ASSESSMENT OF BIOMASS AND SOIL CARBON STOCKS OF EUCALYPTUS GLOBULUS IN GRABOCAN PLANTATIONS ALONG ELEVATION GRADINETS IN MINJARN DISTRCT, NORTHERN ETHIOPIA

M.Sc. THESIS

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HAWASSA UNIVERSITY, WONDO GENET, ETHIOPIA

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A THESIS SUBMITTED TO THE

DEPARTMENT OF FORESTRY, WONDO GENET COLLEGE OF FORESTRY AND ANATURAL RESOURCES,SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY WONDO GENET, ETHIOPIA

IN PARTIAL FULFILMENT OF THE

REQUIREMENTS FOR

THE DEGREE OF

MASTER OF SCIENCE IN FORESTRY

(SPECIALIZATION: FOREST RESOURCE ASSESSMENT AND MONITORING)

APPROVAL SHEET- I

This is to certify that the thesis entitled "***Assessment of Biomass and Soil Carbon Stocks of E. globulus in Grabocan Plantations Along Elevation Gradinets in Minjarn Distrct, Northern Ethiopia***" submitted in partial fulfillment of the requirement for the degree of Master of Sciences with specialization in Forest Resource Assessment and Monitoring of the Graduate Program of the School of Natural Resources and Environmental Studies, Wondo Genet College of Forestry and Natural Resources, is a record of original research carried out by Tegene Tadesse Bekele Id. No. MSC/FRAM/R0019/09, under my supervision; and no part of the thesis has been submitted for any other degree or diploma. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Mesele Negash (PhD)

Name of Major Advisor	Signature	Date

Approval Sheet II

We, the undersigned, members of the board of examiners of the final open defense by Tegene Tadesse have read and evaluated his thesis entitled "Assessment of Biomass and Soil carbon stocks of *E. globules* plantations along elevation gradients of garabocan state plantation, in Minjarnashenkora district, Northern 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 in Forest Resource Assessment and Monitoring

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SGS Aproval Signature Date

Final Approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of Graduate studies (SGS) through the Department/School Graduate Committee (DGC/SGC) of the candidates department.

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Declaration

I, Tegene Tadesse Bekele, hereby the declare that this thesis entitled "Assessment of Biomass and Soil carbon stocks of *E. globules* plantations along elevation gradients of garabocan state plantation, in minjar district, Northern Ethiopia "summited for partial fulfillment of the requirements for the Master of science in Forest Resource Assessment and Monitoring, is the original work done by me under the supervision of Dr. Mesele Negash. This thesis has not been published or summited elsewhere for the requirement of a degree program to the best of my knowledge and belief. Materials or ideas of other authors used in this thesis have been duly acknowledged and referenced well at the end of the main text.

Tegene Tadesse Bekele	________________________	_______________
Name of student	Signature	Date

Dedication

To my wonderful wife and daughters.

Acronyms

AGB	Aboveground Biomass
AGBC	Aboveground Biomass Carbon
ANOVA	Analysis of Variance
BGB	Belowground Biomass
BGBC	Belowground Biomass Carbon
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CRGE	Climate Resilient Green Economy
DBH	Diameter at Brest Height
FAO	Food and Agricultural Organization of United Nations
GPS	Geographical Positioning System
IPCC	Intergovernmental Panel for Climate Change
REDD+	Reducing Emission from Deforestation and Forest Degradation "Plus "conservation, sustainable management of forests and Enhancements of forest carbon stocks
SOC	Soil Organic Carbon
MSDARDB	Minjar-Shenkora District Agriculture and Rural Development Bureau
NSZARDB	North Showa Zone Agriculture and Rural Development Bureau
MSW	Minjarnashenkora Woreda
GBPF	Garabocan Plantation Forest

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Abstract

*Plantation forests can capture and retain carbon in their biomass and soil over time. Carbon stock estimation provides information on the current status of the carbon stock of the forest and important to know the future change by deriving from it. The present study was conducted to estimate the carbon stock and its variation along the elevations gradients in Garabocan state plantation forest found in Amhara Regional State of Ethiopia. After the reconnaissance survey, t*he site was stratified based on three elevations ranges *including lower, middle and higher. Nested plots of size 20m * 20m as main plots were systematically established and used for tree inventory. Three 1m * 1m sub-sample plots within the main plots were selected for soil and litter sampling. Data of trees whose DBH (≥ 5 cm) and total tree height were measured in the main plot using diameter caliper and hypsometer respectively. The litter was collected from three sub-sample plots 1 m x 1 m laid randomly within the main plots. To analyze the total biomass carbon stock was analyzed using locally developed biomass allometric equation for E.globulus at kofele and degaga was used for determining above ground biomass. In this study the carbon stocks in above ground, below ground, litter and soil of E. globulus plantation assessed. A total of 34 sample plots sized constituting 13 lower, 11 meddle and 10 higher elevation, were inventoried and soil sampled. Soil samples for carbon content determination were collected from three randomly selected sub-sample pots 1m * 1m in the main plots from the soil depth 0 - 20 cm, 20 - 40 cm and 40-60 cm using auger method. Similarly, soil samples were taken from 0 - 60 cm soil depth (0 - 20 cm, 20 - 40 cm and 40 - 60 cm in layers) to determine soil bulk density using core method. The result indicated that the average basal area (m^2/ha) in the study site was* 48.72 m^2/ha. *The above ground biomass carbon significantly highest the lower elevation (342.09 ± 43.60 t ha^{-1}), middle elevation (339.03 ± 32.61 t ha^{-1}) and lowest in lower elevation (257.44 ± 18.01 t ha^{-1}). The below ground biomass carbon was also significantly highest in lower elevation (88.94 ± 26.99 t/ha^{-1}) and lowest in upper elevation (66.93 ± 20.19 t/ha^{-1}). The litter biomass carbon stocks in both middle and higher elevations were significantly different from lower elevation. Results showed that bulk density, soil organic carbon concentration (%) varied significantly with elevations (p=0.000) and soil depth (p=0.000). The bulk density value was found to increase when soil depth increased but, soil organic carbon concentration (%) and stock was decreased when soil depth increased for all elevations ranges. The mean soil organic carbon stock was significantly highest in higher elevation (108.9 t/ha^{-1}) and lowest middle elevations (96.89 t/ha^{-1}). It was significantly highest in the top layer of soil (40.19 ± 13.85 t/ha^{-1}) and lowest in sub-surface of soil (29.52 ± 13.74 t/ha^{-1}). With respect to elevations ranges, it was significantly highest in higher elevations and lowest in the middle elevations ranges. The overall, carbon stock (biomass and soil) of the studied plantation was 496.84 t ha^{-1}. The ultimate result entailed that GBPF is a reservoir of high carbon. Thus, GBPF should be given special concern to manage it sustainably, to keep ecosystem services running smoothly and benefit from future carbon financing opportunities.*

Key words; Carbon sequestration, Ecosystem, litter, bulk density

1. INTRODUCTION

1.1 Back ground

Man-made plantation forests are widely practiced and found in the country.The dominant plantation forests are composed of four genera (Eucalyptus, Cupressus, Pinus and Acacia). Eucalyptus accounts for; the lion's share of the plantation forest in the country (90 %) followed by Cupressus lusitanica, Juniperus procera and Pinus spp, respectively (WBISPP, 2005; Moges et al., 2010; Bekele, 2011). Eucalyptus is also the first exotic tree species to be formally introduced to Ethiopia by Emperor Minilik II from Australia in 1890s (Pukkala and Ponjonen, 1990). Sixty different species of genus of Eucalyptus are reported to have been introduced to Ethiopia, but E. globulus and E. camaldulensis are the most wide spread of all (Lemenih and Kassa, 2014). The area coverage of Eucalyptus plantation steadily increased since its introduction, for example it was only 5000 hectares in 1890s (Getahun, 2010) and increased to 896, 240 hectares in 2011 (Bekele, 2011).

The potential of forests in naturally sequestering carbon in the atmosphere, which is important to climate change mitigation and recognized by international climate agreements (IPCC, 2007a). The main carbon pools in tropical forest ecosystems are above ground carbon,beleow ground carbon, litter carbon dead wood and SOC. (Genene Assefa *et al*., 2013). As the result of deforestation and forest degradation make up 12 to 20 % of annual greenhouse gas emission, which is more than all forms of transport combined (Saatchi *et al*., 2011). IPCC (2007a) in its fourth assessment reports emphasized to reduce deforestation and enhance forest carbon stocks as the mitigation option to store and sink the carbon emitted from clearing of forests. Unlike, in the developed countries, Ethiopia does not have enough carbon inventories and data bank to monitor and enhance carbon sequestration potential of different forests. Different scholars like (Biniyam Alemu (2014) agreed on the needs of studying and documenting the vegetation resources of Ethiopia. Even though, various scholars have studied the forest of Ethiopia, only small efforts have been made so far to quantify the forest carbon stock, biomass and soil carbon sequestration potential at small scale level with comparing the forest potential of Ethiopia particularly woodland vegetation. Because of this and to fill some gaps between area limitation and scarcity of data on woodland vegetation carbon stock of the Ethiopian woodland coverage, the study was important to management of forest to show the win-win strategies for the welfare of human society beside their aesthetic, spiritual, and recreational value. However, no related study has been made in the Grabocan plantation forest that aimed to investigating the carbon stock potential. Therefore, this study was undertaken to estimate the carbon stock of the Grabocan plantation forest and to see the variations in carbon stocks of different carbon pools under different elevation gradient.

1.2 Statement of the Problem

Today, due to concerns of climate in global carbon trade, estimating carbon stored in forests is increasingly important. Climate change is a global alarm that should be addressed. In response to this global worry, the government of Ethiopia has aimed at keeping emissions constant by applying abatement measures in sectors such as forestry, agriculture and industry. Afforestation, reforestation, and deforestation prevention recognized as possible means of offsetting anthropogenic carbon emissions and as a result, developed countries have begun to invest in forestry based carbon offset projects in developing countries. Ethiopia designed CRGE and implementing REDD+ and CDM through plantation by planned of forest coverage enhancement, to achieve the economic growth as well as to mitigate the climate change impacts (Negra, C., 2014).

Unlike the developed countries, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. Carbon stock is varying from forest to forest, from soil to soil and the intensity of different silvicultural operations. However, limited number of studies is available regarding carbon stock for the different forest types, the soils underneath and plantations of various species of which *E.globulus* is the major one. Only few activities about carbon sequestration potential published recently (Alefu Chinasho et al., 2015). The role of *E.globulus* in the study areas is for fuel production and this needs estimation amount of biomass contribution. But no adequate study in these regards. Therefore, this study was aimed to investigate the variation on biomass and soil organic carbon stocks of *E.globulus* plantations with elevation gradiants.

1.3 Objectives

1.3.1 General objective

- The general objectives of this study are to determine carbon stocks in Garabocan state plantation, in minjar district, Northern Ethiopia.

1.3.2 Specific objectives

- To determine and compare above and below ground biomass and litter carbon stocks along the elevation gradients in the study site
- To determine and compare soil carbon stocks of *E. globules* plantations along the elevation gradients
- To determine the total carbon stocks (biomass and soil carbon) of plantation forest

1.4 Hypothesis

- H_o: There is no significance difference on biomass and soil organic carbon stock along elevation gradients.
- H_I: There is a significance difference on biomass and soil organic carbon stock along elevation gradients.

1.5 Significance of the study

The study will give significant information to policy makers that may formulate policies that will enhance and compare carbon stocks of the three elevation range mentioned above and also it can provide organized document for researchers, government non-governmental organization as well as other concerned bodies who endeavors for climate change mitigation.

REDD+ (Reducing Emission from Deforestation and Forest Degradation, conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks) requires scientific-based information about all forest types. In this regard, the quantification of above and below ground biomass carbon stocks, soil organic carbon and litter biomass carbon stocks is important to feeding with massive global data sets such as those of the IPCC (Intergovernmental panel on Climate Change), CDM, and REDD+.

The main output of this study will benefit government by filling the information gap on the carbon stock potential of different elevation range of plantation forest in the study area.

2. Literature Review

2.1 The introduction of Eucalyptus tree species in to Ethiopia

Exotic species of Eucalyptus have firstly been introduced in to Ethiopia around the end of the 19th century. As Zewdie (2008) indicated growing Eucalyptus began in Ethiopia around 1890,during the regime of Emperor Menelik II with the aim to minimize the shortage of wood. This effort mainly concentrated on the establishment of Eucalyptus plantations near the capital Addis Abeba and other towns by introducing seeds of 15 species of Eucalyptus from Australia (UNSO, 1991 cited in Zerfu, 2002). The species were grown in central plateaus of Ethiopia at altitudes ranging from 1400 to 3500 m.a.s.l and in rainfall zones of 700-2000 mm per year. Of the introduced species, E. globules performed well in terms of survival and fast growth. E. camaldulensis is the second most common Eucalyptus species often grown in lower altitudes (Zerfu, 2002).

In the Ethiopian highlands, where deforestation and woody biomass crisis are the major problems, Eucalyptus is the prominent tree species in government and community estate plantations. This dominance of Eucalyptus species is mostly due to their relatively easy and fast propagation by coppicing, high rate of biomass production and resistance to browsing which is one important attribute especially in the highlands where free grazing is dominantly practiced. According to Friis (1995) there are around 55 species of Eucalyptus in Ethiopia.

During the early 1980s, the government initiated Eucalyptus planting through state-owned plantation programmes and fuel wood plantation projects were part of the government decisions and led to Eucalyptus plantation establishment programs. (Zerfu, 2002).

2.2 The Role of plnatation forest

In Ethiopia, tree planting carried out by different stake holders. Large-scale plantations, mainly monocultures of Eucalyptus, Cupressus lusitanica and Pinus species have been established with the aim to increase the supply of timber products, protect the remaining natural forest and achieve an ecological restoration of degraded sites. (Anatoli Poultouchidou, 2012). Particularly in the past five years, there has been a mass mobilization in soil and water conservation, which include both physical and biological activities. According to the Federal Democratic Republic of Ethiopia, Ministry of Environment, Forest and Climate Change proposal for REDD+ investment in Ethiopia (2017 - 2020), the total forest coverage of the country is 17.2 million ha covering 15.5 per cent of the country (MEFCC, 2015). According to Ethiopia forest sector review (2017), plantation forest coverage of the country is estimated to be 909,500 ha (MEFCC, 2017). Eucalyptus is one of the most widely planted species in Ethiopia and similarly this species is the best performing exotic species planted out in the studied areas.

Ethiopia is one of the developing countries, which have designed CRGE to achieve the economic growth as well as to mitigate the climate change impacts. Today, the country has prepared to implement REDD+ as well as CDM through plantation by planned forest coverage enhancement (FDRE, 2011).

It is widely recognized that forests have paramount role in climate change mitigation because they store a large amount of carbon in vegetation biomass and soil (Falkowski *et al*., 2000) and they are also a critical component of the global carbon cycle, storing over 80% of global terrestrial above ground carbon (FAO, 2014a). Hence, forest ecosystem is known to be costeffective ways of reducing global CO_2 emissions which is the major GHG causing climate change (Anup *et al*., 2013). They have also tremendous potential to contribute to sustainable development and to a greener economy (FAO, 2014b). Forest ecosystems store carbon through the photosynthetic assimilation of atmospheric CO_2 and the subsequent storage in the form of biomass (trunks, branches, foliage, roots, etc.) (Malhi *et al*., 2002; Houghton, 2005), litter, woody debris, soil organic matter and forest products (Malhi *et al*., 2002), and organic carbon in the soil (Houghton, 2005). As Yitebitu Moges *et al*. (2010) pointed out that the forest resources of Ethiopia can store about 2.76 billion tons of carbon, playing a significant role in the global carbon balance provided that the nightmare scenario on forests is critically managed. In such away, forests being protected and more carbon in the atmosphere sequestered and enhanced carbon stock in the biomass of forests, consequently climate change mitigation through forests can be achieved and enabled to generate forest carbon credit, positive impact to the economy and environment (FAO, 2010b.

2.3 Carbon pools of plantation forests

Tropical plantation forests have important role for carbon stock in a much higher quantity than any other biome (Bracmort and Gorte, 2009). Studies on C-stock in tropical forests have been carried out by several researchers, either measured directly based on destructive sampling in experimental plots (Miyamoto *et al*., 2007) or estimated based on volume data of forest inventories (Brown *et al*., 1989). However, most of the studies focused on the estimation of forest biomass and C-stock at one occasion. Forest biomass and C-stock may be dynamic and changes occur continuously at individual tree and stand levels throughout time due to loss of carbon during deforestation and degradation caused by human activities and accumulation of carbon during regrowth of forests (Miyamoto *et al*., 2007).

It is estimated that the carbon stored globally in the forest biomass amounts to 2,40,439 Mt with an average carbon density of 71.5 t ha^{-1} and a recent estimate indicates that tropical forests account for 247 Gt vegetation carbon, of which 193 Gt is stored above ground (Saatchi *et al*., 2011).

2.4 Carbon pools

Carbon pool refers a system which has the capacity to accumulate or release carbon (IPCC, 2006). There are five carbon pools of terrestrial ecosystem involving biomass, namely the aboveground biomass, belowground biomass, the dead mass of litter, woody debris and soil organic matter (IPCC, 2006). The belowground biomass that comprises all the live roots (IPCC, 2006) plays an important role in the carbon cycle by transferring and storing carbon in the soil (Vashum and Jayakumar, 2012). 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). Soil organic matter is also a chief contributor to the carbon stocks of forests (Lal, 2004).

2.4.1 Above ground biomass Carbon Stock

The above-ground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous undergrowth. For biomass estimation of woody vegetation any live plant greater than or equal to 2 cm DBH will be treated as above ground woody plant. Experience to date with the development of generic regression equations has shown that measurements of DBH explains more than 95% of the variation in tree biomass even in highly species rich tropical forests (Genene Asefa *et al.*, 2013)

The main carbon pools in tropical forest ecosystems are the living biomass of trees and under story vegetation and the dead mass of litter, woody debris and soil organic matter. The carbon stored in the above ground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation (Gibbs *et al.,* 2007). Knowledge of the above ground living biomass density is useful in determining the amount of carbon stored through photosynthesis in the forest stands. The aboveground living biomass is also an excellent indicator of plant growth, condition and yield potential. Thus, estimating above ground living biomass is the most important step in quantifying forest Carbon stocks and monitoring the changes.

2.4.2 Below ground biomass Carbon Stock

The Below ground biomass carbon pool consists of the biomass contained within live roots. As with AGB, although fewer data exists, regression equations from root biomass data have been formulated which predict root biomass based on above-ground biomass carbon (Cairns *et al.*, 1997; Brown, 2002). Cairns *et al.* (1997) review 160 studies covering tropical, temperate and boreal forests and find a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30. Although roots are believed to depend on climate and soil characteristics Cairns *et al*. (1997) found that root to shoot ratios were constant between latitude

2.4.3 Dead litter carbon stock

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. Carbon is stored in trees (stem, branches, leaves and root), understory, and forest litter and forest soils. The decay of litter is one of the main sources of SOC and the quality of litter is significant in this view (Lemma *et al*., 2007). Biniyam Alemu (2014) also stated that, for the systems with high plant diversity, it is likely that they would have litters with different degrees of chemical resistance, creating the possibility of longer residence of C 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 N content would have faster rate of decomposition.

2.4.4 Dead wood organic matter

The DOM wood carbon pool includes all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10 cm. Often ignored, or assumed in equilibrium, 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.

2.4.5 Soil organic carbon

SOC includes carbon in both mineral and organic soils and is a major reserve of terrestrial carbon (Lal and Bruce, 1999). Inorganic forms of carbon are also found in soil: however, forest management has greater impact on organic carbon and so inorganic carbon impact is largely unaccounted. SOC is influenced through land use and management activities that affect the litter input, for example how much harvested biomass is left as residue, and SOC output rates, for example tillage intensity affecting microbial survival. In SOC accounting, factors affecting the estimates include the depth to which carbon is accounted. The mechanism of species driven C sequestration in soil is influenced by two major activities, above ground litter decomposition and below ground root activity (Binyam Alemu, 2014).

2.5 Factors influencing forest carbon stock

Elevation is environmental factors that affect carbon stock of forest ecosystem in Ethiopia which has been widely recognized (Adugna *et al*., 2013; Mohammed et al., 2014; Yohannes *et al*., 2015). According to Yohannes *et al.* (2015), elevation has significant effect on the amount of biomass and soil carbon stocks. Study conducted in Bale Mountains also showed that topographic is likely to influence the physical and chemical properties of soils by creating micro-climatic. Identifying the factors which influencing carbon stock of forest is very important for the management of forest resource sustainable (Houghton, 2005). Carbon stock of a given forest can be influenced by many factors like inherent potential of the tree and the physical ecosystem in which the tree exists (Houghton, 2005). The most important being the species composition, stand age, site quality, genetic variation, stand density, management regime, previous land use and environmental factors such as altitude, slope and aspect gradients (Clark, 2000; Fahey *et al*. (2010). Intensive silviculture, with shorter harvesting intervals and more intensive logging (i.e., thinning, clear-cuts) generally reduces net carbon storage rates and carbon storage at the stand level, when compared with low-intensity siliviculture (e.g., the selection system) (McKinley *et al*., 2011). In addition, low intensity silviculture may create stand structures and a composition more suitable for storing carbon, and disturbance resistance that may prevent catastrophic events such as wildfires. According to McKinley *et al*. (2011), high-severity fire can increase soil erosion, alter nutrient cycling, and decrease post-fire seedling recruitment, thus leading to long-term losses of carbon stocks of forest.

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

This study was conducted in Minjarnashenkora District, Amhara National Regional State, Central Ethiopia. It is located at about 130 km North-East of Addis Ababa.The forest stand planted in the 1980s and the forest has an elevation gradient ranging from 2204 to 2506 m. It was bounded by Oromiya region in the south, East and West and in the North (H/Mariam & Berhet woreda). It is found between latitudes 8°53′00″ N to 8°54′00″ N and between longitudes 39°16′30″E to 39017′30″ E (Figure 2)

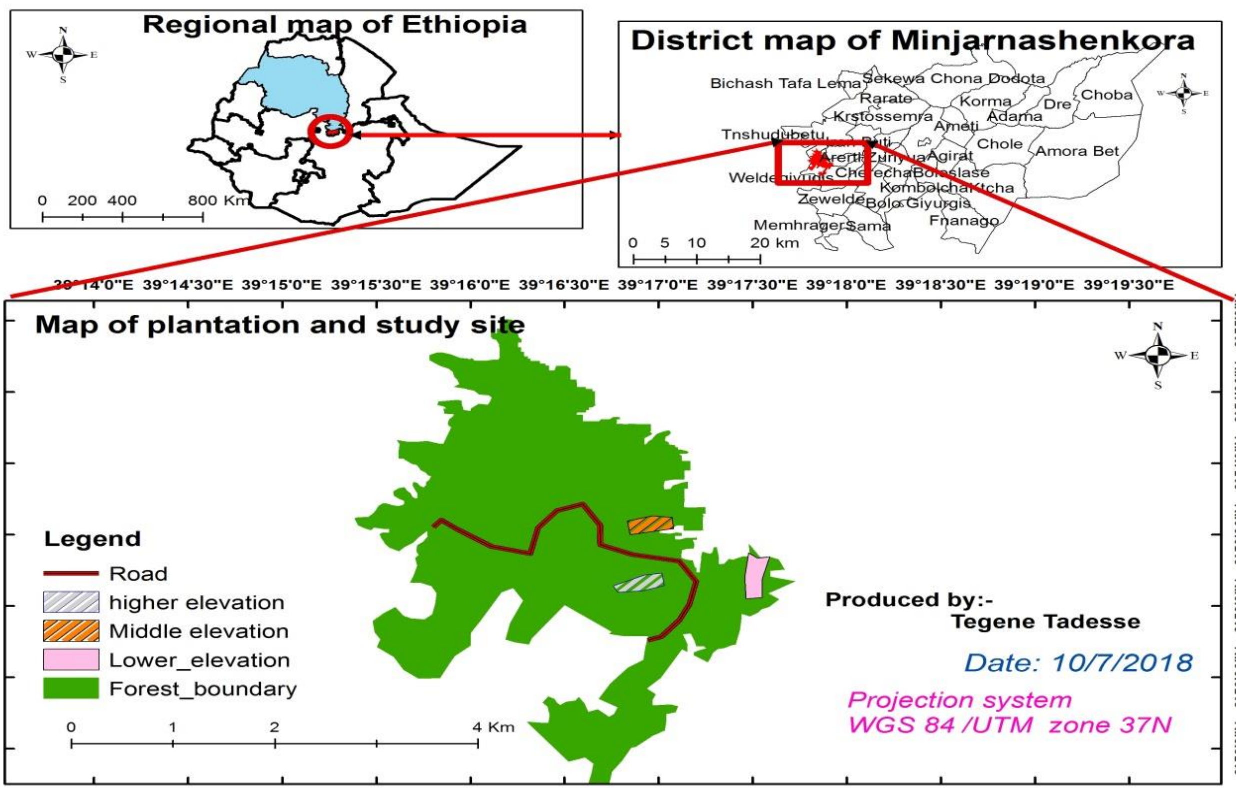

Figure 1:-Location map of the study site

3.1.2 Topography and soil

Based on the information from MSDARDB, the elevation of the plantation forest ranges from 2204-2506 m. According to MSDARDB the district has different soil types suitable to harvest various kinds of grains. The most dominant soil type in the district is vertisols its coverage in the woreda (district) is about 46.5% of the total area. Even though their area coverage is very low there are also other types of soils, these are gray soil, black soil and red soil possessing the share of the total area 19.5 %, 19 % and 15 % respectively (Table 1). The dominant soil types with slightly acidic reaction, of soil texture were clay loam found in the forest ecosystem. MSDARDB, (2014) (Table 1).

Table 1:- Soil pH and textural class of the three studied elevations in the site

Elevation	Mean (±SD)				
	pH	Sandy, %	Clay, %	Silt, %	Textural class
Lower elevation	6.12 ± 0.60	32.25 ± 4.13	34.03 ± 5.15	32.69 ± 5.43	Clay-loam
Meddle elevation	6.02 ± 0.47	34.06 ± 4.52	33.79 ± 5.19	27.79 ± 5.47	Clay-loam
Higher elevation	6.31 ± 0.59	33.36 ± 3.57	35.50 ± 5.87	29.80 ± 4.36	Clay-loam
p-value	0.120	0.170	0.390	0.000	

3.1.3 Climate

Climate has a great effect in shaping the day to day social, economic and cultural activities of human beings. Consequently varies types of climate diversified the societal way of life. Since Ethiopia is a mountainous country the distribution of temperature and rainfall varies mainly depends on the altitudinal variation as a result there are five agro climatic zones in the country. According to the MSEARDB report largest area of the Minjar Shenkora district is found under the Weyna-Dega agro climatic region accounting about (70.9 %) of the total area. While the rest of the district lies under kola and Dega climatic regions accounting 24.8 % and 4.3 % share of the total area respectively (Figure 2).

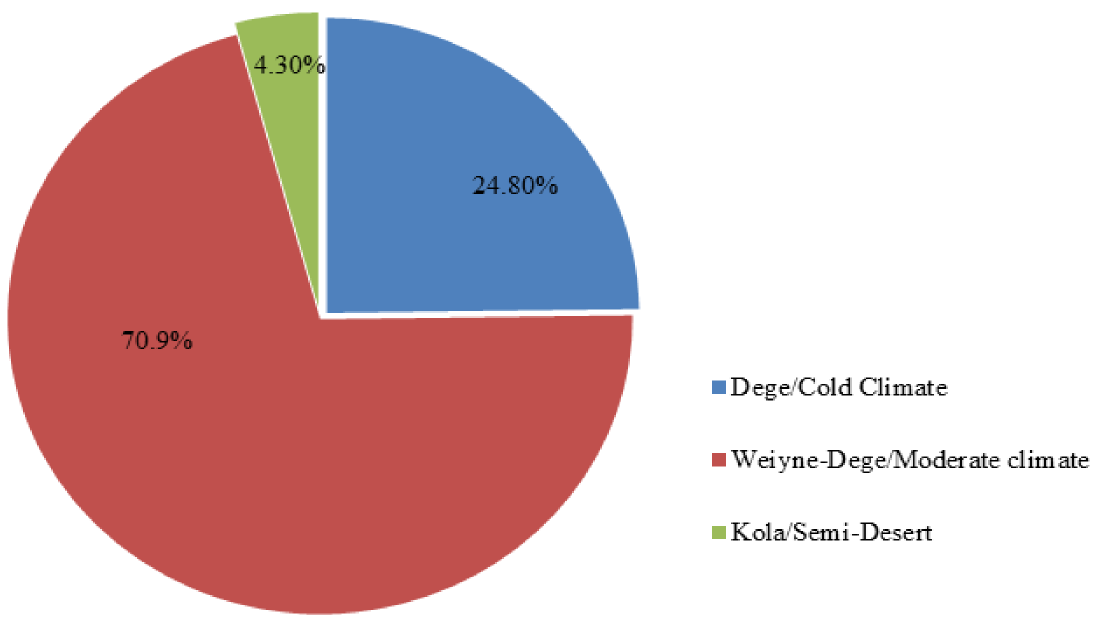

Figure 2:- Climate of Minjar-Shenkora Wereda

Source: MSDARDB (2014)

According to North Shewa Agricultural and Rural Development Bureau, Minjar Shenkora district has annual average temperature range between 13.21^0c and 23.02^0c. The rainfall pattern is similar to other parts of Ethiopia with the long rainy season starting in June and extending to September, while the short rainy season begins in March and extend to May.

3.1.4 Vegetation

According to MSDARDB, (2014) data vegetation coverage of the district is shrubs around hillside and some trees are scattered on farmlands. The tree species found on farmland are most of them are acacia species. *Eucalyptus* trees are widely planted around their homestead for the purpose construction, firewood and income generating MSDARDB, (2014).

3.1.5 Population

According to the Central Statistics Agency (CSA) of Ethiopia (2007) census report on Amhara region, the total population of MSW is 128,879. The number of rural dwellers of the district is 116,642, which holds the largest portion of the total population of the whole area. As a result of this the livelihood of the largest number of households in the area depends on the agricultural activities which accounts about 93.72 % of the total number of household in the district. A very small number of the total population of the area depend on other non-agricultural activities like trade, handcraft and daily laborer the portion of house hold engaged in these are 3.9%, 1.16 % and 1.2 %. (CSA, 2007)

3.2 Methodology

3.2.1 Delineation and stratification of study area

The boundaries of the study forest area was delineated to accurately measure forest carbon stock in the study area using GPS points were used for delineation of boundary of the study area. In order to form relatively homogeneous units and obtain accurate data from the field work. The studied plantation site was into three elevation ranges i.e lower (2204 – 2306m), middle (2307 – 2398m) and higher (2399 – 2506m) elevations.

3.2.2 Sampling Techniques

The field work for forest inventory was conducted from January 05 to March10, 2018. A main plot of 20 m x 20 m (400 m^2 equivalent to 0.04 ha), a systematic sampling method was used with the distance between transect 65m and 70m between sample plot. A compass bearing was used to allow the transects to be parallel with one another. A total of 34 plots sized 20m x 20m constituting 13 in lower, 11 in middle and 10 in higher elevations were taken (Pearson *et al.,* 2005).

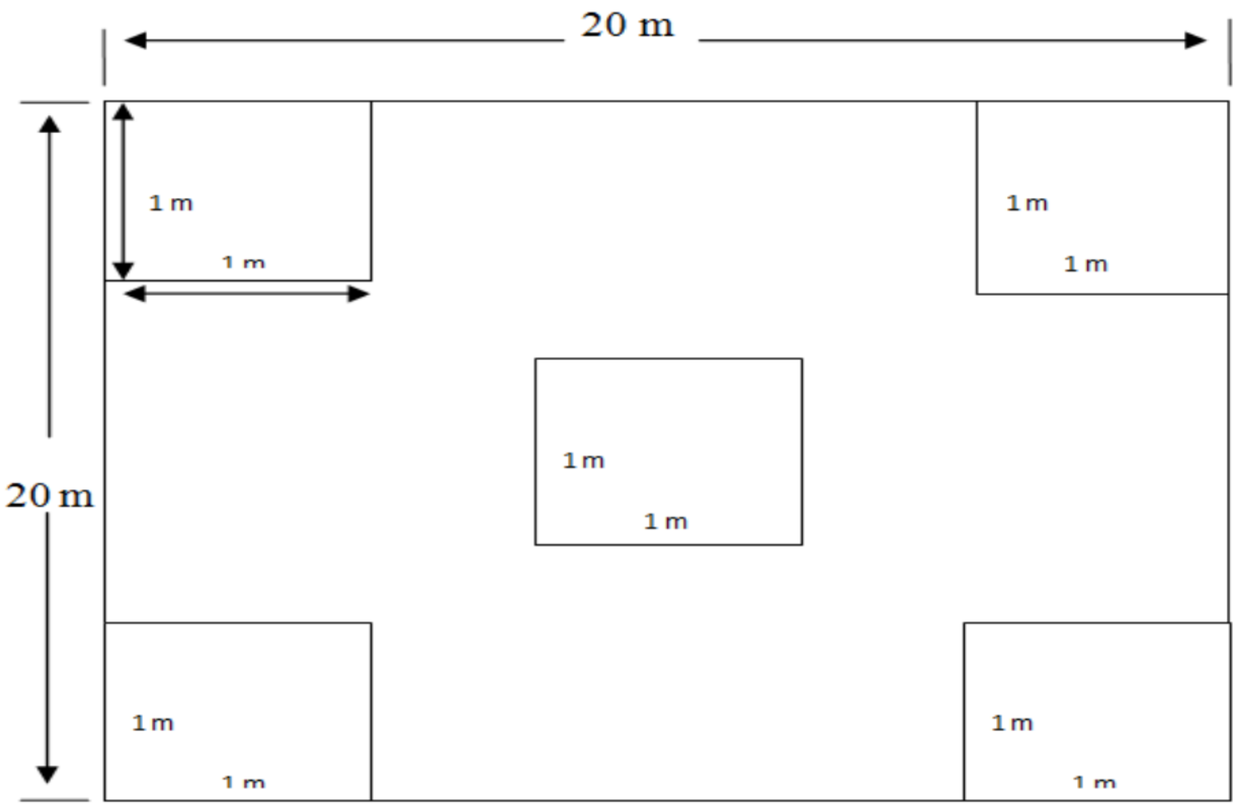

Figure 3:- Design of main plot and sub-plots for sampling of carbon pools

3.2.3 Methods of data collection

3.2.3.1 Inventory of tree (Diameter and Height measurement)

The DBH (diameter at breast height) and height (H) of the plant with diameter ≥ 5 cm in the study area were measured. The diameter of tree at (1.3 m above the ground) and height of all woody plants were measured using an instrument called caliper and hypsometer respectively. Trees on a slope area were measured on the uphill side. For the trees near the plot side that have > 50% of their basal area falls within the plot was included and, trees overhanging into the plot are excluded, but trees with their trunks inside the sampling plot and branches outside were included (Karky and Banskota, 2007,MacDicken, 1997).

3.2.3.2 Litter sampling

The samples of litter (leaves, twinges, fruits or flowers, and barks) were collected in three square sub-plots of 1m X 1m. The all three sampled litter were collected, weighed and recorded in the field. To determine oven dry mass to fresh weight ratio a composite sample of 100 g of evenly mixed sub-samples were brought to Wondo Genet College of Forestry and Natural Resources (WGCFNRs) laboratory to analysis (Snowdon *et al.*,2002) (Figure 3).

Dead wood was not measured in the forest due to the nonexistence of dead wood within the sample plots in all elevation because of collection deadwood production for fuel wood.

3.2.3.3 Soil Sampling

Soil samples were collected from the three elevation class where the three elevation site was assigned. Two set of soil sample were taken soil samples were collected within three $1m^2$ sub-plots in which litter samples were taken, one set for determination of SOC content and another set for determination of soil bulk density. The soil sample for SOC determination were a total of 102 composite soil samples collected from (0-20 cm),(20-40), and (40-60) depth were collected from the two corners by lottery methods and the center of each sample plot 20 m × 20 m per elevation site using core sampler, the three soil samples from each sample plot were pooled to form one homogenized composite sample, Additional, 102 separate soil samples from similar soil depth were taken using core sampler for bulk density determination (Figure 3).

3.3 Data Analysis methods

3.3.1 Above ground and below ground biomass carbon

The above ground biomass (AGB) was estimated using allometric equation developed by Fantu Weldeyohanis, (2007) was used.

$\log Y = -1.189 + 1.391(\log DBH^2)$…………………………………………………..Equation 1

Where, y = Estimation of above Ground Biomass (kg/ha.)

DBH = Diameter at breast height (cm)

Then the biomass density (the number of tons of biomass per hectare) was calculated by multiplying the dry mass by an expansion factor calculated from the sample plot size (Pearson *et al.*, 2005).

Expansion factor $= \frac{10000m2}{plot\ area\ m2}$…………………………………................Equation 2

According to IPCC, (2006), The biomass stock density of a sampling plot was converted to carbon stock densities using carbon fraction of 0.47, (IPCC,2006).

Measuring below ground tree biomass (roots) is not as easy as the above ground biomass. It is more complex, time consuming, destructive and almost never measured, but instead it is included through a relationship to above ground biomass (usually a root-to-shoot ratio). MacDicken (1997), stated that, the appropriate method used for estimation of below ground biomass (BGB) can be obtained as 26% of above ground tree biomass i.e., root-to-shoot ratio is used. Thus, the equation developed by MacDicken (1997) to estimate below ground biomass was used.

BGB= AGB*0.26………………………………………………………………..Equation 3

The biomass stock density of a sampling plot was converted to carbon stock densities by default carbon fraction of 0.47, as the dry biomass contains 47 % organic carbon in the tropical and sub-tropical region (IPCC,2006).

3.3.2 Litter biomass carbon

In order to determine the carbon stocks of the litter were air dried for one day and oven dried at 70 °C for 48 hrs (Pearson *et al.,* 2005).

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

$$LB=\frac{Wfield}{A} * Wsubsampl(dry)/Wsubsample(fresh) * 10000 \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4}$$

Where; LB – Biomass of leaf litter (t $/ha^{-1}$)

Wfield – 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, wet = Weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g) (pearson *et al*, 2005)

Carbon Stocks in litter biomass

$$CL= LB * 0.37\ \% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 5}$$

Where CL= total carbon stocks in the dead litter in (t $/ha^{-1}$).

LB = litter biomass

Therefore, the carbon content of litter biomass is about 37 % by dry weight, (IPCC, 2006).

3.3.3 soil organic carbon (SOC)

Soil chemical and physical analyses were conducted at WGCFNRs by following the standard laboratory procedures. Soil samples were air-dried at room temperature, homogenized and passed through a 2 mm sieve for chemical and physical analysis. The soil organic carbon stock (t ha^{-1}), firstly bulk density samples were oven dried at 105 °C for 48 hours. After that, each bulk density sample was washed with water. Soil bulk density was then calculated by using the following formula (Pearson et al., 2007).

$V = h \times \pi r^2$……………………………………………………………………… Equation 6

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

h = the height of core sampler in cm and

r = the radius of core sampler in cm.

Moreover, the bulk density of a soil sample can be calculated as follows:-

$BD = ODW/CV$ ………………………………………………………….………..Equation 7

Where BD= Bulk density of the < 2 mm fraction, (g/cm^3), ODW = Oven-dry mass of fine Fraction (< 2 mm) in g, CV is Core volume (cm3),

Soil carbon concentration was analyzed using standard method, (Walkley and Black, 1934) procedure. SOC stocks (t ha^{-1}) were calculated as the product of carbon content (%), bulk density (g cm^3), and layer thickness (cm);

$SOCs = BD * Soil\ depth * \%C$……………………….……………………..…….. ….Equation 8

Where, SOC = Soil Organic Carbon stock per unit area (t/ ha^{-1})

BD = soil bulk density (g cm^3)

Soil depth is soil depth (cm) and %C is Carbon concentration.

3.3.4 Total Ecosystem Carbon Stock

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

C density = $CAGTB + CBGB + C\ Lit + SOC$……………………….……… Equation 9

Where: C density = Carbon stock density for all pools (t ha^{-1})

C AGTB = Carbon in above ground tree biomass (t /ha^{-1})

CBGB = Carbon in below ground biomass (t ha^{-1})

C Lit = Carbon in dead litter (t ha^{-1}) and SOC =Soil organic carbon (t /ha).

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

3.4 Statistical Analysis

Microsoft Excel Version 2010 was used for processing biomass and soil data. The variation in carbon stocks for each elevation frequency was described by the mean and standard deviation. To test for differences in soil carbon stocks between the three studied elevation frequencies, General Linear Model and for biomass carbon one-way ANOVA were performed ($p = 0.05$). SPSS Statistics software (version 16.0) was used for the statistical analysis. Tukey HSD used for mean comparison. All statistics evaluated at 95 % confidence level. Finally, the entire tables for biomass and soil carbon stocks were also produced using Microsoft Excel Version 2010.

4. Results

4.1 Forest stand characteristics

Stand characteristics of studied forest across the elevation ranges were shown in (Table 2). The average number of stems per hectors was 564 stems.The middle elevation stem density (614 stems ha^{-1}) was higher than upper elevation (588 stems ha^{-1}) and lower (489 stems ha^{-1}), there were a significant differences of stems density ha^{-1} along elevation ranges (p=0.005). As compared with the three elevation ranges, the average DBH (31.91) of the tree were larger at lower elevation than middle and higher elevation and also high significance among elevations. The basal area of the forest land was $48.72m^2$/ha. The mean basal area of the middle elevation was higher than the lower and upper elevations and there was significant differences along elevation ranges (p=0.037).

Table 2:- Mean ± standerd deviation of stand characteristics of forest ecosystem.

Elevation ranges	DBH,cm	Stem density(stems ha^{-1})	Basal area,m^2 /ha^{-1}
Lower Elevation	34.63 ± 2.92^a	489 ± 98.22^a	50.57 ± 10.41^a
Middle elevation	32.35 ± 2.37^b	614 ± 83.18^b	53.08 ± 5.91^b
Higher elevation	28.77 ± 2.37^c	588 ± 91.47^c	42.52 ± 10.65^c
P-value	0.000	0.005	0.037

N.B. Values followed by the same letter across a column are not significantly different using the ANOVA mean comparison test at p=0.05.

4.2 Carbon Stock in different Pools

4.2.1 Above and below ground carbon

The total mean above biomass carbon of the forest was 312.85 t/ha^{-1}. The estimated mean above ground biomass carbon of lower, middle, and higher elevations were (342.09 ± 103.82 t/ha^{-1}, 339.03 ± 42.90 t/ha^{-1}) and 257.44 ± 77.66 t/ha^{-1}) respectively (Table 3). Result showed that mean above ground biomass carbon of lower elevation was significantly higher than middle elevation (p=0.022) and higher elevation (p=0.003). But, no significance variation between lower and middle elevation. In contrast, the estimated mean below ground biomass carbon stock of lower elevation (88.14 ± 11.15 t/ha-1) was significantly difference than higher elevation (66.93 ± 20.19 t/ha-1) p= 0.032). However, there were no significant difference of above between middle and higher elevations (p=0.310) and below ground biomass carbon stock of between middle and lower elevations (p=0.210)

4.2.2 Litter carbon

The total mean litter biomass carbon stock of the forest was (0.0022 ± 0.001 t/ha^{-1}). The mean litter biomass carbon stock of lower, middle and higher (0.004 ± 0.002 t/ha-1, 0.042 ± 0.001 t/ha^{-1} and 0.022 ± 0.003 t/ha^{-1}) respectively. According to the results, it was significantly higher in the middle elevation than lower elevation (p = 0.003). It was also significantly higher in upper elevation than lower elevation (p = 0.04) and ther also significantly difernce in all elevation ranges (p = 0.020).

Table 3:- Mean ± standerd deviation value of Biomass carbon stocks on the elevation ranges.

Elevation ranges	Elevation(m)	AGBC (t ha^{-1})	BGBC (t ha^{-1})	LBC (t ha^{-1})
Lower elevation	2204-2306	342.09 ± 103.82[b]	88.94 ± 26.99[a]	0.004 ± 0.002[a]
Middle elevation	2307-2398	339.03 ± 42.90[a]	88.14 ± 11.15[a]	0.042 ± 0.001[b]
Higher elevation	2399-2506	257.44 ± 77.66[a]	66.93 ± 20.19[b]	0.022 ± 0.003[c]
p-value		0.035	0.035	0.020

N.B. Values followed by the same letter across a column are not significantly different using the ANOVA mean comparison test at p = 0.05.

AGBC (t/ha^{-1})-Above Ground Biomass Carbon, BGBC (t/ha^{-1}) - Below Ground Biomass Carbon and LBC (t/ha^{-1}) - Litter Biomass Carbon

4.2.3 Soil organic carbon stocks in three elevation class

Bulk density and SOC concentration (%) varied significantly with elevation ranges (p = 0.000) and soil depths (p = 0.000) and also there interaction effect was significantly different (p = 0.05). Whereas, the SOC varied significantly with soil depths (p = 0.010) but, not significantly difference by elevations p = 0.531 and there interactions (p = 0.268) soil depths There were significantly highest in top surface of soil depths (0-20 cm) and lowest in the bottom surface of the soil depths (40-60 cm).

Table 4:- Summary of ANOVA results for BD, SOC % and SOC with relation elevation.

Source of variation	BD (g cm^{-3})		SOC (%)		SOC (t /ha^{-1})	
	MS	P-value	MS	P-value	MS	P-value
Elevation	1.22	0.000	4.765	0.0000	112.78	0.531
Soil depth	1.67	0.000	5.11	0.0000	850.63	0.010
Elevation X depth	0.095	0.268	0.65	0.053	233.42	0.268

BD (g cm^{-3})– bulk density, SOC (%) –soil organic carbon stocs (%), SOC – soil organic carbon stock t/ha^{-1}, d.f-degree of freedom and MS-mean Square

Table 5:- Mean ± Standard deviation of BD, SOC % and soil organic stock with elevations

Variables	soil depth			Elevation ranges		
	0-20	20-40	40-60	lower	middle	higher
BD (g cm^{-3})	1.01 ± 0.13^c	1.2 ± 0.24^b	1.41 ± 0.21^a	1.22 ± 0.25^b	0.98 ± 0.33^c	1.37 ± 0.14^a
SOC (%)	1.91 ± 0.30^b	1.56 ± 0.59^a	1.13 ± 0.54^c	1.54 ± 0.46^a	1.92 ± 0.62^a	1.13 ± 0.36^a
SOC (t /ha^{-1})	40.19 ± 13.85^b	32.91 ± 12.46^a	29.52 ± 13.74^a	102.08 ± 33.82^a	96.89 ± 40.81^a	108.90 ± 45.54^a

BD (g cm^{-3})– bulk density, SOC (%) –soil organic carbon concentration (%), SOC – soil organic carbon stock t/ha^{-1},

N.B. Values followed by the same letter across a column are not significantly different using the ANOVA mean comparison test at p=0.05.

4.2.4 Total ecosystem carbon

The total ecosystem carbon stock in the study area both in total biomass and soil (0-60 cm) was 496.84 t/ha^{-1}. The highest share of total biomass carbon to total ecosystem carbon stocks was high in lower elevation (28.94 %), followed by middle elevation (28.66 %) and higher elevation (21.76 %). The share of SOC to the total ecosystem carbon stocks was highest for the higher (7.30 %) than lower (6.84 %) and middle (6.50 %) elevation. Whereas, the contribution of litter carbon to total ecosystem carbon stocks was relatively low in all elevation (<1 %). This was due to harvesting of the litter biomass for fuel consumption in the studied site. The total carbon stock density of each carbon pools in different elevation ranges of the study area were completed by summing up all the mean values of each pool within specified altitude classes.

Table 6:- Mean ecosystem carbon stock along the three elevation gradients

Elevation ranges	**TAGC t/ha^{-1}**	**TBGC t/ha^{-1}**	**TBC t/ha^{-1}**	**SOC t/ha^{-1}**	**TC t/ha^{-1}**
Lower	342.09 ± 103.82[a]	88.94 ± 26.99[a]	0.004 ± 0.002[a]	102.08 ± 11.27a	533.11 ±142.08[a]
Middle	339.03 ± 42.90[b]	88.14± 11.15[a]	0.042 ± 0.001[b]	96.89 ± 13.60a	524.15 ± 67.65[b]
High	257.44 ± 77.66[c]	66.93 ± 20.19[b]	0.022 ± 0.003[c]	108.90 ± 15.18a	433.27 ± 113.03[c]

N.B. Values followed by the same letter across a column are not significantly different using the ANOVA mean comparison test at p=0.05.

5. Discussion

5.1 Carbon stocks in Different carbon pools

5.1.1 Above ground biomass carbon stocks

The mean aboveground of the current study was estimated by allometry correlation with DBH. Consequently, most of the finding was in agreement with other studies (Genene Asefa *et al.,* 2013). Howevr, the mean above ground biomass carbon stock of trees in lower, middle and upper elevations in this study (342.09 t/ha^{-1}, 339.03 t/ ha^{-1} and 257.44 t/ha^{-1} respectively) were higher than the result obtained in the assessment of aboveground biomass and carbon pools in Ethiopia (114.48 t/ha^{-1}) Metz *et al*. (2007. The variation might come from difference in management of the forest, the use of different allometric models for biomass estimation may explain in the variation of estimates in different areas. Thus, reliance on allometric equations could be one of the major limitations resulting in large variations of such estimates. The higher biomass carbon stocks in the lower was might be due to as elevation increased, DBH of the trees decreased. In addition, it was because large size tree appeared in the lower elevation followed by middle and higher elevations. This is due to the decreasing of a layer of large DBH trees at higher elevation ranges naturally.The significantly higher biomass carbon stock in the lower elevation than middle and higher elevation (Table 6) were mainly because as elevation increased, the DBH of the tree decreased. In addition, it was because larger tree size trees appeared in yhe lower elevation followed by middle and higher elevation.This is due to the decreasing of layer of large DBH trees at the higher elevation ranges of the forest site and the layer of large DBH tree increase towards the lower elevation ranges naturally. The difference in biomass and carbon accumulation in lower elevation could be largely due to difference in growth rates of the plants. The present study was in agreement with other studies (Belay et al.,2014).

5.1.2 Below ground biomass carbon stocks

The lower, middle, and upper elevations below ground biomass carbon were (88.94 t/ha^{-1}, 88.14 t/ha-1, and 66.93 t/ha-1) respectively. The variations due to largest trees have much more potential to produce larger quantities of below ground biomass as compare to the smallest trees. The total mean below ground biomass carbon of the present study was 81.33 t /ha-1. The same as above ground biomass of carbon stocks, the lower elevation was significantly higher than middle and higher elevations in below ground biomass carbon stocks. The present study was higher than the finding of (Metz et al. (2007) (23.92 t/ ha-1). The difference might be due to difference in tree DBH and the difference in allometric equations used (table 3). The lower elevation belowground biomass carbon stocks was significantly higher than higher elevations. But, there were no significant difference between middle and lower elevation (Table 3). The reason for this difference in elevation range was due to the existence of large trees in lower elevation than middle and higher elevations.This was because, largest trees have much more potential to produce larger qountities of belowground biomass compare to the smallest trees. The presnt study was supported by the finding of (Tibebu and Teshome.,2015).

5.1.3 Litter biomass carbon stock

Litter biomass carbon stocks of higher and middle elevation significantly higher than lower class. The reason for variation was it may be easy to collect as fuel wood compared to the other elevation ranges. The litter biomass carbon stock of middle and higher elevations were significantly higher than lower elevation (Table 3). The reason for variation was it might easy to collect as fuel wood compare to the middle and higher elevation. Additionally, more litter biomass might be stored in middle elevation as it far from settlements. As indicated by Belay *et.al.* (2014), litter biomass carbon stock was found to increase with increasing elevation.

5.1.4 Soil organic carbon content

The bulk density values increased with increased soil depths among all elevation. This was because in the upper layer of soil depths there was more accumulation of organic matter as compare to the other depths. This result was supported by many authors (Iqbiai and Tiwari, 2013; Teshome *et.al*, 2013). Generally, it was observed that higher elevation had the highest bulk density followed by lower elevation and least bulk density values were found in middle elevation. The highest bulk density in the higher elevations might be due to lower organic matter accumulation or lacks of organic matter (litter) in upper elevations were one reason to the highest bulk density observed.

The concentration (%) and stock of soil organic carbon were opposite to bulk density results. This shows that as soil depth increased, the SOC decreased. This variation was due to the existence of higher organic matter at the top soil layer mainly due to accumulation of decomposed forest litter and dead and decayed logs over the floor. These variations were similar to a study by Iqbai and Tiwari. (2013). As indicated in the results section, soils from higher elevation have higher soil organic carbon content than in lower and middle elevation. This could be because of the topography of the stand location. Higher elevation is situated on gentle slope with less erosion impact and with better sediment deposition than lower and middle elevations which were located on sloppy positions susceptible to high surface erosion impact and thus, have less sediment deposition. Stocking density may also be another important factor for the difference in soil organic carbon content. Higher elevation has the highest stocking density than lower and middle. The more the number of trees, the more could be the contribution to soil organic matter which is an essential source of soil organic carbon. The SOC content decreased with increasing soil depth for all the Elevation. This could be due to the decrease in organic debris content of soil with increasing depth. For instance average higher 40.2 t /ha^{-1} in upper soil sections and lower 29.5 t /ha^{-1} in lower soil sections has been observed. The nearer the samples are to the top layer, the more is the input of different litter components to the soil. Zerfu, (2002), a similar trend of average soil organic carbon change across depth in this study at the same site, higher 33.9 t /ha^{-1} in upper and lower 19.8 t /ha^{-1} in lower soil sections. In their study on *Eucalyptus* plantation in Hawaii also showed that the higher 10.5 t /ha^{-1} soil carbon content in the 0 to 15 cm depth and about 7.9 t /ha^{-1} lower content was observed in the 30-45 soil horizon. Those researcher result implication that as soil depth increased the SOC content decreased.

The SOC concentration (%) and stock were significantly higher in top surface of soil depth (0-20) than subsurface soil depth (Table 5). The reason might be accumulation of litter fall and rapid decomposition in top layer of soil the soil depth which will increase organic matter that can help to maintain soil moisture reserve that could promote increased concentration of SOC. Moreover, litter decomposition is one of source of soil organic and the process is dependent on quality of litter fall (Mafongoya et al., 1998). Litter decomposition rates are also frequently considered to be regulated by soil organism, environmental and chemical nature of the litter (Gallrado and Merino, 1993). The physical environment, especially soil moisture, temperature and relatively humidity are important in litter decomposition as these regulate the biological activities of microbes in soil (Sayer, 2006).

5.1.5 Total carbon stocks

The forest aboveground biomass carbon stocks highest, although has low level of SOC stock. One reason why there was more carbon stocks in the forest might be due to the ability of plants to capture CO_2 through the process of photosynthesis. The distribution of carbon stocks between biomass and soil differ among elevation ranges. The biomass carbon stocks result of present study is comparable larger with the report by (Akindele *et al*., 2010), in Nigeria. Generally, the mean total carbon stocks of the ecosystem were consistent with other study of Keith1 *et al*. (2009) at moist highlands of Victoria, in southeastern Australia. The present study showed that forest had a maximum carbon sequestration potential and provides significant mitigation options by managing them for increased storage of carbon pool.

The recent IPCC report estimated that the global forestry sector represents over 50% of global greenhouse mitigation potential (IPCC, 2007a). Consequently, forestry became the focus of global climate change policy and is given a key position in international climate treaties. While sustainable management, planting and rehabilitation of forest can conserve or increase forest carbon stock; deforestation, degradation and poor forest management will decrease forest carbon stock. The highest carbon content in the forest ecosystem implied the highest potential to decrease GHGs.

6. CONCLUSIONS AND RECOMMANDATIONS

6.1 CONCLUSION

Different carbon stocks exist in different forest types and eco region depending on environmental factors (elevation, aspect, and topography), biological factors (tree species composition, stand age, stand density) and anthropogenic factors (disturbance history, logging intensity). Contributed the larger share of the total biomass carbon stocks along the elevation ranges. More biomass carbon was accumulated in the lower elevation while the SOC stocks were high in higher, lower and middle elevations. The present study revealed that the variation in elevation has significant effects on ecosystem carbon stocks, and more carbon accumulated in the biomass than soil and hence, the plantation forest in the study would play important role to preserve carbon in long-term while supporting the livelihoods. In general, the mean carbon density in the present study in all carbon pools showed greater carbon at lower forest strata than the middle and higher forest strata. This can be due to the existence of tree species in the large diameter class. The soil carbon stock constitutes the lowest stocks from above graund carbon pools. The overall carbon density of the Forest in this study was 496.84 (t ha^{-1}). This was equivalent to 1,821.75 t ha^{-1} CO_2. Therefore, Grabocan plantation state forest has the potential to mitigate huge amount of CO_2 from the atmosphere. The ANOVA result showed that at 95 % confidence interval, the carbon stocks in the different carbon pools (Above ground carbon, below ground carbon, litter carbon and soil) were different due to environmental factors such as elevation.

6.2 RECOMMENDATIONS

Grabocan plantation forest is important for storage of carbon, soil protection/conservation and different ecological services. However, the forest are facing a variety of threats, including illegal tree harvesting, destructive fuel wood collection, charcoal burning, cutting and free grazing, and agricultural practices near the forest. In the long term, these threats, if not removed, will contribute to diminished quantities of Carbon stored in this forest ecosystem system.

So, based on the findings of this study the following recommendations were made for Grabocan plantation forest.

- The amount of carbon sequestered in this study site was significant. In Ethiopia, there are large *E globules* plantation planted in different parts of the country so conducting similar research on those resources to would benefit the local people and the country.
- Further research should focus on developing and applying the country specific allometric equations. This will increase the reliability and acceptance of the existing data on forest carbon stocks.
- understanding of the response of biomass and soil carbon pools to this factor. Additional topographic aspect related research is needed to improve the scientific
- Furthermore, this forest ecosystem has a potential for emission reduction and hence, would serve to benefit from carbon financing schemes, and that would assist government's development strategies to sustainably management the plantation ecosystems.

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APPENDIX

Elevation Range(2204-2306)						
Elevation class	Plot No.	Coordinates		Altitude	Slope	Aspect
		Latitude	Longitude	(m.a.s.l)	(%)	
Lower elevation	1	08°53′00″	039°17′03″	2228	0.07	S
Lower elevation	2	08°53′00″	039°17′03″	2204	0.1	S
Lower elevation	3	08°53′08″	039°17′01″	2215	0.08	S
Lower elevation	4	08°53′32″	039°17′00″	2218	0.06	S
Lower elevation	5	08°53′05″	039°17′00″	2214	0.05	S
Lower elevation	6	08°53′00″	039°17′02″	2225	0.12	S
Lower elevation	7	08°53′08″	039°17′32″	2221	0.12	S
Lower elevation	8	08°53′10″	039°17′01″	2210	0.055	N
Lower elevation	9	08°53′03″	039°17′29″	2306	0.1	N
Lower elevation	10	08°53′17″	039°17′29″	2248	0.1	N
Lower elevation	11	08°53′15″	039°17′29″	2245	0.12	N
Lower elevation	12	08°53′17″	039°17′29″	2247	0.1	N
Lower elevation	13	08°53′20″	039°17′29″	2306	0.07	N
Elevation Range(2307-2398)						
Elevation class	Plot No.	Coordinates		Altitude	Slope	Aspect
		Latitude	Longitude	(m.a.s.l)	(%)	
Midle elevation	1	08°53′34″	039°17′02″	2307	15.5	260sw
Midle elevation	2	08°53′34″	039°16′02″	2339	13	260sw
Midle elevation	3	08°53′34″	039°16′02″	2310	10	260sw
Midle elevation	4	08°53′34″	039°16′02″	2395	12	260sw
Midle elevation	5	08°53′34″	039°16′02″	2307	9	260sw
Midle elevation	6	08°53′34″	039°16′02″	2339	12	260sw
Midle elevation	7	08°53′34″	039°16′02″	2313	6	80NE
Midle elevation	8	08°53′32″	039°16′02″	2398	6	80NE
Midle elevation	9	08°53′34″	039°16′03″	2307	12	80NE
Midle elevation	10	08°53′34″	039°16′05″	2339	5	80NE
Midle elevation	11	08°53′34″	039°16′04″	2316	7	80NE
Elevation Range (2399-2506)						
Elevation class	Plot No.	Coordinates		Altitude	Slope	Aspect
		Latitude	Longitude	(m.a.s.l)	(%)	
Higher elevation	1	08°53′00″	039°17′10″	2484	12.5	60°NE
Higher elevation	2	08°53′08″	039°16′49″	2485	11	60°NE
Higher elevation	3	08°53′09″	039°16′53″	2480	14.5	60 °NE
Higher elevation	4	08°53′11″	039°16′55″	2399	12.5	60° NE
Higher elevation	5	08°53′12″	039°16′54″	2449	15	60° NE
Higher elevation	6	08°53′10″	039°17′00″	2426	17.5	240° SW
Higher elevation	7	08°53′10″	039°16′56″	2403	9	240° SW
Higher elevation	8	08°53′07″	039°16′55″	2483	12	240° SW
Higher elevation	9	08°53′07″	039°16′51″	2506	10	240° SW
Higher elevation	10	08°53′07″	039°16′52″	2493	8	240° SW

Apendexies 1:- Geographical Location of Minijar GBPF sampling plot.

Elevation Range(2204-2306)							
Plot #	AGB(t/ha)	AGC(t/ha)	BGB(t/ha)	BGC(t/ha)	BLC/t/ha	(T. C/t/ha)	(T. CO2/t/ha)
1	493.95	232.16	128.43	60.36	0.0053	292.52	1073.56
2	637.57	299.66	165.77	77.91	0.0066	377.58	1385.71
3	635.53	298.7	165.24	77.66	0.0031	376.36	1381.25
4	556.91	261.75	144.8	68.05	0.0048	329.81	1210.4
5	630.72	296.44	163.99	77.07	0.0057	373.52	1370.81
6	774.82	364.17	201.45	94.68	0.0023	458.85	1683.99
7	955.75	449.2	248.49	116.79	0.0042	566	2077.21
8	789.03	370.84	205.15	96.42	0.0024	467.26	1714.86
9	428.68	201.48	111.46	52.38	0.0034	253.87	931.69
10	708.83	333.15	184.3	86.62	0.0029	419.77	1540.57
11	621.39	292.05	161.56	75.93	0.0036	367.99	1350.52
12	1208.34	567.92	314.17	147.66	0.0045	715.58	2626.19
13	1020.46	479.61	265.32	124.7	0.0047	604.32	2217.85
Elevation Range(2204-2306)							
Plot #	AGB(t/ha)	AGC(t/ha)	BGB(t/ha)	BGC(t/ha)	BLC/t/ha	(T. C/t/ha)	(T. CO2/t/ha)
1	651.59	306.25	169.41	79.62	0.003	385.87	1416.15
2	570.96	268.35	148.45	69.77	0.001	338.12	1240.9
3	801.96	376.92	208.51	98	0.003	474.92	1742.97
4	731.67	343.88	190.23	89.41	0.002	433.29	1590.19
5	909.05	427.25	236.35	111.09	0.001	538.34	1975.72
6	720.63	338.7	187.36	88.06	0.001	426.76	1566.2
7	773.55	363.57	201.12	94.53	0.001	458.1	1681.23
8	686.73	322.76	178.55	83.92	0.002	406.68	1492.52
9	626.97	294.67	163.01	76.62	0.002	371.29	1362.64
10	753.28	354.04	195.85	92.05	0.001	446.09	1637.16
11	708.43	332.96	184.19	86.57	0.003	419.54	1539.7
Elevation Range(2204-2306)							
Plot #	AGB(t/ha)	AGC(t/ha)	BGB(t/ha)	BGC(t/ha)	BLC/t/ha	(T. C/t/ha)	(T. CO2/t/ha)
1	525.1	246.79	136.52	64.17	0.01	310.97	1141.27
2	766	360.02	199.16	93.61	0.001	453.63	1664.82
3	660.52	310.44	171.73	80.72	0.001	391.16	1435.55
4	530.53	249.35	137.94	64.83	0.001	314.18	1153.04
5	666.52	313.26	173.29	81.45	0.001	394.71	1448.6
6	622.93	292.78	161.96	76.12	0.002	368.9	1353.87
7	619.87	291.34	161.17	75.75	0.00	367.09	1347.22
8	284.87	133.89	74.07	34.81	0.006	168.71	619.15
9	246.98	116.08	64.22	30.18	0.001	146.26	536.79
10	554.1	260.43	144.07	67.71	0.000	328.14	1204.27

Apendexies 2:- Above and below ground biomass summary

Lower Elevation								
Elevation class	plot No.	**Soil Properties**						
		Sand%	Clay%	Silt%	Textural_class	BD(gm/ cm3)	SOC (%	Soil pH
Lower Elevation	1	29	34	37	Clay_Loam	0.89	1.83	6
Lower Elevation	2	37	39	25	Clay_Loam	0.95	1.29	6.48
Lower Elevation	3	34	39	27	Clay_Loam	0.94	1.98	6
Lower Elevation	4	34	33	33	Clay_Loam	1.09	1.04	6.67
Lower Elevation	5	33	31	36	Clay_Loam	1.38	1.46	6.39
Lower Elevation	6	38	28	34	Clay_Loam	1.42	1.66	6.17
Lower Elevation	7	30	34	36	Clay_Loam	1.63	2.09	5.43
Lower Elevation	8	36	29	35	Clay_Loam	1.36	1.83	5.86
Lower Elevation	9	31	32	37	Clay_Loam	1.04	1.27	6
Lower Elevation	10	33	40	27	clay	1.26	1.98	6.03
Lower Elevation	11	32	32	36	Clay_Loam	1.4	1.13	6.25
Lower Elevation	12	31	40	30	Clay	1.34	1.2	5.7
Lower Elevation	13	32	32	36	Clay_Loam	1.21	1.27	6.63
Midele Elevation								
Elevation class	plot No.	Soil Properties						
		Sand%	Clay%	Silt%	Textural_class	Bulk Den	SOC (%D	Soil pH
Midle elevation	1	37	31	32	Clay_Loam	0.72	2.97	6
Midle elevation	2	34	39	27	Clay_Loam	0.85	2.28	6.03
Midle elevation	3	37	36	27	Clay_Loam	0.96	1.16	6.38
Midle elevation	4	30	39	31	Clay_Loam	0.73	1.83	6.02
Midle elevation	5	36	36	28	Clay_Loam	0.72	2.33	5.95
Midle elevation	6	41	34	25	Clay_Loam	0.89	2.04	6.05
Midle elevation	7	36	27	37	Clay_Loam	1.42	1.14	6.24
Midle elevation	8	38	32	30	Clay_Loam	1.42	1.67	5.96
Midle elevation	9	32	38	29	Clay_Loam	0.73	2.15	5.8
Midle elevation	10	36	36	28	Clay_Loam	1.37	2.15	5.77
Midle elevation	11	35	33	32	Clay_Loam	0.99	1.43	6
Higher Elevation								
Elevation class	plot No.	Soil Properties						
		Sand%	Clay%	Silt%	Textural_class	Bulk Der	SOC (%	Soil pH
Higher Elevation	1	32	35	33	Clay_Loam	1.41	1.07	7.17
Higher Elevation	2	30	41	29	Clay	1.39	1.02	6.1
Higher Elevation	3	32	41	27	Clay	1.41	0.86	5.98
Higher Elevation	4	32	35	32	Clay_Loam	1.6	1.72	6.07
Higher Elevation	5	34	37	29	Clay_Loam	1.42	1.11	6.25
Higher Elevation	6	31	40	29	Clay	1.29	1.85	6.03
Higher Elevation	7	34	30	36	Clay_Loam	1.2	0.87	6.12
Higher Elevation	8	40	34	27	Clay_Loam	1.4	0.89	6.59
Higher Elevation	9	30	34	36	Clay_Loam	1.43	1	6.93
Higher Elevation	10	33	38	29	Clay_Loam	1.2	0.92	5.83

Apendexies 3:- Statsitical mean values of soil physico-chemical properties along study site.

Tree DBH and Ht measurement (photo:by wuye yelewukelkay,2018)

Litter collection (photo by:Tegene Tadesse,2018)

Soil sample collection (photo by: Wuye yelewukelkay,2018)

Data Recording (photo:by wuye yelewukelkay,2018)

Photo: 4:- Photo taken from field data collection