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Comparison of Carbon Stocks along an Elevation Gradient in Furi Forest, Central Ethiopia

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Abstract

This study was conducted in the Furi forest of central Ethiopia. The overall objective of this study was to evaluate total carbon stocks along an elevation gradient of the Furi forest. Plant biomass and their carbon stock were organized along altitudinal gradients in different layers. A total of 48 quadrats of 20m x 20 m was laid at the Lower altitude (LA), Middle altitude (MA) and Upper altitude(UA) of the forest with three horizontal transects and at 50m altitude interval were employed to collect the data. Soil samples were collected from two soil profiles (0-30cm and 30-60 cm) to analyze the soil bulk density (BD) and carbon percentage (%C). Valuation of aboveground and belowground biomass and carbon stocks was done and the results were analyzed statically in one-way ANOVA. Aboveground and belowground carbon stocks were significantly higher in the MA gradient with 58.74 $tonha^{-1}$ and 11.74 ton ha^{-1}, respectively. However, UA had the lowest ($P<0.05$) AGC (49.76 ton ha^{-1}) and BGC (9.95 ton ha^{-1}) than others. Deadwood carbon was only found in the LA and MA altitudinal gradients. However, there was no significant difference in dead wood carbon (DWC). Lower altitude (LA), MA and UA had significant SOC values for both upper (0-30cm) and lower (30-60) layers.

Keywords: Altitude, Carbon Pool, Biomass, aboveground, belowground

Introduction

Furi Forest is one of the remaining forests in central Ethiopia. It is highly subjected to exploitation by the local communities around the forest; including for the purpose of home consumption and markets. As the population increases, the forest has been converted to agriculture and settlement leading to a loss of the forest area (Friis *et al.*, 2010).

Among all the terrestrial ecosystems, forests contain the largest store of carbon (Reynaldo *et al*., 2012). Where the forest is destroyed, CO_2 is released back into the atmosphere through respiration, combustion or decomposition (Paustian *et al.*, 2016)Even though there are some natural and mixed forest areas in central parts of Ethiopia, their potential regarding the carbon stock have not been studied and documented. Especially regarding the altitudinal variation of their carbon stock potential, there were no studies conducted. Therefore, this study on the Furi forest was initiated to fill the gap in this need for basic information about the carbon stock potential of the area with their variation along altitudinal gradients. Specifically, to determine the carbon stock of different carbon pools along an elevation gradient of Furi forest and the trend of total carbon stock along altitude in the study area.

Materials and methods

Description of the Study Area

This study was conducted in Furi forest, located in Sebeta Awas District; Delati *kebele* (the lowest administrative unit) located 30 km southwest of Finfine, the capital city of Ethiopia. It is found between $38^0$37´30" and $38^0$40´30" E and $8^0$51´0" and $8^0$55´30" N in Oromia National Regional State. It is part of the central plateau and covers an altitudinal range of 1750-2350 m.a.s.l., and covers an area of 920 ha.

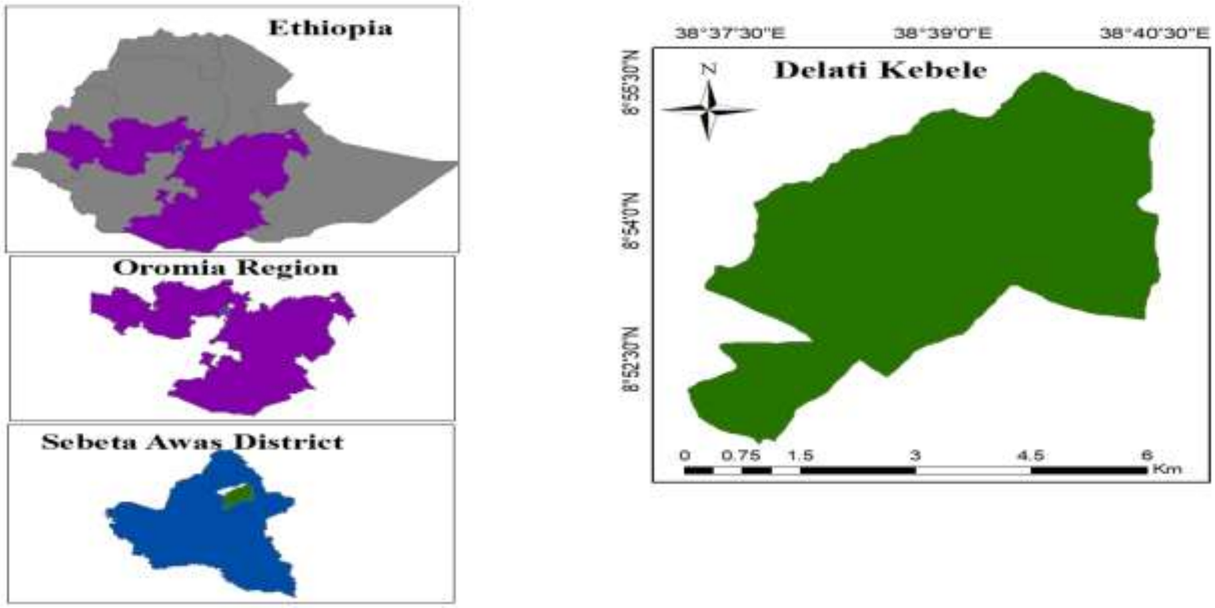

Figure 1. Map of study Area

The geology of Furi forest includes rocks, marine sediments and volcanism. The area has a mean annual temperature of 24.5 ^{0}C and an average annual rainfall of about 1094 mm. The forest region is surrounded by semi-arid or arid climatic areas (Dagnachew 2016).

Research Design

The stratified sampling by elevation segments was used. The sections were defined at every 200-elevation difference starting from the lower to the upper part of the forest. Four quadrats each with 20 m x 20 m (400 m^2) were laid out with three horizontal transects at 50m-altitude intervals. A total of 48 quadrats were laid at Lower altitude (LA), Middle altitude (MA) and upper altitude (UA) to collect the data. In each quadrat, all tree diameters in the quadrats were measured at breast height (1.37m) and the total tree height of each tree were measured (Henry *et al*., 2011).

For this study, data was acquired from both primary and secondary sources.

Carbon Stock Estimation

Determination of basal area (BA)

Basal area was calculated, for all trees with a diameter at breast height ≥ 5 cm.

$BA = \pi/4(DBH)^2$ *(*Burger, 2001)

Where BA is the basal area, π is with a value of 3.14 and DBH is the diameter of the trees at breast height.

Estimation of aboveground biomass

The aboveground biomass was estimated as:

$AGB = 0.0673 (\rho (dbh)^2 H)^{0.976}$ (Chave *et al*., 2014).

Where, ρ = wood density, dbh= diameter at breast height and H=Height

Estimation of aboveground carbon content

The dry biomass contains 50 % organic carbon.

$AGC = AGB \times 0.5$

Where, AGC = aboveground carbon content, AGB= aboveground biomass (Pearson *et al*., 2005.

Estimation of belowground carbon

Belowground biomass was estimated by a factor of 0.2 (Mokany *et al*. 2006).

Belowground biomass = Aboveground forest biomass × 0.2

Where BGB is belowground biomass, AGB is above-ground biomass, and 0.2 is the conversion factor.

$BGC = BGB \times 0.5$

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

Estimation of Soil Organic Carbon

The soil was sampled at a constant depth of 60 cm.

$V = \pi r^2 h$, (0-30cm and 30-60cm separately)

Where V is the volume of the soil in the core sampler augur in cm^3, h is the height of the core sampler augur in cm, and r is the radius of the core sampler in cm (Pearson *et al*., 2005). Moreover, the bulk density of a soil sample was calculated as follows:

$BD = \frac{W_{av,dry}}{V}$ (0-30cm and 30-60cm separately)

Where BD is the bulk density of the soil sample, Wav, dry is the average air-dry weight of the soil sample per the quadrat, V is the volume of the soil sample in the core sampler in cm^3 then the SOC was changed into hectare, and expressed in terms of ton ha^{-1}(Pearson, 2005).

$SOC_1 = BD1 * D_1 * \% C_1$

$SOC_2 = BD_2 * D_2 * \% C_2$

$SOC = SOC_1 + SOC_2$

Where, SOC_1= soil organic carbon stock of 0-30cm per unit area (t ha^{-1}), SOC_2= soil organic carbon stock of 30-60cm per unit area (t ha^{-1}), BD_1 = soil bulk density from 0-30cm (g cm^{-3}), BD_2 = soil bulk density from 30-60cm (g cm^{-3}), D_1= depth from 0-30cm which was 30cm, D_2 = depth from 30-60cm which was 30cm, and $\%C_1$ = Carbon concentration (%) of 0-30cm was determined in the laboratory and $\%C_2$ = Carbon concentration (%) of 30-60cm was determined in the laboratory.

Total Carbon Stock Estimation

The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of that stratum using the following formula (Subedi *et al*., 2010).

TCS = CAGB + CBB + CDW + SOC

Where; TCS = Total carbon stock, CAGB = Carbon of the aboveground biomass, CBB = Carbon of the belowground biomass, CDW = Carbon of dead wood, and SOC = Soil organic carbon

Soil Laboratory Analysis

The soil samples for bulk density were taken to the laboratory and dried at 105°C in the oven for 24 hours to take the dry weight of samples and then bulk density was calculated. For analysis of soil Organic Carbon, the soil sample was grained and made 0.5mm, which is suitable for sieving Then Walkley and Black Method was employed. The quantitative structure analysis was made using R version 3.6.1 software. The significant difference means was assessed using the least significant difference (LSD) at a 0.05 level of probability (Gomez and Gomez, 1984) and finally, the result was presented in graph and table form.

Results and discussion

Estimation of Carbon Stock

The result revealed that the mean aboveground biomass and carbon stock stored in Furi forest were 109.55±9.2 and 54.78±5.2 ton ha^{-1}, respectively. The minimum and maximum AGC stocks were 29.14 and 62.54 ton ha^{-1}. The mean AGC result was relatively lower than Ades forest (259.01 ton ha^{-1}) (Kidanemariam *et al*., 2015), Adaba-Dodola (228 ton ha^{-1}) (Muluken, 2014), Banja forest (338.7 ton ha^{-1}) (Fantahun, 2016), Egidu forest (around 300 ton ha^{-1}) (Adugna and Teshome, 2017) and (146.3-ton ha^{-1}) (Dagnachew, 2016). While the result is relatively higher than reported for

Gedam forest and Gra-Kasu (21 ton ha^{-1}) (Tesfay, 2017). The reason for such variation might be vegetation type, biodiversity status with other physical and biological components variation contributed to such great variation of different studies. (Bikila, 2014) also supported this.

The ANOVA analysis indicated that there is a significant difference for AGC in the three altitudinal gradients ($F_{2, 69}$= 2.8, $P<0.05$). The highest AGC was recorded in the MA gradient (58.74 ton ha^{-1}). However, UA had significantly lower AGC with 49.76 ton ha^{-1} than LA (55.83 ton ha^{-1}). This result revealed that altitudinal gradient influences AGC, which can be expressed in the way that as altitude increases AGC also increases. In other words, they have a direct relationship. The result is also in line with (Guru *et al.*, 2012). The reason for such a pattern might be due to the presence of large trees like *Juniperus procera* and *Cupressus lusitanica* in MA.

The mean BGC of Furi forest was found to be 10.96 ton ha^{-1}. The minimum and maximum belowground carbon stock values of 5.83 and 12.51 ton ha^{-1} were estimated in the area like the AGC this result is also higher than some reports and similarly lower than the others (Muluken, 2014).

Similarly, the ANOVA result indicated that there was significant variation in BGC between the three altitudinal gradients ($P<0.05$). Therefore, the mean BGC of LA, MA, and UA were 11.17±1.8, 11.74±4.7, and 9.95±5.4 ton ha^{-1}, respectively. This indicates that MA had significantly the highest BGC than LA and UA ($P<0.05$). The reason for such differences might be similar to that of the reason given above for AGC.

Table 1. Woody species' means above and belowground carbon stock at the three altitudes

Gradients	**Carbon pools**	
	AGC (ton ha^{-1})	**BGC (ton ha^{-1})**
LA	55.83	11.17
MA	58.74	11.74
UA	49.76	9.95

Dead woody carbon stock

Dead woody plants were recorded only in three quadrats in LA and MA. There was no any dead wood plant recorded in the UA. This might be due to the less agriculture expansion, settlement, use for firewood at UA compare to LA and MA. The mean carbon stock from the deadwood in this study was found 0.04 ton ha^{-1}. This result was relatively lower than Gra-Kasu forest (0.33-ton

ha^{-1}) (Tesfay, 2017), Adi-Goshu (0.48-ton ha-1) (Binyam, 2012). The average value of DWC for LA and MA were 0.02 and 0.07 ton/ha, respectively. However, there were no significant difference in DWC between the two altitudinal gradients ($F_{2, 69}$=1.24, P>0.05)

Soil Organic Carbon

The average bulk density of soil in the Furi forest was estimated to be 1.29 $g.cm^{-3}$ and 1.32 $g.cm^{-3}$ and the lowest and the highest bulk density values were 0.95 1.55 $g.cm^{-3}$ and 1.04 and 1.61 for (0-30cm) and (0-60cm), respectively. The percentages of the carbon content of the soil in the study area range from 2.18% to 3.55% with a mean value of 2.87% for upper layer (0-30cm) and 1.31% to 2.20% with a mean value of 1.76% for the lower layer (30-60cm). The finding is slightly lower than the Adaba-Dodola community forest, which had 9.93 g.cm-3 soil bulk density and 6.3% organic carbon (Muluken *et al*. 2014). While, it is slightly higher than the Ades forest (0.5$g.cm^{-3}$ bulk density and 2.1 percent of carbon) (Kidanemariam, 2014).

Accordingly, in this study, the overall average soil organic carbon investigated in the study area was found to be 182.65 ton ha^{-1} with a minimum and maximum value of 81.22 and 360.48 ton ha^{-1} respectively. The average soil organic carbon of 0-30cm investigated in the study area was found to be 133.78 ton ha^{-1} with a minimum and maximum value of 74.01 ton ha^{-1} and 217.40 ton ha^{-1},and the average soil organic carbon of 30-60cm investigated in the study area was found to be 48.06 ton ha^{-1} with a minimum and maximum value of 10.11 and 144.91 ton ha^{-1} respectively.

Comparatively, this result was lower than some forests in Ethiopia like the Edigu forest (277ton ha^{-1}) (Adugna et al., 2013), Tara Gedam forest (274 ton ha^{-1}) (Mohammed et al., 2017), Humbo forest (225.98 ton ha^{-1}) (Alefu et al., 2015) and Egdu forest (279.72 ton ha^{-1}) (Adugna and Teshome, 2017). While it is higher compared with Menagasha Suba State Forest (131 ton ha^{-1}) as Mesfin, (2011) reported, Bihere Tsige Central Closed Public Park (113 ton ha^{-1}) as Marshet and Teshome (2015) mentioned, Meskel gedam forest (114 ton ha^{-1}) as Dagnachew (2016) pointed out, Semen Mountain National Park (92.7 ton ha^{-1}) as revealed by Habtamu and Zerihun (2016) and Gra-kahsu Forest (16.6 ton ha^{-1}) as Tesfay (2017) indicated. Such variation between different forests may arise due to the presence of different ecological components like climate, humidity, soil texture, topography and precipitation in different forest types of the country.

Statistical analysis also pointed out that there was a significant difference in SOC of the three altitudinal gradients ($F_{2,69}$=12.21, P<0.05). The SOC pattern with altitude followed the inversely proportional pattern for both layers. In other word as altitude increase SOC will gradually decline from lower to upper altitude. Accordingly, the LA had significantly the highest SOC value (159.80 tonha^{-1}) followed by MA (128.65ton ha^{-1}) ($P<0.05$) and the UA had a significantly lower amount of SOC as compared to others (112.91 tonha^{-1}) for upper layer (0-30cm). Similarly, the LA had significantly the highest SOC value (87.45ton /ha) followed by MA (36.86 tonha^{-1}) ($P<0.05$) and the UA had significantly lower amount of SOC as compared to others (22.29 tonha^{-1}) for lower layer (30-60cm). Kidane (2014) and Dagnachew (2016) also reported similar decreasing pattern of SOC with respect to altitude. The reason for such decrement trend of SOC with altitude may be due to higher temperature in LA facilities decomposition in lower altitude soils. Relatively intensive sun light radiation as less dominated by large trees with closed canopy in LA may also facilitate organic matter formation on the soil. On the other hand, the human and animal intervention are also high in LA which may lead to accumulation of manure and other organic substance which in return might also resulted in accelerated decomposition of litters. As Kidane (2014), Alefu et al. (2015) and Dagnachew (2016) indicated soil type, siltation as a result of soil erosion and topography, and leaching and run off might be created a condition for such trend with high SOC at the lower gradient and declines as go higher in altitude.

Table 2. Mean soil bulk density, % carbon and SOC across altitudinal gradients

Soil parameter	**Altitudinal class**							
	LA		**MA**		**UP**		**Average**	
	0-30	**30-60**	**0-30**	**30-60**	**0-30**	**30-60**	**0-30**	**30-60**
BD(g.cm^{-3})	1.21	1.25	1.30	1.34	1.35	1.36	1.29	1.32
%C	4.4	2.33	3.28	0.92	2.80	0.55	3.5	1.27
SOC(ton ha^{-1})	159.80	87.45	128.65	36.86	112.91	22.29	133.78	48.87

Contrary to the altitude, the average soil bulk density of the study area increased with the altitudinal and depth of the soil for both layers (0-30cm and 30-60cm). On the other hand, Percentage organic carbon decreased with depth increment. This might be due to the presence of high decomposable inputs on the surface than the subsurface. The trend across soil depth is also in line with the report of Muluken (2014).

Total carbon stock

The carbon stock distribution of all carbon pools within sample plots ranged from a minimum of 116.21 ton ha^{-1} to a maximum of 435.6-ton ha^{-1}. However, the mean total carbon stock and CO_2 equivalent values of the forest were to be found 248.43 and 911.72 $tonha^{-1}$, respectively. The total carbon of the Furi forest is relatively higher than Humbo forest (225 ton ha^{-1}) and Semien Mountain National Park (168 ton ha^{-1}) according to (Mesfin, 2011), (Alefu et al., 2015), (Dagnachew, 2016) and (Habtamu and Zerihun, 2016), and lower than Menagasha Suba State Forest (286.5 ton ha^{-1}), Meskel Gedam forest (310.4 ton ha^{-1}), and Adugna et al. (2013), (Mohammed *et al.* (2014), Mulken *et al*. (2015) and Fantahun (2016) reported a relatively higher amount of total carbon in Egdu Forest (614 $tonha^{-1}$), Tara Gedam Forest (613 $tonha^{-1}$), Adaba-Dodola community forest (507.3 $tonha^{-1}$) and Banja forest (639 ton ha^{-1}), respectively.

Table 3. Total carbon stock in the three-altitudinal classes of Furi forest ($tonha^{-1}$**)**

Carbon pools	**Altitudinal**			
	LA	**MA**	**UA**	**Average**
AGC (ton ha^{-1})	55.83±8.56	58.74±4.47	49.76±9.67	50.78±7.57
BGC (ton ha^{-1})	11.17±0.55	11.74±1.44	9.95±0.33	11.95±0.77
DWC (ton ha^{-1})	0.02±0.002	0.05±0.006	0	0.02±0.004
SOC (ton ha^{-1})	247.25±14.75	165.51±8.30	135.2±5.75	176.65±9.60
TC (ton ha^{-1})	314.27±16.44	236.04±5.46	194.91±5.57	241.41±9.16
Co_2 Equivalent	1153.37±12.22	866.27±7.31	715.32±3.14	901.65±8.42

Where LA = Lower Altitude, MA = Middle Altitude and UA= Upper Altitude

The highest TC was obtained in the LA (314.27 $tonha^{-1}$), followed by MA (236.04 $tonha^{-1}$). While the lowest TC was obtained in UA with 194.91 $tonha^{-1}$. In the present study, all carbon pool results were varied within the altitudinal gradient. The middle altitude takes the most AGC and BGC carbon storage and much more depleted carbon storage is observed on higher altitudes, this result consistent with Samein Mountains National Park (Soromessa *et al*., 2015). The reason for variation may be due to the variation of species structure in different forests.

Another important observation in this study was with regard to the contribution of each carbon pool to the total carbon stock. Normally, soils are the largest carbon pools in global terrestrial ecosystems, because they can contain three times more carbon than that contained in plant species (Schlesinger, 1990). Most studies show that the soil organic carbon is greater than the aboveground carbon. Similarly, in this study, the SOC had the highest carbon proportion with 70% contribution to TC. AGC was the second most dominant carbon pool of the Furi forest covering about 22%.

Conclusion

The TC stock by Furi forest was around 248.41 tonha^{-1}. However, there was a significant variation in ABC, BGC, and SOC of the three altitudinal gradients. The highest AGC value was observed in the MA gradient and the lowest in UA. This indicates that there is high biomass in MA. A similar result was also obtained for BGC as it is derived from AGC. However, regarding SOC its relationship with altitude is inversely proportional with altitudinal. Therefore, the highest SOC were recorded in LA followed by MA. The reason for such a decrement trend of SOC with altitude is higher temperature facilities decomposition, high human and animal intervention in lower gradient had contributed to add additional organic matter to the soil. However, in the case of DWC carbon, there was no significant difference observed. SOC had highly contributed (73.53%) for the total carbon stock of the area followed by AGC (22.05%) and BGC (4.41%). DWC had an insignificant contribution to the total carbon.

Generally carbon stock potential in MA had a better performance than the others. This suggested that there is a need for better intervention in law enforcement and management in the others especially in LA and UA especially LA as it is highly affected by anthropogenic activities.

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