Carbon stock of woody species along Altitude gradient in Alemsaga Forest, South Gondar, North Western Ethiopia

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Abstract—

Purpose: *Forest ecosystems play a significant role in the climate change mitigation and biodiversity conservation. Therefore carbon determination provide clear indications of the possibilities of promoting forest development and management for mitigating of climate change through soil and vegetation carbon sequestration. The study was carried out to quantify carbon stock potential in Alemsaga Forest, South Gondar zone.*

***Research method:** Vegetation data Collection was made using a systematic sampling method; laying six transect lines with 500 m apart and 54 quadrants of 20 m X 20 m established 200 m distant to each other along the transect lines. In these plots, abundance, DBH and heights of all woody species were recorded, and soil sample was collected 1m X1m* from the four corners and center of each quadrant. *General allometric model was used for estimating above and belowground biomass. The organic carbon content of the soil samples was determined in the laboratory.*

***Finding:** A total of 66 woody plant species belong to 42 families were identified*, Fabaceae was the most dominant families. *The total mean above and belowground carbon stock was 216.86 ton/ha and 114.71 ton/ha respectively and soil organic carbon (SOC) 103.15 ton/ha. Above and belowground carbon increased as altitude decreased, but SOC increases with increase of altitude.*

***Originality/value:** Carbon stock estimation in the forest helps to manage the forests sustainably from the ecological, economic and environmental points of view and opportunities for economic benefit through carbon trading to farmers.*

Key word: Altitude, Carbon stock, Forest, Woody species.

I. INTRODUCTION

Forests provide a diversity of ecosystem services including converting carbon dioxide into oxygen and biomass, acting as a carbon sink, aiding in regulating climate, protection of hydrological services, biodiversity conservation and aesthetic values (Scherr *et al*., 2004). Climate change is a real recent problem that harmfully affects environmental norms and populations, causing a severe negative impact worldwide. It is supposed that the aim of decreasing carbon sources and increasing the carbon sink that can be attained through keeping and maintaining the carbon pools in existing forests is among the top priorities of climate change mitigation (Brown *et al*., 1996). Carbon sequestration is the removal of CO_2 from the atmosphere and storing it in the ocean, vegetation, soil and geological formation (IPCC, 2000). Forests are a current focus for action since they play a significant contribution to mitigating climate change by absorbing carbon emission from the atmosphere (IPCC, 2000).

The sequestration of carbon is one of the many ecosystem services supported by biodiversity (Maestre *et al.*, 2012). Therefore biodiversity is very important for carbon storage to enhance nutrient availability and socio economic benefits (Brown, 2002). Carbon is initially sequestered through photosynthesis before being transferred to one of a number of terrestrial pools including aboveground biomass, dead wood, litter, roots and soil (Gorte, 2009). Carbon stock can be influenced by different factors, including altitude, tree species, climate, soil nutrient availability, disturbance and management regime (Houghton, 2005). Carbon stock in trees increases with temperature, nutrient availability , soil moisture and tree density, and SOC increase with precipitation, and decrease with temperature (Jobbagy and Jackson, 2000).These pools are then subject to gains and losses depending on rates of growth, mortality and decomposition that are in turn affected by varying human and natural disturbances (Maestre *et al.*, 2012).

Alemsaga Forest is found in the western edge of the Farta district of Northern Ethiopia. The area is protected starting from 1978 with the objectives of providing seed source, maintaining the remnant natural forests and recovering the degraded area. Between 1990 and 1992, during the government transition, the area was converted into pasture and farm lands. After political stability in 1993 of the country the area was re-protected as forest area (Farta woreda agricultural office, 2017). Deforestation and grazing are ongoing challenges for conservation of study forest (Farta woreda agricultural office, 2017). Carbon determination may provide clear indications of the possibilities of promoting forest development and management for mitigating of climate change through soil and vegetation carbon sequestration. Therefore, the study was to quantify above and belowground biomass, and their carbon stock of forest, to quantify soil organic carbon stock, and to determine the variation of carbon stock along altitudinal gradient.

II. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted on Alemesaga forest, Farta woreda, south Gondar zone; Amhara region of north western Ethiopia (Figure 1).The forest covers 780 ha including plantation forest. The soils are reddish brown or brown of clay loam, slit clay and sandy loam texture, and freely draining with predominantly nithosols and leptosol. The forest has an elevation range between 2100 m and 2470 m above sea level.

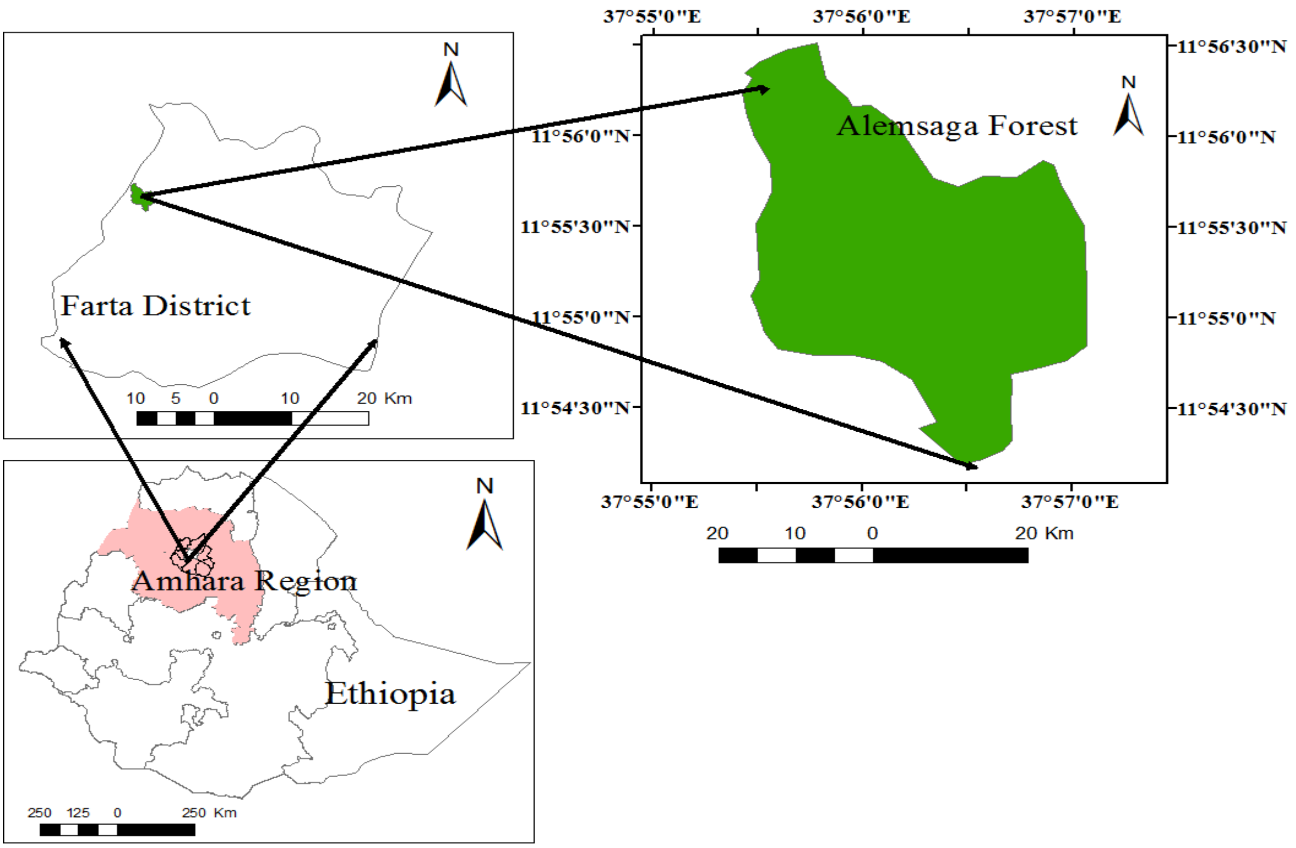

FIGURE 1: Map of Alemsaga forest, South Gondar, North Western Ethiopia

2.2 Climate

The mean monthly temperatures 14.62°C (Figure 2). The agro ecological zone of this forest is moist wenadega. The rainfall pattern is unimodal, which obtain high rainfall from June to August and long term average of 1484 mm (Debre Tabor metrological station, 2018).

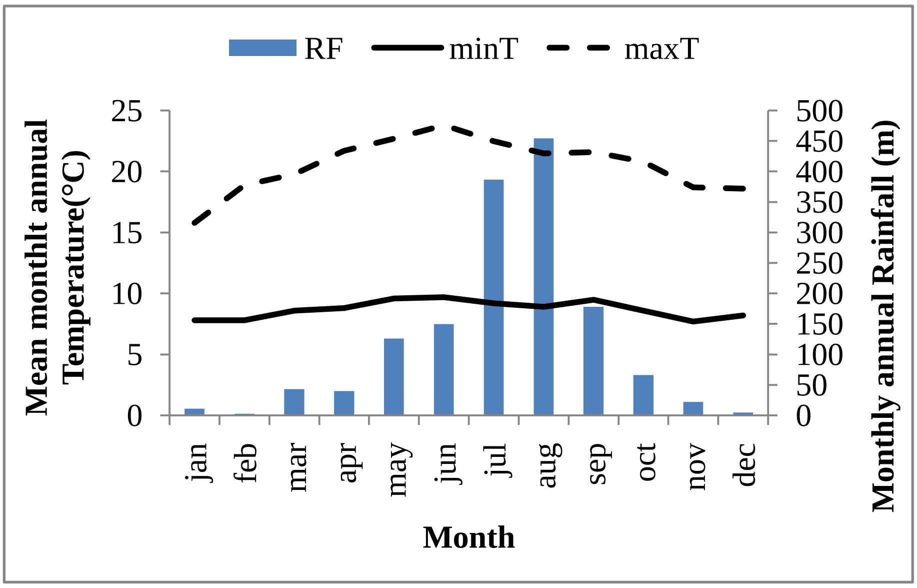

FIGURE 2: Average rainfall (mm) and temperature (°C) (1990-2017) in Alemsaga forest South Gondar, North Western Ethiopia (Debre Tabor metrological station, 2018).

III. SAMPLING TECHNIQUES AND SAMPLING SIZE

A Stratified systematic sampling technique was employed in this study. The stratified based on altitude gradient. The distance between transect line and plots was determined based on vegetation density, spatial heterogeneity of vegetation and size of the forest (Tefera *et al.*, 2005).To reduce edge effect transects were laid at a distance of 50 m far from both edges of forests. The first transect line was laid randomly at the edge of northern direction forest started from top to bottom of the mountain Totally six transect lines laid dawn with 500 m apart and, 54 quadrants (20m x 20m) were established 200m distance to each other along the transect lines. The GPS points also that helped to indicate each sample plots (Figure 3).

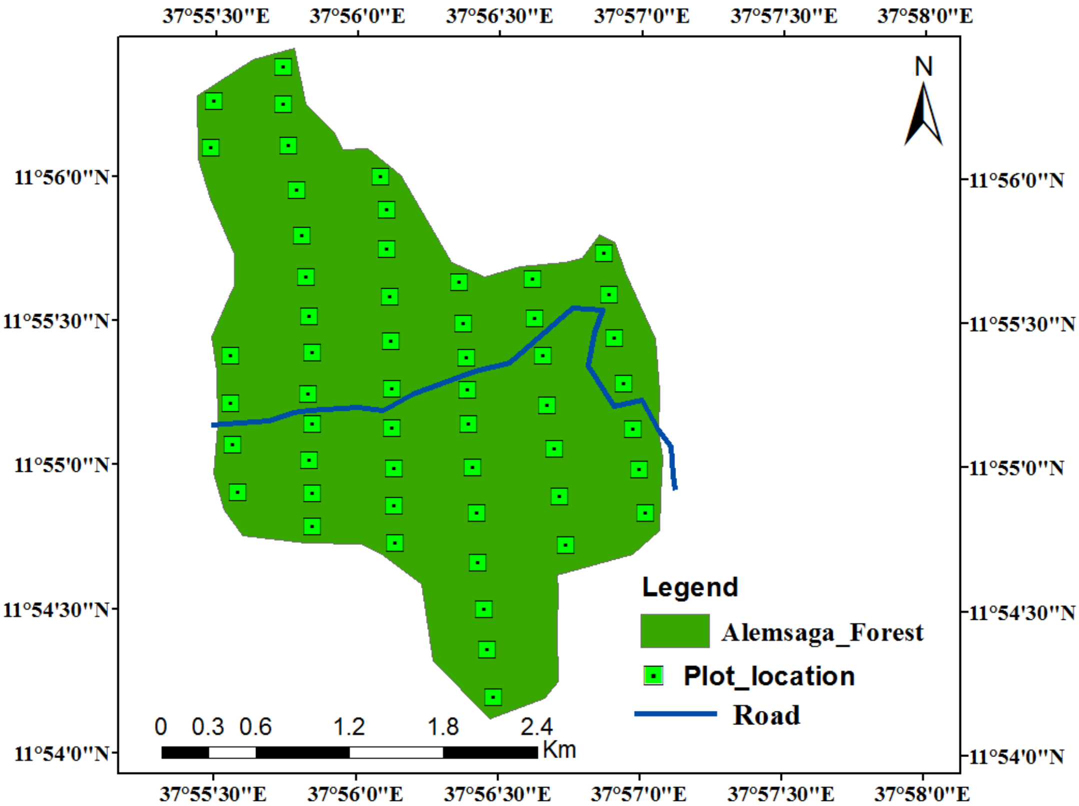

FIGURE 3: Plot location in Alemsaga forest, South Gondar, North western Ethiopia

3.1 Vegetation data collection

In each plot woody vegetation was counted, diameter was measured at breast height (DBH) and height from the ground. DBH was measured using diameter tape and tree height was measured using clinometer. Plant identification was done in the field by the knowledge of the local people and using Flora of Ethiopia and Eritrea.

3.2 Soil sampling

The carbon in the soil is concentrated in the top 30 cm layer of soil profiles, (IPCC, 2006). Therefore soil organic carbon pool was sampled up to the depth of 30 cm in this study. According to the principles of Pearson e*t al.*, (2005) soil samples for soil carbon determination was collected from the field within the area of $1m^2$ five subplots within each major plot. The samples were dug using auger at depth of up to 30 cm from the four corners and center of each quadrant, and sample for bulk density (BD) was collected using a core sampler. Mixing of soils was done properly by taking an equal amount of soil from each subplot to make a composite in order to make homogeneity.

3.3 Data analysis

3.3.1 Estimation of aboveground carbon stock (AGC)

To estimate the above and belowground biomass/carbon, a nondestructive approach which involves the use of allomoteric models were used. The popular allomotric equation of Chave *et al*. (2014) was used in this study to determine the biomass of tree species having ≥ 5 cm DBH as it fits to biophysical conditions of the study area. . The model:

$$AGB = 0.0673 \times (\rho D^2 H)^{\wedge}0.976 \quad (1)$$

Where, AGB – aboveground biomass (kg),

H– Height of tree (m),

D– Diameter (cm) at breast height (1.3m), and

ρ– Wood density (t/m^3), the African trees average wood density values (0.58 ton/m^3) (Brown et al., 1997).

The tree biomass was converted into C by multiplying the above ground tree biomass by 0.5 (Brown, 2002).

$$\mathrm{AGC} = \mathrm{AGB} \; \mathrm{X} \; 0.5 \quad (2)$$

Where, AGC – Aboveground carbon

3.3.2 Estimation of belowground carbon stock (BGC)

Estimation of below ground biomass is much more difficult and time consuming due to uncertainty of root biomass measurement. Root biomass is often estimated from root-shoot ratios (R/S) by taking 25% of aboveground biomass (Cairns *et al*., 1997).

$$\mathrm{BGB} = \mathrm{AGB} \times 0.25 \quad (3)$$

$$\mathrm{BGC} = \mathrm{BGB} \; \mathrm{x} \; 0.5 \quad (4)$$

Where, BGC = carbon content of below ground biomass, BGB= below ground biomass

3.3.3 Estimation of soil organic carbon (SOC)

The carbon stock of soil was done by using Pearson *et al*., (2005) formula,

$$\mathrm{SOC} = \mathrm{BD} * \mathrm{D} * \%\,\mathrm{C} \quad (5)$$

Where, SOC= soil organic carbon stock per unit area (t/ha),

BD = soil bulk density ($g\ cm^3$),

D = the total depth at which the sample was taken (30 cm), and

%C = Carbon concentration (%).

About 100 gm of evenly mixed soil samples from the five subplots was taken to the laboratory, and then the carbon content of the soil samples was determined in the laboratory using (Walkley-Black Method, 1934). Determination of percentage of organic carbon was conducted in Bahir Dar regional soil laboratory center.

Then the bulk density of a soil sample was calculated as follows:

$$\text{Bulk density } (gm/cm^3) = \frac{\text{Oven dry weight of the soil}}{\text{Volume of the core}} \quad (6)$$

The volume of the soil in the core sampler was calculated as follows:

$$V = h * \Pi r\text{^}2 \quad (7)$$

Where, V is the 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).

3.3.4 Estimation of total carbon stock

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.

$$\text{TC} = \text{AGC} + \text{BGC} + \text{SOC} \quad (8)$$

Where, TC = Total Carbon stock for all pools (ton/ha) and AGC=aboveground carbon stock (t/ha), BGC= belowground carbon stock (ton/ha.

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

3.4 Statistical Analysis

The significance of species diversity and carbon stock was analyzed by using Statistical Package for Social Science (SPSS) software version 20. The relationship between each parameter was tested by descriptive statistics such as mean, standard deviation, minimum and maximum value. The significant difference of above and below ground carbon stock, and soil organic carbon stock along altitude at 5% of the level of significance tested by one-way ANOVA, and Gabriel post-hoc test for multiple comparisons was used. The above and belowground carbon stock were transformed using ln transformation.

IV. RESULTS AND DISCUSSIONS

4.1 Floristic composition

A total of 66 woody plant species belong to 42 families were identified, Fabaceae was the most dominant families. The most frequent species were *Dodonaea angustifolia*, *Croton macrostachyu and Carissa edulis* with 70.37 %, 64.81 and 53.70 % of occurrence respectively.

4.2 Biomass and Carbon Stock in Different Carbon Pools

4.2.1 Above ground Biomass (AGB) and Carbon Stock (AGC)

The mean AGB and AGC stock was 183.7±141.03ton/ha and 91.85±70.51ton/ha respectively. The minimum and maximum AGB was 43.79 ton/ha and 772.12 tons/ha, and the minimum and maximum AGC was 21.90 and 386.06 ton/ha respectively. The minimum and maximum above ground carbon dioxide equivalent (Co_2equ) 80.36 and 1416.84 ton/ha respectively. The mean abovegroundCo_2equof the study forest was 337.09±259.78 ton/ha.

When compared with other dry Afromontane forest, it was less than the AGC stock of Mount Zequalla Monastery (237.75 ton/ha) (Abel *et al.*, 2014); Egdu Forest (278.08 ton/ha) (Adugna *et al*., 2013;); Mengesha saba state forest (133 ton/ha) (Mesfin, 2011); Tara Gadam forest (306.37 ton/ha) (Mohammed et *al.*, 2015) and Woody Plants of Arba Minch Ground Water Forest (414.70 t/ha) (Belay *et al*., 2014). This is due to the presences of dominant small size tree species, and might be selective removal of trees of mature tree for charcoal, fuel wood, timber production and house construction due to weak management practices. In contrast, the value of AGC stock in the study forest was higher than the AGC stock, estimated in the Mountain Dirki woodland (41.5 ton/ha) (Deresa, 2015), Humbo forest (30.77 ton/ha) (Alefu *et al.*, 2015). This variation might be the age of the trees, environmental gradient, tree species, and management option of the forest.

4.2.2 Below ground Biomass (BGB) and Carbon Stock (BGC)

The mean value of BGB and BGC stock was 45±35t/ha and 22.86±17.69ton/ha respectively. The minimum and maximum BGB was 10.94 ton/ha and 193.03 ton/ha respectively. The minimum and maximum BGC was 5.47 and 96.52 ton/ha respectively. The mean below ground CO_2 equivalent of the study forest was84.76± 64.69 ton/ha. The minimum and maximum belowground CO_2 equivalent was 20.09 and 354.21ton/ha respectively.

When compared with other dry Afromontane forest, it was less than the BGC stock of woody plants of the Mount Zequalla Monastery (47.6 ton/ha) (Abel *et al.*, 2014); Egdu Forest (55.62 ton/ha) (Adugna *et al*., 2013;); Mengesha saba state forest (26.99 ton/ha) (Mesfin, 2011); Tara Gadam forest (61.52 ton/ha) (Mohammed et *al.*, 2015) and Woody Plants of Arba Minch Ground Water Forest (83.48 t/ha) (Belay *et al*., 2014). This is due to the presences of dominant small size tree species, different management practices and methods used for estimated biomass.

4.3 Soil Organic Carbon (SOC)

The bulk density of the soil profile found in the study site was ranged from 0.8 g/cm^3 of minimum to 1.69 g/ cm^3 maximum value with the average value of 1.24 g/cm^3. The minimum and maximum soil organic mater in the study site was 3% and 8% respectively. The highest and the lowest soil carbon stock of the study forest range from 198.07 and 35.4 ton/ha, respectively. The mean SOC stock of the study forest was 102.15± 33.62 ton/ha. The soil carbon of the study site sequestered CO_2equ with the minimum and maximum value of 129.97 and 726.92 ton/ha, respectively.

When compared with other studies, it was less than the SOC stock of Danaba Community Forest (186.40 ton/ha) (Muluken *et al*., 2015); and Tara Gadam forest (274.32 ton/ha) (Mohammed et *al.*, 2015); Egdu Forest (277.56 ton/ha) (Adugna *et al*., 2013) and Menagasha Saba State Forest (121.8 ton/ha) (Mesfin, 2011).

The higher SOC was found as compared to other study forest such as Park Forest (69.238) ton/ha in Addis Ababa (Meseret, 2013); Mount Zequalla Monastery (57.6 ton/ha) (Abel *et al.*, 2014) and Woody Plants of Arba Minch Ground Water Forest (83.80 ton/ha) (Belay *et al.*, 2014). This indicates that the study forest had high organic matter content and high decomposition of litter in the soil, which results maximum storage of carbon. The possibility for high carbon stock in soil can be due to the presence temperature, litter fall accumulation, presence of tree species, topography, and soil nutrient availability and rate of decomposition (Xiaoli *et al.*, 2010).

4.4 Total carbon stock of Alemsaga forest

The total mean carbon stock of Alemsaga forest was achieved by summing up the carbon stock found in each carbon pool. In the present study, the largest carbon stock was contributed by the soil carbon pool which accounted 47.2% of the three carbon pools and the second was AGC pool which accounted for 42.24%. The least was recorded in BGC stock, which accounted for 10.56% (Table 1).Therefore; the total carbon stock of Alemsaga forest was 216.86 tons/ha and contributed in CO_2 equivalent with the value of 796.74 ton/ha (Table 1).

TABLE 1
SUMMARY OF MEAN ± STANDARD DEVIATION CARBON STOCK IN DIFFERENT CARBON POOLS IN ALEMSAGA FOREST, SOUTH GONDAR, NORTH WESTERN ETHIOPIA.

Carbon pool	(ton/ha)	%	CO_{2equv}
Aboveground carbon stock	91.85±70.51	42.24	337.09±259.78
Belowground carbon stock	22.86±17.69	10.56	84.76± 64.69
Soil organic carbon	102.15±33.62	47.2	374.89±123.39
Total	216.86	100	796.74

When compared with other studies, it was less than the total carbon stock of Danaba Community Forest (505.83 ton/ha) (Muluken *et al*., 2015); and Tara Gadam forest (642.21 ton/ha) (Mohammed et *al.*, 2015); Egdu Forest (611.26 ton/ha) (Adugna *et al*., 2013) and Menagasha Saba State Forest (281.27 ton/ha) (Mesfin, 2011).The differences might be the size of tree, species composition, management practice and liter fall accumulation in the soil.

4.5 Carbon stock variation along altitudinal gradient

The mean AGC was 123.59±84.81ton/ha, 88.9± 66.59 ton/ha and 51.57 ±20.23 ton/ha for the lower class, middle class and higher altitude class respectively. The mean BGC stock was 30.89±21.2 ton/ha, 22.23±16.64 ton/ha and 12.86±5.06 ton/ha for the lower, middle and higher altitudinal class respectively. The result showed that the lower altitude was higher than middle and higher altitude with the carbon content of the woody plant species. There was a significant difference both AGC and BGC stocks along an altitude gradient ($p< 0.01$) (Table 2).

Forests have a large potential for temporary and long term carbon storage and the forest biomass and carbon stock is influenced by altitudinal variations (Alves *et al*., 2010).This may be due to the absence of matured large trees at higher altitude and lower altitudinal gradient was surrounded by a river and there were some big trees and possibly also due to the favorable conditions for tree growth in the lower part. The upper part of the forest was dominated by lower plants such as grasses, herbs shrub and bushes, there were a low number of mature trees, which have lower biomass. The same result in the Semen Mountain National Park (Tibebu and Teshome, 2015), Mountain Dirki woodland (Deresa, 2015), and Egdu Forest (277.56 ton/ha) (Adugna *et al*., (2013), while it showed dissimilarity with the study by Mohammed *et al*., (2015) in Tar Gedam Forest, (Muluken *et al*., 2015) Danaba Community Forest .

The mean SOC in higher altitude, middle and lower class were 112.3±28.53ton/ha, 99.8.1±37.79 ton/ha and 97.26±28.53ton/ha respectively (Table 2). The result showed that the maximum carbon stock was found at higher altitude class, but the variation of the mean carbon stock was not different along altitude gradient ($p>0.05$) (Table 2). As a whole the higher part of altitude contains higher amounts of carbon stocks in soil might be the contained indigenous shrubs and grass which have enough litter fall, but in lower and middle altitude was unsuitable for the growth of herbs and grasses due to a huge closed canopies of *Juniperus procera* L, *Eucalyptus camaldulensis*, and *Eucalyptus globules* up to the near ground. SOC were commonly higher in the indigenous shrubs and trees than the plantation forest (Guo and Gifford, 2002).

The result of this study was similar to the study of (Alem, 2015) in selected public parks. The result of SOC showed, there was a slight variation of carbon stock along altitudinal class of the study area. SOC increased with precipitation, and decreased with temperature (Jobbagy and Jackson, 2000). In the study forest, in general increasing trend the mean of SOC with increasing altitude was observed due to open canopy in higher altitudinal class might favor the growth of annual herbs and grasses, which agreed with the result found by Belay *et al*., (2014) in Woody Plants of Arba Minch Ground Water Forest.

TABLE 2
THE MEAN ± SD CARBON STOCKS (TON/HA) ALONG ALTITUDE GRADIENT IN ALEMSAGA FOREST, SOUTH GONDAR, NORTH WESTERN ETHIOPIA.

Altitude	Carbon stock (ton/ha)		
	AGC	BGC	SOC
Lower	$123.57±84.85^{a}$	$30.89±21.21^{a}$	$97.26±37.79^{a}$
Middle	$86.9±67.19^{ab}$	$22.23±16.79^{ab}$	$99.81±28.53^{a}$
Higher	$56.54±22.32^{b}$	$14.13±22.32^{b}$	$112.3±28.53^{a}$
P	0.01	0.01	0.419

The different letter the mean value has significant differences at ($p<0.05$)

V. CONCLUSIONS AND RECOMMENDATIONS

The mean above and below ground carbon stock was 91.43±70.78ton/ha and 22.86±17.69 ton/ha respectively. In general the result showed that, the lower altitude have higher carbon stock of woody species due to the presences of larger DBH trees species and favorable environmental condition such as moisture and nutrient availability. The mean SOC of the study site was 102.15± 33.62 t/ha, but the higher part of altitude contains higher amounts of carbon stocks in soil might be the contained indigenous shrubs and grass which have enough litter fall.

Forest soil was also found to be a good reservoir of carbon stock in the study forest as relative carbon stock was found. The total carbon stock in all carbon pools were 216.68 with the corresponding value of 796.74 ton/ha CO_2eq.Therefore, proper protection and management of woody species are very important for conservation of biodiversity as well as carbon storage.

Generally, the present study can contribute towards the understanding of above and below ground carbon stock, and soil organic carbon. Therefore, further studies should be conducted on soil seed bank, regeneration status and population structure is important for future restoration/rehabilitation and better conservation of forest resources in the area.

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