Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.21, 2015

Forest Carbon Stock in Woody Plants of Ades Forest, Western Hararghe Zone of Ethiopia and its Variation along Environmental Factors: Implication for Climate Change Mitigation

Kidanemariam Kassahun*, Teshome Soromessa, Satishkumar Belliethathan
Center for Environmental Sciences, College of Natural Sciences, P. O. Box 1176, Addis Ababa University, Ethiopia

Abstract
Forests play an important role in the global carbon cycle. They are not only having a significant impact on climate change, but also influence it. Through their destruction, forests can be serious sources of greenhouse gases and through their sustainable management they can be important sinks of the same gases. The study was accompanied to estimate the carbon stock and its variation along environmental gradient. The general objective of this study is to determine the carbon sequestration potential of Ades forest and indicating its contribution to climate change mitigation. Sample plots were laid along line transects based on altitudinal variation of the study area. A randomly sampling plot (10 m x 20 m) in each site was established. The procedures were based on data collection and analysis of carbon accumulating in different carbon pools. The forest was arranged in classes based on different criteria in order to use appropriate methods for estimation of forest biomass. The mean total carbon stock density of Ades forest was found to be 585.40ton/ha which is ranged about 97.54to5919.52 ton/ha, of which 259.17 ton/ha, 52.20 ton/ha, 2.34 ton /ha and 271.69 ton/ ha comprised by above the ground biomass, below the ground biomass, litter carbon and soil organic carbon respectively. Altitude, aspect and slop gradients are such a factors that affect the carbon stock potential in above ground biomass, below ground biomass, litter biomass and soil organic carbon. The middle altitudinal zone of the study site had better carbon stock potential than the rest classes due to the presence of high DBH class of individuals' and suitable environmental condition whereas the carbon stock of AGC, BGC.LC and SOC showed an increasing trend with increasing slop. The total carbon stock value have direct relationship with altitude and slope, it increases with increasing slope and altitude. The amount of total carbon stock was higher on the southern aspect as compared to other aspects. The current study shows that carbon stock value of Ades forest was highly affected by environmental factors such as altitude, slope and aspects, but aspect was the only factor that showed significance difference in carbon stocks of the forest and this condition concluded that the forest should be conserved and managed for further carbon reservoirs.

Keywords: *Ades forest, biomass, carbon stock, environmental factors, global climate change*

INTRODUCTION

Global warming is undoubtedly one of the major environmental issues of the world. This phenomenon is affecting global climate by increasing earth's temperature (Intergovernmental Panel on Climate Change (IPCC, 2007). The most common of which is carbon dioxide (CO_2). If the carbon dioxide emission continues at the current rate, its concentration in the atmosphere will be doubled by the end of 21st century. Realizing the threat of global warming, United Nations (UN) established the Intergovernmental Panel on Climate Change and created the Kyoto Protocol (by United Nations Framework Convention on Climate Change – UNFCCC) as the first international agreement on mitigating GHGs. The goal of this protocol is to reduce the GHGs of committed countries by at least 5% compared to the 1990 level by the period 2008 – 2012. In order to reduce the GHGs in the atmosphere, two key activities are relevant (IPCC, 2007): reduce the anthropogenic emissions of CO_2, and create or promote carbon (C) sinks in the biosphere. The second option proposes storing atmospheric C in the biosphere, and in that context, land-use systems such as agroforestry have considerable importance.

Managing forest resources has become one of the most important agenda in climate negotiations, which has resulted in proliferations of financial mechanisms such as clean development mechanisms(CDM) and reducing emission from deforestation and forest degradation (REDD). The clean development mechanism was proposed by the Kyoto protocol as an instrument to reduce emissions with particular purpose of enhancing cooperation between developed countries implementing their emission reduction at low cost , and developing countries receive capital for environmentally viable forest investments that contributes to sustainable development. Similarly reducing emissions from deforestation and forest degradation opens an opportunity for the development of sustainable forest management and utilization in developing countries which have historically experienced high rates of deforestation and forest degradation due to financial and technical constraints (UNFCCC, 2009). To asses such financial resources and economic incentives, developing countries are expected, among others, to Reduce deforestation and degradation of existing forest and Expanding the size of existing forest carbon stocks. Capturing and storing carbon in biomass and soils in the agriculture and forest sector has gained widespread acceptance as a potential greenhouse gas mitigation strategy. Scientists increasingly understand the mechanisms by which various land-use practices can sequester carbon. Such practices include the introduction of cover crops on fallow land, the conversion of conventional tillage to conservation tillage, and the retirement of land from active production to a grass cover or trees. However, the policy design for implementing carbon sequestration activities is still being developed, and significant uncertainties remain concerning the cost effectiveness of carbon sequestration relative to other climate change mitigation strategies (Gibbs *et al.,* 2007). Carbon stock evaluation in mountain forest helps for managing the forests sustainably from the economic and environmental points of view for the welfare of human society beside their aesthetic, spiritual, and recreational value. Many scholars also agreed on significance of studying the vegetation resources of Ethiopia, among others, Teshome Soromessa *et al.* (2004); Ensermu Kelbessa and Teshome Soromessa (2008); Teshome Soromessa *et al.* (2011); Fekadu Gurmessa *et al.* (2011 & 2012); Adugna Feyissa *et. al.* (2013); Teshome Soromessa (2013); Teshome Soromessa and Ensermu Kelbessa (2013a & 2013b); Teshome Soromessa and Ensermu Kelbessa (2014); Mohammed Gedefaw *et. al.* (2014) are some of them. However, no study has been conducted in Ades Forest that has been intended at evaluating carbon sequestration potential. Therefore, this study was undertaken to estimate the carbon stock potential of Ades Forest in relation to environmental gradients.

MATERIALS AND METHODS

Description of the study area

The study was takes place in Ades forest which is located in between 1029419m E__1030017m E and 746685m N__ 746986m N. The site faraway 407 km from East of Addis Ababa and 30 km from Hirna town at western Hararghe Zone of Oromia National Regional State, Ethiopia (Figure 1). Hirna town is a town at a district level which is near to Assebe Teferi (42 km) zone of West Hararghe on the Addis Ababa to Harar road. The altitudinal gradients of Ades forest ranges from 2513 to 2743 m above sea level. The forest coverage of the study site is 618 ha and contains various species of plants and animals.

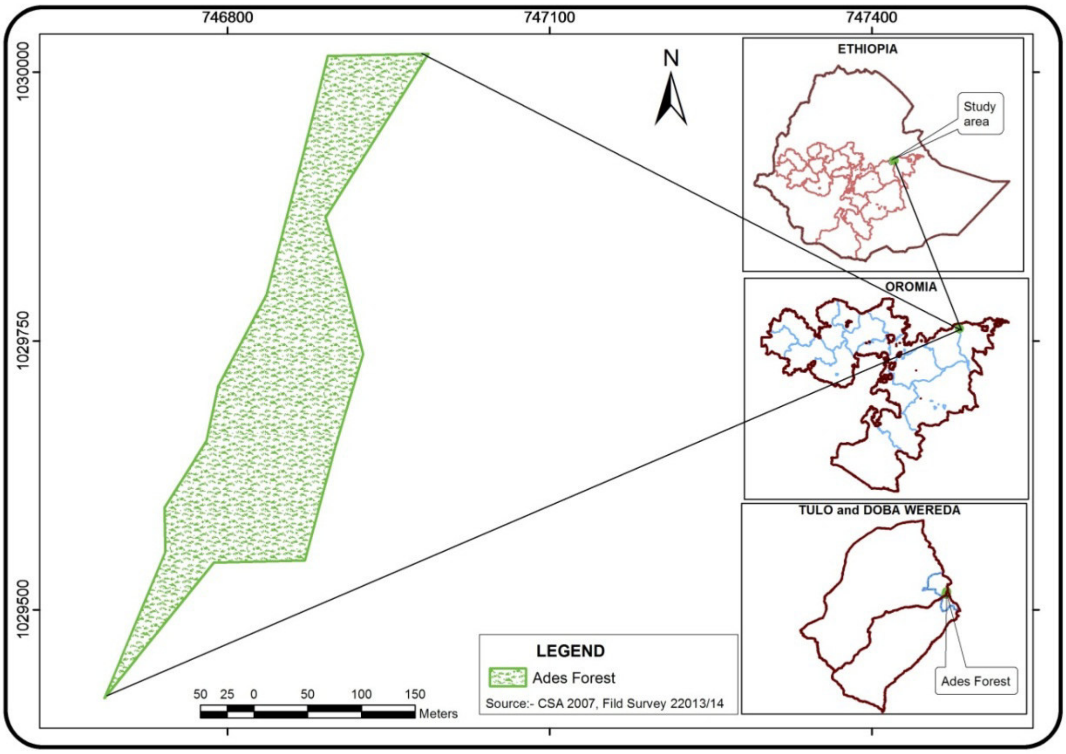

Figure 6: The Study Area of Ades Forest, Oromia, Ethiopia

Methodology

The study was conducted in the Ades which is located in the eastern region of Ethiopia at the zone of west Hararghe. The methodology and procedures used to estimate carbon stocks are simple step-by-step procedures using standard carbon inventory principles and techniques. Procedures were based on data collection and analysis of carbon accumulating in the above-ground biomass; below-ground biomass, leaf litter, and soil carbon of forests using verifiable modern methods. As indicated in (Pearson *et al.,* 2005 and 2007), the followings are the steps followed in forest carbon measurement during the field data collection.

Delineation of the forest boundaries

The boundaries of the study forest area were delineated to facilitate accurate measurement and accounting of the forest carbon stock (Bhishma *et al*., 2010). GPS points were used for delineation of boundary of the study area by taking the coordination of each turning point. The result of GPS point that was taken from Ades forest to indicate each sample plots was recorded.

Sampling Techniques

Simple random sampling method was used to take samples. Sample plots were laid along line transects based on altitudinal variation of the study area. A randomly sampling plot (10 m x 20 m) in each site was established. To reveal the tree composition and biomass, all live trees with a diameter ≥ 5 cm were recorded as indicated by (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 as well as species diversity in a sampling plot. DBH was measured by using caliper and meter. Trees with multiple stems connected near the ground were counted as single individuals and bole circumference was measured separately. Tree height was recorded by using a measuring hypsometer. The methodology and procedures used to estimate carbon stocks were simple step-by-step procedures using standard carbon inventory principles and techniques (Pearson *et al.,* 2005 and 2007). Procedures were based on data collection and analysis of carbon accumulating in the above-ground biomass; below-ground biomass, leaf litter, and soil carbon of forests using verifiable modern methods.

Stratification of the Study Area

Stratification helps in the forest to get accurate data, to save time and energy in addition, to maintain the homogeneity of the area. Altitude was the major parameter to classify the study area. The strata were defined at each elevation, starting from the lowest to the top of the mountain. Based on altitudinal variation, the study site was stratified into three zones namely: lower (2513 -2589 m), middle (2590 -2666 m) and higher (2667-2743 m). 2513m was measured as a lower altitude because; the forest starts at this altitude value and 2743m was considered as an upper altitude due to the boundary of the study forest stopped at this point. Slope gradient was the second parameter to classify the area. Slop classified into lower (0-20%), middle (21-40%) and higher (> 40%). The classification of Ades forest by slope was similar with classifications based on altitude starting from the first point to take samples. Aspect was also another parameter that was considered in the study forest and classified in to eight classes: N (north), NE (northeast), S (south), SE (southeast), E (east), NW (northwest), W (west) and SW (southwest).

Vegetation data collection and identification

The estimations of above and below ground carbon depend on the above ground biomass of living tree species. To estimate the above ground biomass all tree species within selected sample plots DBH ≥ 5cm were identified and recorded. Plant identification was done in the field by using Flora of Ethiopia and Eritrea. For those species difficult to identify in the field, fresh specimens were collected and then pressed properly for identification at the National Herbarium of Addis Ababa University.

Field carbon stock measurement

The major activities of carbon measurement during the field data collection were above-ground tree biomass, below-ground biomass, leaf litter and soil organic carbon measurements. Detailed methods are explained under the following sub-headings.

Aboveground tree biomass (AGTB)
The AGTB carbon pool consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The DBH (at 1.3m) and height of individual trees greater than or equal to 5cm DBH were measured in each sampling plots that is 200 m^2(10mx20m) in radius using Clinometer, diameter tape and linear tape, starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice. The aboveground biomass is estimated from the field measurements at specific sites (quadrats) with which the land scape was sampled in the area or watershed of concern.

Below ground biomass

As indicated by MacDicken (1997), this carbon pool is 20% of above ground biomass.

Litters

The leaf litter is defined as all dead organic surface material on top of the mineral soil. A quadrate with a size of 1 m × 1 m was established to sample litters. In each sample plots a total of five small quadrates were laid to minimize heterogeneity.

The litter samples were taken in sub-quadrate of 1 m × 1 m along diagonal from one corner to the other. The leaf litter within the 1m^2 sub plots were collected by manual and weighed.

Laboratory analysis: The 100gm sub-sample wet weights were taken for laboratory and oven dried at 105^{o}C. The oven dry weight was taken from each sub-sample. The five sub-sample oven dried collected from each quadrant were mixed homogenously. Then carbon fraction was measured in the laboratory,

Soil Organic Carbon (SOC)

Soil samples were collected from the five sub-plots used for litter collection. A 30 cm soil probe was used to collect the soil samples. Samples were collected using a 30 cm depth core sampler with a diameter of 5 cm. All samples were placed in paper bags with appropriate label. Five equal weights of each sample from each sub-plot were taken and mixed homogenously while a composite sub sample of 100 gm from each plot was submitted for laboratory analysis. In order to obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) soil depth, (2) bulk density and (3) the concentrations of organic carbon within the sample (Pearson *et al.*, 2005). For convenience and cost-efficiency, it is recommended to sample to a constant depth, maintaining a constant sample volume rather than mass. 100 grams of composite sample was collected from one plot from three depths (0-10 cm, 10-20 cm, and 20-30 cm) by digging the soil with the help of standardized 100 or 300 cm^3 metal soil sampling corer. The soil samples collected from plot were brought to the laboratory placing in a sample paper bags to determine the bulk density and amounts of soil organic matter.

Estimation of carbon stocks in different carbon pools

Estimation of Above Ground carbon stock (AGC)

Bhishma *et al.* (2010) defined allometric equation as a statistical relationship between key characteristic dimensions of trees that are fairly easy to measure, such as DBH or height, and other properties that are more difficult to assess, such as above-ground biomass. The equation used to calculate the above ground biomass is given below:

$AGB = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2)$ ……………………….. (equ….2)

Where, AGB is above ground biomass, DBH is diameter at breast height.

Estimation of above ground carbon content

$AGC = AGB \times 0.5$

Where, AGC = above ground carbon content

AGB= above ground biomass.

To estimate the amount of CO_2 sequestered in the above ground biomass, the above ground carbon has to be, multiplied by 3.67. Because the ratio of CO_2 to C is (44/12) =3.67. The biomass estimation method used in the study was based on linear regression analysis approach. The linear regression equation approach requires the selection of the regression equation that is best adapted to the conditions in the study area. Linear regression models have been fitted to data in various situations of variable site and ecological conditions globally. The work done by Brown *et al*. (1989) estimation of biomass of tropical forests using regression equations of biomass as a function of diameter at breast height is central to the use of this approach. Some of the equations reported by Brown *et al*. (1989) have become standard practice because of their wide applicability. Ades forest has trees with diameter at breast height greater than 5cm and having average rainfall ranging between 600mm and 1,250mm, is used to the biomass estimation method that was advanced by Brown *et al*. (1989).

Estimation of Below Ground carbon stock (BGC)

Below ground biomass estimation is much more difficult and time consuming than estimating aboveground biomass (Geider *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. The plant uses part of the Carbon in the roots to increase the total tree biomass through photosynthesis, although Carbon is also lost through the respiration, exudation and decomposition of the roots. Some roots can extend to great depths, but the greatest proportion of the total root mass is within the first 30 cm of the soil surface. Carbon loss or accumulation in the ground is intense in the top layer of soil profiles (0-30 cm.).Sampling should concentrate on this section of the soil profile. As indicated by MacDicken (1997), standard method for estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 is used. The equation is given below:

$BGB = AGB \times 0.2$ ……………………………………………….. (equ….3)

Where, BGB is below ground biomass, AGB is above ground biomass, 0.2 is conversion factor (or 20% of AGB).

To estimate the carbon content and amount of CO_2 in BGB, the same procedure was applied like that of AGB.

BGC = BGB x 0.5

Where, BGC = carbon content of below ground biomass

BGB= below ground biomass

To get CO_2 the below ground carbon has to be multiplied by 3.67.

Estimation of Carbon Stocks in the Litter Biomass (LC)

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

$$LB = \frac{Wfield}{A} * \frac{Wsub\ sample(dry)}{Wsub\ sample(fresh)} * \frac{1}{10{,}000}$$ ……………………….. *(*equ….4)

Where: LB = Litter biomass (ha^{-1})

W field = weight of wet field sample of litter sampled within an area of size 1 m^2 (g);

A = size of the area in which litter 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).

The carbon content of vegetation is surprisingly constant across a wide variety of tissue types and species. Schlesinger (1991) noted that Carbon content of biomass is almost always found to be between 45 and 50% (by oven-dry mass). In many applications, the carbon content of vegetation is estimated by simply taking a fraction of the biomass by multiplying 0.5.

C= 0.5* LB

Where C= is carbon content by mass, and LB= is oven-dry biomass.

Therefore, total carbon content of litter (ton/ha) =Total dry litter biomass* carbon fraction

CL = LBM × % C………………………………………………………... (equ….5)

Where, CL is total carbon stocks in the litter in ton/ha, %C is carbon fraction determined in the laboratory (Pearson *et al*. 2005). The litter carbon has to be multiplied by 3.67 to get the amount of CO_2 sequestered in litter bio-mass.

Estimation of Soil Organic Carbon

The carbon stock of soil was done by using the following formula which is recommended by Pearson *et al*. (2005) from the volume and bulk density of the soil.

V = h × π r2 ……………………………….…… (equ…6)

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 (Pearson *et al.,* 2005). More over the bulk density of a soil sample was calculated as follows:

BD = Wav, dry /V ……………………………………. (equ…7)

Where, BD is bulk density of the soil sample per, Wav, dry is average air dry weight of soil sample per the quadrant, V is volume of the soil sample in the core sampler auger in cm^3 (Pearson *et al.,* 2005).

SOC = BD * D * % C ………………………………... (equ…8)

Where, SOC= soil organic carbon stock per unit area (t ha-1), BD = soil bulk density (g cm-3), D = the total depth at which the sample was taken (30 cm), and %C = Carbon concentration (%)

Estimation of Total Carbon Stock Density

The total carbon stock is calculated by summing 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:

CT = AGC + BGC + LC +SOC……………………….. (equ…9)

Where: CT = Total Carbon stock for all pools (ton/ha), AGC=above ground carbon stock (ton/ha), BGC= below ground carbon stock (ton/ha), LC=litter carbon stock (ton/ha) and SOC= soil organic carbon (ton/ha). The total carbon stock was then converted to tons of CO2 equivalent by multiplying it by 44/12, or 3.67 as indicated by (Pearson *et al*., 2007)

Data Analysis

After the data collection is completed from the field and laboratory, the analysis of data was accomplished by organizing and recording on the excel data sheet. The data that gained from the field such as DBH, height of each species, moist weight and dry weight of litter, dead wood and soil were analyzed using Statistical Package for Social Science (SPSS) software version 20. The relationship between different parameter was tested by linear regression and One Way ANOVA. The height and diameter data were arranged in classes for applying appropriate model of biomass estimation equation. The forest was arranged in classes based on different criteria in order to use appropriate methods for estimation of forest biomass.

RESULTS

Carbon stocks in different plots

Carbon stock in above ground biomass (AGC)

The maximum and minimum above ground carbon stock potential of Ades forest was 4634.563 and 11.17808 ton/ha respectively. The mean above ground carbon stock of the study area was 259.165 ton/ha. The maximum and minimum carbon dioxide (CO_2) sequestration of the study site was 17008.85 and 41.02354 ton/ha respectively. The mean above ground carbon dioxide sequestration of the study area was 951.1356 ton/ha.

Carbon stock in below ground (BGC)

The biomass of below ground helps to determine the carbon stock of the study area. The maximum and minimum value of carbon sequestered in below ground biomass was 926.9126 and 2.2356 ton/ha respectively. The mean value of below ground carbon stock was 52.1946 ton/ha. The average carbon dioxide sequestration of below ground biomass was 191.5545 ton/ha.

Carbon stock in litter biomass

The litter carbon concentration per sample plot in the laboratory analysis was resulted in with the maximum value of 47.2 and the minimum of 35.3 ton/ha respectively. And this condition shows variations within plots. The mean carbon concentration of the study site without including the rest of three plots which had no litter was 41.5 ton/ha, Similarly the litter biomass of the study area shows some variation between plots and based on this the maximum and minimum value of the litter biomass were 0.0614 and 0.0459 ton/ha respectively. The maximum and minimum carbon stock in litter biomass were 2.89 and 1.62 ton/ha respectively. The mean total carbon stock of the study site was 2.34 ton/ha. Carbon dioxide sequestrations of the study site were also resulted in with the maximum and minimum value of 10.63 and 5.94 ton/ha respectively, with the mean value of 9.44 ton/ha.

Carbon stock in soil (SOC)

The bulk density of the soil profile found in the study site was ranged from 0.50 g/cm^3 of minimum to 1.33 g/cm^3 maximum value with the average value of 0.81 g/cm^3. The bulk density of the soil representing the occurrence of organic matter in the soil mineral. The maximum and minimum soil organic matter in the study area was 32.76g/cm^3 and 3.90 g/cm^3 respectively. The highest and the lowest soil carbon stock of the Ades forest ranges about 538.71 ton/ha and 66.53ton/ha respectively. The mean soil carbon stock of the study site was 271.69 ton/ha. The soil carbon of the study area sequestered carbon dioxide with the maximum and minimum value of 1977.05 ton/ha and 244.16 ton/ha respectively. The total carbon stock of Ades forest was obtained by adding all carbon value of each pool which revealed (above ground carbon, below ground carbon, liter carbon and soil organic carbon) for the entire sample plots of the study site. As a result of these, the total carbon stock of Ades forest ranged about the maximum 5919.52 ton /ha and minimum value of 97.54 ton/ha. The mean carbon mass in all carbon pool was 585.39 ton /ha.

Table 1: Biomass and Carbon Stock of Ades forest in different carbon pool of the study site

Total No. of Plots	**Diverse Carbon Pools**						
72	AGB	AGC	BGB	BGC	LB	LC	SOC
Mean Value (ton/ha)	521.78	259.17	105.59	52.19	0.0539	2.3409	271.69

Environmental factors affecting Carbon Stock of the study site

Carbon stock Vs altitude

Altitudinal variation disturbs carbon stock of different carbon pools of the forest. As indicated by table 2. The middle altitude part of the forest is high in Above ground biomass and carbon stock while the biomass and the carbon stock of lower and higher altitude is relatively low than the middle one. The mean value of biomass and carbon stock of the middle altitude is 592.60 and 296.30 ton/ha, lower altitude is 525.67 and 262.69 ton/ha, and the higher altitude is 402.59 and 201.30 ton/ha respectively. Similar fashion has been observed in below ground biomass and carbon stock that was recorded with higher value of the middle altitude in which 118.52 and 59.26 ton/ha, lower altitude was 105.08 and 52.54 ton/ha. and the higher altitude was 80.52 and 40.26 ton/ha respectively. As mentioned in the above the highest carbon stock has been scored at the middle altitude followed by the lower and the higher altitude respectively. But the condition is highly insignificant at 95% confidence interval for the case of AGC (F=0.189, P=0.828), BGC, (F=0.154, P=0.857) LC (F=0.043, P=0.958) and SOC (F=0.456, P=0.635). As it is indicated by table 2, the carbon stock value of the litter carbon was low at the lower altitude where as high in the higher altitude. On the other hand the soil organic carbon was high in the lower and higher altitudinal zone with a fair carbon stock potential in the middle altitude of the study site.

There were 288.31, 259.31 and 281.67 ton/ha carbon stock has been recorded in the lower, middle and higher altitude respectively in the soil pool of Ades forest. As the total result shows (table 2) high amount of carbon stock was recorded in the middle altitude (617.22 ton/ha) followed by lower altitude (605.75 ton/ha) and the higher altitude (525.62 ton/ha). See the following table.

Table 2: Carbon stock with Altitude Gradient

Altitude class	**Altitude Range**	**No of plots**	**AGB**	**AGC**	**BGB**	**BGC**	**LB**	**LC**	**SOC**	**Total Carbon stock ton/ha**
Lower	2513 -2589	13	525.37	262.68	105.08	52.55	0.05	2.22	288.30	605.75
Middle	2590 -2666	36	592.59	296.29	118.52	59.26	0.05	2.35	259.31	617.21
Higher	2667-2743	23	402.59	201.29	80.52	40.26	0.03	2.41	281.67	525.62

Carbon stock Vs Aspect

Aspect was also another factor which affects the biomass and carbon stock of above ground biomass, below ground biomass, litter and soil in different direction. Based on the result of this study, the mean above ground carbon was highest on Southern part of the study forest (889.51 ton/ha) followed by the northern direction (**N**) (235.92 ton/ha). The lowest carbon stock was recorded on (**W**) aspect (117.28 ton/ha) followed by North West direction (**NW**) (122.04 ton/ha). The study also showed that, there was also similar fashion that has been observed in below ground carbon. The mean BGB was highest on (**S**) aspect (355.80 ton/ha) followed by north aspect (**N**) (98.84 ton/ha). The lowest carbon density was recorded on (**W**) (23.46 ton/ha) followed by the North West direction (**NW**) (24.41 ton/ha). Whereas, the highest carbon stock on litter biomass was recorded on (**NW**) aspect (0.0580 ton/ha) followed by south west direction (**SW**) (0.0570 ton/ha). The lowest carbon value on litter biomass was recorded on (**W**) aspect (0.0456 ton/ha) followed by the direction of south east (**SE**) (0.0502 ton/ha). Higher value of mean soil organic carbon was recorded on south west (**SW**) (148.23 ton/ha) and followed by the direction of south (**S**) (147.04 ton/ha). Minimum value of soil organic carbon (SOC) was recorded on western direction (**W**) (157.27ton/ha) and followed by northwest (**NW**) (241.60 ton/ha). The aspect factor has significance impact on soil carbon stock and below ground carbon of the forest at 95% confidence interval (α=0.05) with(F=2.552, P=0.022) and(F=2.590 , P=0.022) respectively. But the rest carbon pools namely the litter carbon and above ground carbon was not statistically significance at α=0.05 with (F=0.851, P=0.550) and (F=1.803, P=0.102) respectively.

Table 3. Mean carbon stocks (ton/ ha) of different pools in different aspect

Aspect	No of Plot	AGB	AGC	BGB	BGC	LB	LC	SOC	TOTAL
W	8	216.69	117.28	46.91	23.46	0.05	2.1502	157.27	300.16
NW	7	244.09	122.04	48.82	24.41	0.06	2.5941	241.59	390.64
NE	8	366.44	183.30	73.29	36.64	0.06	2.4508	249.45	471.84
N	11	494.21	235.92	98.84	49.55	0.06	2.3706	251.85	539.69
SW	11	245.55	122.78	60.08	24.56	0.06	2.51	325.58	475.43
E	11	421.90	210.95	84.38	42.19	0.05	2.22	286.37	541.73
SE	11	434.12	217.06	86.82	43.41	0.05	2.14	320.36	582.97
S	11	1779.02	889.51	355.80	177.90	0.06	2.44	320.94	1390.79

Table 4: One-way ANOVA results of the three factors indicated above were shown below to show a significance difference in the carbon stocks values of different pools:

Environmental factors	Carbon pools	F-value	P-value
ALTITUDE	AGC	0.189	0.828
	BGC	0.154	0.857
	LC	0.043	0.958
	SOC	0.456	0.635
SLOPE	AGC	1.429	0.246
	BGC	1.128	0.330
	LC	0.079	0.924
	SOC	2.328	0.105
ASPECT	AGC	1.803	0.102
	BGC	2.590	**0.020**
	LC	0.851	0.550
	SOC	2.552	**0.022**

**Bold values are significant at α=0.05 (95%)

DISCUSSION

Carbon stock and Structure of the Forest

Ades Forest is characterized by dry afromontane forest type vegetation. The height class, DBH class and also the species configuration of the study site is varied one another. The altitude of the Ades forest ranges about 2513-2743 m and due to the variability of these conditions, it undergoes to dry afromontane forest (1500-3400 m). The study area is mostly dominated by those of indigenous tree species such as *Juniperus procera, Podocarpus falcatus and Olea europea*. Human interaction like farming and deforestation is clearly observed in the study area which might lead for the forest disturbance. As indicated by Bisahw (2003) the increasing population of Ethiopia has resulted in excessive forest clearing for agricultural use, overgrazing and exploitation of the existing forests for fuel wood, fodder and construction materials.

According to Houghton (2001), the forest has a large potential for temporary and long term carbon storage. A greater amount of carbon stock has been observed in a species which has counted long lived in the study site and also species which are densely populated in the pool. As a result the current study of the site indicates unbalanced tendency of carbon stock input in the above ground. High biomass rate has been held by species such as *Schefflera abyssinica, Podocarpus falcatus, Hagenia abyssinica and Maytenus undata*, on the other hand species such as *Clerodendrum myricoides , Combretum molle and Carissa spinarum* had less contribution. The maximum and minimum above the ground biomass in the carbon pool was 9269.13 and 22.36 ton/ha respectively. The average biomass stock recorded in above ground biomass was also 521.7475 ton/ha. In relation with other recent studies the biomass and carbon stock of the study site (Ades forest) was almost proportional with a little bit variation to Egdu forest (Adugna Feyissa, 2012) and Tara Gedam forest (Mohammed Gedefaw, 2013). As indicated by Murphy and Lugo (1997), the global AGB in tropical dry and wet forests ranged between 30-275 ton/ha and 213-1173 ton/ha respectively and due to this, the result of the study site had almost a positive carbon stock potential and this indicates the forest status was well managed and protected even if some human interference could be there.

As indicated in the methodology part estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 was used MacDicken (1997). The minimum and maximum value of below ground biomass in Ades forest revealed that 4.47and 1853.83 ton/ha respectively. The average mean value was 105.568 ton/ha. In comparable with other studies the liter carbon stock value was less than Egdu forest (Adugna Feyissa, 2012) and highly exceeded than the previous study of Tara Gedam forest (Mohammed Gedefaw, 2013). The values of the current study (Ades forest) even greater than the standard value that was testified in tropical dry forests (2.1 t ha^{-1}), IPCC, (2006). According to (Fisher and Binkly, 2000) as cited by Adugna Feysa, the type of species, age and density of the forest vegetation can influence the carbon stock potential of the forest. There are a number of trees in the study site which are, comparatively still youngest and regenerating and this condition could be the cause for the small amount of fall of litter. And the other fact is, most of the trees in the Ades forest has small sized and conical type of leaf (conifers), decomposition is also another major reason for making less amount of litter carbon in the study area due to the cause of reducing the surface litter carbon, and these situation could be the main factors for smaller value of litter carbon than some other studies. Bulk density of Ades forest was ranged about the minimum value of 0.5g cm^{-3} and the maximum value of 1.34 g cm^{-3}. The mean bulk density of the study site was 0.81 g cm^{-3}. Bulk density can be affected by consolidation, compaction and also the amount of soil organic matter found in the soil (Morisada *et al*., 2004, Leifeld *et al*., 2004). The carbon stock and organic matter of the soil have direct relationship, as the laboratory result indicates the carbon pools of the study site which had large amount of organic matter had recorded high carbon stock value, and thus, the higher mean value of soil organic carbon of Ades forest is probably owing to the existing of high soil organic matter. Soil organic carbon of the forest again highly depends on the moisture, decomposition of litter carbon, climatic zone, temperature, slope, altitude, aspect and the nature of soil as well. Carbon enters the soil as roots, litter, harvest residues, and animal manure. It is stored primarily as soil organic matter (SOM). The density (w/v) of carbon is highest near the surface, but SOM decomposes rapidly, releasing CO_2 to the atmosphere. As the study shows that Ades forest plays a great role for the mitigation of climate change phenomena by its solid potential of carbon dioxide sequestration.

Table 5: Comparison of carbon stocks of this study in different pools with other previous studies

Study places	AGC	BGC	LC	SOC
Ades Forest	259.17	52.20	2.34	271.69
Egdu Forest	278.08	55.62	3.47	277.56
Tara Gedam Forest	306.36	61.52	0.90	274.32

Environmental factors disturbing different carbon pools

Altitude is recognized to have a major effect on the variety, biomass and carbon stock in the forest ecosystems (Luo *et al*., 2005). The current study indicates that, the middle altitude showed an increasing carbon stock potential and followed by the bottom (lower) altitude and decreased when we go to up or top of the mountain . This condition suggests that, the lower and the upper parts of the forest have scattered type of plant arrangement and displayed lack of large trees as compared with the middle altitude and due to suitable environmental condition most species of plants habit in the middle part and result in high biomass and carbon stock values. The presence of species characterized by large individuals occurring on middle altitude could have an effect on AGB and carbon stock, because few large individuals can account for large proportion of the plots above and below ground carbon (Brown and Lugo, 1992). This could perhaps be the case in the present study area, whereas, bigger trees with maximum DBH were more common in middle altitude and somehow in lower altitude areas. The litter carbon pool of Ades forest exhibits an increasing trend with increasing altitudinal variation, and this condition suggested that at the hilly area of the mountain, the distribution and the number of trees reduced, and hence abundant litter fall could be available and this situation may be the cause for having exceeded litter carbon than the rest of other altitudinal gradients. In densely populated trees, few litters were found due to the nearness of plants each other make their litter not fall down (Demel Teketay, 1996). Results of the study indicated that, the highest SOC content (288.31 ton/ha) was found in the lower altitude this is because of the place was naturally undisturbed forest and the other case is because of siltation as a result of soil erosion, whereas lowest soil organic carbon (259.32) was observed in the middle altitude due to some human interference such as cropping and also less decomposition of organic matter. The soil organic carbon of higher altitude was very close with the result of the lower altitude which ranges about (281.67) ton/ha due to fast decomposition of organic matter and as a result of decreasing temperature and increasing precipitation(Zhu *et al.,* 2011) found that SOC increased with increasing altitude which is similar to the current study . Decomposition has made a substantial role as it may increase the amount of soil organic carbon regarding with increasing altitudinal gradients. In general the carbon pool of Ades forest did not show significant variation along altitudinal gradient as above ground carbon, below ground carbon, litter carbon and soil organic carbon. Likewise Slope gradient is also another environmental factor which affects and limits the spreading of carbon stock in the study site. The result of carbon stock in the study site of different carbon pool showed insignificant difference along slop gradient. The four types of carbon pools (Above and Below ground, Litter and soil) in the Ades forest revealed high amount of carbon as the range of the slop increasing, this was happened because the number of carbon pools which were found in the middle and higher slop gradients were highly exceeded than the lower one .and this condition was the reason for having a contradictory result of carbon stock than other studies . In a steeply slop the above ground and below ground biomass of the carbon pool reduced due to less vegetation coverage as a result of soil erosion, on other hand the above and below ground biomass and carbon density showed higher values in lower slope because of having high vegetation coverage due to the case of siltation and other favorable condition. Similar pattern has been observed in the litter and soil organic carbon with the same reason mentioned above.

The third type of environmental factor which affect the carbon stock of the Ades forest is an aspect. It plays a great roll to forecast the delivery and carbon potential of the carbon pool of the study site. The result of the study showed that, higher mean value of above and below ground biomass and carbon stock has been recorded on the south (S) direction and small amount for the western (W) direction. The reason behind to had this result mentioning above was due to the presence of high moisture content and favorable environmental condition such as the type and fertility of the soil for the southern aspect of the study area whereas the reverse is true to the western direction of the site. The same result happened with similar reason for the litter pool and soil organic carbon.

CONCLUSION

The study shows that Ades forest makes a significant contribution to carbon sequestration and therefore can generate carbon credits in Ethiopia. It is also expected that much income can be earned by selling carbon credits in the carbon market through CDM projects. A total of 44 different species were recorded of which *Juniperus procera* and *Podocarpus falcatus* were the most dominant species. The DBH and height distribution of Ades forest varied from species to species .Those of plants which have lower DBH and height classes of Ades forest showed high potential of carbon storage. The middle altitudinal zone of the study site was dominated by small sized and dense forest, and this implies that most carbon stock accounted on this region. The overall carbon stock potential of the study area varied from one carbon pool to another pool due to unequal distribution of biomass on each plots. The average carbon stocks of the different carbon pools of Ades forest was higher than most study results of forests done in Ethiopia in carbon sequestration potentials of forests except some recent studies .This situation designates the potential benefits of the study forest for climate change mitigation. Environmental gradients such as Altitude Slope and Aspect were the major factors that played a great roll on the storage of carbon stock in different carbon pool of the study site. The carbon stock of above ground and below ground carbon of the middle altitude showed an exceeding value than the rest of carbon pools this was because of suitable and convenient conditioning and due to the presence of abundant vegetation coverage ,whereas the carbon stock of the litter carbon showed an increasing trend with increasing altitudes. The carbon stock in the soil pool was higher in lower and upper altitude with sound carbon stocks in the middle altitudinal classes. The slop gradient of the study site also revealed increasing carbon stock with increasing slope to the above ground and below ground carbon as well as the soil organic carbon. On another case the litter carbon showed high carbon stock in the middle slop and lower slop respectively, but exhibited lower value in the higher slop gradient. The total carbon stock (AGC, BGC, LC and SOC) was recorded higher on the southern aspect of the study site due to promising environmental conditioning and moisture content as well. Whereas the lower carbon stock has been recorded on the direction of western aspect. In general the carbon stock potential of the current study has been highly correlated with environmental factors which were knowingly the altitude, slop and different aspects and hence played a major roll on climate change mitigation with the means of sequestering carbon.

RECOMMENDATIONS

Based on the result which was carried out on the study site (Ades forest), the following recommendation have been made.

- There was high human interference observed in the study site such as deforestation, overgrazing and farming as well, so the regional government should have to give attention and creating awareness to the local people regarding with forest management and sustainable use of natural resources.
- It is better to provide an alternative source of energy for the local people in order to protect the Ades forest from deforestation for the purpose of satisfying their fuel demand.
- Research should be undertaken to collect data on the quantity, distribution and partitioning of carbon, and any changes taking place over time in the different sections of the forest such as indigenous and the disturbed forest, as well as the planted trees by farmers.
- consideration should be given to updating the methodology to improve the accuracy and reliability of the outcomes including: allometric equations that include species-specific wood densities
- Integration of indigenous knowledge with modern conservation approach in the planning and implementation process must be encouraged.

REFERENCES

Adugna Feyissa (2012). Forest Carbon Stock and Variations along Environmental Gradients in Egdu Forest: Implications of Managing Forests for Climate Change Mitigation MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Adugna Feyissa, Teshome Soromessa and Mekuria Argaw (2013). Forest Carbon Stocks and Variations along Altitudinal Gradients in Egdu Forest: Implications of Managing Forests for Climate Change Mitigation. STAR: Science, Technology and Arts Research Journal, 2(4): 40-46.

Badeg Bishaw (2003). Deforestation and land degradation on the Ethiopian highlands: Bhishma, P. S., Shiva, S. P., Ajay, P., Eak, B. R., Sanjeeb, B., Tibendra, R. B., Shambhu, C., and Rijan, T. 2010. Forest Carbon Stock Measurement: 64

Brown, S. A. J., Gillespie, J. R. and Lugo, A. E. 1989. Biomass estimation methods for tropical forests with application to forest inventory data. *Forest Science*, **35**(4): 881–902.

Brown, S. and Lugo A. E. 1992. Above-ground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia* **17**: 8-18.

Demel Teketay (1996). Germination ecology of 12 indigenous and 8 exotic multipurpose leguminous species from Ethiopia. Forest Ecology and Management 80: 209-223.

Ensermu Kelbessa & Teshome Soromessa. (2008). Interfaces of Regeneration, Structure, Diversity and Uses of Some woody Species in Bonga Forest, a Unique Gene Reserve for Wild Coffee. Sinet: Eth. J. Sci. 31(2): 121-134.

Fekadu Gurmessa, Teshome Soromessa and Ensermu Kelbessa (2011). Floristic Composition and Community analysis of Komto Afromontane Moist Forest of East Wellega, West Ethiopia. STAR: Science, Technology and Arts Research Journal, 2(2): 58-69.

Fekadu Gurmessa, Teshome Soromessa and Ensermu Kelbessa (2012). Structure and Regeneration status of Komto Afromontane Moist forest, East Wellega Zone, West Ethiopia. Journal of Forestry Research, 23 (2): 205-216.

Fisher, R. F. and Binkley, D. (2000). Ecology and Management of Forest Soils. John Willey &Sons, Inc. New York, USA.

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

Gibbs. H.K., Brown, S., Niles, J.O. and Foley, J.A., (2007). Monitoring and estimating forest carbon stocks: Making REDD a reality. *Environmental Resource Letters* **2**:1-13

Houghton, R.A. and Skole, D.L. (2001). Carbon. In: The Earth as transformed by human action. (Eds Turner, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T. and Meyer, W.B.), Cambridge University Press, Cambridge, pp 393–408.

Intergovernmental Panel on Climate Change (2006). IPCC Guidelines for National Greenhouse Gas Inventories Volume 4. Prepared by National Greenhouse Gas Inventories Program, (Eggleston H.S., Buendia L., Miwa K., Ngara T. and 68 Tanabe, K. eds), Institute for Global Environmental Strategies (IGES) Publishing, Hayama, Japan.

Intergovernmental Panel on Climate Change, (2007a). Mitigation of Climate Change. Report of Working Group III. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change, (2007b). Highlights from Climate Change. The Physical Science Basis. Summary for Policy Makers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., Miller, H. L., eds). Cambridge University Press, Institute of Terrestrial Ecology, Edinburgh, pp. 545-552.

Leifeld, J., Bassin, S. & Fuhrer, J. (2004). Carbon stock in Swiss agriculture soils predicted by land use soil characteristics, and altitude. Agriculture, Ecosystem and Environment.

Lugo, A.E., 1997. The apparent paradox of re-establishing species richness on degraded lands with tree monocultures. *Forest Ecology and management* **99**: 9-19

Luo, T. X., Brown, S., Pan, Y. D., Shi, P. L., Ouyang, H., Yu, Z. L., Zhu, H. Z. (2005). Root biomass along subtropical to alpine gradients: global implication from Tibetan transects studies. *Forest Ecology Management* **206**:349–363.

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

Mohammed Gedefaw (2013). Forest carbon stocks in woody plants of Tara Gedam forest and its variations along Environmental factors: Implication for climate change mitigation MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

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

Morisada, K., Ono, K. and Kanomata, H. (2004). Organic Carbon Stock in forest soils in Japan.

Pearson, T., Walker, S. and Brown, S., (2005). Sourcebook for land-use, land-use change and forestry projects. Winrock 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. 6-1

Teshome Soromessa., Demel Teketay and Sebsebe Demissew. (2004). Ecological study of the vegetation in Gamo Gofa zone, Southern Ethiopia. Tropical Ecology 45(2): 209-221.

Teshome Soromessa, Ensermu Kelbessa, Afework Bekele, Getinet Masresha, Desalegn Ejigu, Melese Yihune & Fisseha Itanna (2011). Current Status and Significance of Faunal and Floral Diversity of the Simien Mountains, Northern Ethiopia. A poster presented on December 30-31, 2011 during the conference on Thematic Research Organized by Addis Ababa University, Addis Ababa, Ethiopia.

Teshome Soromessa (2013). Ecological Phytogeography: A Case Study of Commiphora Species: STAR: Science, Technology and Arts Research Journal, 2(3): 93-104.

Teshome Soromessa and Ensermu Kelbessa (2013a). Diversity, Ecology and Regeneration Studies of Bonga, Borana and Chilimo Forests of Ethiopia. Lambert Academic Publishing, Saarbrücken, Germany, Pp 140, ISBN 978-3-659-41509-8.

Teshome Soromessa and Ensermu Kelbessa (2013b). Diversity and Endemicity of Chilimo Forest, Central Ethiopia. Bioscience Discovery, 4(1): 1-4.

Teshome Soromessa and Ensermu Kelbessa (2014). Interplay of regeneration, structure and uses of some woody species in Chilimo Forest, Central Ethiopia. STAR: Science, Technology and Arts Research Journal, 3(1): 90-100.

Schlesinger, W.H. (1991). Biogeochemistry, an Analysis of Global Change. New York, USA, 73 Academic Press.

UNITED NATION FFRAMEWORKE CONVATION FOR CLIMATE CHANGE (2009). Project Design document form for afforestation and reforestation project activities (CDM-AR-POD) version 04; CDM. Executive Bound.

Zhu, B., Xiangping Wang, Jingyun Fang, Shilong Piao, Haihua Shen, Shuqing Zhao, ChanghuiPeng. (2011). Altitudinal changes in carbon storage of temperate forests on Mt Changbai, Northeast China. Carbon cycle process in East Asia. *Journal of Plant* Resource **10**:1-14.