COMPARATIVE ASSESSMENT OF BIOMASS AND SOIL ORGANIC CARBON POTENTIAL OF MONASTERY FOREST RESERVE AND ADJACENT NATURAL FOREST A CASE STUDY IN GOBA DISTRICT, SOUTHEASTERN ETHIOPIA.

MSc. THESIS

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NOVEMBER, 2019

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Approval sheet I

This is to certify that the thesis entitled ‘‘Comparative Assessment of biomass and soil organic carbon Potential of Monastery Forest Reserve and Adjacent Natural forest a Case Study in Goba District, Southeastern Ethiopia. ’’ submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Forest Resource Assessment and Monitoring, the Graduate Program of the Department of General Forestry, Hawassa University Wondo Genet College of Forestry and Natural Resources, and it is a record of original research carried out by Aschalew Tekola Id. No MSc/FRAM/R006/10, under my supervision, and no part of the thesis has been submitted for educational institutions for achieving any academic awards.

The assistance 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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Principal Supervisor	Signature	Date

Approval sheet II

We the undersigned members of the Board of examiners of the final open defense by *Aschalew Tekola Ademe* have read and evaluated his thesis entitled ‘‘Comparative Assessment of biomass and soil organic carbon Potential of Monastery Forest Reserve and Adjacent Natural forest a Case Study in Goba district, southeastern Ethiopia and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science with specialization in *Forest Resource Assessment and Monitoring*.

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Declaration

I, the undersigned declare that this Thesis is my original work and it has not been presented in other universities, colleges or institutes for a degree or other purpose. All sources of the materials used have been duly acknowledged.

Name: Aschalew Tekola Signature: ____________________ Date: __________________

Lists of Acronyms

AGB Above Ground Biomass

AGBC Above Ground Biomass Carbon

ANF Adjacent Natural Forest

ANOVA Analysis of Variance

BGB Below-Ground Biomass

BGBC Below-Ground Biomass Carbon

CDM Clean Development Mechanism

CT Carbon Total

DBH Diameter at breast height

DD Deforestation and Degradation

EOTC Ethiopian Orthodox Tewahido Church

FAO United nation Food and Agricultural Organization

FREL Forest Reference Emission Level

GtCs Giga tone of Carbons

GHGs Green House Gasses

IPCC Intergovernmental Panel for Climate Change

LB Litter Biomass

LC Litter Carbon

LULUCF Land Use, Land Use Change and Forestry

MEA Millennium Ecosystem Assessment

MEFCC Ministry of Environment Forest and climate change

PPM Parts Per Million

REDD Reduction Emission from Deforestation and Forest Degradation

SCBD Secretariat of the Convention on Biological Diversity.

SNF Surrounding Natural Forest

SOM Soil Organic Matter

SOC Soil Organic Carbon

SPSS Statistical Package for Social Science

SSA Sub Saharan Africa

THMF Tekle-Haimanot Monastery Forest

WB World Bank

UNEP United Nation Environmental Program

USDA United States Department of Agriculture

USEPA United States Environmental Protection Agency

UNFCCC United Nations Framework Convention on Climate Change

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Abstract

Forests are known to play an important role in regulating the global climate. They play a key role as both sinks and sources of carbon dioxide. Churches and monasteries have a long history of planting, protecting and conserving of trees. This study was conducted to assess and compare the biomass and soil carbon stock under monastery forest in relation to the adjacent natural forest at Goba Town of Bale Zone, Oromia Regional state. Two adjacent forests: Tekle-Haymanot monastery forest and the adjacent natural forest were selected. Three parallel transect lines with 90m in-between the lines and plots were laid across each forest and a total of sixty main plots of 20×20m (thirty each) were assigned systematically for biomass inventory and soil carbon(SOC)stock determinations. A total of forty composite soil samples were collected from corner of each main plot nested for soil carbon analysis while bulk density samples were taken from the center of main plots. Result showed that mean above and below ground biomass carbon varied significantly ($P<0.01$) and ($P<0.01$) with forest type respectively, were higher under the monastery (159tha^{-1} and 42tha^{-1}, respectively) than in the adjacent natural forest (105tha^{-1} and 27tha^{-1} respectively). The mean SOC stock showed no significant variation with the forest types, but marginally higher under the Monastery forest (127.9tha^{-1}) than in the adjacent natural forest (119tha^{-1}). SOC stock showed a decreasing trend with depth while the bulk density increases. The total carbon density under the Monastery forest was (328.9 tha^{-1}) much higher than the adjacent natural forest (251 tha^{-1}). Church and Monasteries play a great role on indigenous and religious knowledge in forest protection and management practices that have developed over generations through experiences but state managed natural forests have poor management and protection practices and considered as open access resources by the surrounding community . Therefore, the results of this study have positive role in reduction of greenhouse gases and show contributing of monastery and church forest for climate change mitigation.

Key Words: Above ground biomass carbon stock, Allometric equations, Litter

1. Introduction

1.1 Back ground

Forests play an important role in the global carbon cycle as both source and sink of carbon. Climate change is one of the most widely recognized environmental issues today. A consensus in the climate science research community has emerged that continued emission of greenhouse gases (GHG) will result in further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems (IPCC, 2014). Emissions of GHGs into the atmosphere are likely to increase the earth's mean surface temperature, thereby affecting physical and biological systems (Rosenzweig et al., 2008; Trenberth et al., 2009; UNFCCC, 2011). Many effects of temperature increase have been observed, including threats to natural phenomena, societal disturbances and threats to economic growth (IPCC, 2007; UNFCCC, 2011). Greenhouse gases emitted into the atmosphere by human activities were reported as a cause for an increment of global mean temperature of approximately 0.74°C (1.33°F) over the past century (IPCC, 2007). Estimates of projected temperature increases over the 21st century range between approximately 1.8°C and 4.9°C (3.2°F and 8.8°F) (IPCC, 2007).

Temperature increases generally consistent with historical trends, with the greatest temperature increases over land and at high northern latitudes and less warming over the southern hemisphere (Kang *et al*., 2008). Carbon sequestration is the process of removing excess carbon dioxide (CO_2) from the atmosphere and depositing it in a reservoir such as the oceans, terrestrial biomass, soils and geologic formation (UNFCCC, 1997). It is a way to mitigate the accumulation of greenhouse gases in the atmosphere released by the burning of fossil fuel and other anthropogenic activities.

Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes. Forests are known to play an important role in regulating the global climate. They play a key role as both sinks and sources of carbon dioxide. Most terrestrial biomass carbon storage is in tree trunks, branches, foliage, and roots which is often called biomass. Therefore, forest biomass is an important element in the carbon cycle, specifically in carbon sequestration. Forests have been used to quantify pools and fluxes of greenhouse gases (GHGs) from the terrestrial biosphere associated with land use land cover changes (Cairns *et al*., 2003). Moreover, forests are thought to provide a more cost-effective means of reducing global CO_2 emissions than other sectors (IPCC, 2007). It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown *et al*., 1996). In addition to being sequestered in vegetation, carbon is also sequestered in forest soils. Carbon is the organic content of the soil, generally in the partially decomposed vegetation (humus) on the surface and in the upper soil layers, in the organisms that decompose vegetation (decomposers) and in the fine roots (Gorte, 2009). The amount of carbon sequestered in forest soils varies widely, depending on the environment and the history of the site.

According to UNFCCC (2017) report the forest cover of Ethiopia increased from 13.78% to 15.5%. The aboveground carbon pools of tropical forests in their natural condition contain more carbon per unit area than any other land cover type (Bazzaz, 1998). The main carbon pools in tropical forest ecosystems are the living biomass of trees and understory vegetation and the dead mass of litter, woody debris and soil organic matter, but the aboveground carbon storage in natural forests is higher than in any other vegetation (Assefa., *et al* 2013).

Ethiopia is bringing many challenges due to its low adaptive capacity on Impacts of climate changes. The reason behind is because of its geographic exposure and complexity, low income, and great reliance on climate sensitive economic sectors particularly agriculture and pastoralist (Davies, *et al* 2008; FAO, 2016). Rainfall is becoming increasingly erratic that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture (Edame.,*et al* 2011) and droughts followed often by floods are more frequent (Edwards, 2010) which is due to rapid deforestation and degradation of land resources. Population increment has resulted in extensive forest clearing for agricultural use, over grazing, and exploitation of the existing forest for fuel wood, fodder, and construction materials.

The Ethiopian Orthodox Tewahido Churches and monasteries have a long history of planting, protecting and conserving of trees. Most of the time a traveler sees a patch of indigenous old aged trees in any parts of the country especially in the northern highlands of Ethiopia; most probably he/she can be sure that there is an Orthodox Church or monastery in the area. (Alemayehu Wassie, 2002).

This observation is not only a recent phenomenon, but goes back many years as the event of deforestation has been occurring in the area for centuries. Many travelers on their route have observed and had an impression that old aged indigenous trees were becoming confined around churches, (Melaku,1992). Compounds of Churches and monasteries are serving as in situ conservation and hot spot sites for biodiversity resources, mainly indigenous trees and shrubs of Ethiopia, which in turn give prestige for the religious sites. As a result, these forests are sanctuaries for different organisms ranging from microbes to large animals, which have almost disappeared elsewhere. (Taye 1998).

Ethiopian Orthodox Tewahido churches in particular have a long experience in conserving and protecting flora and fauna in their respective compounds. It had a cumulative knowledge of thousands of years, experiences of many people, wisdom of the spirit mediums, the wise council of elders and the leadership of religious leaders, institutions in managing and conserving resources and strong sanctions and 'gizet' for outliers (Alemayehu Wassie.,2002).

1.2 Statement of the problems

In most parts of Ethiopia patchy and remnant forests are conserved and protected in and around religious institutions especially in Orthodox churches and Monasteries, out sides of the church area mostly forests are degraded and deforested by peoples who are living in the area. Church forests are giving to the area so many benefits like improving its micro amelioration, providing ecosystem services, contribute for bio-diversity conservations, carbon stock storage and also habitat for wild animals. According to Tulu (2011), Church and Monastery compounds have significant role for climate change mitigation and adaptation purpose. What the Ethiopian Orthodox Tewahido Church (EOTC) has done to conserve a significant proportion of the forests in the country, the church does not receive the recognition and support it deserves (Taye *et al.*, unpublished). Thus, we have to recognize this tradition as an opportunity and explore possibilities of using it in future conservation programs in this Monastery.

Studying the tradition behind conserving, protecting and managing of these resources and the prospect of adopting this religious culture, values and ethics is important to scale up at the country level forest development program, and also to show its significance with regard to the contribution to carbon stock storage. Carbon stock evaluation in church forests helps to manage the forests sustainably from the ecological, economic and environmental points of view for the welfare of human society. In response to this problem, the purpose of this study is to quantify

Carbon stock of monastery forests in above and below ground, dead litter, and soil organic carbon pool. This will help to bridge the current research gap in carbon related study in church forests, and give relevant information for researchers, policy makers and other conservation organization.

1.3 General objective

The overall objective of the study is to estimate biomass and soil organic carbon stocks potential of Tekle- Haymanot Monastery forest.

1.3.1 Specific objective

- ✓ To estimate the above, below ground biomass carbon stock and soil organic carbon of Tekle-Haymanot monastery and the adjacent natural forest.
- ✓ To compare ecosystem carbon stock of Tekle-Haymanot Monastery Forest and the adjacent natural forest at ecosystem level.

1.4 Research Questions

- ✓ Do biomass and soil organic carbon stocks vary between monastery forests and adjacent natural forest?

1.5 Significance of the study

Forests worldwide are known to be critically important habitats in terms of the biological diversity they contain and ecological functions they serve (SCBD. 2001). Ethiopian Orthodox Tewahido Church (EOTC) has long history in conservation and protection of Indigenous forest species that have a great carbon stocks and riches in biodiversity potentials. It is important to recognize these forests as an opportunity to explore possibilities in climate change mitigation by reducing emission of GHGs from atmosphere and also play a significant role for sustainable forest management practice.

In most REDD+ systems, it is proposed that developed countries would pay developing countries for emissions reduced below a certain reference level and see carbon markets as an opportunity to reduce emissions cost-effectively, whereas many developing countries see potential for economic benefits, particularly where carbon markets are linked to DD (Jodie Keane *et al*., 2010).

The expected result of comparison of carbon stock of Tekle-Haymanot monastery forest and the adjacent natural forest have significant differences. This research out puts is important to provide references, information and organized document for further investigation to researcher, decision maker, legislative body, government and non-governmental organization and other concerned body endeavors for climate change mitigation.

2. Lliterature review

Global Climate Change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average, also climate change may be limited to a specific region, or may occur across the whole Earth (IPCC, 2001).

The IPCC report (2007) indicates that most of the observed increase in global average temperatures since the mid-20th Century is very likely due to observed increases in anthropogenic greenhouse gas concentrations. Climate changes and global warming are the largest environmental problems of all time; the level of scientific proof achieved in recent years leaves no doubts that human activity is the primary cause of these processes (IPCC, 2007). Average global temperatures already register an increase of 0.7°C, caused by the growing concentration of atmospheric greenhouse gases (GHG) (IPCC, 2007). The increasing frequency of extreme natural phenomena such as hurricanes, cyclones, torrential rains and prolonged droughts has already affected the lives of millions of people around the world. United Nations Framework Convention on Climate Change (UNFCCC) was formulated aiming at reducing global greenhouse gas emissions. Article 4 of the UNFCCC requires preventing and minimizing climate change by limiting anthropogenic emissions of greenhouse and protecting and enhancing greenhouse gasses and reservoirs.

The (IPPC, 2007) highlighted that Africa will be one of the continents that will be hard hit by the impact of climate change due to an increased temperature and water scarcity. Yet Africa represents only 3.6 percent of emissions. The IPCC Report pointed out that there is “very high confidence” that agricultural production and food security in many African countries could be severely affected by climate change and variability. In Africa, the yields of crops in some countries could be reduced as much as 50 percent by 2020, with smallholders being the most affected (FAO, 2011).

Ethiopia is one of the developing countries, which are more vulnerable to climate variability and change (FAO, 2011). Low level of socio-economic development, inadequate infrastructure, lack of institutional capacity and a higher dependency on natural resources base make the country more vulnerable to climatic factors including climate variability and extreme climate events. Ethiopia is particularly vulnerable to global climate change, given its massive reliance on agriculture (FAO, 2011).

As religion is one of the strong and powerful indigenous institutions, religious perspective towards conservation, the past and present experience in the field of interest should coincide to our planning and objective settings if sustainability is to be achieved. Although the main purpose of churches is as places for worship, burials and meditating religious festivals, they also provide valuable and secured habitats for plants and animals, as well as microorganisms and green spaces for people to rest the stressed mind (Taye Bekele, 1998)

2.1 Global Carbon Cycle and Forest

Forest play a critical role in reducing ambient CO_2 levels by sequestering atmospheric carbon into the growth of woody biomass through the process of photosynthesis. They are both sources and sinker of carbon (Brown and Pearce, 1994). Forest Soils are important component of the global carbon cycle which stocks large amount of soil organic carbon (SOC) and are the largest reservoirs in the world. SOC plays important role in alleviating the effects of greenhouse gases and storing, enhancing soil quality, sustaining and improving food production, maintaining clean water and reducing CO_2 in the atmosphere. However, of the 2.6 billion tons of carbon that forests annually absorb, 60% is emitted back into the atmosphere through deforestation. Beside regulating climate change, forests provide number of important local services that can reduce communities vulnerabilities to climate change such as water flow, reduce run off, erosion, siltation, flooding as well as in the production of food and medicine. These are all known together as Ecosystem services of forests (Zerihun Getu *et al*., 2011).Forest carbon management must be an important element of any international agreement on climate change. Forest carbon flows comprise a significant part of overall global greenhouse gas emissions. While global forests as a whole may be a net sink (IPCC, 2007), global emissions from deforestation contribute between 20 and 25 percent of all greenhouse gas emissions. The size of the total global carbon pool in forest vegetation has been estimated at 359GtC (giga tones of carbon), compared to annual global carbon emissions from industrial sources of approximately 6.3 GtC (IPCC, 2000).The potential impact on the global carbon cycle of both natural and anthropogenic changes in forests is enormous. In the 1990s, gross deforestation was slightly higher, at 13.1million ha/yr. Due to afforestation, landscape restoration and natural expansion of forests, it is estimate that net loss of forest is 7.3 million ha/yr. The loss is still largest in South America, Africa and Southeast Asia. There is considerable interest on the role of terrestrial ecosystems in climate change, more specifically on the global carbon cycle. The world's tropical forests covering 17.6M km^2 contain 428Gt C in vegetation and soils. It is estimated that about 60GtC is exchanged between terrestrial ecosystems and the atmosphere every year. Land Use, Land-Use Change and Forestry (LULUCF) activities, mainly tropical deforestation, are also significant net sources of CO_2, accounting for 1.6GtC/yr of anthropogenic emissions (Watson et al. 2000).The carbon dioxide in the atmosphere is 2% of the amount in the ocean, only slightly higher than the amount of carbon bound in the biomass plants and only half that stored in soil. Tropical forest deforestation is estimated to emit about 2 billion tone of carbon per year during the 1990s, which is roughly equivalent to 25% of annual global greenhouse gas emissions. This indicates any disturbances in the forest due to natural and human influences lead to more carbon released in to the atmosphere than the amount used by vegetation during photosynthesis (Brown, 2002). To overcome the conditions, sustainable management strategies are mandatory; therefore, it is necessary to make the forest carbon sinker rather than source. Currently, the biosphere constitutes a carbon sink that absorbs about represents about 30 percent of fossil-fuel emissions (IPCC, 2000).

The IPCC Third Assessment Report (TAR) concluded that the forest sector has a biophysical mitigation potential of 5,380 $MtCO_2$/yr on average up until 2050, where as the carbon mitigation potentials from reducing deforestation, forest management, forestation, and agro-forestry differ greatly by activity, regions, system boundary and the time horizon over which the options are compared. In the short term, the carbon mitigation benefits of reducing deforestation are greater than the benefits of forestation (Kauppi *et al*., 2001).

2.2 Carbon Sequestration in the Ecosystem

Carbon sequestration means that carbon dioxide is captured from the atmosphere through photosynthesis by the tree or plant to store it in its trunk, branches, twigs, leaves and fruit and oxygen is released to the air in return. Also the roots of the trees and plants take up carbon dioxide. Decomposing organic materials increase the amount of carbon stored in the soil, which is higher than the total amount in the vegetation and the atmosphere. Animals breathe in oxygen and breathe out CO_2 and through their feces carbon and N_2O is released to the soil (FAO, 2010). It is a phenomenon for the storage of CO_2 or other forms of carbon to mitigate global warming and its one of the important article of Kyoto Protocol, through biological, chemical or physical processes; CO_2 is captured from the atmosphere (IPCC, 2007).In comparison with engineering technologies of geologic or oceanic sequestration, soils and vegetation is a cost-effective option. It is a win-win strategy, a low hanging fruit, and an essential development option regardless of the debate on climate change. It is a strategy that humanity cannot afford to neglect. Carbon sequestration enhances soil quality and the associated water and nutrient cycles and thereby it enhances the productive potential of the land on which all terrestrial life depends (WB, 1999).Based on the above description the following is considered as ecosystem part and means of carbon sequestration globally. These are oceanic, geologic and terrestrial carbon sequestration.

Terrestrial carbon sequestration is the process through which CO_2 from the atmosphere is sequestered by trees, plants and crops through photosynthesis, and stored as carbon in biomass and soils. Therefore, a carbon sink occurs when carbon sequestration is greater than carbon releases over some time period (Mathews and Robertson, 2002).The Kyoto Protocol to the UN Framework Convention on Climate Change(UNFCCC, 1997) has provided a vehicle for considering the effects of carbon sinks and sources as well as addressing issues related to fossil fuels emissions. Carbon sequestration is a way to mitigate the accumulation of greenhouse gases in the atmosphere released by the burning of fossil fuels and other anthropogenic activities .Forest ecosystem plays very important role in the global carbon cycle and climate change mitigation. The main components of terrestrial carbon storage are aboveground and below ground biomass dead litter and soil organic matter (Watson, 2008).

Emissions from deforestation and forest degradation' (REDD) under the UN Framework Convention on Climate Change (UNFCCC) as a strategy to tackle climate change. The scope of the debate has recently been expanded beyond DD emissions to include, in addition, such activities as supporting sustainable management of forests (which would include some carbon fluxes in and out of the forest, but little net change) and carbon stock enhancement through tree planting or natural regeneration (leading to the acronym 'REDD+). In most REDD+ systems, it is proposed that developed countries would pay developing countries for emissions reduced below a certain reference level, thus linking finance to performance. There are numerous options for how they could be designed, varying in terms of factors such as how reference levels are established, how finance is delivered and definitions of what emissions sources to target. Much interest has focused on the potential of carbon trading for financing REDD+. Many developed countries see carbon markets as an opportunity to reduce emissions cost-effectively, whereas many developing countries see potential for economic benefits, particularly where carbon markets are linked to DD (Jodie Keane *et al*., 2010).

REDD+ is one of the few areas where progress was made in Copenhagen and the efforts put into designing and piloting REDD+ systems may offer useful insights for the development of mitigation activities in other sectors. This note looks at four insights from REDD+, focusing on market based approaches and the potential opportunities and risks for developing countries.

2.3 Carbon Stock Pools

2.3.1 Aboveground Biomass Carbon Stock

Carbon sequestration is the potential of removed CO_2 from the atmosphere and it can be stored indefinitely through the process of photosynthesis (Watson *et al*., 2000). These sinks can be above ground biomass (trees), living biomass below the ground in the soil (roots and microorganisms) or in the deeper sub-surface environments (Nair *et al*., 2009). Forests are major contributors to terrestrial carbon sink, mitigating climate change and associated economic benefits (Waston *et al*., 2000; Sheikh *et al*, 2009). 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 *et al*). 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).

Even though the climate protection role of forests is apparent, it is complex to determine how much of the forest carbon sink and reservoir can be managed to mitigate atmospheric CO_2 and in what way to buildup.

2.3.2 Belowground biomass carbon stock

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 60 cm, root carbon inputs can be substantial, although the amount declines sharply with soil depth (Cairns *et al*., 1997). Root biomass in ecosystems is often estimated from root-to shoot ratios. The ratio ranges from 0.18 to 0.30, with tropical forests in the lower range and the temperate and boreal forests in the higher range (Cairns *et al*., 1997). Roots make a significant contribution to SOC. About 50% of the carbon fixed in photosynthesis is transported belowground and partitioned among root growth, Rhizosphere respiration, and assimilation to soil organic matter. Roots help in accumulation of SOC by their decomposition and supply carbon to soil through the process known as rhizo deposition (Rees *et al*., 2005).Increased production and turnover rates of roots lead to increased SOC accumulation following root decomposition (Matamala *et al*., 2003).

2.3.3 Soil organic matter (SOM)

SOM includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal *et al*., 1999). Inorganic forms of carbon are also found in soil, however forest management has 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 30 cm, and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years (Watson, 2008).

2.3.4 Dead Wood 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. 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 . The quantity of dead wood does not generally correlate with any index of stand structure. 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%) (MacDicken,1997).

Dead trees serve many key functions in the ecosystems (Franklin *et al*., 1987). Since dead trees

may persist for centuries and they can influence ecosystems as long as living trees. Woody detritus reduces erosion, they are a major source of energy and nutrients, serves as a seedbed for plants and they are a major habitat for microbes, invertebrates and vertebrates (Harmon *et al*., 1986).

2.3.5 Litter Carbon Stock

Carbon is stored in trees (stem, branches, leaves and root), understory, forest litter and soils. The Mechanism of species driven carbon sequestration in soil is influenced by two major activities, aboveground litter decomposition and belowground root activity (Lemma *et al*., 2007). Litter decomposition is one of the major sources of SOC and the quality of litter is very important in this regard (Mafongoya *et al*). In the systems with high plant diversity, litters are present with different degrees of chemical resistance, creating the possibility of longer residence of carbon through slower decomposition of litters from some species. Lignin in litter is highly resistant to decomposition and therefore, litter with high lignin content would have slower decomposition rate (Mafongoya *et al*., 1998). In contrast, litter with low lignin, phenols, and high nitrogen content would have faster rate of decomposition (Aber *et al*., 1991).

2.3,6 Carbon trade and Clean Development Mechanism

The carbon trade is an idea that came about in response to the Kyoto Protocol. The Kyoto Protocol is an agreement under which industrialized countries will reduce their greenhouse gas emissions between the years 2008 to 2012 to levels that are 5.2% lower than those of 1990. Deforestation and degradation (DD) constitute 12 to 17% of global greenhouse gas emissions, with most arising from the exploitation of tropical forest resources in developing countries (IPCC, 2007, Vander Werf *et al*., 2009 ;). This has led to increasing interest in developing mechanisms.

'Reduce emissions from deforestation and forest degradation' (REDD) under the UN Framework Convention on Climate Change (UNFCCC) as a strategy to tackle climate change.

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2.3.7 The Role of Ethiopia Orthodox Tewahido Church Forest for Conservation of Biodiversity and Climate Change Mitigation.

Ethiopian Orthodox Tewahido Churches is an indigenous and integral Christian Church of Africa, being one of the most ancient churches in the world and long history of planting, protecting and preserving trees (Abiyou Tilahun *et al*., 2015). Church forests are in carbon sequestration and climate regulation is highly significant (Tulu Tolla, 2011). They are also serving as conservation sites and hot spots of biodiversity, mainly indigenous trees and shrubs of Ethiopia, which, in turn, give prestige to the religious sites. In addition to their biodiversity benefits, climate change mitigation, cultural values, provisioning services, and provide regulating or supporting services such as pollination, erosion control and water flow regulation. It also gives as important value for ecosystems and economic significance too (Alemayehu Wasie, 2002). Those trees are not only meeting the economic and ecological needs of the people, but also form an integral part of their culture and spiritual tradition (Yeraswork Admassie, 1995).

3. Material and methods

3.1 Description of the Study Area

3.1.1 Geographic and Topography Location

This study was conducted in the Southeastern part of Ethiopia Oromia regional state Bale zone Goba woreda about 445 km far from Addis Ababa. It is located between a latitude and longitude of 7 ^{0} 1' North and 39^{0}59' East. The altitude ranges from 2743 to 4200 m.a.s.l with the cold (Dega) climate. The rainy season is from the end of May until early November. The annual total rainfall of the study area ranges between 600 and 1400mm, while the annual mean minimum and maximum temperatures of Goba town are 5 and 22°C respectively. The soil type in the study area is Vertisols. (Source Goba woreda Agricultural development office).

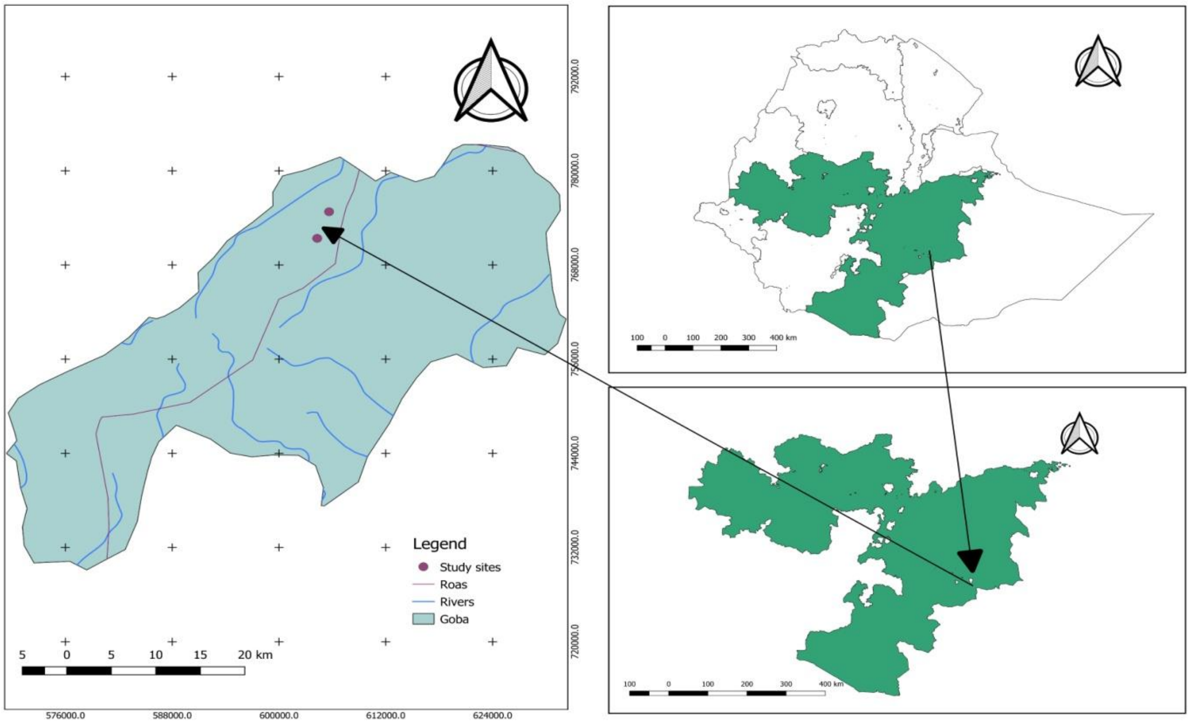

Figure 1 Map of the study area.

3.1.2 Vegetation

The study area is classified under dry afro mountane and *Junipers procera, Olea africana* and *Hagenia abyssinica* plant species are common species in the area. Vegetation formations in the Bale Mountains belong mainly to the Afromontane and Afroalpine (Nigatu *et al*., 1989), showing marked vegetation zonations are thought to be one of the greatest centres of endemism containing diverse gene reserves (Hillman, 1986). At altitudes between 2390 and 2800m, the vegetation is dominated by *Scheffera. abyssinica* and *Hagenia. abyssinica*. Above this vegetation zone, and between 2800m and approximately 3250m, the most characteristic vegetation community is *Hypericum revoltum*, *Erica arborea*, *Schefflera volkensii*. The upper altitudinal limit varies at different aspects and gives way to a sub-Afroalpine vegetation type characterized *as E. arborea* bush land (Nigatu *et al*., 1989).

3.2 Methodology

3.2.1 Sampling design

Reconnaissance survey was conducted to see the overall situation of the area, the area was delineated using GPS to determine the required number of transect lines. Systematic sampling methods was employed then the transect line were established based on the size and shape of the forests, three transect line was aliened systematically, distance between the transect line and the plots were 90m. The plots were laid at the center of the transect line in each study forest. The monastery forest is 36.3 ha while the adjacent natural forest is 41.5 ha and both forests are found within the same agro ecological zone. 30 sample plots from Monastery Forest 30 sample plots, from Adjacent Natural Forest totally 60 sample plots were established, The size of the plots for tree inventory was (20 m × 20 m; 400m^2).

3.3 Field Measurements

3.3.1 Vegetation Data Collection and Identification

All live trees with a diameter ≥ 5 cm were recorded following the methods and procedures of Pearson *et al*.(2005 and 2007). The diameter was measured at breast height (DBH, 1.3 m height from the ground) to estimate biomass and the size class distribution of trees in a sampling plot. Those trees on the border were included when ≥50% of their basal area fell within the plot and excluded if <50% of their basal area fell outside the plot. Trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included (Bhishma *et al*., 2010). DBH were measured by using caliper and tree heights were measured by using Sunnto hypsometer. Plant identification was done in the field by using Flora of Ethiopia and Eritrea volume 2, part 1 (Edwards *et al*., 2000),

3.4 Estimation of carbon stocks in different carbon pools

3.4.1 Estimation of above ground tree biomass (AGTB)

This study was applied equations developed analysis for the only reasonable method to estimate tree biomass without destructive sampling (Jenkins *et al*., 2003). The selection of the appropriate allometric equation is crucial to estimate aboveground tree biomass (Bhishma*et et al*., 2010).

There are different allometric equations that have been developed by many researchers to estimate the above ground biomass carbon. These equations are different depending on the types of species, geographical locations, forest stand types, climate and others (Baker *et al*., 2004).

To develop and use of locally developed allometric equations used to generate a reliable estimate of forest carbon stocks for AGB. But to develop allometric relationships a large number of trees needs to be harvested, this makes it time-consuming and expensive (Gibbs *et al.*, 2007). Although, many allometric equations had been developed globally, no African site had been included in previous efforts (Chave *et al*., 2005) except the pan tropical AGB model developed by Chave *et al*. (2014). The model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors (Chave *et al*., 2014; Victor, 2015). According to Henry *et al*. (2010), equations that integrate more than one tree dimension improve the reliability of forest biomass estimation. Therefore, the model of Chave *et al*. (2014) was used by many studies and has been the best model for carbon stock assessment in Africa (Victor, 2015, MEFCC, 2016;) on the basis of climatic condition, DBH of trees and forest type of the study area to determine biomass of tree species having ≥ 5 cm DBH. This study uses the following equations to calculate AGB (stem plus bark, branches and foliage) of trees. The model that was used to calculate the above ground biomass is given below.

$$\mathbf{AGB = 0.0673 \times (PD^2H)^{0.976}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\textit{eq.1})$$

Where AGB= above ground biomass in Kg

P = Wood density of each tree species in g cm^3 and it was obtained from global wood density database (Chave *et al*., 2009; Zanne *et al*., 2009; UNFCCC, 2016)

D= diameter at breast height in cm

H= height in m

3.4.2 Estimation of Below Ground Biomass (BGB)

Below ground biomass estimation is much more difficult and time consuming than estimating aboveground biomass (Guider et al., 2001). Roots play an important role in the carbon cycle as they transfer considerable amounts of carbon to the ground, where it may be stored for a relatively long period of time. As indicated by Mac Dicken (1997), the ratio ranges from 0.18 to 0.30, with tropical forests in the lower range than the temperate and boreal forests. (Cairns *et al*., 1997). According to IPCC (2006) estimation of below ground biomass can be obtained as: On average BGB is 0.26 % of AGB. The equation is given below:

BGB = AGB × 0.26 …………………………………………………………………………. (*eq.2*)

For both AGB and BGB, the biomass stock density were attain in Kg m^2 by means of dividing the sum of all individual weights (in Kg) of a sampling plot by the area of sampling plot. The value converted to ton/ha by multiplying it by 10. AGB was converted to tree AGC stock (t/ha^{-1}) using a carbon fraction of 0.47 (IPCC 2006; Paustian *et al*. 2006).While multiplication factor 3.67 (44/12) was used to estimate CO_2 equivalent (Pearson *et al*., 2007).

3.4.3 Estimating of carbon in Litter Biomass Sampling

The leaf litter is defined as all dead organic surface material on top of the mineral soil. Samples that have ≤ 10 cm diameter of all dead and dried leaves, twigs, branches and fruit pods an area of

1m by 1m ($1m^2$) diagonally two at the corner and one at the center of the plots were collected, weighted and recorded on the field then 100 g of composited samples taken for laboratory analysis placing in a labeled to which plot they belongs.

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

$$\boldsymbol{LB} = \frac{wfield}{A} * \frac{Wsub_{sample(dry)}}{Wsub_{sample(fresh)}} * \frac{1}{10{,}000} \text{ ....(eq.3)}$$

LB = Litter (biomass of litter ton/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 were collected (ha).

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

A composited 100g of fresh weight was oven dried at 70℃ for 24 hours to determine dry to fresh weight ratios (Ullah and Al-Amin, 2012;)

Once the litter biomass is obtained, then Carbon stock in dead litter biomass was calculated by using the following formula.

LC = LB × 0.37 ………………………………………………………………………… (eq.4)

Where, LC is total carbon stocks in the dead litter in ton/ha, 0.37 is carbon fraction (IPCC, 2006), LB is oven dry mass of litter biomass.

3.4.4 Soil bulk density Sampling

A total of 40 Soil samples were collected from 0-20 and 20-40 cm for soil bulk density analysis. Samples were collected from the center of every second plots using modified cylindrical cores (20 cm height and 6 cm diameter) for calculating the volume and density of oven dry mass of soil samples. The bulk density samples were oven-dried at 105 °C for 24 h and weighed (Pearson *et al*., 2005). The collected sample were labeled and inserted in to individual plastic bag and sent to Wondo Genet College of forestry and natural resources laboratory. Then the following formula was used to calculate the soil bulk density. (Pearson *et al*., 2005)

$$V = h * \pi r^2 \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (eq.5)$$

Where, V is volume of the soil in the core sampler in cm^3 h is the height of core sampler in cm, and r is the radius of core sampler in cm.

Bulk density:

BD (gm/cm^3) = (oven dry weight of the soil) / (volume of the core) …………………. *(eq.6)*

3.4.5 Soil Sampling

A total of 40 composite soil samples were collected from 0-20 and 20-40 cm depth for Soil carbon concentration analysis. Samples were collected from the four corners of every second plots using auger. 250 g of composited samples taken for laboratory analysis placing in a labeled to which plot they belongs. All soil samples were analyzed at Wondo Genet College of Forestry and Natural Resources laboratory.

Soil carbon concentration preparation procedure was soil samples air-dried at approximately 40° C, for 48 hours or until constant mass has been achieved, exposing soil to the air in a large temperature controlled room It can assist the drying process to break-up any large soil. Aggregates within the soil was crushed and broken up and each soil sample was sieved to separate the <2 mm fraction from any gravel or larger detritus (≥2 mm).

Soil carbon concentration was analyzed using standard method, by Walkey-Black procedure (a wet combustion of organic matter with a mixture of potassium dichromate and sulfuric acid and residual potassium dichromate titrated against ferrous sulfate) (Jackson, 1967; Reeuwijk, 2002). The carbon stock of soil used the following formula which is recommended by Aynekulu., *et al* (2011).

SOC = *(C /100) * P * D *(1- frag /100)* *100..(*eq. 7*)

Where: SOC = soil organic carbon stock (t C/ha^{-1}).

C = soil organic carbon concentration of soil fines (fraction < 2 mm) determined in the laboratory (%, g kg^{-1})

P = soil bulk density (g /cm^{3})

D = depth of the sampled soil layer (cm)

Fragment = % volume of coarse fragments/100

100 is used to convert the unit to convert to t C/ ha^{-1}

Note: SOC is determined on the fine soil fraction (< 2 mm) and the bulk density should be corrected for the proportion of the soil volume occupied by coarse fragments (> 2 mm)

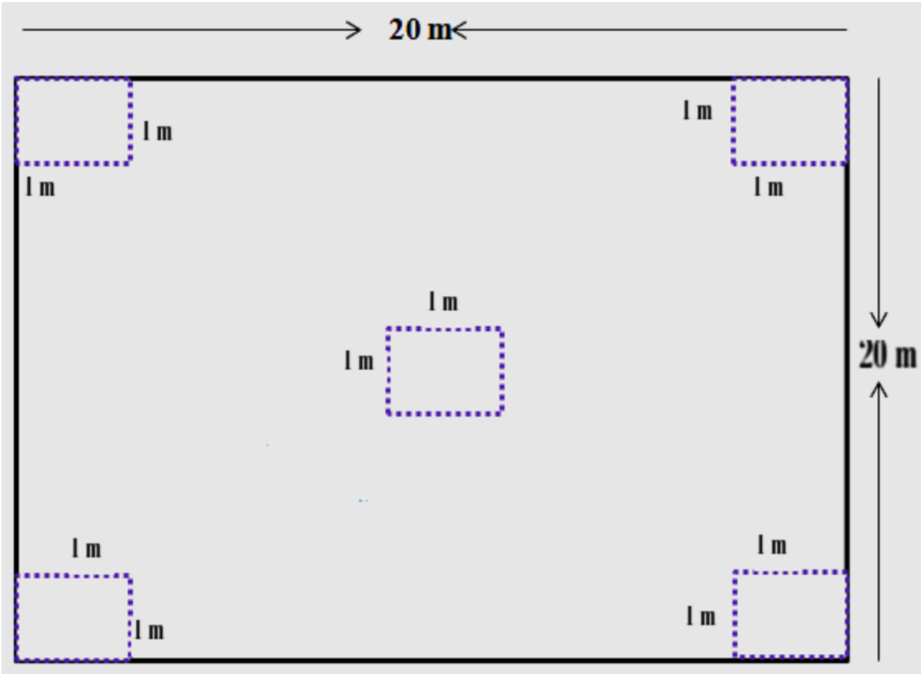

Figure 2 Sample plot size and design of main plot, sub-plots for liter and soil samplings.

3.5.6 Estimation of Total Carbon Stock Density

The total carbon stock was calculated by summing of the carbon stock densities of the individual Carbon pools of the stratum using the Pearson *et al*., (2005) formula. Carbon stock density of a study area was calculated by:

CT = AGC + BGC + LC +SOC……………………………………………………… (*eq.8*)

CT = Total Carbon stock for all pools (t/ha).

AGC=above ground carbon stock (t/ha).

BGC= below ground carbon stock (t/ha).

LC=litter carbon stock (t/ha).

SOCs= soil organic carbon stock (t/ha).

The total carbon stock was converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 as indicated by (Pearson *et al*., 2007)

3.6 Data analysis

The data of DBH, height and frequency of each species, fresh weight and dry weight of soil were organized and analyzed by using excel 2010 and using of statistical package software (SPSS 16.0 version), one way ANOVA at 95% confidence interval and different tables and figures were used to summarize the results.

4. Result

4.1 Forest characteristics

Five tree species were identified and recorded in the studied dry afromontane forest , the dominant tree species is *Juniperus procera* (68%) followed by *Olea africana* (18 %), *Maytenus arbutifolia* (6 %), *Hagenia abyssinica* (4%), *Rosa abyssinica* (3%). From all 60 plots, a total of 948 stems were recorded. The average number of stems per hectare in Tekle-Haymanot Monastery Forest and Adjacent Natural Forest was 429.1 and 360.8 respectively.

The average Basal area m^2/ha of the forest in the monastery was 43.9.± 8.01 while that of the adjacent natural forest was 29 ± 6; it is statistically significant ($P < 0.01$). The total numbers of trees recorded in monastery and Adjacent natural forest were 515 and 433 respectively.

The mean stem density (stems ha^{-1}) of monastery forest was 429.1 ± 77.4 while the adjacent natural forest was 360.8 ± 73.8; it is statistically significant ($P < 0.01$). (Table 1)

Table 1. The average DBH, H, BA and stem density of tree species in study sites.

Parameters	THMF	ANF	P value
DBH, cm	33.7±2.38	29.1±3.82	0.01
H,m	16.6±0.6	15.7±0.9	0.25
BA, m^2/ha	43.9.± 8.01	29 ± 6	0.01
Stem density (stems ha^{-1})	429.1 ± 77.4	360.8 ± 73.8	0.01

Where THMF (Tekle-Haymanot monastery forest) and ANF (Adjacent natural forest)

The frequency distribution of tree species of monastery forest showed that *Juniperus procera* was the most frequent tree species occurred in the study area with 100 % frequency and *Olea africana* was the second with 97 % followed by *Maytenus arbutifolia* with 37%, the remaining two species *Hagenia abyssinica* and *Rosa abyssinica* were with least frequently occurred species with 23% and 20 % respectively, were as in case of adjacent forest were *Juniperus procera* and *Olea africana* was the most frequent tree species occurred in the study area with 100 % frequency and also *Maytenus arbutifolia* with 60% , the remaining two species *Rosa abyssinica* and *Hagenia abyssinica* were the least frequency occurred with 43% and 27% respectively.

4.2 Biomass Carbon Stocks (t/ha-1)

The average above ground and below ground biomass carbon stock of the forest in the monastery were159±30 and 42 ±7.78 respectively while that of the adjacent natural forest were 105±29 and 27±7.97 respectively. This difference in aboveground and belowground biomass carbon stock between the monastery and adjacent natural forest was statistically significant (P < 0.01).

The estimated mean litter biomass carbon stock of monastery forest and adjacent natural forest were 0.015±0.002 and 0.013±0.003 respectively. The litter biomass carbon stock of the study sites was no significant variation (P = 0.15). Table 2)

Table 2 Tree biomass carbon stocks estimate in monastery and adjacent natural forest.

Biomass	Study site	Mean	Min	Max	P value
AGBC	THMF	159±30	105	235	P < 0.01
	ANF	105±29	61	220	
BGBC	THMF	42±7.78	29	61	P < 0.01
	ANF	27±7.97	12	57	
LBC	THMF	0.015±0.002	0.01	0.024	P = 0.15
	ANF	0.013±0.003	0.01	0.02	

4.3 Soil bulk density and soil organic carbon concentration.

The mean Soil bulk density of the 0-20 cm depth in monastery forest was 0.72 ± 0.03 while the adjacent natural forest was 0.75 ± 0.08 g/cm^3 , the result showed no significant variation (P= 0.28)

The mean soil bulk density of 20-40 cm depth in monastery forest was 0.78 ± 0.02 while that of the adjacent natural forest was 0.82 ± 0.08 g/cm^3 respectively, with the (P= 0.14). The result showing no significantly differences. The soil bulk density was increased with a corresponding increase in soil depth across the sites.

The mean soil organic carbon concentration % of 0-20cm depth in monastery forest was 5.7 ± 1.02 while the adjacent natural forest was 5 ± 0.77 respectively with the (P= 0.1). The result showing no significantly differences.

The mean soil organic carbon concentration % of 20-40cm depth in monastery forest was 4.2 ± 0.66 while the adjacent natural forest was 3.8 ± 0.91 respectively with the (P= 0.3)

the result showed no significant variation. The soil organic carbon concentration values were decreased with the increasing depths. (Table 3)

Table 3 Soil bulk density and soil organic carbon concentration in monastery and adjacent natural forest.

Soil depth, cm	Parameters	THMF	ANF	P value
0-20	BD, g/cm^3	0.72 ± 0.03	0.75 ± 0.08	0.28
	C %	5.7 ± 1.02	5 ± 0.77	0.1
20-40	BD, g/cm^3	0.78 ± 0.02	0.82 ± 0.08	0.14
	C %	4.2 ± 0.66	3.8 ± 0.91	0.3

4.4 Soil organic carbon stocks in the study sites.

The mean SOC of 0-20 cm depth in monastery forest was 67.9±13.6 t/ha^{-1} while that of the adjacent natural forest was 61±13 t/ha^{-1} respectively. The mean SOC stock showed no significant variation (P=0.24) with forest types but marginally higher under monastery forest. The minimum and maximum soil organic carbon were 49 and 89 t/ha^{-1} under the monastery forest and 33 and 82 t/ha^{-1} in Adjacent natural forest respectively.

The mean SOC of 20-40 cm depth in monastery forest was 60±9.4 t/ha^{-1} while that of the adjacent natural forest is 58±14.3 t/ha^{-1} respectively, with the (P= 0.8). The result showing no significantly differences. The soil organic carbon contents decreased with increase in the soil depth. Soil organic percent concentration was higher in the top 20cm than the layer below. The minimum and maximum soil organic carbon in the 20 -40 cm depth was 42 and 74 t/ha^{-1} under the monastery forest and 31 and 81 t/ha^{-1} in the adjacent natural forest respectively.

Total soil organic carbon stocks of monastery and adjacent natural forest was 127.9 and 119 t/ha^{-1} respectively, the result showed that monastery forest contained higher SOC than that of adjacent natural forest. (Table 4)

Table 4 Mean soil organic carbon stocks in different depths of monastery and adjacent natural forest.

Soil depth,cm	THMF	ANF	P value
0-20	67.9±13.6	61±13	0.24
20-40	60±9.4	58±14.3	0.8
0-40	**127.9**	**119**	

4.5 Total carbon stock t/ha^{-1} in monastery forest and adjacent natural forest

In the present study the largest carbon stock was contributed by the above ground biomass carbon pool in Tekle-Haymanot monastery forest which accounted for 48.3 % (159) and the second carbon stock was the soil carbon pool 38.9 % (127.9.) while the below ground biomass carbon pool accounted for 12.8 % (42) and the least carbon pool was in the litter carbon pool 0.015% (0.004).

In case of Adjacent natural forest study site the study result showed that the largest carbon stock was in soil carbon pool which accounted for 47.4% (119 ha^{-1}) the second was recorded in above ground biomass carbon pool which accounted for 41.8% (105 ha^{-1}) the third was the below ground biomass carbon pool which accounted for 10.7% (27 t/ ha^{-1}) and the least carbon pool was in the litter, which was 0.005% (0.013 t/ha^{-1}) respectively. The estimated total carbon stock of monastery forest was 328.9t/ha^{-1}, it was higher than that of adjacent natural forest 251 t/ha^{-1}, its Co_2e result was 1207 and 921.2 t/ha^{-1} respectively, The present study result showed that the Tekle-Haymanot monastery forest have high carbon storage than the Adjacent natural forest. (Figure 3)

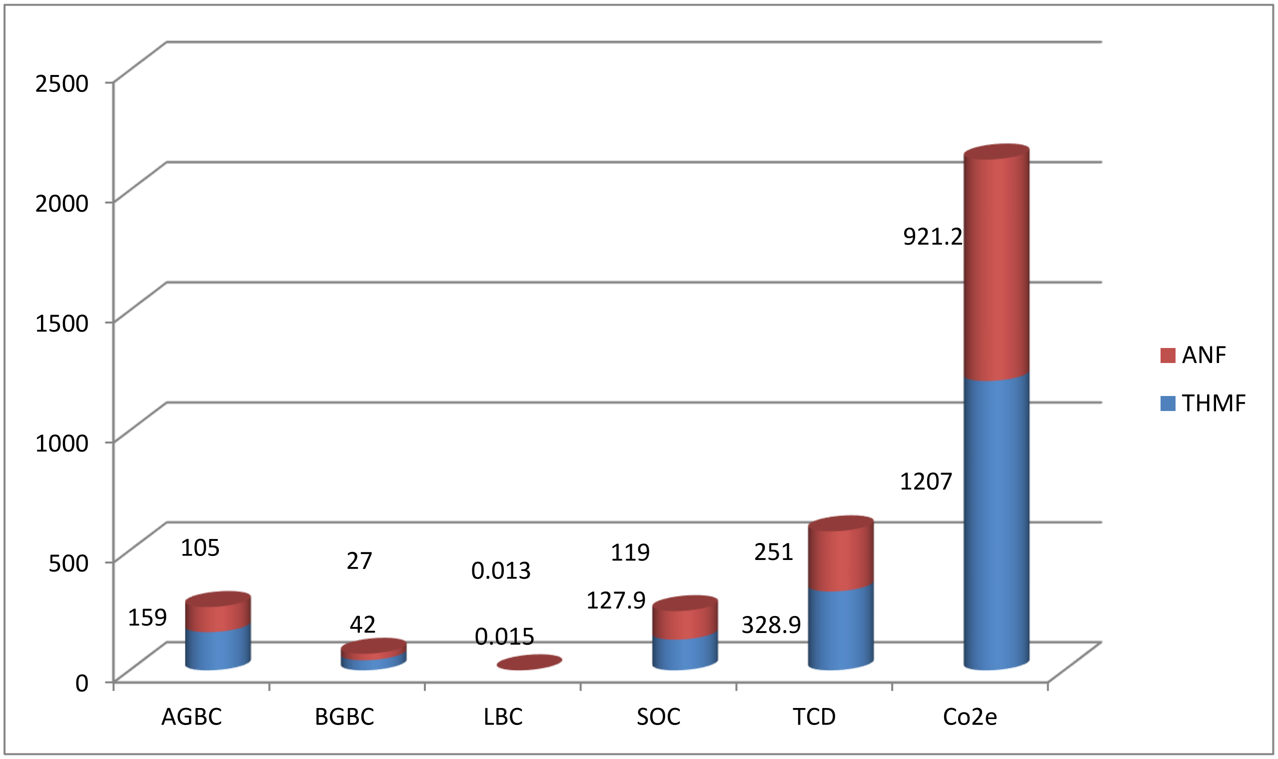

Figure 3 Total means biomass and soil organic carbon stock in monastery and adjacent natural forest.

5.Discussion

Biomass carbon was higher in monastery forest than the adjacent natural forest. The variation might come from variation of tree size, stem density and forest management.

The implications of the indigenous forest management practices which were made in line with its religious and cultural knowledge sustainability and its believers that have developed over generations through experiences. But the result was proportional with little variation than the previous studies conducted at similar biomes Meskele Gedam Dry Afromontane Forest (Dagnachew Tefera, 2016) and Menagasha Suba State Forest (MesfinSahile, 2011) and also less than Tara Gedam Forest (Mohammed Gedefaw *et al*., 2014 and greater than Selected Church Forest (Tulu Tola., 2011). This difference may be from types of species, geographical location tree size, tree density and forest management.

The most important carbon components of forest carbon is tree biomass carbon that vary among the plots of the same forest as there is considerable variation in tree size and density. Biomass is also affected by the species present and age of trees (Shibuya et al. 2005). Carbon stock was reported higher in older forest than in a regenerative forest (Ranabhat et al. 2008). Therefore, this may be one of the reasons that bring variation between carbon stocks.

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. The tree parameters used to calculate the biomass of the forest in the current study were DBH, basic Wood Density and Height. On the other side, the previous studies used only tree DBH to estimate the biomass of the corresponding forests. For example the model used for estimating aboveground carbon stock of Tara Gedam Forest (Mohammed Gedefaw *et al*., 2014) . This model excludes wood density and total height of trees, but the present study uses the model developed by (Chave *et al*., 2014).

The mean carbon stock in litter pool of the present study was 0.015 t/ha^{-1} less than the previous studies by Meskele Gedam Dry Forest (Dagnachew Tefera, 2016), Menagasha Suba State Forest (Mesfin Sahile, 2011), Selected Church Forest (Tulu Tola.2011) and also less than (2.1 t/ha^{-1}, IPCC, 2006), According to Fisher and Binkly (2000), the amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate. Similarly, the tree stands in the forest area were relatively not densely populated and this could result in low amount of litter fall .The reason for the small carbon stock of litter in the present study minimum stem and basal area contributes very low litter biomass carbon and probably due to high run off occurred and might cause for small carbon account in this pool.

Mean soil organic carbon stock of monastery forest was higher than the adjacent natural forest due to Protection and management practice by religious leaders and villagers with better practices than the adjacent natural forest. As compared present studies of SOC was almost proportional with the previous studies by Meskele Gedam Dry Afromontane Forest (Dagnachew Tefera, 2016), Menagasha Suba State Forest (MesfinSahile, 2011) and Selected Church Forest in Addis Ababa ((Tulu Tola, 2011) and also less than Tara Gedam Forest (Mohammed Gedefaw *et al*., 2014) .This similarity may be comes due to organic matter content , the type of climate and application of similar indigenous and religious knowledge in forest management practices.

The SOC content was decreased down to the soil depth increases. Soil depth 0-20 cm significance difference to the soil depth of 20-40 cm and contained significantly higher SOC stock. Bulk density values were increased with the increasing depths in study sites. But, the reverse was true for percent of SOC. In case of soil coarse fragment it has inversely proportional to SOC concentration. The result indicated that the monastery forest has high organic matter content in the soil. Therefore, according to Sheikh *et al*., (2009) the higher mean SOC stock was may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock.

As compared the total carbon density of the present study was lower than the previous studied by Tara Gedam Forest (Mohammed Gedefaw *et al.*, 2014).This result probably the study area forest characterized lower tree size and tree density and also proportional with Meskele Gedam Dry Afromontane Forest (Dagnachew Tefera, 2016), Menagasha Suba State Forest (Mesfin Sahile, 2011) and Selected Church Forest in Addis Ababa ((Tulu Tola, 2011).

The present study result shown that Tekle-Haymanot monastery forest have high carbon storage than the adjacent natural forest therefore monastery forest have high potential to decrease the rate of enrichment of atmospheric CO_2 concentration and play an important role on climate change mitigation. Church and Monasteries play a great role on indigenous and religious knowledge in forest management practices; this shows that there is a good store of indigenous forest management practices in the church, monastery and its believers that have developed over generations through experiences.

5.1 CONCLUSION AND RECOMMENDATIONS

5.2 Conclusion

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This study estimates carbon stock of (above ground, below ground, litter and soil organic carbon) between Monastery and Adjacent Natural forest. On the basis of the study and its major findings, the following conclusions are drawn.

The present study identified that total above and belowground carbon stock were higher in the Monastery Forest than the Adjacent Natural forest but the mean litter and soil organic carbon stock in the Monastery Forest were no significant difference than the Adjacent Natural forest. The total carbon stock of Tekle-Haymanot monastery Forest was 328.9t/ha^{-1}, it was higher than that of adjacent natural forest which has 251t/ha^{-1}, its Co_2e result was 1207 and 921.2t/ha^{-1} respectively. The church and monastery forests have high potential to decrease the rate of enrichment of atmospheric CO_2 concentration and play an important role on climate change mitigation.

5.3 Recommendations

- Church and monastery forests have high carbon stock potential and it should be attached with REDD+ and other projects in order to conserve forest resource and enhance the existed carbon stock.
- Awareness creation and environmental award should be given for church leaders and churches, also financial support for environmental services that are providing by churches, it will initiate the church leaders and believers for further natural resource development and sustainable forest management activities.
- Most of our community is directly and indirectly relay on their respective religions, cultures and taboos. Therefore Government should be given attention for those religious and social institutions as a central point of natural forest conservation and sustainable development actors.
- Further studies are recommended in other aspects of monastery and church forests.

6. References

Aber, J.D., Melillo, J.M. 1991. Terrestrial ecosystems. Saunders College Publishing. Philadephia, PA, USA.

Abiyou Tilahun, Hailu Terefe, Teshome Soromessa 2015. The Contribution of Ethiopian Orthodox Tewahido Church in Forest Management and Its Best Practices to be Scaled up in North Shewa Zone of Amhara Region, Ethiopia. *Agriculture, Forestry and Fisheries*. pp. 123- 137.

Alemayehu Wassie 2002. Opportunities, Constraints and Prospects of Ethiopian Orthodox Tewahido Churches in Conserving Forest Resources: The Case of Churches in South Gonder, Northern Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatterberg, Sweden.Baker, T. R. 2004. Variation in wood density determines spatial patterns in Amazonian forest biomass. Global ChangeBiology10, 545-562.

Assefa, G., Mengistu, T., Getu, Z., Zewdie, S. 2013. Training manual on: Forest carbon pools and carbon stock assessment in the context of SFM and REDD+. Wondo Genet, Ethiopia: Hawassa University Wondo Genet College of Forestry and Natural Resources.

Aynekulu, E, Vagen, T-G, Shepherd,k.,Winowiecki., L, 2011. A protocol for modeling, measurement and monitoring soil carbon stocks in agricultural landscapes. Version 1.1.World Agro forestry centre, Nairobi.

Azene Bekele. 1993. Useful Trees and Shrubs for Ethiopia: Identification, Propagation and Management for Agricultural and Pastoral Communities. RSCU/SIDA.

Baker, T. R., Philips, O. L., Malhi, Y, Almeida, S., Arroyo, L. and Di Fiore, A., 2004. Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology* 10: 545-562.

Bazzaz, F. A. 1998. Tropical forests in a future climate: Changes in biological diversity and impact on the global carbon cycle. Climatic Change, 39, 317–336.

Bhishma, P. S. 2010. Forest Carbon Stock Measurement: Guidelines for measuring carbon stocks in community-managed forests. In Asia Network for Sustainable Agriculture and Bio-resources (ANSAB) pp.17-43. Kathmandu, Nepal: publishing Funded by Norwegian Agency for Development.

Brown, S., 2002. Measuring carbon in forests: current status and future challenges. *Environmental Pollution* 116: 363-372.

Brown, K., Pearce, D. 1994. The economic value of non-market benefits of tropical forests: carbon storage. In: The Economics of Project Appraisal and the Environment: New Horizon in Environment Economics (Weiss, J.,eds.). Edward Elgar, London pp. 102-123.

Brown, S. A. 1989. Biomass estimation methods for tropical forests with application to forest inventory data. Forest Science, 35, 881–902.

Cairns, M. A., Brown, S., Helmer, E. H., Baumgarder, G.A. 1997. Root biomass Allocation is the Worlds Upland Forests. *Oecologia*..

Cairns, M.A., Brown, S., Helmer, E.H., Baumgardner, G.A. 2003. Root biomass allocation in the world‘s upland forests. *Oecologia* 111: 1-11.

Chave, J., Andalo, C.,Brown, S., Cairns, A., Chambers, Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, P., Nelson, W., Ogawa, H., Puig, H., Riéra, B., and Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia.; 145:87–99.

Chave J, R.-M.M. 2014.Improved allometric models to estimate the above ground biomass of tropical trees.Global change biology, 20, 3177–3190.

Dagnachew Tefera., 2016. Carbon Stock of Meskele-Gedam Forest and Its Contribution to Climate Change Mitigation.

Davies, J., Nori, M. 2008. Managing and mitigating climate change through pastoralism. Climate Change, Energy Change and Conservation. Policy Matters, 16,190.

Dixon, R.K. 1995. Agroforestry systems: Sources or sink of greenhouse gases? *Agroforestry Systems* 31:99-116.

Edame, E. G., Ekpenyong, B. A., Fonta, M. W., Duru, E. J. C. 2011. Climate change, food security and agricultural productivity in Africa: Issues and policy directions. International Journal of Humanities and Social Science, 1, 21.

Edwards, S., Mesfin Tadesse., Sebsebe Demissew. and Hedberg, I. 2000. *Flora of Ethiopia and Eritrea, 1st edn, Volume 2, Part 1*: Addis Ababa, Ethiopia and Uppsala, Sweden.

Edwards, S. (Ed.). 2010. Examination of Urban Agriculture in East Africa.Ethiopian Environment Review No. 1. Forum for environment. Addis Ababa Ethiopia: Forum for Environment.

FAO 2010. Carbon Finance Possibilities for Agriculture, Forestry and other Land Use Projects in a Smallholder Context. Environment and Natural Resource Management Working Paper 34. Rom, Italy.

FAO. 2011. Strengthening Capacity for Climate Change Adaptation in the Agriculture Sector in Ethiopia.

FAO (Food and Agricultural Organization of the United Nations). 2015. Global forest resources assessment 2015. Rome, Italy: Desk reference. Freestone and Streck 2009. Legal Aspects of Carbon Trading: Kyoto, Copenhagen, and beyond, First Edition, (London, United Kingdom; Oxford University Press).

FAO (Food and Agricultural Organization of the United Nations). 2016. Climate change and food security: Risks and responses. Rome, Italy: FAO.

Gorte, R. W. 2009. Carbon Sequestration in Forests.Congressional Research Service. CRS Report for Congress, (Eggleston, H. S, Buendia, L. and Miwa, K. eds). Prepared for Members and Committees of Congress. Greenhouse Gas Inventories Programmed. CRS Publishing, USA, Pp. 123.

Geider, J.R., Delucia, H.E., Falkowsk, G.P., Finzi, C.A., Grime, P.J., Grace, J., Kana, M.T.,Roche, J. 2001. Primary productivity of planet earth: biological determinants and physical constraints in terrestrial and aquatic habitats. *Global Change Biology* 7: 849-882.

Henry, H., Besnard, A., Asante, W. A., Eshun, J., Adu-Bredu, S., Valentini, R., Saint-Andre, L. 2010. Wood density, phytomass variations within and among trees, and allometric equations in s tropical rainforest of Africa. Forest Ecology and Management Journal, 260 2010, 1375–1388.

IPCC 2000 .IPCC Special Report on Land Use, Land-Use Change and Forestry.A special report of the Intergovernmental Panel on Climate Change.Approved at IPCC Plenary XVI (Montreal, 1-8 May, 2000) .IPCC Secretariat, c/o World Meteorological Organization, Geneva, Switzerland. Athttp://www.ipcc.ch/ IPCC, Land Use, Land-Use Change, and

Forestry, A Special Report of the Intergovernmental Panel on Climate Change, Cambridge, UK, 2000.

IPCC 2000. Land Use, Land Use Change & Forestry. *Special Report, Inter- Governmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, pp. 127-180.

IPCC 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. IPCC Third Assessment Report. Intergovernmental Panel on Climate Change. IPCC Secretariat, c/o World Meteorological Organization, Geneva, Switzerland. At http://www.ipcc.ch/.

IPCC 2006 *IPCC guidelines for national greenhouse gas inventories.* Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). Hayama: Institute for Global Environmental Strategies.

IPCC 2007. Climate change 2007: the physical science basis Lemma, B., Kleja, D., B., Olsson, M.,Nilsson, I. .Factors controlling soil organic carbon sequestration under exotic tree plantations: A case study using the CO2 Fix model in southwestern Ethiopia. Forest Ecol.Manage. 252(1-3): 124-131.

IPCC. 2007. The Physical Science Basis. Contribution of working Group I to the Fourth Assessment Report of the Intergovernmental.

IPCC 2014. Climate change 2014: synthesis report. In: Core Written Team, Pachauri, R.K., Meyer,L.A. (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, p. 51-151.

Jackson ML.1967. Soil Chemical Analysis. New Delhi, Prentice Hall of India Pvt. Ltd.

Jenkins JC. C. D. 2003. National-scale biomass estimators for the United States tree species. Forest Science 49, 12-35.

Jodie Keane, James MacGregor, Sheila Page, Leo Peskett and Vera Thorstensen 2010. Development, trade and carbon reduction. Working Paper 315, pp 1-8.

Kauppi, P; and Sedjo, R; 2001.Technological and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geo-engineering. In: Metz, B; (Eds.‖Climate Change 2001: Mitigation. IPCC, Cambridge University Press, New York, Chapter 4, pp. 303–353.

Kang, S. M., I. M. Held, D. M. W. Frierson, and M. Zhao, 2008. The response of the ITCZ to extra tropical thermal forcing: Idealized slab-ocean experiments with a GCM. Journal of Climate, 21 (14), 3521–3532.

Lal, R. and Bruce, J. 1999. The Potential of World Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Environmental Science and Policy 2:177–185.

Lemma, B., Kleja, D., B., Olsson, M., and Nilsson, I., 2007. Factors controlling soil organic carbon sequestration under exotic tree plantations: A case study using the CO_2 Fix model in southwestern Ethiopia. *forest ecology and management.*

MacDicken, K.G. 1997. A Guide to Monitoring Carbon Storage in Forestry and Agro- forestry Projects. In: Forest Carbon Monitoring Program. Win rock International Institute for Agricultural Development, Arlington, Virginia.

Matamala, R., Gonzàlez- Meler, M.A., Jastrow, J.D., Norby, R.J., and Schlesinger, W.H., 2003.

Matthews, R. and Rtoberston, K. 2002. Answer to Ten Frequently Asked Question about Bioenergy, Carbon Sinks and their role in Global Climate Change. IEA Bioenergy Task

38: Greenhouse Gases Balance and Bio energy Systems, Joanneum, Research, Graz, Austria.

MEFCC (Ministry of Environment, Forest and Climate Change). 2016. Ethiopia's Forest Reference Level submission to the United Nations Framework Convention for Climate Change. Addis Ababa, Ethiopia: Nova Science Publisher.

Melaku B., 1992. *Forest History of Ethiopia from Early times to* 1974. Walia: Journal of the Ethiopian wildlife and Natural History Society; 1998, No. 19, pp.3-9.

Mesfin Sahile 2011 . Estimating and Mapping of Carbon Stocks based on Remote Sensing, GIS and Ground Survey in the Menagesha Suba State Forest. M.Sc. Thesis (unpublished), Addis Ababa University.

Mohammed Gedefaw, Teshome Soromessa , Satishkumar Belliethathan 2014. Forest Carbon Stocks in Woody Plants of Tara Gedam Forest: Implication for Climate Change Mitigation. 3(1): 101-107.

Paustian, K, Antle JM, Sheehan J, Paul EA. 2006. Agriculture's role in greenhouse gas mitigation. Arlington: PEW Center on Global Climate Change.

Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for land-use, land-use change and forestry projects: Win rock International and the Bio-carbon fund of the World Bank. Arlington, USA, pp. 19-35.

Pearson, T.R., Brown, S.L. and Birdsey, R.A. 2007. Measurement guidelines for the sequestration of forest carbon: Northern research Station, Department of Agriculture, Washington, D.C, pp. 6-15.

Rees, R.M., Bingham, I., Baddeley, J., and Watson, C.A., 2005. The role of plants and land management in sequestering soil carbon in temperate arable and grassland ecosystems. *Geoderma*128: 130-154.

Reeuwijk Van LP., 2002. *Procedures for Soil Analysis.* Food and Agriculture Organization of United satate. International Soil reference and Information Centre, Wagenigen, Natherland.

Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., et al., 2008. Attributing Physical and biological impacts to anthropogenic climate change. Nature 453, 353-357.

SCBD. 2001. The Value of Forest Ecosystems. Montreal: Secretariat of the Convention on Biological Diversity.

Sheikh, M.A., Kumar, M., Bussmann, R.W. 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and Management.*

Sibanda, B., 1997. Governance and the environment of natural resources in Zimbabwe. (No. 34) Pp. 27-31.

Taye Bekele, 1998. *Biodiversity Conservation:* MSc in Forestry Graduates Magazine

Trenberth, K.E., Fasullo, J.T., Kiehl, J., 2009. Earth's Global Energy Budget. Bulletin of the American Meteorological Society 90, 311-323.

Tulu Tolla 2011. Estimation of Carbon Stock in Church Forests: Implications for Managing Church for Forest Carbon Emission Reduction. Master's Thesis, Addis Ababa University, Addis Ababa.

Ullah, M.R., and Al-Amin M., 2012. "Above- and below-ground carbon stock estimation in a natural forest of Bangladesh", Journal of Forest Science, 58(8), 372–379.

UNFCCC, 2017 Forest reference emission level report of Ethiopia.

UNFCCC, 2016. Ethiopia's forest reference level submission.

UNFCCC, 2011. Fact sheet: Climate change science - the status of climate change science today.

UNFCCC/ CCNUCC 2009. Project Design document form for afforestation and reforestation project activities (CDM-AR-PDD) - Version 04; CDM. Executive Board.

UNFCCC 1997. Kyoto Protocol to the United Nation Framework Convention on Climate Change. Retrieved 18/09/2010, from http://unfccc.int. University Press, Cambridge, UK.

Van der Werf, G. R. Morton, D. C., DeFries, R. S., Olivier, J. G. J., Kasibhatla, P. S., Jackson R.B.,Collatz, G. J. and Randerson, J. T. 2009. 'CO_2 emissions from forest loss', Natur Geoscience 2, 737-738.

Victor, D. 2015. To burn or not to burn: Transition from savanna to forest in the 'mise endéfens' in Manzonzi (Bas - Congo province in the Democratic Republic of Congo) (Submitted Master's Thesis). Ghent University, Ghent, Belgium.

Watson, C. 2008. Forest Carbon Accountings : Overview and Principles CDM Capacity Development in East and Southern Africa , London School of Economics and Political Science, UK.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J., Dokken, D.J. (eds) 2000. Land Use, Land-Use Change, and Forestry. Intergovernmental Panel on Climate Change (IPCC), Special report. Cambridge University Press, UK. 375 pp.

Yeraswork Admassie 1995. Twenty years to now here: property rights, land management and conservation in Etthiopia. PhD Dissertation, Uppsala:Uppsala University.

Yitebitu Moges, Zewdu Eshetu and Sisay Nune., 2010. Ethiopian Forest Resources: Current Status and Future Management Options in View of Access to Carbon Finances. A Review: Prepared for the Ethiopian Climate Research and Networking and the United Nations Development Program (UNDP).

Zanne AE, L.-G.G. 2009.Dryad Digital Repository.

Zerihun Getu, Gemedo Dale, Motuma Tafa, Njogu, J. G and Tesfaye Gonfa 2011. Carbon stock assessment in different land uses.

APPENDICES.

Appendix 1: Plot wise above and below ground biomass and carbon stock of THM (Tekle-Haymanot Monastery Forest)

Plot number	AGB kg/ Plot	AGB kg/ha^{-1}	AGB t/ha^{-1}	AGC t/ha^{-1}	AGC co_2e t/ha^{-1}	BGB t/ha^{-1}	BGC t/ha^{-1}	BGC co_2e t/ha^{-1}
1	13438.2	335954.6	336	158	579.86	87	41	150.47
2	16341.2	408531.0	409	192	704.64	106	50	183.5
3	13855.7	346391.5	346	163	598.21	90	42	154.14
4	15219.5	380487.8	380	179	656.93	99	46	168.82
5	12761.6	319039.5	319	150	550.5	83	39	143.13
6	10602.8	265069.1	265	125	458.75	69	32	117.44
7	14075.3	351882.2	352	165	605.55	91	43	157.81
8	16210.8	405270.9	405	190	697.3	105	52	190.84
9	13562.0	339049.1	339	159	583.53	88	41	150.47
10	15235.9	380897.5	381	179	656.93	99	47	172.49
11	14519.9	362997.1	367	171	627.57	94	44	161.48
12	13053.3	326332.5	326	153	561.51	85	40	146.8
13	11763.5	294087.1	294	138	506.46	76	36	132.12
14	12242.6	306065.7	306	144	528.48	80	37	135.79
15	12083.0	302076.2	302	142	521.14	79	37	135.79
16	12647.6	316191.0	316	149	546.83	82	39	143.13
17	10667.1	266678.5	267	125	458.75	69	34	124.78
18	12337.1	308428.7	308	145	532.15	80	36	132.12
19	17172.5	429311.3	429	202	741.34	112	52	190.84
20	11553.9	288847.4	289	136	499.12	75	35	128.45

21	11990.0	299750.0	299	140	513.8	78	37	135.79
22	11368.0	284200.3	284	134	491.78	74	35	128.45
23	9468.1	236701.4	237	111	407.37	62	29	106.43
24	20015.1	500376.6	500	235	862.45	130	61	223.87
25	14988.0	374700.9	375	176	645.92	97	46	168.82
26	12502.2	312555.3	313	147	539.49	81	38	139.46
27	16299.7	407492.9	407	192	704.64	106	50	183.5
28	9419.1	235477.4	235	105	385.35	61	29	106.43
29	18670.6	466765.4	467	219	803.73	121	57	209.19
30	13332.3	333308.2	333	157	576.19	87	41	150.47

Appendix 2 : Plot wise above and below ground biomass and carbon stock of ANF (Adjacent Natural Forest)

Plot number	AGB kg/ Plot	AGB kg/ha^{-1}	AGB t/ha^{-1}	AGC t/ha^{-1}	AGC co$_2$e t/ha^{-1}	BGB t/ha^{-1}	BGC t/ha^{-1}	BGC co$_2$e t/ha^{-1}
1	9382.8	234570.1	235	110	405	61	29	106.4
2	10556.4	263910.4	264	124	455	69	32	117.4
3	5877.9	146946.4	147	69	253	38	18	66.1
4	8867.7	221693.4	222	104	382	58	27	99.1
5	5258.5	131462.6	131	62	228	34	16	58.7
6	10320.3	258008.7	258	121	444	67	32	117.4
7	9228.3	230708.4	231	108	396	60	28	102.8
8	7445.5	186138.3	186	87	319	48	23	84.4
9	7596.1	189902.7	190	89	327	49	23	84.4

10	8367.4	209184.0	209	98	360	54	26	95.4
11	8711.7	217791.9	218	102	374	57	27	99.1
12	8567.5	214186.7	214	101	371	56	26	95.4
13	7527.3	188183.5	188	88	323	49	23	84.4
14	5449.8	136245.2	136	64	235	35	17	62.4
15	10179.5	254487.0	254	120	440	66	31	113.8
16	6563.6	164089.9	164	77	283	43	20	73.4
17	9896.1	247402.4	247	116	426	64	30	110.1
18	8753.4	218834.4	219	103	378	57	24	88.1
19	8622.9	215572.3	216	101	371	56	26	95.4
20	11639.7	290992.3	291	137	503	76	36	132.1
21	8059.1	201476.5	201	95	349	52	25	91.8
22	18747.1	468676.5	469	220	807	122	57	209.2
23	9457.7	236442.9	236	111	407	62	29	106.4
24	5209.2	130229.6	130	61	224	34	12	44.0
25	8585.8	214643.8	215	101	371	56	26	95.4
26	10552.6	263815.4	264	124	455	69	32	117.4
27	11873.8	296845.6	297	140	514	77	36	132.1
28	10272.4	256811.2	257	121	444	67	31	113.8
29	7905.7	197643.2	198	93	341	51	24	88.1
30	9736.5	243412.5	243	114	418	63	30	110.1

Appendix 3 : Plot wise Litter biomass and carbon stock of THMF (Tekle-Haymanot Monastery Forest)

PLOT no	fresh wt at field (g)	Area	Fresh wt sample (g)	oven dry wt (g)	LB (t/ha^{-1})	LBC (t/ha^{-1})	LBC co_2 e (t/ha^{-1})
1	580	$1m^2$	100	90.3	0.052	0.019	0.071
2	600	$1m^2$	100	79.6	0.048	0.018	0.065
3	400	$1m^2$	100	87.9	0.035	0.013	0.048
4	380	$1m^2$	100	88.3	0.034	0.012	0.046
5	480	$1m^2$	100	84.9	0.041	0.015	0.055
6	550	$1m^2$	100	85	0.047	0.017	0.063
7	550	$1m^2$	100	85.8	0.047	0.017	0.064
8	550	$1m^2$	100	84.3	0.046	0.017	0.063
9	450	$1m^2$	100	84.4	0.038	0.014	0.052
10	550	$1m^2$	100	74.9	0.041	0.015	0.056
11	600	$1m^2$	100	85.6	0.051	0.019	0.070
12	400	$1m^2$	100	84.6	0.034	0.013	0.046
13	450	$1m^2$	100	86.4	0.039	0.014	0.053
14	350	$1m^2$	100	86.7	0.030	0.011	0.041
15	400	$1m^2$	100	85.7	0.034	0.013	0.047
16	450	$1m^2$	100	86.3	0.039	0.014	0.053
17	480	$1m^2$	100	85.1	0.041	0.015	0.055
18	500	$1m^2$	100	87.1	0.044	0.016	0.059
19	450	$1m^2$	100	82.7	0.037	0.014	0.051
20	550	$1m^2$	100	86.8	0.048	0.018	0.065

21	500	$1m^2$	100	82.2	0.041	0.015	0.056
22	600	$1m^2$	100	80.6	0.048	0.018	0.066
23	480	$1m^2$	100	79.9	0.038	0.014	0.052
24	400	$1m^2$	100	79.8	0.032	0.012	0.043
25	400	$1m^2$	100	85.7	0.034	0.013	0.047
26	500	$1m^2$	100	87.6	0.044	0.016	0.059
27	400	$1m^2$	100	81.5	0.033	0.012	0.044
28	480	$1m^2$	100	78.4	0.038	0.014	0.051
29	380	$1m^2$	100	83.8	0.032	0.012	0.043
30	500	$1m^2$	100	84.2	0.042	0.016	0.057

Appendix 4 : Plot wise Litter biomass and carbon stock of ANF (Adjacent Natural Forest)

PLOT no	fresh wt at field (g)	Area	Fresh wt sample (g)	oven dry wt (g)	LB (t/ha^{-1})	LBC (t/ha^{-1})	LBC co_2 e (t/ha^{-1})
1	250	$1m^2$	100	84.6	0.02	0.008	0.029
2	380	$1m^2$	100	84.2	0.03	0.012	0.043
3	300	$1m^2$	100	87.2	0.03	0.010	0.036
4	250	$1m^2$	100	84.1	0.02	0.008	0.029
5	340	$1m^2$	100	91.5	0.03	0.012	0.042
6	400	$1m^2$	100	85.7	0.03	0.013	0.047
7	480	$1m^2$	100	89	0.04	0.016	0.058
8	380	$1m^2$	100	84.8	0.03	0.012	0.044

9	350	$1m^2$	100	82.8	0.03	0.011	0.039
10	600	$1m^2$	100	88.2	0.05	0.020	0.072
11	350	$1m^2$	100	86	0.03	0.011	0.041
12	450	$1m^2$	100	86.6	0.04	0.014	0.053
13	350	$1m^2$	100	88.7	0.03	0.011	0.042
14	350	$1m^2$	100	85.9	0.03	0.011	0.041
15	400	$1m^2$	100	87.3	0.03	0.013	0.047
16	480	$1m^2$	100	87.5	0.04	0.016	0.057
17	380	$1m^2$	100	83.3	0.03	0.012	0.043
18	250	$1m^2$	100	87.5	0.02	0.008	0.030
19	400	$1m^2$	100	89.9	0.04	0.013	0.049
20	320	$1m^2$	100	87.2	0.03	0.010	0.038
21	400	$1m^2$	100	91	0.04	0.013	0.049
22	550	$1m^2$	100	87	0.05	0.018	0.065
23	500	$1m^2$	100	90.8	0.05	0.017	0.062
24	300	$1m^2$	100	86.5	0.03	0.010	0.035
25	450	$1m^2$	100	89.6	0.04	0.015	0.055
26	450	$1m^2$	100	91.4	0.04	0.015	0.056
27	350	$1m^2$	100	88.5	0.03	0.011	0.042
28	580	$1m^2$	100	87.8	0.05	0.019	0.069
29	450	$1m^2$	100	90.1	0.04	0.015	0.055
30	380	$1m^2$	100	87.3	0.03	0.012	0.045

Appendix 5 : Plot wise soil organic carbon stock of THMF (Tekle-Haymanot Monastery Forest)

SN	plot no.	Study site	Layer	BD (gm) /cm^3	% of coarse fragment	Core volume	% OC	SOC (t/ha^{-1})	CO_2 e (t/ha^{-1})
1	1	THMF	0 -20	0.76	12.1	565.2	4.5	60	221
2	4	THMF	0 -20	0.72	19.4	565.2	6.3	73	268
3	7	THMF	0 -20	0.76	14.1	565.2	5.3	69	254
4	10	THMF	0 -20	0.73	27.2	565.2	4.64	49	181
5	13	THMF	0 -20	0.68	14.2	565.2	7.06	82	302
6	16	THMF	0 -20	0.72	14.8	565.2	5.72	70	258
7	19	THMF	0 -20	0.67	4.5	565.2	4.3	55	202
8	22	THMF	0 -20	0.69	8.5	565.2	7.07	89	328
9	25	THMF	0 -20	0.71	35.1	565.2	5.65	52	191
10	28	THMF	0 -20	0.73	15.7	565.2	6.48	80	293
11	1	THMF	20 -40	0.8	2.8	565.2	3.7	58	211
12	4	THMF	20 -40	0.78	9.9	565.2	5.18	73	267
13	7	THMF	20 -40	0.81	6.6	565.2	4	61	222
14	10	THMF	20 -40	0.79	5.3	565.2	3.93	59	216
15	13	THMF	20 -40	0.74	3.6	565.2	4.31	61	226
16	16	THMF	20 -40	0.76	9.3	565.2	5.38	74	272
17	19	THMF	20 -40	0.74	4.5	565.2	3.53	50	183
18	22	THMF	20 -40	0.79	24	565.2	3.52	42	155
19	25	THMF	20 -40	0.82	11.9	565.2	3.86	56	205
20	28	THMF	20 -40	0.78	15.7	565.2	4.66	61	225

Appendix 6 : Plot wise soil organic carbon stock of ANF (Adjacent Natural Forest)

SN	plot no.	Study site	Layer	BD (gm) /cm^3	% of coarse fragment	Core volume	% OC	SOC (t/ha^{-1})	CO_2 e (t/ha^{-1})
1	1	ANF	0 -20	0.69	2.2	565.2	3.76	51	186
2	4	ANF	0 -20	0.71	14	565.2	5.02	61	225
3	7	ANF	0 -20	0.66	11.8	565.2	5.07	59	217
4	10	ANF	0 -20	0.71	54.5	565.2	5.13	33	122
5	13	ANF	0 -20	0.77	5.2	565.2	4.02	59	215
6	16	ANF	0 -20	0.71	8.1	565.2	6.25	82	299
7	19	ANF	0 -20	0.64	16.4	565.2	5.87	63	231
8	22	ANF	0 -20	0.72	10	565.2	5.58	72	265
9	25	ANF	0 -20	0.75	12.6	565.2	4.5	59	217
10	28	ANF	0 -20	0.79	11.3	565.2	4.92	69	253
11	1	ANF	20 -40	0.79	2.8	565.2	2.02	31	114
12	4	ANF	20 -40	0.93	4.3	565.2	3.16	56	206
13	7	ANF	20 -40	0.72	6.6	565.2	3.85	52	190
14	10	ANF	20 -40	0.78	5.4	565.2	4.18	62	226
15	13	ANF	20 -40	0.83	13.1	565.2	3.22	46	170
16	16	ANF	20 -40	0.87	9.9	565.2	5.18	81	298
17	19	ANF	20 -40	0.73	10.2	565.2	4.18	55	201
18	22	ANF	20 -40	0.78	5.9	565.2	5	73	269
19	25	ANF	20 -40	0.82	11.9	565.2	3.83	55	203
20	28	ANF	20 -40	0.99	7.9	565.2	3.83	70	256

Appendix 7 : Location data of THMF (Tekle-Haymanot Monastery forest)

Plot No.	Transect line	Altitude (m)	Latitude (X), (UTM)	Longitude (Y), (UTM)
1	1	2770	605632	774786
2	1	2767	605530	774781
3	1	2760	605436	774779
4	1	2749	605334	774780
5	1	2755	605231	774788
6	1	2759	605133	774784
7	1	2752	605030	774781
8	1	2765	604928	774783
9	1	2767	604832	774783
10	1	2770	604728	774788
11	1	2755	604632	774782
12	2	2760	604635	774889
13	2	2750	604732	774877
14	2	2757	604834	774889
15	2	2768	604933	774881
16	2	2769	605037	774885
17	2	2774	605102	774882
18	2	2769	605232	774880
19	2	2773	605334	774879
20	2	2768	605431	774883
21	3	2765	605435	774987
22	3	2760	605332	774985

23	3	2764	605230	774989
24	3	2755	605135	774986
25	3	2758	605027	774982
26	3	2765	604936	774985
27	3	2767	604833	774984
28	3	2770	604731	774987
29	3	2772	604629	774981
30	3	2769	604530	774990

Appendix 8 : Location data of ANF (Adjacent Natural Forest)

Plot No.	Transect line	Altitude (m)	Latitude (X), (UTM)	Longitude (Y), (UTM)
1	1	2810	604293	771394
2	1	2795	604291	771490
3	1	2802	604290	771593
4	1	2804	604288	771691
5	1	2809	604289	771793
6	1	2803	604295	771891
7	1	2795	604287	771995
8	1	2803	604291	772094
9	1	2797	604284	772191
10	1	2805	604290	772294
11	2	2810	604183	772292

12	2	2808	604194	772193
13	2	2806	604197	772093
14	2	2805	604191	771989
15	2	2809	604195	771894
16	2	2803	604190	771795
17	2	2805	604188	771692
18	2	2808	604193	771590
19	2	2809	604195	771493
20	2	2803	604091	771394
21	3	2810	604087	771392
22	3	2813	604094	771495
23	3	2811	604092	771594
24	3	2814	604095	771696
25	3	2812	604092	771795
26	3	2810	604089	771893
27	3	2808	604092	771992
28	3	2811	604090	772094
29	3	2810	604095	772193
30	3	2812	604091	772294

Appendix 9 : Botanical name, number of tree species and abundance, mean DBH and Height and frequency of species

Botanical name	Vernacular name in Amharric	Number of trees	Abundance	Number of stem/ ha^{-1}	Mean DBH	Mean Height	Frequency %
Juniperus procera	Yehabesha tsid	647	60	270	34	17	100
Olea africana	Weira	170	56	71	27	15	93.33
Rosa abyssinica	Kega	33	13	14	8	6.5	21
Maytenus arbutifolia	Atat	58	31	24	38	17	51.66
Hagenia abyssinica	Kosso	40	19	17	42	20	31.66