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Assessment of Soil Carbon Stock Status of Sekelemariam Dry Evergreen Montane Forest Along Altitudinal Gradient: Implication for Climate Change Mitigation

Yitayal Tebeje Workie

College of Agriculture and Natural Resources, Debre Markos University, Debre Markos, Ethiopia

Email address:
yitayal_tebeje@dmu.edu.et

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Abstract: This study was conducted in Sekelemariam Dry Evergreen Montane Forest which is situated within 37° 27' and 37° 30' east, and 10° 34' and 10° 36' north, near Dembecha Town in west Gojam Zone, North Western Ethiopia. It is characterized by steeply sloped areas with huge Rocky Mountains extended throughout the middle parts of the forest. The aim of this study was to estimate the soil carbon stock potential of the forest. A systematic transect sampling technique was adopted in this study and following these transects plots of 1mx1m ($1m^2$) data was taken from the field. The carbon stock density of soil organic carbon was calculated from the volume and bulk density of the soil as $V = h\times\pi\ r^2$. The data analysis was conducted using Microsoft excel sheet used as platform in carbon calculations, and SPSS software version 20 to determine the impact of altitude gradient and slope factors on soil carbon stock potential and to compare the relationship between dependent and independent variables. The carbon stock of the SOC showed increasing trend with increasing elevation. In contrast to the elevation, the forest soil carbon stock decreases as increasing slope gradient. Soil laboratory analysis was conducted in Holeta Agricultural Research center to determine the soil organic carbon density and was estimated to be101.56 ± 3.66 t C ha-1. All in all, this study gives estimation of the soil carbon stock in Sekelemariam State Forest.

Keywords: Soil Carbon Stock, Soil Organic Carbon, Slope Gradient, Altitudinal Gradient

1. Introduction

1.1. Background

The issue of global climate change has become a central issue and concern of the world by all people at local, regional, national and international levels. Global warming and climate change arising due to the greenhouse effect / Greenhouse Gas (GHG) emissions resulting from the effects of development activities in various business sectors, including land use, changes in the function and forest allocation, forest and land fires, a decrease in quality of forests from uncontrolled utilization, as well as the burning of fossil energy [17].

Anthropogenic emission of carbon dioxide leads to global warming and climate change affecting the biodiversity and destabilizing food and livelihood security. Rise in atmospheric CO_2 is because of large scale burning of oil, coal and natural gas, which are the energy sources for modern industrial economies and due to deforestation [13]. Forests are one of the major pools of carbon since plants fix atmospheric carbon in the tissues; thereby transform carbon from atmosphere to the biological systems.

Forests ecosystems sequester and store more carbon than any other terrestrial ecosystem and hence are an important natural ‘brake’ on climate change. More than 40% of the total organic C in terrestrial ecosystems is stored in forest soil and thus management practices need to address the soil carbon pool. Converting natural forests to agricultural land results in the mineralization of soil organic C (SOC), thus reducing SOC stocks and increasing atmospheric CO2 concentrations [2]. The decreases in SOC following a land-use change are difficult to predict due to variations in the factors that drive SOC mineralization, e.g., forest type, climate, and soil properties [10]. Drake et al., [5] reported that total quantity of C entering the soil via litter fall and all belowground C inputs increased 17% from c. 1.50 kg C m^2 year1 under ambient CO_2 to c. 1.75 kg C m^2 year-1 under elevated CO_2. However, these increases in C entering the soil under elevated CO_2 was matched by increased C loss attributable to significant increases in fine and coarse root respiratory fluxes (i.e., autotrophic respiration) and a significant increase in heterotrophic respiration [5].

When forests are destroyed or degraded, their stored carbon is released into the atmosphere as carbon dioxide (CO_2) [13]. These alterations cascade through the ecosystem, resulting in increased temperature altered rainfall patterns and degraded soil profiles. Carbon accumulation potential in forests is large and the period of carbon retention is long [13], so, they offer the possibility of sequestering significant amounts of additional carbon in relatively short period and keep it for many years.

According to FAO [6], the forest resources of Ethiopia store an estimated 2.76 billion tons of carbon, playing a significant role in the global carbon balance. The largest store of carbon in the country is found in the woodlands (46%) and the shrub lands (34%), while the high forests store about 16%. REDD negotiations and other carbon related policies and projects should not neglect the woodland and shrub land resources. Likewise, trees outside forests are often overlooked.

1.2. Statement of the Problem

Long-term monitoring has shown that the amount of CO_2 in the atmosphere is increasing due to human activities. This is causing the earth to warm and the oceans to become more acidic. Unless the amount of CO_2 and other greenhouse gases emitting to the atmosphere can be reduced dramatically, scientists predict that the temperature of the earth will continue to rise, and this rise in temperature will cause the climate to change, sea levels to rise, and ocean and land environments to be adversely affected.

Forests ecosystems sequester and store more carbon than any other terrestrial ecosystem and hence are an important natural 'brake' on climate change. More than 40% of the total organic C in terrestrial ecosystems is stored in forest soil and thus management practices need to address the soil carbon pool.

Although forests have a great potential for carbon storage, they are often not given due attention by researchers and development organizations and the responsible government, concerning about carbon and climate change at large [18].

Soils are fundamental to our life and must be recognized and valued for their importance in global feedbacks to climate change and in particular their large potential to mitigate climate change.

The effects of changes in soil management, such as increased soil disturbance and aeration, the addition of fertilizers, and changes in residue amount and quality, have often been cited as primary factors in the changes of soil organic matter from native levels [8].

Although there are case studies on soil carbon pools for selected parts of Ethiopia estimate on national soil carbon pools is missing. National soil database carbon pools estimate, which currently does not exist in Ethiopia [7]. According to Adugna et al., [1], information on carbon stocks of forest is limited in Ethiopia. The carbon sequestration potential of Sekelemariam Forest has therefore not been assessed yet.

1.3. Objectives

This study was conducted to achieve the following objectives:

1) To investigate the altitudinal variations in soil stock potential of the study area
2) To analyze the role of forest in forest soil carbon sequestration
3) To investigate the soil carbon stock potential along slope gradients
4) To provide baseline information for future conservation and management of the forest and the soil

2. Materials and Methods

2.1. Geographical Location

This study was conducted in Dembecha district, Amhara National Regional State, north wstern parts of Ethiopia which is situated within 37° 27' and 37° 30' east, and 10° 34' and 10° 36' north, near Dembecha Town in west Gojam Zone. The study covers 543 hectares. The natural plants of the forest has been deforested and converted to plantations through rehabilitation programs. The forest has an altitudinal gradient ranging from 2249 m to 2470 m above sea level. This forest contains diverse fauna and flora species which are currently found in danger.

2.2. Topography and Climate

The Forest is characterized by dissected plateaus bordered by cultivated lands in all directions. The natural forest vegetation is concentrated at the middle and lowest altitudes, while the upper altitude which is the top plateau area of the forest is mainly occupied by plantations. It is characterized by steeply sloped areas with huge Rocky Mountains extended throughout the middle parts of the forest. The forest also consists of small and seasonal rivers drained from the top of the forest to the lower settlement areas.

The mean annual rainfall of the study area is 1502.01mm ranging from 1283.10mm minimum in 2009 to maximum of 1639.4 mm in 2010 with the rains mainly falling from the end of May to September. The mean temperature of the surrounding area is about 18.74°C with a maximum of 27.04°C and minimum of 9.65°C and is generally characterized by moderate climate.

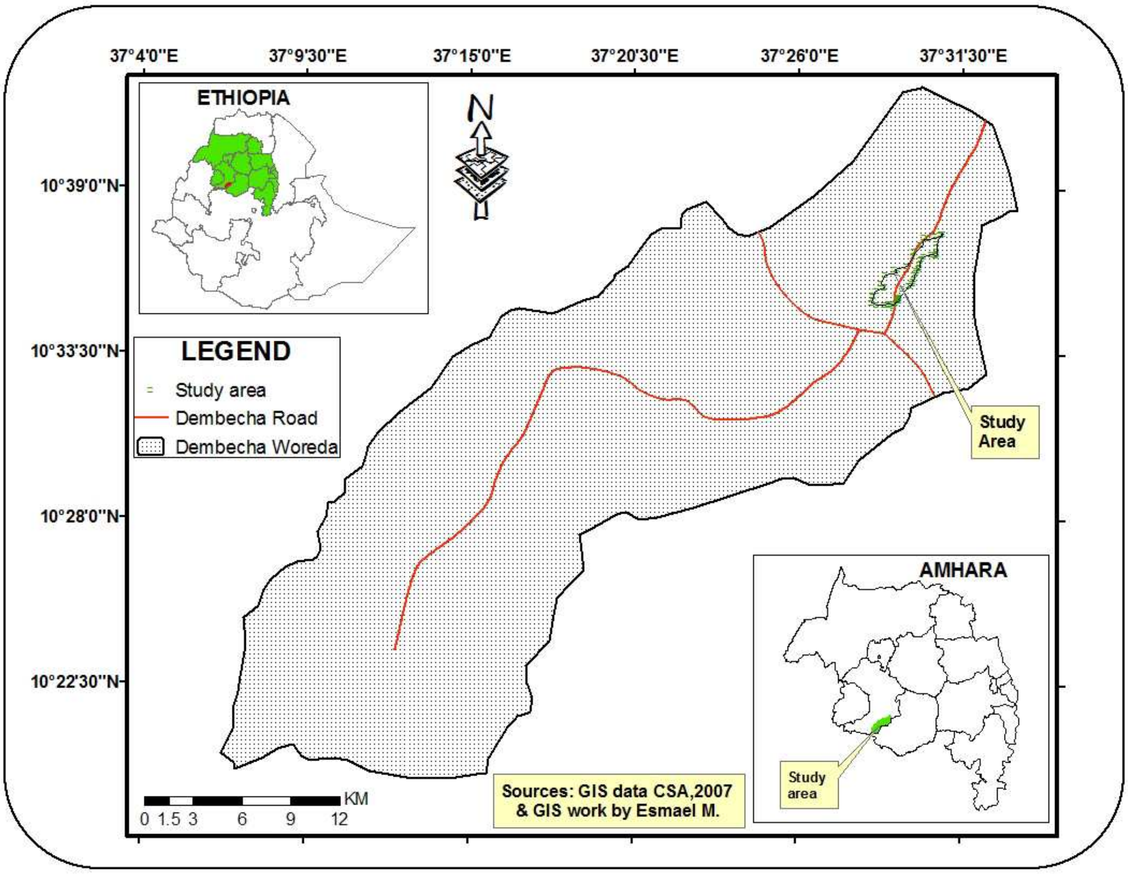

Figure 1. *Map of Ethiopia showing Regional States and the Study Area.*

2.3. Methodology

2.3.1. Delineation of the Study Area

Delineation of study boundary using GPS tracking and stratification of the study area depending on environmental gradient was the first step in measuring and estimating carbon stocks in the above mentioned carbon pools.

2.3.2. Sampling Techniques

Once the study area has been delineated, the study site was divided into different strata of homogeneous units as possible based on the altitudinal gradients of the forest as bottom, middle and top. Thus, altitude was taken as the criteria for stratification, since the study area has an altitudinal variation which is easily possible to determine the relationship between environmental gradient and forest carbon stock of the study area.

Sampling sites from the forest were arranged by the line transects from the bottom area of the forest to top directions covering the whole range of altitudes. A plot of 10 m x 20 m (200 m^2) was applied along the transect lines at approximately 200 m to 250 m distance between each plot.

2.3.3. Shape of Sample Plots

According to Brown [4], even though both rectangular and circular plots are applicable in most of the forest carbon measurements, rectangular plots are more advantageous and recommended for this study.

2.4. Field Measurements

Vegetation Survey: Diameter and Height Measurement

The Soil sample was collected from four sub-quadrats of 1 m × 1 m (m^2) of the large plot 10mx20m (200m^2) at each corner the quadrat. A total of 500 gram mixed sample was taken from each a quadrat. Altitude was measured for each sample plot using GPS 60 with a precision level of ±7/8 and for each sample plot the latitude and longitude coordinates were taken in UTM coordinates. Similarly, slope for each plot was recorded using a clinometer.

2.5. Determination of Soil Organic Carbon

Soil is the largest carbon reservoir pool of terrestrial ecosystem and plays a key role in the global carbon budget and greenhouse effect [12].

Soil organic carbon was determined through samples collected from the default depth 30 cm prescribed by the IPCC (2006) [9]. Based on findings that support as much as 60% of stored carbon has been found at this depth [11] and that at lower depths, stored carbon tends more stable since the soil is less altered by mechanization practices or by changes in forest cover.

The activities of carbon measurement during the field data collection was soil organic carbon measurements.

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 [16].

To obtain an accurate inventory of organic carbon, soil depth, soil bulk density (calculated from the oven-dry weight of soil from a known volume of sampled material), and concentrations of organic carbon within the sample [10]. The soil samples for soil carbon determination were collected at the plot prepared 1mx1m ($1m^2$) a pit of up to 30 cm in depth was dug to best represent forest types in terms of slope, vegetation, density, and cover.

The soil samples collected from the plot were labeled and tagged brought to the laboratory, placing them in sample plastic bags. The samples were taken to Holeta Agricultural Research Center. Then, the bulk density and amounts of soil organic carbon were determined.

The carbon stock density of soil organic carbon can be calculated as recommended by Pearson *et al.,* [14]. from the volume and bulk density of the soil as

$$V = h \times \pi r^2 \quad (1)$$

More over the bulk density of a soil sample can be calculated as follows:

$$BD = \frac{Wav,dry}{V} \quad (2)$$

where BD is bulk density of the soil sample per, $W_{av,\ dry}$ 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 [14].

$$SOC = BD * d *\% C \quad (3)$$

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 (%).

2.6. Data Analysis

The data analysis was done using Microsoft excel sheet and SPSS version 16 software. Soil data collected from field and data determined from laboratory analysis such as dry weight of soil, bulk density of soil and soil carbon contents were analyzed using Microsoft excel as a platform in the biomass and carbon calculations as well as Statistical Product for Service Solutions (SPSS) software version 16 to determine the relationship between dependant and independent variables and other statistical parameters. One simple T-Test was used to compute the mean values and mean standard errors of the variables.

3. Results and Discussion

3.1. Soil Organic Carbon and Bulk Density Determination

The potential long term average soil carbon storage was calculated separately for each of the different plots along altitudinal variations. Thus, in this study, 66 sample plots were recorded (for this particular study of carbon stock estimation) from the study site, Sekelemariam State Forest.

Table 1. *Laboratory analysis for soil organic carbon and bulk density determination.*

Field No	Depth (cm)	Volume (ml)	wt of dry sample (g)	Bulk density (g/cm^3)	%OC	SOC	$SOCO_2$
1	30	70ml	73.8	1.1	2.84	93.720	343.95
2	>>	>>	67.7	0.97	3.74	108.834	399.42
3	>>	>>	68.8	0.98	3.51	103.194	378.72
4	>>	>>	65.9	0.94	2.46	69.372	254.60
5	>>	>>	73.5	1.1	2.88	95.040	348.80
6	>>	>>	64.3	0.92	2.84	78.384	287.67
7	>>	>>	67.5	0.96	2.1	60.480	221.96
8	>>	>>	65.5	0.94	2.34	65.988	242.18
9	>>	>>	69.1	0.99	2.03	60.291	221.27
10	>>	>>	70.8	1.01	2.22	67.266	246.87
11	>>	>>	69.8	1	2.53	75.900	278.55
12	>>	>>	69.2	0.99	1.99	59.103	216.91
13	>>	>>	73.1	1.04	2.42	75.504	277.10
14	>>	>>	76	1.1	2.77	91.410	335.47
15	>>	>>	69.8	1	2.65	79.500	291.77
16	>>	>>	69.6	0.99	1.99	59.103	216.91
17	>>	>>	69	0.99	3.51	104.247	382.59
18	>>	>>	69.1	0.99	2.84	84.348	309.56
19	>>	>>	72.6	1.04	2.53	78.936	289.70
20	>>	>>	69.2	1	2.3	69.000	250.70
21	>>	>>	73.3	1.05	3.59	113.085	415.02
22	>>	>>	64.6	0.92	2.88	79.488	291.72
23	>>	>>	69.1	0.99	2.53	75.141	275.
24	>>	>>	74	1.1	1.83	60.390	221.63
25	>>	>>	68.1	0.97	3.43	99.813	366.31
26	>>	>>	78.9	1.13	2.07	70.173	257.53
27	>>	>>	72.8	1.1	3.43	113.190	415.41
28	>>	>>	68.7	1	2.07	62.100	227.91
29	>>	>>	67.1	0.96	3.43	98.784	362.54
30	>>	>>	74	1	3.74	112.200	411.77

Field No	Depth (cm)	Volume (ml)	wt of dry sample (g)	Bulk density (g/cm^3)	%OC	SOC	$SOCO_2$
31	>>	>>	73.5	1.1	2.73	90.090	330.63
32	>>	>>	73.2	1.1	2.73	90.090	330.63
33	>>	>>	73.0	1.1	2.81	92.730	340.32
34	>>	>>	75.9	1.1	3.82	126.060	462.64
35	>>	>>	73.8	1.1	3.12	102.960	377.86
36	>>	>>	74.7	1.1	4.83	159.390	584.96
37	>>	>>	70.7	0.99	4.44	131.868	483.96
38	>>	>>	70.5	0.99	4.21	125.037	458.89
39	>>	>>	70.8	1	2.57	77.100	282.96
40	>>	>>	71.5	1	3.27	98.100	360.03
41	>>	>>	69.0	1	2.42	72.600	266.44
42	>>	>>	74.0	1.1	4.44	146.520	537.73
43	>>	>>	76.1	1.1	4.44	146.520	537.73
44	>>	>>	72.3	1.1	2.65	87.450	320.94
45	>>	>>	69.7	1	3.59	107.700	395.26
46	>>	>>	69.5	1	4.99	149.700	549.40
47	>>	>>	70.5	1	2.81	84.300	309.38
48	>>	>>	70.9	1	3.43	102.900	377.64
49	>>	>>	68.2	1.1	3.59	118.470	434.78
50	>>	>>	62.8	0.95	3.59	102.315	375.50
51	>>	>>	65.5	0.98	4.05	119.070	436.99
52	>>	>>	72.9	1	3.74	112.200	411.77
53	>>	>>	83.7	0.97	5.69	165.579	607.67
54	>>	>>	84.5	0.97	3.51	102.141	374.86
55	>>	>>	77.8	1	4.05	121.500	445.91
56	>>	>>	88.2	1	4.91	147.300	540.59
57	>>	>>	81.7	1	4.05	121.500	445.91
58	>>	>>	74.3	0.96	4.6	132.480	486.20
59	>>	>>	81.6	1	5.92	177.600	651.79
60	>>	>>	83.4	1.1	5.53	182.490	669.74
61	>>	>>	82.4	0.98	3.59	105.546	387.35
62	>>	>>	86.1	1	3.66	109.800	402.97
63	>>	>>	83.5	0.98	3.2	94.080	345.27
64	>>	>>	71.8	1	4.6	138.000	506.46
65	>>	>>	77.7	1	2.96	88.800	325.90
66	>>	>>	86.3	1	3.66	109.800	402.97

According to the Lab analysis shown above in Table 1, the minimum and maximum bulk density identified in soil lab analysis was 0.92 and 1.13, respectively. The study site was found to measure an overall mean value of 101.00$\pm$3.66 tones ha^{-1} at (95%) CI. A total of 6703.08 tones SOC were estimated from the total study site. Soil CO_2 concentration also had similar pattern with soil organic carbon concentration with a mean value of $372.73\pm13.45\ t\ ha^{-1}$.

3.2. Soil Organic Carbon Stock in Different Slope Gradients

It was found that the highest mean carbon content was computed in lower slope classes i.e. 124.44$\pm$7.69 ton ha^{-1} and lowest in higher slopes i.e. 81.49$\pm$6.81ton ha^{-1} with 95% CI. The lowest total SOC was measured in slope classes between 31-40.

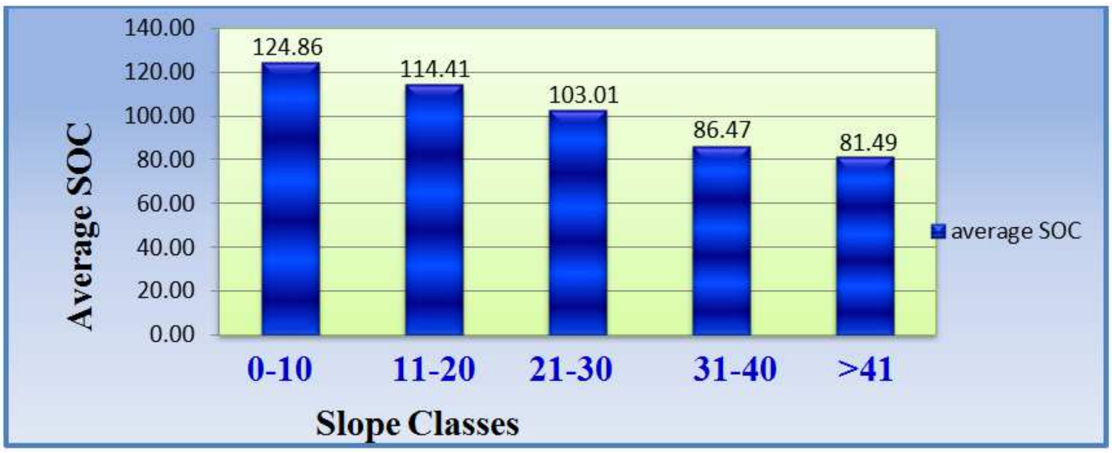

Figure 2. *Shows the average soil carbon distribution graph in different slope classes.*

In general, as it is shown in figure 2 above, the overall SOC distribution along different slope gradients decreases with increasing slope. However, there was no statistically significant (F=0.858, P=0.643).

Table 2. *The total and mean soil carbon stock in varying altitudes.*

Elevation	Total SOC	Total SCO_2	Mean SOC	Mean SCO_2
Lower	1692.02	6209.70	80.57±3.75	295.70±13.76
Middle	1170.25	4294.81	90.02±5.60	330.37±20.55
Higher	3810.82	14095.79	120.03±5.01	440.49±18.40

In spite of the stock variations in different altitudinal ranges, there was no statistically significant difference between mean values (F=0.739, P=0.788). In general, increasing or decreasing altitudinal gradients in the study site has direct relationship with SOC stock distribution pattern. As elevation increases, the SOC stock potential increases and also decreases in decreasing elevation.

4. Conclusion

The research was conducted to estimate and quantify the soil carbon stock of the forest in the established 66 ($1m^2$) plots. The soil organic carbon content of this forest has been assessed with respect to different environmental variables like slope and altitude gradients. All in all, this study gives estimation of the soil carbon stock in Sekelemariam State Forest. As the results show that there are significant variations in soil stock potential along varying elevation and slope. The middle elevation of the study area is relatively a higher slope gradient and is occupied by sparsely populated natural plants.

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