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Carbon Stock Estimation Along Altitudinal Gradient in Sekele-Mariam Dry Evergreen Montane Forest, North-Western Ethiopia

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Abstract: This study was conducted to estimate carbon stock along altitudinal gradient of Sekele-Mariam dry Afromontane forest, North- Western Ethiopia. A systematic random sampling was employed to collect tree/shrub diameter and height, litter and soil data. A total of 60 plots with 50m*50m size each with nested plot (1m*1m) size for litter and soil were laid on the transect line. Diameter at breast height (DBH) of trees/shrubs with DBH ≥ 5cm and height were measured. Carbon stock was estimated using allometric equation and soil organic carbon was analyzed in the laboratory following Walkley Black method. The result of this study revealed that Sekele-Mariam forest had stored a total of 185.71 ton carbon/ha within its aboveground, belowground, litter biomasses and soil. The higher carbon stock in all carbon pools was found at the higher altitudinal range (2395-2460 m a.s.l.). Analysis of variance (ANOVA) result indicated that carbon stock between altitudinal gradient was not significant. The study area had smaller stock of carbon in its biomass and therefore, better forest conservation and management are the best strategy to enhance the carbon stock of the study area.

Keywords: Biomass, Carbon Sequestration, Climate Change, Soil Organic Carbon, Sekele-Mariam Forest

1. Introduction

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural ‘brake’ on climate change [14]. The biomass and carbon stocks in forests are important indicators of forests’ productive capacities, energy potential, and capacity to sequester carbon. The role of forests as terrestrial sinks and source of CO_2 has received increasing attention since the adoption of the 1997 Kyoto Protocol to the United Nation Framework Convention on Climate Change [11]. The world’s forests store 289 Gt of carbon on their biomass [10]. However, carbon stock in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005-2010 globally, due to forest cover change [10]. The carbon stored in the aboveground living biomass of trees is typically the largest carbon pool and is directly influenced by deforestation and forest degradation [16]. Ethiopia has one of the largest forest resources in the horn of Africa [22]. The country’s Forest resources supply most of the wood products used with in the country, as well as a large volume of diverse non-timber forest product [21]. The forest resources play significant roles in the livelihoods of the community and the national economy at large. Their direct roles include provisions of energy, construction wood, poles, timber and non-timber forest products (NTFPs) that are highly prized for their food, medicinal and commercial values [1]. Moreover, forests play a vital role in climate change mitigation through sequestering carbon dioxide from the atmosphere. Ethiopia’s forest resources have store 219 million ton of carbon in their living biomass [10]. Despite their economic and environmental value, the countries’ forests resources are under threat. Deforestation and forest degradation activities are the main sources of forest carbon stock loss and GHGs emission. According to [7], 37% of the total greenhouse gas emission in the country comes from forestry due to anthropogenic activities (deforestation and forest degradation). Currently the country is implementing a robust system for monitoring and measuring carbon emissions and removals to enable the country to report and verify actions on deforestation and forest degradation and other activities aiming to conserve, sustainably manage and increase forest carbon stocks [23].

Forest carbon stock is highly variable due to various factors and processes operating in the systems. Forest carbon stock is affected by different environmental factors such as: altitude, aspect and slope by affecting the distribution of tree species [12]. Dry Afromontane forest stores a huge amount of aboveground carbon compared to other terrestrial ecosystems in Ethiopia [18]. Despite their immense carbon sequestration potential most forests of the country lacks carbon stock data/ information. Nowadays, estimates of carbon stock in forests is critical in carbon credit programs- quantities of assimilated carbon claimed against CO_2 emission. Sekele-Mariam forest is one of the dry Afromontane forest in West Gojjam Zone North-Western Ethiopia and its carbon stock potential is not studied yet. Altitude is one of the key environmental factor that had significant impact on carbon pools (aboveground, belowground, litter and soil) [15].

2. Materials and Methods

2.1. Description of the Study Area

Sekele-Mariam forest is located in Dembecha district, West Gojjam Zone of Amhara National Regional State, Ethiopia at about 350 km north of Addis Ababa. The forest lies between 10°35'- 10°37'N latitudes and 37°28' - 37°30E longitudes. The forest covers an area of 532.42 hectare. Sekele-Mariam forest is characterized by rugged terrain with an altitude ranges from 2259 m to 2460 m a.s.l. The study area is categorized under mid highlands locally known as ''Weyna Dega'' agro-climatic zone. The mean minimum and maximum temperature of the study area were 8.5°C and 29°C respectively and had an average temperature of 18.5°C. The average annual rainfall was 1368 mm and had unimodal rainfall distribution [9]. Sekele-Mariam forest is categorized under dry evergreen montane forest of vegetation classification of Ethiopia [29] and is characterized by *Croton, macrostachyus Albizia gummifera, Calpurnia aurea, Acacia abyssinica, Maytenus obscura Buddleia polystachy, Bersama abyssinica, Carissa spinarum, Nuxia congesta, Acacia lahai, Clausena anisata, Rosa abyssinica, Grewia ferruginea, Vernonia auriculifera, Pavetta abyssinica* among others.

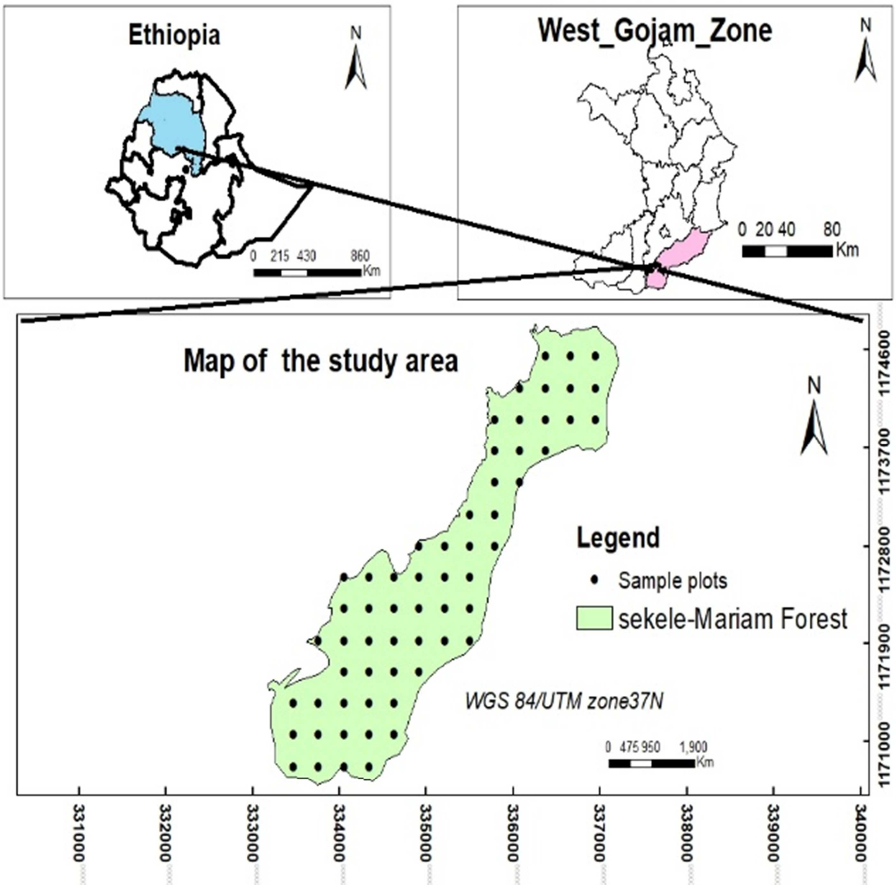

Figure 1. *Map of Ethiopia showing West Gojjam Zone and the study area (Sekele-Mariam forest).*

2.2. Sampling design and techniques

The spatial boundaries of the study area were defined and geographic coordinates and elevation of the strata were taken using Geographical Positioning System (GPS) to generate the map of the study area. with the aid of GIS software (Q 2.2-GIS). Considering the topography of the forest the study area was stratified in to three different strata based on altitudinal variation as; lower altitude (2259-2326) considered as dry Weyna Dega; middle altitude (2327-2394) and higher altitude (2395-2460) a.s.l which is considered as wet Weyna Dega agro-climatic zone.

The number of plots to be measured were determined using pragmatic approach [28] and therefore, a total of 60 sample plots were sampled. Systematic transect sampling was employed and thus, four transect lines were laid with an interval of 200 m between each transect line and square sample plots with an area of 2500 m^2 (50m*50m) each was designed along transect lines with 300 m gaps between each plots. Within the large plot (50m*50m) dendrometric parameters was measured. Moreover, nested plot of 1m*1m subplot for litter and soil sample were taken [3, 2].

2.3. Data Collection Methods

In each plot trees with ≥ 5 cm DBH were measured at 1.3 m above the ground since in carbon stock measurement the minimum diameter is often 5 cm DBH as recommended by [17, 25]. For inclined terrain DBH tree measurement at 1.3 m was taken on uphill position. The DBH of trees/shrubs were measured using caliper and range finder was used for height measurement. Woody species with their vernacular name of the study was recorded in the species checklist.

2.4. Field Carbon Stock Measurement

2.4.1. Above and Below Ground Biomass

The DBH (at 1.3 m) of each trees and shrubs with ≥ 5 cm diameter in each sample plot was measured using caliper and rangefinder was used for height measurement. The biomass was calculated using allometric equations developed by [5] shown below:

$$AGB= 0.0673*(WD*DBH^2*Ht)^{0.976} \quad (1)$$

Where, AGB = Aboveground biomass (Kg); WD = Wood density (g/cm^3); DBH = diameter at breast height (cm); Ht = Total height of the tree (m)

Belowground biomass was estimated using IPCC root –to-shoot ratio value of 0.26 for tropical dry forests [17] i.e.:

$$BGB = AGB \times 0.26 \quad (2)$$

Where, BGB is belowground biomass (Kg), AGB is aboveground biomass, 0.26 is conversion factor

The biomass was converted to units of carbon stock by multiplying by a carbon fraction of 0.47 and 3.67 respectively [17].

2.4.2. Litter Biomass

According to [24], estimation of the amount of biomass in the litter is calculated as:

$$LB = \frac{Wfield}{A} * \left(\frac{Wsubsampledry}{Wsubsamplefresh}\right) * \frac{1}{10000} \quad (3)$$

Where: LB = Litter (biomass of litter ton/ha)

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 collected (ha);

W (sub, fresh) = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content.

$W(_{subsample}dry)$ = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g).

The total carbon content of litter (ton/ha) =Total dry litter biomass*Carbon fraction; mathematically;

$$C_T = LB \times \% C \quad (4)$$

Where, C_T is total carbon stocks in the dead litter in ton/ ha, %C is carbon fraction determined in the laboratory [24].

2.4.3. Soil Organic Carbon

Soil organic carbon was determined in the laboratory following Walkley-Black Method. In the laboratory, soil samples were dried at 105°C for 24 hours to remove the soil moisture and to determine the percentage of organic carbon as well as the bulk density [24]. According to [24], the soil organic carbon was calculated from the bulk density and volume of the soil as follows:

$$BD = \frac{Wdry}{V} \quad (5)$$

Where,

BD = bulk density (g/cm^3) of the soil sample,

Wdry = air dry weight (g) of soil sample,

V = volume (cm^3) of the soil sample

The volume of each soil sample in turn was calculated as;

$$V= h*\pi r^2 \quad (6)$$

Where,

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

h = the height of core sampler augur in cm, and

r = the radius of core sampler in cm.

Then, soil organic carbon was calculated as follows:

$$SOC = BD * D * \% C \quad (7)$$

Where,

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

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

D = the total depth at which the sample was taken (40 cm i.e. 0-20 cm and 20-40 cm) and

%C = Carbon concentration (%)

2.5. Total Carbon Stock

The total carbon stock density was calculated by adding the carbon stock densities of the individual carbon pools using [24] formula as follows;

C_T= AGC+BGC+CL+SOC (8)

Where,

C_T= Carbon stock density for all pools (ton/ ha),

AGC= Carbon in above -ground tree biomass (ton C/ ha),

BGC = Carbon in below-ground biomass (ton C/ ha)

CL= Carbon in dead litter (ton C/ ha) and

SOC = Soil organic carbon (ton C/ha).

2.6. Data Analysis

The data analysis of various carbon pools measured (DBH, fresh weight and dry weight of litter and soil) was done in Statistical Package for Social Science (SPSS) software version 23, Analysis of Variance (ANOVA) was used to test the relationship between carbon stocks with altitude at 95% confidence interval.

3. Results

3.1. Carbon Stock in Different Carbon Pools

As depicted in (Table 1), the soil component shares the highest carbon stock followed by aboveground carbon of the total forest carbon stock, whereas the belowground and litter contributed the lowest carbon stock.

Table 1. *Mean carbon stock of the different carbon pools in Sekele-Mariam forest (60 plots).*

	Carbon Pools				
	AGC	BGC	LC	SOC	Total
Mean (ton/ha)	37.54	9.76	0.02	138.39	185.71
Percentage (%)	20.21	5.26	0.01	74.52	100

Table 2. *Comparison of carbon stock (ton/ha) of Sekele-Mariam forest with other similar forest type in Ethiopia.*

Study areas	AGC	BGC	LC	SOC	Total	References
Sekele-Mariam forest	37.54	9.76	0.02	138.39	185.71	Current study area
Humbo forest	30.77	14.46	12.54	168.20	225.97	Chinasho *et al*., 2015
Zequala Monastery forest	237.20	47.60	6.99	57.62	349.41	Girma *et al*., 2014
Tara Gedam forest	306.37	61.52	0.90	274.32	643.11	Gedefaw *et al.,* 2014
Meskel Gedam forest	146.34	29.27	3.03	131.79	310.43	Dagnachew Tefera, 2016
Egdu forest	278.08	55.62	3.47	277.56	614.73	Feyissa *et al*., 2013

3.2. Carbon Stock Along Altitudinal Gradient in Carbon Pools

There was distinct variation of mean carbon stock in each carbon pools with different altitudinal ranges but, the variation of each carbon pools (AGC, BGC, LC, SOC) is statistically insignificant at 95% confidence interval (Table 3).

Table 3. *Mean carbon stock (ton/ha) along altitudinal gradient of Sekele-Mariam forest.*

Altitude class	AGC	BGC	LC	SOC
Lower	34.73	9.02	0.01	128.29
Middle	28.96	7.52	0.01	149.35
Higher	42.40	11.02	0.02	137.28
F value	1.487	1.487	3.233	1.049
P value	0.235	0.235	0.047	0.364

4. Discussion

The mean aboveground carbon stock of Sekele-Mariam forest was smaller as compared to previously studied similar forest type of Ethiopia except Humbo forest. The variation of carbon in the aboveground biomass may be due to intensive forest degradation mainly fuel-wood collection. Moreover, stand structure and composition, topography, altitude and micro climate variation may have also contributed for the variation of carbon in the aboveground biomass. Besides, variation in tree dendrological parameters measured, allometric equations applied, carbon fraction used and root-shoot ratio used to estimate below ground biomass may also have resulted in the discrepancy of estimation of aboveground and belowground biomass and carbon stock. In line with allomertic equation most researchers used [4] equation to estimate forest carbon stock in Ethiopia. Moreover, they used a carbon fraction of 0.5 suggested in the IPCC 2003 Good Practice Guidance. The different types of models used for biomass estimation have impact on the value of carbon estimated in a given forest [21].

The mean carbon stock in litter pool of the current study was 0.02 ton/ha which is lower than other similar forest type indicated in (Table 2). The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density), climate and relatively fast decomposition rate in the tropics [13]. The reason for smaller litter carbon may be due to fast decomposition rate and less amount of litter fall in the study area.

As reported in Luke [20], the average soil organic carbon in Ethiopia ranges from 94 to 133 ton/ha which is smaller compared to the present study and the IPCC default values (31 to 130 ton/ha) for different tropical soils [17]. In this study, the soil carbon pool had the highest carbon stock compared to other pools in the study area. Soil is the largest carbon pools in global terrestrial ecosystems, because they can contain three times more carbon than that contained in vegetation [27], The mean carbon stock of soil organic pool in the study area was lower as compared with other studies except Zequala forest and Meskel Gedam forest (Table 2). This could be due to the existence of low soil organic matter, the accumulation of soil organic carbon depends on the quantity of litter [19] and root activity such as rhizodeposition and decomposition [26].

The highest total carbon stock was recorded in the higher altitudinal range whereas smaller carbon stock was recorded in lower altitudinal range. The carbon stock in all carbon pools of the study area varied with altitudinal ranges. but did not show direct increment or decrement. This study showed that the mean carbon stock in all carbon pools exhibits an increasing trend with increasing altitudinal variation, the reason for this may be due to, disturbance level and species composition and density occurred in the altitudinal ranges. As noted from field observation, more wood collection for construction and fuel wood was highly pronounced in lower altitude than the higher one. Overall, the carbon pool of Sekele-Mariam forest did not show significant variation along altitudinal gradient as aboveground carbon, belowground carbon, litter carbon and soil organic carbon. Similar finding was reported from [6]. The reason for such statistically insignificant result in the carbon pools may be due to the similar species composition and soil type throughout the altitudinal gradient of the forest.

5. Conclusion

Sekele-Mariam. forest had stored a total of 185.71 ton C/ ha in its biomass. The largest carbon stock was found in the soil organic carbon followed by the aboveground biomass The carbon stock of the study area was smaller compared to other studies of similar forest type in Ethiopia. Carbon stock in different carbon pools (aboveground and belowground biomass, litter biomass and soil) has a potential to decrease the rate of improvement of atmospheric concentration of carbon dioxide. Increase in carbon stock in Dry Afromontane forest can be achieved through sustainable forest management and enrichment planting. Furthermore, attention has to be given on the conservation of the Dry Afromontane forest to enhance the carbon sequestration capacity so as to mitigate climate change. Carbon stock in all carbon pools was varied with altitude. but, the variation was not statistically significant at 95% confidence interval.

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