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1 author:

Belay Melese Wolde
Wollo University

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Original Research

Forest Carbon Stocks in Woody Plants of Arba Minch Ground Water Forest and its Variations along Environmental Gradients

Belay Melese Wolde[1*], Ensermu Kelbessa[2] and Teshome Soromessa[3]

[1]Department of Biology, Arba Minch University, Post Box No: 21, Arba Minch, Ethiopia

[2]Plant Biology and Biodiversity Management, Addis Ababa University, Post Box No: 1176, Addis Ababa, Ethiopia

[3]Center for Environmental Science, Addis Ababa University, Post Box No: 1176, Addis Ababa, Ethiopia

Abstract

The role of forests in mitigating the effect of climate change depends on the carbon sequestration potential and management. This study was conducted to estimate the carbon stock and its variation along environmental gradients in Arba Minch Ground Water Forest. The data was collected from the field by measuring plants with a DBH of >5cm in quadrat plots of 10 X 20 m and the carbon stocks of each plant were analyzed by using allometric equations. From this study the mean total carbon stock density of Arba Minch Ground Water Forest was found to be 583.27 t ha^{-1}, of which 829.12 t ha^{-1}, 165.88 t ha^{-1}, 1.28 t ha^{-1}, 83.80 t ha^{-1} was contained in the above ground carbon, belowground carbon, litter carbon and soil organic carbon (0-30 cm depth) 0respectively. Similarly, the analysis of carbon stock variation of different carbon pools on eight different aspects of the forest area showed a significant variation with the exception of litter carbon stock and this is due to fast decomposition rate of litters and low amount of litter fall in the forest. The amount of carbon stock in above and belowground biomass, soil organic carbon and the total carbon stock was higher on the southern aspect as compared to other aspects. This study concluded that the carbon stock value of Arba Minch Ground Water Forest is large, and this will serve as a potential entry point for the engagement of the forest in REDD project.

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***Corresponding Author:**

Belay Melese Wolde

E-mail:
Belaymls@gmail.com
Belay85@yahoo.com

INTRODUCTION

Worldwide concern for natural and biological resources is higher than ever before. Issues such as climate change, loss of biodiversity, ozone layer depletion, or desertification have taken the center of attention in the global discourses. This is mainly caused by anthropogenic greenhouse gas emissions of carbon dioxide mainly from the burning of fossil fuels, deforestation and emission of other greenhouse gas.

Global greenhouse gas (GHG) emissions due to human activities are the causes of change in climate and have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (IPCC, 2007). When the concentration of these GHGs in the atmosphere increases, the temperature of the Earth's surface also rises as increasing amounts of solar radiation is trapped inside the GHGs (Samalca *et al.*, 2009).

Forest management activities are increasingly taking into consideration the role of forests as carbon sinks and there is a pressing need for more information about factors that determine carbon storage potential in forests (McEwan *et al*., 2011).

Increase in the concentration of CO_2 in the atmosphere, from about 280 to more than 380 parts per million (ppm) over the last 250 years, is causing measurable global warming (IPCC, 2007). According to North East State Forestry State (NEFA) (2002), global mean temperature will increase by 1^0C by the year 2025 and 3^0C by the year 2100. Thus, the global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to these concerns have focused on reducing emissions of GHGs, especially CO_2, and on measuring carbon absorbed by and stored in forests, soils, and oceans. One option for slowing the rise of GHG concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests (Broadmeadow and Robert, 2003; IPCC, 2000; IPCC, 2007).

Forests play a critical role in the natural global carbon cycle by capturing carbon from the atmosphere through photosynthesis, converting that photosynthesized carbon to forest biomass, and emitting carbon back into the atmosphere during respiration and decomposition. It sequesters and stores more carbon than any terrestrial ecosystem i.e. they store more than 80% of all terrestrial aboveground carbon and more than 70% of all soil organic carbon (Jandl *et al*., 2006; Perschel *et al*., 2007;

Sundquist *et al.,* 2008). As a result, forest ecosystems are regarded as the largest terrestrial carbon pool. According to the IPCC (2007) report, forests have an average biophysical mitigation potential of 5,380 Mt CO$_2$/yr until 2050.

In addition to being sequestered in vegetation, carbon is also sequestered in forest soils. Carbon is the organic content of the soil, generally in the partially decomposed vegetation (humus) on the surface and in the upper soil layers, in the organisms that decompose vegetation (decomposers), and in the fine roots (Gorte, 2009). The amount of carbon sequestered in forest soils varies widely, depending on the environment and the history of the site. However, Ethiopia is laches no periodic inventory data of forests and carbon stocks and this makes the country fail to develop sustainable forest management planning that attracts climate finances. 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 and 2012); Adugna Feyissa *et. al.* (2013); Teshome Soromessa (2013); Teshome Soromessa and Ensermu Kelbessa (2013a and 2013b); Teshome Soromessa and Ensermu Kelbessa (2014); Mohammed Gedefaw *et al.* (2014) are some of them. However, no study has been conducted in Arba Minch Ground Water Forest that has been intended at evaluating carbon sequestration potential. Therefore, this study was undertaken to estimate the carbon stock potential of Arba Minch Ground Water Forest in relation to environmental gradients.

MATERIALS AND METHODS

Description of the Study Area

This study was conducted in Arba Minch Ground Water Forest which is found at a distance of 505 km south of Addis Ababa. The forest is part of Nech Sar National Park (NSNP) at present administered by the Ethiopian Wildlife Conservation Authority (EWCA). The Ground water Forest is found in the western part of the Park's headquarters with a low ground water table that supports a dense ground water forest, whose floristic make-up is diverse and it remains green all year round (figure 1). It is located between $5^0$51'- $6^0$05'N Latitude and $37^0$32'-$37^0$48'E Longitude in the Southern Nations, Nationalities and People Regional State (SNNPRS) with an altitudinal range of 1108-1650 m a. s. l. Arba Minch Ground Water Forest is covering some 2120 ha and it is home for a wealth variety of fauna and flora species. The annual rain fall of the study are follows bimodal distribution and the main wet season is April to June with a second wet period in September to October ranging from 30 mm in a very dry to more than 1200 mm in the wettest season. The mean annual maximum and minimum temperature are 33.3 and 13.4 ^{0}C respectively.

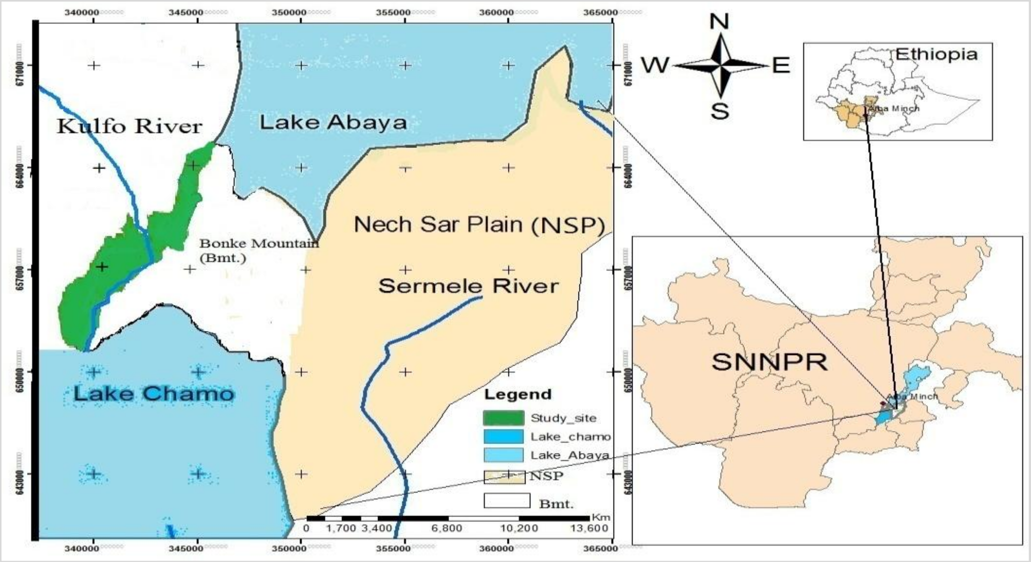

Figure 1: Map of Ethiopia showing SNNPR and the study area

Tree Measurement

Trees with DBH ≥ 5 cm were measured in each plot using diameter tape. Each tree was recorded individually, together with its species name and ID. Trees with multiple stems at 1.3 m height were treated as a single individual and DBH of the largest stem was taken. Trees with multiple stems or fork below 1.3 m height were also treated as a single individual (Kent and Coker, 1992).

Litter

Litter samples were collected in a 1 x 1 m square sub-plot within the larger plot. A total of five sub-plots (four at corners and one in the center) were used for litter collection. In each plot, five samples of fine litter, including leaves, twinges, fruits/flowers, and barks were collected and placed in a weighing bag. A composite sample of 100 gm was taken for the laboratory analysis placing in a plastic bag and oven dried at 105 ^{0}C for 48 hours and weighed for analysis of total carbon concentrations.

Soil Sampling

Soil samples were collected from the five sub sub-plots (30 cm x 30 cm each) in the four corners and one at the center of each plot. 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. 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 taken for the laboratory analysis.

Estimation of Carbon in the Aboveground Biomass

The general equation that was used to calculate the aboveground biomass is given below:

$Y = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2)$ ………. (eq.1)

Where, Y is aboveground biomass, DBH is diameter at breast height.

Estimation of Carbon in Belowground Biomass

According to MacDicken (1997), standard method for estimation of belowground biomass can be obtained as 20% of aboveground tree biomass i.e., root-to-shoot ratio value of 1:5 is used. Similarly, Pearson *et al.* (2005) described this method as it is more efficient and effective to apply a regression model to determine belowground biomass from the knowledge of biomass in aboveground. Thus, the equation developed by MacDicken (1997) to estimate belowground biomass was used.

$BGB = AGB * 0.2$……………………………….(eq.2)

Where, BGB is belowground biomass, AGB is aboveground biomass, 0.2 is conversion factor (or 20% of AGB).

Estimation of Carbon in the Litter Biomass

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

$$\mathrm{LB} = \frac{Wfield}{A} * \frac{\mathrm{W\,Sub - sumple(dry)}}{\mathrm{W\,Sub - sumple(Fresh)}} * \frac{1}{10{,}000} \ldots\ldots (eq.3)$$

Where: LB = Litter (biomass of litter t 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).
Carbon stocks in leaf litter biomass

$CL = LB * \% C$………………………………….(eq.4)

Where, CL is total carbon stocks in the leaf litter in t ha^{-1}, % C is carbon fraction determined in the laboratory.

Estimation of Carbon in Soil Organic Carbon (SOC)

The carbon stock density of soil organic carbon was calculated as recommended by Pearson *et al.* (2005) from the volume and bulk density of the soil.

$V = h \times \pi r^2$………………….....………..(eq.5)

Where, V is volume of the soil in the core sampler in cm^3, h is the height of core sampler in cm, and r is the radius of core sampler in cm. Moreover, the bulk density of a soil sample can be calculated as follows:

$$\mathrm{BD} = \frac{\mathrm{Wav,\ dry}}{\mathrm{V}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathrm{eq.}6)$$

Where, BD is bulk density of the soil sample per plot, Wav, dry = is average air dry weight of soil sample per the quadrate, V is volume of the soil sample in the core sampler in cm^3. Then, the carbon stock in soil was calculated as follows:

$SOC = BD * d * \% C$ ……………………………… (eq.7)

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 (%) determined in the laboratory.

Total Carbon Stock Density

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

C density = CAGB + CBGB + C Lit + SOC…….……(eq.8)

Where:
C density = Carbon stock density for all pools (t ha^{-1})
C AGTB = Carbon in aboveground tree biomass (t ha^{-1})
CBGB = Carbon in belowground biomass (t ha^{-1})
C Lit = Carbon in dead litter (t ha^{-1})
SOC = Soil organic carbon (t ha^{-1}). 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).

RESULTS

The analysis of carbon stock in different carbon pools of the study forest showed different capacity of carbon storage (Table 1). The average carbon stock in the forest area was large and the result is comparable to forests in other tropical countries but higher than most study results of forests in Ethiopia (Table 2). This indicates the contribution of the forest for carbon sequestration and hence mitigation of climate changes.

Table 1: Shows the amount of biomass and carbon stock in above ground and below ground biomass, litter biomass and their carbon stocks and soil organic carbon.

Total Plots	**Carbon Pools**						
70	**AGB (t ha^{-1})**	**AGC (t ha^{-1})**	**BGB (t ha^{-1})**	**BGC (t ha^{-1})**	**LB (t ha^{-1})**	**LC (t ha^{-1})**	**SOC (t ha^{-1})**
Mean values (t ha^{-1})	829.12	414.70	165.88	83.48	0.036	1.27	83.80

Table 2: Comparison of carbon stock (t ha^{-1}) of the present result with other studies

Study Place	**AGC**	**BGC**	**LC**	**SOC**
Arba Minch Ground Water Forest (present study)	414.70	83.48	1.28	83.80
Egdu Forest (Adugna Feyissa et al., 2013)	278.08	55.62	3.47	277.56
Menagasha Suba State Forest (Mesfin Sahile, 2011)	133.00	26.99	5.26	121.28
Selected Church Forest (Tulu Tolla, 2011)	122.85	25.97	4.95	135.94

Carbon Stocks of Different Pools along Altitudinal Variation

The presence of variation in altitudinal gradient affects the carbon stock of different pools in the forest. The lower parts of altitude is high in above ground carbon stocks while the middle and upper parts of altitude have low to moderate carbon stocks in above ground carbon. 637.75, 309.02 and 517.68 (t ha^{-1}) carbon stocks were recorded at the lower, middle and upper altitude respectively in above ground carbon (Table 3). Similar trend was shown in below ground carbon in which 127.54, 62.81 and 103.54 (t ha^{-1})carbon stocks were recorded in the lower, middle and upper altitude respectively with highest value found at the lower part of altitudinal classes followed by the upper and middle parts. But the differences were not very much significance at 95% confidence interval (F= 2.812, *P*= 0.067) in AGC and (F=2.650, *P*=0.078) in BGC stocks (Table 4). In contrast to the aboveground and belowground biomass, the litter carbon density show clear patterns along the altitudinal gradient and reached higher in upper altitude and low in the lower altitude with the mean carbon value of 1.34 and 1.17 t ha^{-1} respectively, but they were not statistically significant at α=0.05 (F= 0.782, p= 0.462). However, in the case of SOC, the trend changed. There was a significance difference at α=0.05 (F= 3.451, *P*= 0.037) SOC stocks. The carbon stock in the soil pool was higher in lower altitude and lower in the middle altitude with moderate carbon stocks in the middle altitudinal classes. 89.24, 80.07 and 83.30 t ha^{-1} stocks of carbon were recorded in the lower, middle and upper altitude respectively in the soil pool. In general, the lower part of the altitude contains more carbon stocks (855.71 t ha^{-1}), followed by the upper (705.81t ha^{-1}) and the middle altitudinal gradient (453.15 t ha^{-1}).

Carbon Stocks of Different Pools and Aspect

Aspect was another parameter that affects the carbon stocks of different pools through which the direction of the plots were found to determine in which direction the highest and lowest carbon stocks is found in the study forest. Based on the result that obtained, the mean AGC stock was lowest in NE 64.77 t ha^{-1} and highest in S 679.62 t ha^{-1}. Similar trend was observed for carbon stocks in below ground carbon pool with the highest value 135.59 t ha^{-1}in South (S) direction and 19.38 ton/ha in North East (NE) direction. On the other hand, the highest carbon stocks in litter biomass was recorded in the (S) 1.60 t ha^{-1} and the minimum carbon stock was recorded in North East (NE) (0.91 t ha^{-1} aspect. The carbon stocks in soil was also recorded the minimum value in Northeast (NE) 28.08 t ha^{-1} and the highest or maximum value 127.29 t ha^{-1} in West (S) direction. In all carbon pools there was a significance difference in carbon stocks of the forest at 95% confidence interval (α=0.05) except the litter carbon and below ground carbon stock among aspects (Table 5). In general, the mean minimum and maximum total carbon stock was recorded on NE 113.14 t ha^{-1} and S 929.29 t ha^{-1} aspect, respectively (Table 5).

Table 3: Mean carbon stock (t ha^{-1}) in different pools along altitudinal gradient

Altitude class	Altitude range (m a. s. l)	AGC (t ha^{-1})	BGC (t ha^{-1})	LC (t ha^{-1})	SOC (t ha^{-1})	Total C stock (t ha^{-1})
Lower	1125-1156	637.75	127.54	1.17	89.24	855.71
Middle	1157-1188	309.02	62.81	1.25	80.07	453.15
Upper	1189-1220	517.68	103.54	1.34	83.30	705.81

Table 4: Mean carbon stock (t ha^{-1}) in different pools in different aspects

Aspects(facing)	AGC (t ha^{-1})	BGC (t ha^{-1})	LC (t ha^{-1})	SOC (t ha^{-1})	Total C stock (t ha^{-1})
S	679.62	135.92	1.60	112.14	929.29
SW	358.600	71.72	1.31	126.10	557.73
SE	625.45	125.09	1.30	75.47	827.32
E	369.36	73.87	1.39	38.07	482.70
N	350.64	70.12	1.15	69.41	491.34
NE	64.77	19.38	0.91	28.08	113.14
NW	382.51	76.50	1.40	97.18	557.59
W	615.36	123.07	1.26	127.29	866.98

Table 5: Summary of values of significance for one-way ANOVA between the two environmental variables (altitude and aspect gradient) for AGC, BGC, LC and SOC stock.

Environmental Variables	Carbon pools	F-value	p-value
Altitude	AGC	2.812	0.067
	BGC	2.650	0.078
	LC	0.782	0.462
	SOC	3.451	0.037
Aspect	AGC	3.360	0.004
	BGC	3.182	0.006
	LC	2.015	0.067
	SOC	4.377	0.001

**Bold values are significant at the *P*< 0.05 level

DISCUSSION

While comparing with other studies, the mean carbon stock in above and belowground biomass of Arba Minch Ground Water Forest was twice higher than those reported from Egdu Forest (Adugna Feyissa *et al.,* 2013), Menagasha Suba State Forest (Mesfin Sahile, 2011) and selected church forests in Addis Ababa (Tulu Tolla, 2011) (Table 2). However, this result is comparable to those reported for the global aboveground carbon stock in tropical dry and wet forests that range between 13.5-122.85 t ha^{-1} and 95-527.85 t ha^{-1}, respectively (Murphy and Lugo, 1986). Tree species in the forest area were dense and protection due to its reserved status. The higher carbon stock in aboveground biomass in the study site could be related to the higher tree density in forest area growing along the Kulfo River and presence of protection from human interference.

The mean carbon stock in litter pool of the present study was less compared to values recorded from other forests (Table 2). The values reported for tropical dry forest is 2.1 t ha^{-1} which is greater than the present study value (1.28 0110t ha$^{-1)}$ (IPCC, 2006). The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate (Fisher and Binkly, 2000). Similarly, since the study area is located in tropical areas, the rate of decomposition is relatively fast (Fisher and Binkly, 2000). Thus, the lowest carbon stock in litter pool could probably be due to the high decomposition rate and less amount of litter fall due to the ever greenness of the Forest year round. The mean bulk density of the forest site was low (0.85 g cm^{-3}, ranging between 0.72 to 0.98 g cm^{-3}) which indicates that the study site has high organic matter content in the soil (Brady, 1974). Thus, the higher mean SOC stock is may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of carbon stock (Sheikh *et al.,* 2009). Overall, the present result revealed that the study forest had large carbon stock and thus sequestered large amount of CO_2 contributing to the mitigation of global climate change.

Influence of Environmental Variables on Carbon Stock

In many previous works (Luo *et al*., 2005; Alves *et al.*, 2010), altitude has been known to have a major impact on the diversity, biomass and carbon stock in the forest ecosystems. In many studies, in other parts of the world, it has been reported that the result of above and belowground tree biomass and its carbon stock decline with an increase in altitude (Luo *et al*., 2005; Zhu *et al.*, 2011).

In the present study area, it was observed that the mean above and belowground biomass carbon and SOC showed relatively a decreasing trend with increasing altitude though there was no significant variation in carbon stock in all carbon pools except SOC along altitudinal gradient. There were similar results also reported in tropical Atlantic moist forest in Brazil by Alves *et al.* (2010), in central Amazonian forest (de Castilho *et al.,* 2006), in moist temperate valley slopes of the Garhwal Himalaya of India (Gairola *et al.,* 2011) and in Mt Changbai of China (Zhu et *al.*, 2011). The presence of species characterized by large individuals occurring on higher altitude could have an effect on AGB and carbon stock, because few large individuals can account for large proportion of the plots above and belowground carbon (Brown and Lugo, 1992). This could not probably be the case in the present study area, where bigger trees with maximum DBH were more frequent in lower altitude and flat areas.

On the other hand, unlike the other carbon pools, the mean carbon density in litter pool of the present study showed no clear pattern with altitude. Thus, the biomass and carbon density of litter relatively both peaked in higher altitude of the study forest. Similar result was reported in Mt Changbai of China (Zhu et *al.*, 2011) indicating insignificant relation between the litter carbon and altitude with absence of clear pattern along the gradient. According to Harmon *et al.* (1986), although the rate of decomposition of litter altered by temperature and moisture, factors like stand age, forest types and disturbance play more important role in regulation of litter pool size. The absence of the clear pattern in litter carbon density of the present study may be due to the decline in litter fall amount and decomposition with increasing altitude (Zhang *et al.*, 2008) in Arba Minch Ground Water Forest.

As indicated by Jobbagy and Jackson (2000), SOC density increased with precipitation and decreased with temperature. In the present study, relatively, an overall increasing trend in mean SOC density with increasing altitude (decreasing temperature and increasing precipitation) was observed. Zhu *et al.* (2011) found that SOC increased with increasing altitude which is similar to the present study. As altitude increases the NPP and the carbon input (litter fall) to the soil decreases. Overall, this present result points out that forest carbon pool density of the study area shows significant variation and a clear pattern along altitudinal gradient as aboveground, belowground, litter and soil carbon density. This further revealed that the carbon pool components of forest ecosystem may respond to altitude differently and plays an important role in knowing possible change in carbon stock and thus carbon sequestration capacity in response to future climate change (Zhu *et al.*, 2011).

Aspect is one of environmental factors that can affect the carbon stock of forests in different carbon pools and thus, it can be used as a useful variable to predict the forest carbon stock in different carbon pools. Results of the present study revealed that higher mean values of above and belowground biomass and carbon stocks on S and SE aspects compared to the other aspects whereas, the lowest mean values were recorded on the NE and N aspect. Similarly, in the carbon stock study of Apennine Beech Forest by Bayat (2011) it was found that aspect can affect 20% of the variation in AGB and the highest value of aboveground biomass appeared in southern aspects of this forest. Overall, the southern aspects of the study area had higher values of above and belowground biomass and carbon stocks as compared to northern aspects. This can be attributed to the occurrence of moisture and favorable environment on the southern aspects as we close to the Lakes.

In addition, the higher values of soil organic carbon on the western aspects have been reported in the present study which may be due to the presence of cooler and moist climate on the western aspect. This may also be the probable cause for high decomposition rate of a litter which further enhanced large carbon stocks on the western aspect compared to the other aspects. Aspect has significant relationship with biomass in forest areas due to the interaction between soil radiation and soil properties such as soil moisture and soil nutrients (Bayat, 2011). The present study also shows statistically higher values on the southern aspects than the northern aspects. The difference might be due to the difference in litter fall amount and its decomposition rate. In addition, the absence of high decomposition rate of litter on northern aspects may contribute for the presence of high litter biomass and carbon than the southern aspects.

CONCLUSION

Analysis of variation of carbon stock in different carbon pools of the forest area responded differently along different environmental gradients. The carbon stock in above and belowground carbon showed a decreasing trend with increasing altitudes but litter carbon did not show a clear pattern along altitude gradients. On the other hand, except in the litter carbon pool, the carbon stock in aboveground, belowground and soil carbon pools were significantly different in different aspects of the forest area. The total carbon stock was found to be higher on southern side of the forest which could be attributed to the occurrence of moist climate and favorable environment on the southern aspects. Overall, the present study result revealed that because of different factors affecting forest carbon stocks, these carbon stocks of different forest ecosystem components showed distinct patterns along environmental gradients and thus these variables can play different roles in carbon sequestration.

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