetation.

2.3.5. Dead Wood Biomass carbon (DWB) and estimation method

All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country (Schoene, 2002). This carbon pool can contain 10-20% of that in the AGB pool in mature forest (Delaney et al., 1998). However, in immature forests and plantations both standing and fallen dead wood are likely to be insignificant in the first 30-60 years of establishment. The primary method for assessing the carbon stock in the DOM wood pool is to sample and assess the wet-to-dry weight ratio, with large pieces of DOM 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 (less 20 %) and leaves (less 2-3 %) (MacDicken, 1997). Methods to establish the ratio of living to dead biomass are under investigation, but data is limited on the decline of wood density as a result of decay (Brown, 2002).

3. MATERIALS AND METHODs

3.1 Description of Study site

Debub Ari wereda is one of the eight weredas in South Omo Zone, which is found in the Southern Nations, Nationalities and Peoples' Region of Ethiopia. Its geographical locations are 5^0.67'-6^0.19' N & 36^0.30'-36^0.73'E. Being a part of the South Omo Zone, Debub Ari is bordered on the South by Jinka city, on the west by SalmagoWereda, on the North by Semen Ari Wereda and on the East by Malle Wereda. Gazer is the capital of the Wereda which is 17 km from Zonal capital Jinka. The total area of the Wereda is 1492.65sq/km^2 (Bizuayehu Ayele et.al, 2016).

Based on projections of the 2007 census conducted by CSA the Wereda has a total population of 234,659 of whom 2.08 % of its population are urban dwellers. The majority of the inhabitants practiced traditional beliefs, with 68.84% of the population reporting the belief, 19.01 % were protestant and 3.89 % practiced Ethiopian Orthodox Christianity. (CSA, 2007)

The altitude of the wereda ranges between 1200-3418 m.a.s.l. There are three major agro ecologies namely kola10 % woynadega70 % and Dega20 % are found in the woreda. The mean annual RF is 800-1200mm and the mean annual temperature ranges between10.1-27.5^{0c} **(**Bizuayehu Ayele et.al, 2016). The wereda has 41 rural and 5 urban kebeles.

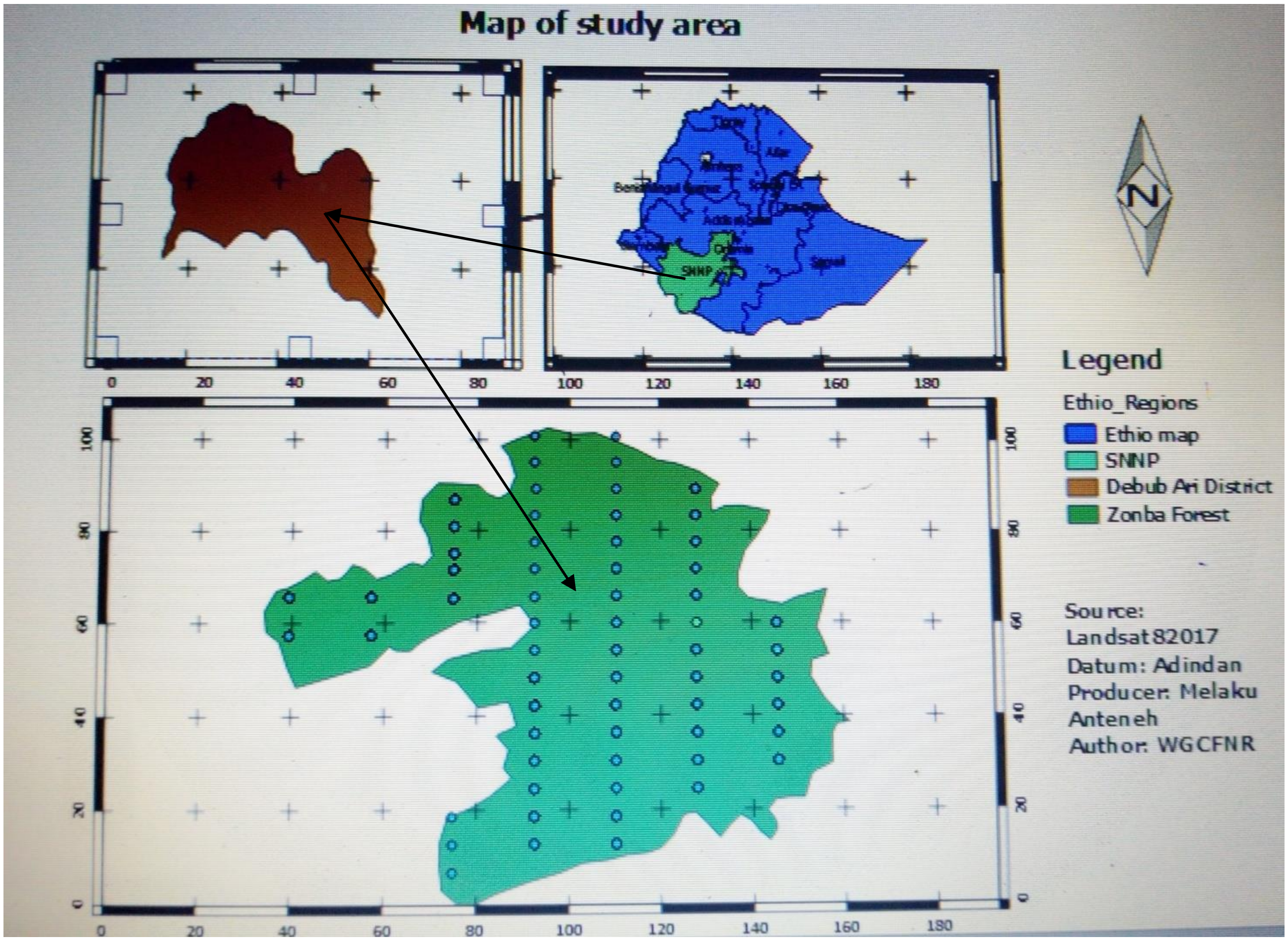

Figure 1: Location map of the study area

3.2 Field Data Collection

Reconnaissance survey was carried out across the forest in order to obtain an impression in site conditions and physiognomy of the vegetation. GPS tracking were used for boundary delineation. Then stratification was done based on altitudinal variation to obtain homogenous units, this increase the precision of measuring and estimating carbon stock. At the end, the study site classify into two stratums: Lower altitude （1800-2107m.a.s.l） and higher altitude (2108-2415m.a.s.l). The cutting point to determine the only two strata were the altitude and topographical and plant distribution or density difference of the site. In this study, transect approach was applied for tree sampling and measurement. Sampling sites from the forest were arranged by eight line transects at an interval from the bottom to the top of the forest. A plot of 20m x 20m (400m2) was systematically set 100 meter gap within transect and 300m gap between transect were systematically recorded. The appropriate alignment of transects were done using GPS and compass. The total numbers of sample plots in study site were 62 while, 31 in each stratum were located depending on their altitude. Trees above and equal to 5 cm in DBH within sample plots were measured by using caliper and diameter tape. Five smaller sub plot of 1 square meter in size were established at the center and at corner of each plot to collect leaf litter and soil (Brown, 1997; Hairiah *et al.,* 2001). Together with field tree vegetation measurement the location of each plot including altitude was recorded by GPS. In order to identify measured tree species; a complete list of trees in each plot was done. In order to eliminate any influence of the road effects on the forest biomass, all the quadrates were laid at 50m away from nearest roads. DBH and H class will develop with appropriate range to determine the dominant class and also the status of forest. Primary data were obtained through field measurements in the study area.

3.2.1. Biomass data collection

To reveal below and above ground biomass, all tree species with DBH ≥ 5 cm were measured in each quadrant using Caliper and Diameter Tape. In addition, the total tree height (to the top of the crown) was measured using Hypsometer (Brown, 2002; Pearson *et al.,* 2007).Each tree was recorded individually, together with its species name and ID. Trees/Shrubs with multiple stems below 1.3 m height were treated as a different individual and the diameter was measured separately for each stem and for buttressed trees, DBH measurement was undertaken from the point just above the buttresses. Trees with multiple stems above 1.3 m height were also treated as one individual and measure the DBH once (Kent and Coker, 1992). Local names of trees were recorded and later scientific names identified from Natural data base for Africa developed by Ermias Dagne, (2011) and Useful trees and shrubs for Ethiopia Azene Bekele, (2007).

The allometric equations developed by Chave et al, (2014) overcome the limitations of the models developed by Chave et al. (2005). The most important predictive variables for forest biomass estimations were DBH, H, basic wood density (ρ), and forest type. So in this study, allometric equation developed by Chave *et al.,* (2014) was used to estimate AGB. Ethiopia was also used this equation for employed Ethiopians forest reference level to summit UNFCCC on 2016.The inclusion of country-specific wood density in the equation significantly improves biomass estimation (Chave et *al.,* 2014). For this reason, the following parameters were needed to express aboveground biomass in carbon stock: diameter at breast height (DBH), tree height, a wood density factor. While DBH and height parameters were measured directly in the field, wood densities of species were obtained from Basic wood density of indigenous and exotic tree species in Ethiopia and other studies and databases (FREEL;2017).

3.2.2. Forest floor and litter sampling

Fresh litter samples were collected and weighted in a 1 x 1 m square sub-quadrant within each quadrant. A total of five sub-quadrants (four at corners and one in the center) were established used for litter collection; and from which, the collected total average sample was weighted. The100g subsample fresh weights were sampled from the five sub-samples collected from each quadrate which was mixed homogeneously and placed in a plastic bag to take it to the laboratory (Pearson *et al.,* 2005).

3.2.3. Mineral Soil data collection

For the purpose of soil sampling, a total of five sub-quadrates with the area of 1 m X 1 m were laid within every three main quadrant in a way those four sub-quadrants at the corner and one at the center. For the determination of soil carbon, 22 samples (11 for each two stratum) were collected from four corners and at the center of every three quadrant to a depth of 40 cm within each quadrant by pressing an auger to a depth of 0-20 cm and 20- 40 cm, and the five soil samples of each layer were composited for both strata (lower and upper altitude) (Roshetko *et al.*, 2002; Takimoto *et al.*, 2008). Five equal weights of each layer soil samples were taken and mixed homogeneously while a 100 g composite sample was taken from each sample layers and quadrant for the determination of organic carbon in the laboratory using Walkley *et al.*, (1934) method. The soil samples were air-dried, well mixed and sieved through a 2mm mesh size sieve for soil carbon analysis following the right technique (Walkley *et al.*, 1934). In addition, from the same quadrates only one pit was selected by lottery method and soil samples for soil bulk density determination were collected from the surface soil (from 0-20 cm and 20-40 cm depths) using 10cm length and 3.5 cm diameter core sampler carefully driven into the soil to avoid compaction (Roshetko *et al.*,2002).

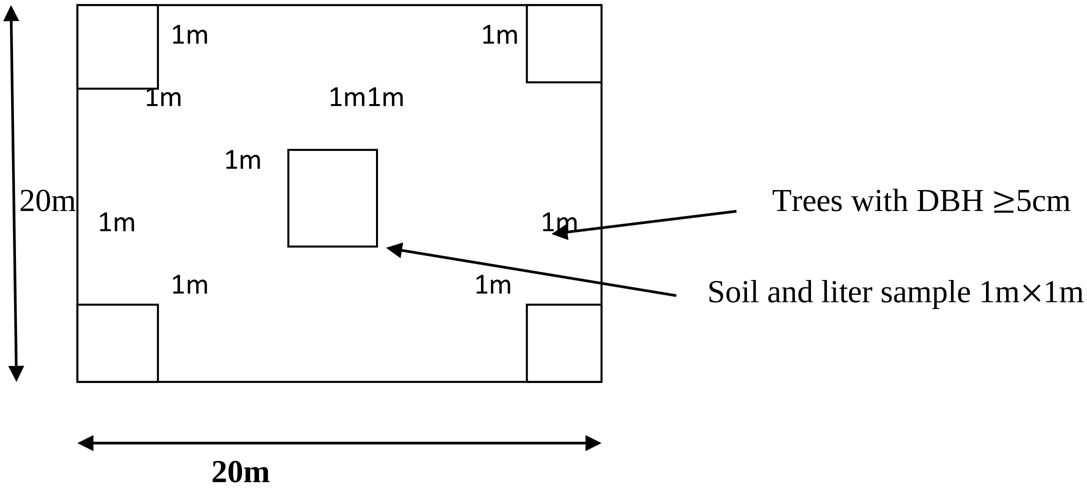

Figure 2: The 20 × 20m ($\mathbf{400m^2}$)quadrate design

3.3. Data Analysis

After the data collection was completed, data analysis of various carbon pools measured in the forests were accomplished by organizing and recording on the excel data sheet. The data obtained from DBH, diameter, height of each tree species, field weight (Ww), fresh weight-(FW) and dry weight (Wdry) of litter and soil were organized by excel 2007 and analyzed using MINITAB software version 17. DBH data was arranged in classes ≤15, >15-30, >30-45, >45-60, >60-75, >75-90, >90-105 and >105 and height class ≤ 10m, >10-20m, >20-30m, >30m to determine the dominant DBH and height class of the tree and also the status of the forest. The relationship between each parameter was tested by Microsoft Excel 2010, One Way ANOVA, and descriptive statistics. Differences at the 95 % (α=0.05) confidence interval was used to see the significance differences.

3.3.1. Above and below ground biomass carbon estimation

In this study, allometric equation given by Chave *et al.*, (2014) was used to estimate AGB.

$$\boldsymbol{AGB = 0.0673 * (\rho * DBH^2 * H)^{0.976}} \qquad (1)$$

Where: AGB = above ground biomass (in kg dry matter), ρ = wood density (g/cm3)

DBH = diameter at breast height (in cm), H = total height of the tree (in m).

Aboveground carbon stock of each tree biomass conversion to carbon, the stock based on (Clark and Kellner, 2012; Basuki et al., 2009; Gibbs et al., 2007; Pearson et al., 2005 and Hairiah et al., 2001).

$$AGCS = AGB * 0.5 \qquad (2)$$

Where, AGCS = Above Ground Carbon Stock, AGB = Above Ground Biomass (kg/tree)

For the estimation of below ground biomass for every tree, the recommended root-to-shoot ratio value of 1: 0.26 was used (IPCC, 2006).

$$\boldsymbol{BGB = AGB * 0.26} \qquad (3)$$

Where, AGB = Above Ground Biomass (kg/tree), BGB = belowground biomass, 0.24 is conversion factor (or 24% of AGB).

3.3.2. Litter biomass carbon estimation

The collected litter samples were oven dried at 105^0C for 48 h using dry ashing method (Allen *et al.,* 1986). Oven-dried samples were taken in pre-weighed crucibles. Then the samples were ignited at 550^0C for one hour in the muffle furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated. The amount of biomass estimation in the leaf litter was calculated as recommended by (Pearson *et al.*, 2005).

$$LB = \frac{Wfield}{A} * \frac{Wsub\text{−}sample(dry)}{Wsub\text{−}sample(fresh)} * \frac{1}{10000} \qquad (4)$$

Where, LB = Litter (biomass of litter t/ha), W field = Weight of wet field sample of litter sampled within an area of Size 1m^2 (g), A= size of the area in which litter was collected (ha), W sub-sample, dry = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and W sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

The percentage of organic carbon storage from the dry ashing in the litter carbon pool was calculated as follows (Allen *et al.*, 1986)

$$\%\text{Ash} = \frac{wc-wa}{wb-wa} * 100 \qquad (5)$$

$$\%C = (100 - Ash\%) * 0.58 \qquad (6)$$

This is by considering 58% carbons in ash-free soil material.

Where, C = organic carbon (%), Wa = the weight of the crucible (g), Wb = the weight of oven dried grind samples and crucibles (g), Wc = the weight of ash and crucibles (g). Finally, carbon in litter t/ha for each sample was determined.

$$\boldsymbol{CL = LB * \%\, C} \qquad (7)$$

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

3.3.3. Soil carbon estimation

The carbon stock density of soil organic was calculated as recommended by Pearson *et al* (2005) from the volume and bulk density of the soil and soil carbon content was calculated via air drying and then baking at 900 °C using an NC-Analyzer Model Sumigraph-NC 90A (Vagen *et al.*, 2013).

$$\boldsymbol{V = hX\pi r^2} \qquad (8)$$

Where V is a volume of the soil in the core sampler augur in cm3, h is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm (Pearson *et al.*, 2005). Moreover, the bulk density of a soil sample can be calculated as follows:

$$\boldsymbol{BD = \frac{Wav,dry}{V}} \qquad (9)$$

Where, BD is the bulk density of the soil sample, Wav, dry is an average air-dry weight of soil sample per quadrant, V is a volume of the soil sample in the core sampler auger in cm3 (Pearson *et al.*, 2005). Then, the soil organic carbon stock pool was calculated using the formula (Pearson *et al.*, 2005):

$$SOC = BD * \mathrm{D} * \%C \qquad (10)$$

Where, SOC= soil organic carbon stock per unit area (t/ha), BD = soil bulk density (g/cm3), D = the total depth at which the sample will be taken (0-20 cm and 21-40 cm), and % C = Carbon concentration (%) determined in the laboratory.

3.3.4. Total ecosystem carbon stock estimation

Finally, the total carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of the stratum using the (Pearson, *et al.*, 2005) formula.

$$\boldsymbol{Cdensity = AGBC + BGBC + LC + SOC} \qquad (11)$$

Where: C density = Carbon stock density for all pools [t/ha], C AGTB = Carbon in above - ground tree biomass (t C/ha), C BGB = Carbon in below-ground biomass (t C/ha), C Lit = Carbon in dead litter (t C/ha), SOC = Soil organic carbon, the total carbon stock is then converted to tons of CO2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al.*,2007).

4. RESULTS

4.1 DBH and height distribution of plant species in Zonba forest

The tree species with highest percentile of their distribution were trees with DBH class >15cm-30cm (45.2%) that followed by DBH class 30cm-45cm (25.66%), DBH class ≤15 cm (15.73%), DBH class 45cm-60cm (6.788%), DBH class 60cm-75cm (2.483%), DBH class 75-90 (1.656%), DBH class 90-105cm (1.82%) and the least DBH class were tree species with DBH class ≥105cm(0.66%) were distributed (Figure 3).The number of tree that distributed in DBH class was not the only factor to the carbon stock potential but also the size of DBH and wood density were main factors. That large numbers of individuals are distributed in the lower and middle DBH classes which later decreases in the successive upper classes but because of other factors, carbon stock not showed consistent trend with distribution. From the eight category of plant DBH class, 15-30cm has the highest density with 273 plants; While DBH class >105cm was the least in number contains 4 plants only.

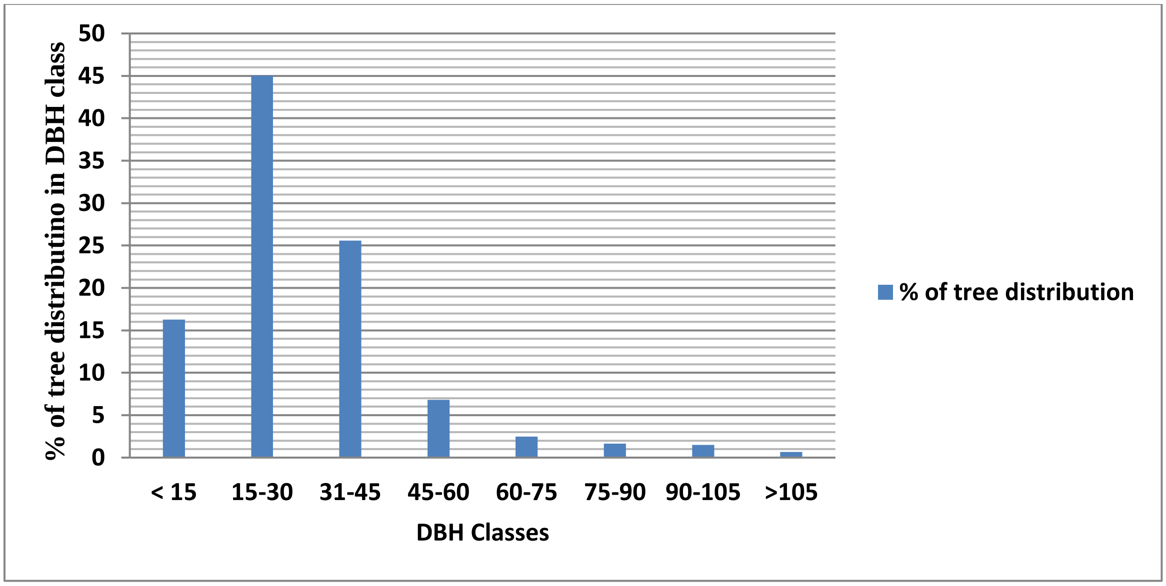

Figure 3: *Percent of trees distribution in DBH classes*

The vegetation structure result showed that the majority of trees were found in middle DBH class. This pattern gradually showed a decreasing trend in higher DBH and Height classes. This kind of distribution indicates that the forest vegetation has a good reproduction and recruitment potential.

In this study, the highest number of species (above half) recorded was in height class 11-20m (54.651%). This was followed by class with middle height 21-30m (33.555%), ≤10m (10.133%)and lower height class (1.66%)(Figure 4). The DBH and height of trees in Zonba natural forest shows the same pattern.

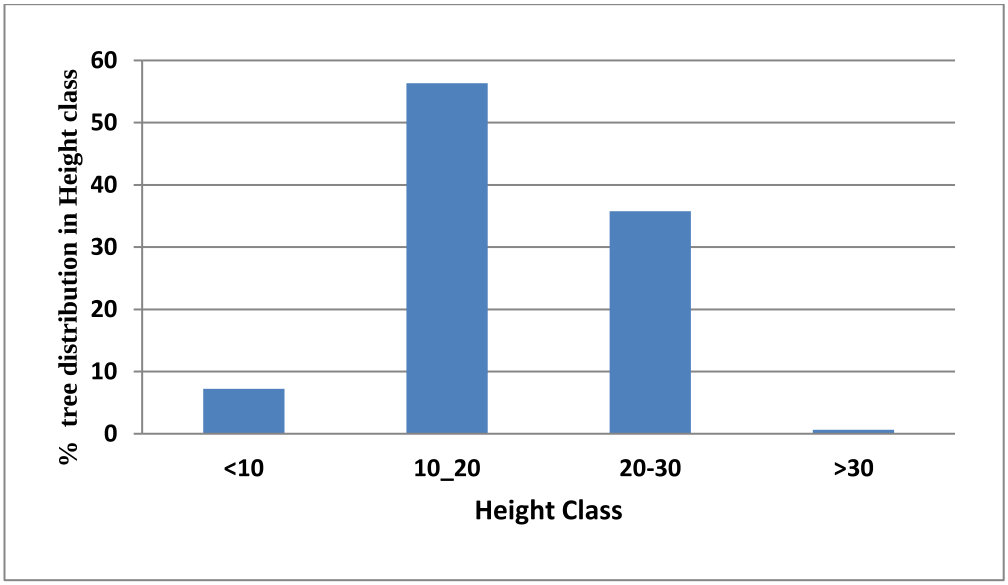

Figure 4: *Percent of trees distribution in Height classes*

4.2 Carbon Stock in the Different Carbon Pools

The carbon stock value of the study site in different carbon pools showed different storage of carbon. The mean aboveground carbon stock in the study site was 155.83t ha-1, while the mean below ground carbon stock of the study site was 37.01ha-1. The mean total carbon stock in litter biomass of the study site was 5.157t ha-1, whereas the mean soil carbon stock of the study site was 66.608 ha-1/ha in the 0 - ≤ 20 cm depth and 48.369t/ha in the >20-40 cm depth (total 114.977t ha-1). In other words, about 49.79 % of the biomass carbon was contained in above ground, while below ground biomass comprised 11. 8 % of the total biomass carbon. It was found that about 1.65 % of the biomass was contained in the litter, whereas 21.28 and 15.456 % were contained in the soil at the depth of 0-20 and 21-40 cm, respectively. The mean carbon potential in all ecosystem level of the study site was 312.96 t ha-1 (Table 1).

Table 1: *Summery mean of carbon density (t/ha) and distribution of each pools (%) in the study site*

	AGC **(t ha-1)**	BGC **(t ha-1)**	SOC **(t ha-1)**	LC **(t ha-1)**	TC**(tha-1)**
Mean C. t/ha	155.83±101.4	37.01±26.11	114.977±10.54	5.157±0.88	312.96±84.33
Percentage	49.79	11.8	36.74	1.65	100

AGC denotes above-ground carbon stock; BGC-below-ground carbon stock; LC-Litter carbon stock; SOC-Soil organic carbon.

4.3 Carbon Stocks of Different Pools along Altitudinal Variation

The presence of variation in altitudinal gradient affects the carbon stock of different pools in the forest. The lower part of altitude is high in aboveground, below ground, soil organic carbon and litter carbon stocks while the upper parts of altitude have low in all carbon stock pools.173.35 t ha-1 and 138.31 t ha-1 above ground carbon stocks were recorded at the lower and upper altitude, respectively. Similar trend was shown in below ground biomass in which 41.6 and 32.42 t ha-1 carbon stocks were recorded in the lower and upper altitude, respectively with the highest value found at the lower part of altitudinal classes followed by the upper parts since it was obtained from the above ground carbon pool. Similarly 5.29t ha-1 in lower and 5.02 t ha-1 of carbon in upper altitude were recorded in litter pool. The carbon stock in the soil pool was higher in lower altitude and lower in the upper altitude. 69.852 and 63.364 t ha-1 stocks of carbon were recorded in the lower and upper altitude, respectively in the soil pool (0-20 cm depth) and 53.189 and 43.5495 t ha-1 stocks of carbon were recorded in the lower and upper altitude, respectively in the soil pool (21-40 cm depth) of Zonba natural Forest. But there was not very much significant different at 95 % confidence interval (F =2.14, P = 0.126) in AGC, (F = 2.14, P = 0.126) in BGC and (F-value = 1.42, p-value = 0.238) in LC. In contrast to litter, above and below ground carbon, the only pool that showed significant difference was SOC stocks (F-value = 6.74, P-value = 0.013) (Table 3).

The total carbon stocks density t/ha of each carbon pools (above and below ground, litter and soil carbon) in different altitude classes of the study area were varied with the altitude classes. As it is indicated by table 2, the lower part of the altitude contains more carbon stock (343.255 t ha-1) followed by the upper (282.66 t ha-1).

Table 2: ***Mean carbon stock (t/ha) and significant value in different forest carbon pools along altitudinal range***

Altitude Class	Altitude range	AGC (t ha-1)	BGC (t ha-1)	SOC (t ha-1)	LC (t ha-1)
Upper	(2108-2415)	138.31±82.8	32.42±19.88	106.913±7.78	5.024±0.844
Lower	(1800-2107)	173.35± 115.1	41.6±27.61	123.041±5.43	5.291±0.918
P-value		0.126	0.126	**0.013**	0.238
F-value		2.14	2.14	6.74	1.42

Bold value is statistically significant at p< 0.05 levels

5. DISCUSSION

5.1 Carbon Stock in the Different Carbon Pools

The present carbon stock study is the first of its kind for Zonba forest and covered an estimate of the biomass and carbon density in forest ecosystem components and the variation of carbon stock along environmental gradients in each carbon pool was done. This is helpful for providing relevant information and understanding the patterns of carbon stock along environmental gradients of a representative tropical dry Afromontane forests. While comparing with other studies, the mean carbon stock in above and belowground biomass of Zonba forest was lower than ArbaMinch Ground Water Forest, Belay Melese et al, (2014) and Tara Gedam Forest, Mohammed Gedefaw et al., (2014). The study results in a different forest and different tree species in Ethiopia showed as an age of tree increase, DBH, basal area, and biomass also increase (Nagash Mamo, 2007; Nagash Mamo et al., 1995). However, its mean carbon stock was higher than those reported from MenagashaSuba State Forest (Mesfin *et al*., 2011) and selected church forests in Addis Ababa (Tura *et al*., 2013) (Table 5). All the above varation may be due to difference in allometric equations used for biomass estimation, anthropogenic disturbance and other complex ecological factors. As stated by Yitebitu Moges et al. (2010), the different types of models used for biomass estimation have impact on the value of carbon estimated in a given forest.

Generally, the mean aboveground carbon values recorded in the study sites were above two-fold the values recommended by IPCC (1997) for tropical dry forest 65.00 t/ha. According to different literature, global above ground carbon in tropical dry and wet forests are ranged between 13.5 - 122.85 t ha-1 and 95 - 527.85 t ha-1, respectively (Murphy and Lugo, 1986). Above ground carbon in Amazonian Brazil forests ranged between 145- 247.5 t ha-1 (Eshetu, 2013). Thus, the above ground carbon reported in the present study was found within the range recommended for various tropical dry and wet forests.

Moreover, the average aboveground carbon in the studied forest sites with the value of 155.83 t ha-1 were three-fold higher than the previous estimates with the value of 50.5 t ha-1of plant biomass carbon stock for forests of Ethiopia Brown, (1997). On the other hand, above ground carbon in tropical and subtropical forests in Puerto Rico ranged between 40-95 t/ha (Weaver and Murphy 1990) and due to this, the result of the study site had almost a positive carbon stock potential and this indicates the forest status was moderately managed and protected by local society even if some human interference could be disturbed there.

Soil organic carbon of the forest depends on not only soil bulk density but also again highly depends on the moisture, decomposition of litter carbon, climatic zone, temperature, slope, altitude, aspect and the nature of soil (Kidanemariam Kassahun, 2014). Accordingly, the higher mean SOC stock is may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock (Sheikh *et al*, 2009).

Overall, the present result revealed that the study forest had good carbon stock and thus sequestered the high amount of CO2 contributing to the mitigation of global climate change.

Table 3: Comparison of carbon stocks (t/ha) of the present study with other studies

Study sites	AGC t/ha	BGC t/ha	SOC t/ha	LC t/ha	TBC t/ha
Zonba natural forest(present study)	155.83	40.516	114.977	5.157	**312.96**
MenageshaSuba stet forest(Mesfin*et al*., 2011)	153.33	26.99	121.28	5.26	**306.86**
Church forest(Tura *et al*.,2013)	122.85	25.97	135.94	4.95	**289.71**
ArbaMinch ground water forest (Chave*et al*.,2014)	414.7	83.48	82.8	1.28	**582.26**
Tara Gedam forest (Mohammed *et al*., 2014)	306.36	61.52	274.32	0.9	**643.1**
WeiraAmba forest(Zelalem*et al*., 2018)	152.33	41.13	129.11	1.3	**323.87**

5.2 Variation of Carbon Stock along Altitudinal Gradient

Altitude is recognized to have a major effect on the biomass and carbon stock in the forest ecosystems (Alves et al., 2010). In the present study area, the lower altitude showed an increasing carbon stock potential followed by the bottom (lower) altitude and decreased when we go to up or top of the mountain though there were no statistical significant variation of carbon stock in above, belowground and litter carbon pools along an altitudinal gradient. This condition suggests that the upper parts of the forest have somehow scattered type of plant arrangement and displayed lack of large trees DBH and H as compared with the lower altitude. In this study due to topographical difference between altitudinal based strata, happening of scroll down of the litter and soil by different agents from upper to lower altitude were expected; while suitable environmental condition were there and most species of plants habit in the lower part result in high biomass and carbon stock values.

The presence of species characterized by large individuals occurring on lower altitude could have an effect on AGB and carbon stock because of few large individuals can account for a large proportion of the quadrants above and below ground carbon (Brown and Lugo., 1992). This could perhaps be the case in the present study area, whereas bigger trees with maximum DBH were more common in lower altitude areas. It might be also due to the topographical nature where the plants those located on the upper altitude had comparatively less distribution, small diameter and height with their less carbon stocks. Similar trend to the present site, there were similar results reported on other studies in Ethiopia of Banja Forest (Fentahun Abere et al., 2017; Ades Forest "un-published"; Kidanemariam Kassahun., 2014; Church forest Tura *et al*., 2013; Menagesha Suba stet forest Mesfin *et al*., 2011 and WeiraAmba forest Zelalem *et al*., 2018), While it showed dissimilarity with the study of Tara Gedam forest, (Mohammed *et al*., 2014) and Arba Minch Ground Water Forest (Belay Melese et al., 2014).

Generally, though there were no significant difference in AGC along altitudinal gradient, some figural variation were observed (F-value = 2.14, P-value = 0.126)

Unlike the other carbon pools, the mean carbon density in litter pool of the present study not showed big difference pattern with altitude. It had shown relatively balanced carbon stock potential trend in both lower (5.291 t ha-1) and upper altitude (5.024 t ha-1). It may be happened due to the presence of compromising between natural and anthropogenic factors. It mean that in the present study site this condition suggested that even though at the hilly area were somehow scattered tree distribution and free litter fallen in the upper altitude, it may be mobilized easily from higher to lower parts due to the sloppiness of the stratum of the upper altitude. Also statistically no significant variation carbon stock in litter pool along altitudinal gradient (F-value = 1.42, 0.238).

Although in many studies was reported that as altitude increase SOC and LB carbon increases (Tsui *et al.,* 2004; *Griffiths et al.,* 2009; Chang *et* al., 2010). In present study was observed that SOC and litter biomass means decreases as altitude increases.

It may be due to the soil moisture in the lower altitude of the study site were protected from direct solar radiation with closed canopy of the vegetation and also secured from high evaporation of the soil moisture that locating in river valley, it was richer than the upper altitude in soil organic carbon . This result was consistent with Mwakisunga and Majule., (2012); Sheikh and Bussmann., (2009) and Sheikh and Kumar., (2012).

The overall trend of total means carbon stock of the forest show similar pattern with AGB and BGB carbon. This might be due to the fact that total carbon density mostly depending on aboveground biomass carbon pool.

6. CONCLUSION AND RECOMMENDATION

Carbon stock study of forests is crucial to show forest potential and role to mitigate climate change risk. Forests have a capability to store substantial amount of carbon within their biomass and soil. In this study, the lower parts of altitude were high in above ground, below ground, soil and litter carbon stocks while the upper parts of altitude had low carbon stock in both carbon pools due to the fact that comparatively there was vegetation with good DBH and height classes, distribution and recorded good performance of SOC stock in the lower altitudinal range. But aboveground, below round and litter carbon pools density showed insignificant variation, whereas Soil carbon pool was significantly different along altitudinal gradients.

Overall, the present study result revealed that these different ecosystem components of carbon stocks showed the same patterns altitudinal gradient.

In the ecosystem level, the average carbon stocks in the study site were good and the result is comparable to some study results of forests in Ethiopia and other tropical countries. This indicates that, the contribution of the forest for carbon sequestration and to enhance mitigation of climate changes.

Zonba forest was found to be moderate amount of carbon reservoir potential compared to similar areas in the country and the continent. The forest has remarkable capacity to store carbon. A contribution for the provision of a carbon sequestration potential of 1147.52CO_2 equivalents could be significantly appreciable contribution to the global climate change mitigation efforts. Hence, the contribution of the traditional ecosystem protection knowledge that made carbon stocking possible should be recognized and valorized. Even though it has a potential to mitigate CO2 concentration in the atmosphere besides of its direct economical use for the livelihood of the local people, it faces some challenges from the local people. There were a number of observations understood during data collection in the field. For instance agricultural expansion, cutting of trees for fire wood and free animal grazing are observed challenges.

Then, the government and other stockholders should be enhancing the awareness of the local community on sustainable utilization and management of forest to increase the carbon stock potential of the site.

Finally, to have more compressive information, farther studies on which focus on supplementary to carbon stock of the forest ecosystem should be needed.

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8. Appendix

APPENDIX 1: AVERAGE DBH AND H OF TREE SPECIES WITH CARBON STOCK OF ZONBA FOREST

Average DBH and H of tree species with carbon stock in LOWER ALTITUDE (1806-2107m.a.sl)

Scientific Name	tree density	Average DBH (cm)	Average height (m)	WD	AVE.AGB kg/tree	AVE.AGC kg/tree	AVE. AGC t/tree	AGC of spps.t/ha
Albiza schimperiana	36	28.208	14.000	0.550	412.345	206.172	0.206	7.422
Celtis africana	2	42.500	22.500	0.760	2078.687	1039.343	1.039	20.787
Combretu mmolle	8	25.000	13.000	0.482	263.564	131.782	0.132	1.054
Cordia africana	7	38.000	20.700	0.482	969.616	484.808	0.485	3.394
Croton macrostachyus	71	20.654	16.345	0.518	243.062	121.531	0.122	8.629
Ertythrina abissinica	8	16.188	11.688	0.426	87.802	43.901	0.044	0.351
Ficus sur	15	71.000	22.700	0.441	3396.223	1698.112	1.698	25.472
Hagenia abissinica	5	16.500	13.600	0.560	139.544	69.772	0.070	0.349
Millettia ferruginea	33	13.818	11.863	0.738	112.504	56.252	0.056	1.856
Podocarpus falcatus	4	64.250	27.375	0.523	3977.564	1988.782	1.989	7.955
Prunus africana	26	32.481	19.212	0.850	1159.469	579.735	0.580	15.073
Strichnos spinosa	93	42.000	21.328	0.712	1802.784	901.392	0.901	83.829
TOTAL	326				14643.163	7321.582	7.322	176.171

Average DBH and H of tree species with carbon stock in upper ALTITUDE (2108-2415 m.a.s.l)

Scientific Name	tree density	Average DBH (cm)	Average height (m)	WD	AVE.AGB kg/tree	AVE.AGC kg/tree	AVE.AGC t/tree	AGC of spps.t/ha
Albiza schimperiana	49	29.000	17.600	0.550	547.881	273.941	0.274	13.423
Celtis africana	24	36.000	19.000	0.760	1259.468	629.734	0.630	15.114
Combretu mmolle	27	41.000	20.500	0.482	1117.850	558.925	0.559	15.091
Cordia africana	28	31.000	17.700	0.518	592.982	296.491	0.296	8.302
Croton macrostachyus	22	20.273	14.000	0.426	164.959	82.480	0.082	1.815
Ertythrina abissinica	5	33.000	17.500	0.560	718.239	359.120	0.359	1.796
Ficus sur	7	14.214	10.429	0.738	104.652	52.326	0.052	0.366
Hagenia abissinica	15	25.467	16.133	0.523	368.286	184.143	0.184	2.762
Millettia ferruginea	23	36.000	18.900	0.850	1401.202	700.601	0.701	16.114
Podocarpus falcatus	76	40.880	21.000	0.712	1681.652	840.826	0.841	63.903
TOTAL	276				7957.172	3978.586	3.979	138.685

APPENDIX 2: SOIL ORGANIC CARBON ALONG ALTITUDE

- Soil organic carbon of Lower altitude (1806-2107m.a.sl)

Stratum No	Sample plot No	Layer	Dry weight	BD	%C	SOC t/ha
1	0	1	738.6733	1.0874	3.2100	69.8113
1	3	1	764.6730	1.1257	2.9930	67.3831
1	6	1	732.6733	1.0786	3.2500	70.1071
1	9	1	762.6733	1.1227	3.0100	67.5886
1	12	1	759.6733	1.1183	2.8610	63.9901
1	25	1	761.7500	1.1214	2.9690	66.5872
1	28	1	868.6733	1.2788	2.8800	73.6576
1	31	1	838.6733	1.2346	2.8810	71.1385
1	34	1	798.6733	1.1757	3.1100	73.1304
1	54	1	808.6733	1.1905	2.8770	68.4985
1	60	1	848.6733	1.2493	3.0610	76.4843
1	0	2	899.2300	1.2796	2.3170	59.2965
1	3	2	879.2000	1.1299	2.3600	53.3293
1	6	2	892.2300	1.1208	2.6710	59.8730
1	9	2	829.9900	1.0659	2.4170	51.5252
1	12	2	899.2300	1.1429	2.1670	49.5331
1	25	2	824.4175	1.0716	2.3810	51.0318
1	28	2	969.2300	1.1559	2.3170	53.5642
1	31	2	879.2300	1.1559	2.3170	53.5642
1	34	2	890.2300	1.1559	2.3170	53.5642
1	54	2	899.2300	1.1559	2.1500	49.7035
1	60	2	929.2300	1.1559	2.1670	50.0965
AVERAGE						123.042

- Soil organic carbon of Upper altitude (2108-2415 m.a.s.l)

Stratum No	Sample plot No	Layer	Dry weight	BD	%C	SOC t/ha
2	14	1	769.7500	1.1332	3.2820	74.3801
2	17	1	761.0100	1.1203	2.6990	60.4730
2	20	1	784.7500	1.1552	2.7410	63.3299
2	23	1	761.7500	0.9902	3.2670	64.6987
2	36	1	710.7500	1.0463	3.1740	66.4190
2	40	1	748.6733	0.9732	2.9100	56.6395
2	43	1	761.7500	0.9902	3.2790	64.9364
2	46	1	761.7500	0.9902	3.2000	63.3719
2	49	1	761.7500	0.9902	3.1890	63.1541
2	52	1	761.7500	0.9902	3.2470	64.3027
2	59	1	748.6733	0.9732	2.8410	55.2965
2	14	2	824.4175	1.2136	2.0090	48.7636
2	17	2	844.4175	1.2431	1.7270	42.9356
2	20	2	814.4175	1.1989	1.8370	44.0478
2	23	2	824.4175	1.0716	2.4710	52.9608
2	36	2	824.4175	1.2136	1.8570	45.0741
2	40	2	889.2300	1.1559	2.0170	46.6288
2	43	2	824.4175	1.0716	1.8310	39.2437
2	46	2	824.4175	1.0716	1.7310	37.1004
2	49	2	824.4175	1.0716	1.6310	34.9571
2	52	2	824.4175	1.0716	2.0070	43.0159
2	59	2	889.2300	1.1559	1.9170	44.3170
AVERAGE						106.9133

APPENDIX 3: LITTER CARBON STOCK ALONG ALTITUDE

- Litter carbon of Lower altitude (1806-2107m.a.sl)

Sample code	LB	%Ash	%OM	%C	LC t/ha
0	0.1017	29.4635	70.5365	40.9112	4.1622
1	0.1039	27.4447	72.5553	42.0820	4.3710
2	0.1147	26.6410	73.3590	42.5482	4.8802
3	0.1142	32.0191	67.9809	39.4289	4.5012
4	0.1183	26.8914	73.1086	42.4030	5.0178
5	0.1158	26.2167	73.7833	42.7943	4.9571
6	0.1139	27.8574	72.1426	41.8427	4.7661
7	0.1122	25.9126	74.0874	42.9707	4.8217
8	0.1217	27.1654	72.8346	42.2441	5.1413
9	0.1222	20.9156	79.0844	45.8690	5.6049
10	0.1263	18.8813	81.1187	47.0489	5.9415
11	0.1252	32.3525	67.6475	39.2356	4.9140
12	0.1289	28.5501	71.4499	41.4409	5.3435
13	0.1165	25.4586	74.5414	43.2340	5.0381
25	0.1438	23.2594	76.7406	44.5096	6.4004
26	0.1559	21.8279	78.1721	45.3398	7.0672
27	0.1398	25.4987	74.5013	43.2107	6.0413
28	0.1401	19.5248	80.4752	46.6756	6.5393
29	0.1481	26.5274	73.4726	42.6141	6.3106
30	0.1438	27.2561	72.7439	42.1915	6.0678
31	0.1303	24.9826	75.0174	43.5101	5.6695

32	0.1055	24.3609	75.6391	43.8707	4.6276
33	0.0958	26.2257	73.7743	42.7891	4.0975
34	0.0924	22.7697	77.2303	44.7936	4.1389
39	0.1637	22.9219	77.0781	44.7053	7.3164
53	0.1097	51.7863	48.2137	27.9639	3.0683
54	0.1244	20.9556	79.0444	45.8457	5.7043
55	0.1263	21.8338	78.1662	45.3364	5.7252
56	0.1244	28.0821	71.9179	41.7124	5.1892
60	0.1067	15.8359	84.1641	48.8152	5.2073
61	0.1121	17.2468	82.7532	47.9969	5.3799
AVERAGE	0.1225	25.6989	74.3011	43.0946	5.2907

- Litter carbon of upper altitude (2108-2415 m.a.s.l)

Sample code	LB	%Ash	%OM	%C	LC t/ha
15	0.1069	25.6136	74.3864	43.1441	4.6135
16	0.1192	25.1491	74.8509	43.4135	5.1732
17	0.0993	29.9828	70.0172	40.6100	4.0338
18	0.0982	28.7764	71.2236	41.3097	4.0562
19	0.0990	28.5416	71.4584	41.4459	4.1026
20	0.0972	27.6657	72.3343	41.9539	4.0785
21	0.0975	27.3962	72.6038	42.1102	4.1048
22	0.1005	26.5112	73.4888	42.6235	4.2851
23	0.1002	26.2901	73.7099	42.7517	4.2840
24	0.0974	25.7729	74.2271	43.0517	4.1946

25	0.1079	17.2070	82.7930	48.0199	5.1817
36	0.1081	24.3050	75.6950	43.9031	4.7481
37	0.1098	18.9140	81.0860	47.0299	5.1660
38	0.1107	28.2356	71.7644	41.6233	4.6079
39	0.1188	19.0019	80.9981	46.9789	5.5806
41	0.1596	17.0099	82.9901	48.1343	7.6836
42	0.1124	23.6981	76.3019	44.2551	4.9739
43	0.1116	22.3140	77.6860	45.0579	5.0295
44	0.1149	26.9744	73.0256	42.3549	4.8671
45	0.1125	16.9682	83.0318	48.1584	5.4197
46	0.1137	17.1379	82.8621	48.0600	5.4640
47	0.1112	16.5768	83.4232	48.3854	5.3813
48	0.1115	17.0962	82.9038	48.0842	5.3610
49	0.1119	23.6992	76.3008	44.2544	4.9511
50	0.0936	25.4457	74.5543	43.2415	4.0490
51	0.1141	16.1006	83.8994	48.6617	5.5509
52	0.1214	19.2709	80.7291	46.8229	5.6845
53	0.1309	23.5366	76.4634	44.3488	5.8045
58	0.1043	16.8422	83.1578	48.2315	5.0314
59	0.1502	18.4924	81.5076	47.2744	7.0983
60	0.1106	19.2768	80.7232	46.8195	5.1759
AVERAGE	0.1115	22.5743	77.4257	44.9069	5.0238

- **Tree information in different altitude**

Altitude	**Tree density**	**Ave.DBH**	**Ave. H**
Upper	276	25.6	14.4
Lower	326	34.2	18