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Carbon Stock Variations Along Altitudinal and Slope Gradient in the Forest Belt of Simen Mountains National Park, Ethiopia

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Abstract: Forests play a significant role in climate change mitigation by sequestering and storing more carbon from the atmosphere which is released by anthropogenic causes. The overall objective of this study was to measure Variations of Carbon Stock along Altitudinal and Slope Gradient in the forest belt of Simen Mountains National Park. And it aimed to add values of the lowland forest belt of the park for climate change mitigation contribution in Ethiopia. The work was accomplished properly using random sampling to estimate the forest carbon in above and below ground biomass by considered each trees and shrubs which had DBH ≥5 cm. Above ground biomass was estimated by using allometric models equation while below ground biomass was determined based on the ratio of below ground biomass to above ground biomass factors. Dead wood, leaf litter, herb and grass (LHG) and soil organic carbon were conducted according to sampling quadrates data and laboratory result. The results shown that, there were twenty species with a density of 2334 trees and shrubs in the study sites which had DBH ≥5 cm. The mean above ground and below ground biomass carbon stock were 270.89±154.50 and 54.18±30.81 t ha^{-1} respectively. The mean above ground biomass carbon per species was 20.42±17.99 t ha^{-1}. The mean carbon in dead wood, LHG and soil carbon were 0.7258±1.0479, 0.019±0.008 and 242.51±46.42 t ha^{-1} respectively. The total Carbone stock variation along altitudinal gradient was 542.6, 550.73 and 627.01 t ha^{-1} for upper, mid and lower altitude respectively by which higher amount of carbon was stored in lower altitude. The total carbon stock variation along slope gradient was 487.3, 557.00 and 625.877 t ha^{-1} for upper, mid and lower slope respectively by which higher amount of carbon was stored in lower altitude. So that in this study both altitude and slope had the same impact on carbon stock potential of the species in the areas of study.

Keywords: Allometric models, Anthropogenic causes, Biomass carbon, Mitigation, Simen Mountains National Park

1. Introduction

Carbon sequestration is the process of removing excess carbon dioxide (CO_2) from the atmosphere and depositing it in a reservoir [1]. It is a way to mitigate the accumulation of greenhouse gases in the atmosphere released by the burning of fossil fuel and other anthropogenic activities. Through biological, chemical or physical processes, CO_2, which is one of the greenhouse gases, can be captured from the atmosphere. While a carbon sink is a reservoir that collects and stores carbon containing chemical compound, it removes CO_2 from the atmosphere through absorption. Forest and soil are potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets [1]. Sustainable forest development and forested landscape expansion is one of the key approaches for reducing atmospheric carbon concentration. It is a safe, environmentally acceptable, and cost-effective way to capture and store substantial amounts of atmospheric carbon. The concurrent development of tradable carbon credits provides financial incentives for considering carbon storage in forest management decisions [2].

Carbon sequestration from atmosphere can be advantageous from both environmental and socio-economic perspectives. There are evidences from several studies in Ethiopia and other countries. The environmental perspective includes the removal of CO_2 from the atmosphere [3], the improvement of soil quality [4], and the increase in biodiversity[5]; while socioeconomic benefits include increased yields [6], monetary incomes from potential carbon trading schemes [7], normalizing droughts through its potential for creating atmospheric condensation making cloud seeding, as well as reducing flood hazards and increasing ground water recharge by increasing water infiltration through soil columns. Globally, forests act as a natural storage for carbon, contributing approximately 80% of terrestrial above-ground, and 40% of terrestrial belowground biomass carbon storage [8]. So biomass is an important element in the carbon cycle, specifically carbon sequestration. It is used to help to quantify pools and fluxes of greenhouse gases (GHG) from the terrestrial biosphere to the atmosphere associated with land use land cover changes [9]. There are many conventional methods for quantification of sequestered carbon. Many of these methods are complicated, expensive and limited in their coverage. Such limitations impede sound quantification and monitoring of carbon [10]. One of such approaches is forest inventory data sets which often provide the required base line data to enable the large area mapping of biomass and subsequent carbon accounting over a range of spatial and temporal scales. However, spatially explicit estimates of biomass over large areas may be limited by the spatial extent of the forest inventory relative to the area of interest (*i.e.*, inventories not spatially exhaustive), or by the omission of inventory attributes required for biomass estimation. These spatial and attribution gaps in the forest inventory may result in an underestimation of large area biomass [11].

This research was conducted with the aim of understanding carbon stock variations along altitudinal and slope gradient in different carbon pools of the forest ecosystem Simen Mountains National Park, Ethiopia

2. Materials and Methods

2.1. Description of the Study Area

This study was undertaken in lowland forest of Simen mountains national park forest, Amhara National Regional State, North Gondar, Ethiopia located at about 846 km North of Addis Ababa. The forest has an altitudinal gradient ranging from 1900 to 3000m above sea level with the highest peak at Ras dashin Mountain. The forest covers 171 hectares. The study area is characterized by moderate climate, locally known as woina dega and it has a mono modal rainfall distribution and the rainy season is from June to August with The annual average rain fall of SMNP 1367mm and the mean annual maximum and minimum temperatures are 11°C and 19°C, respectively.

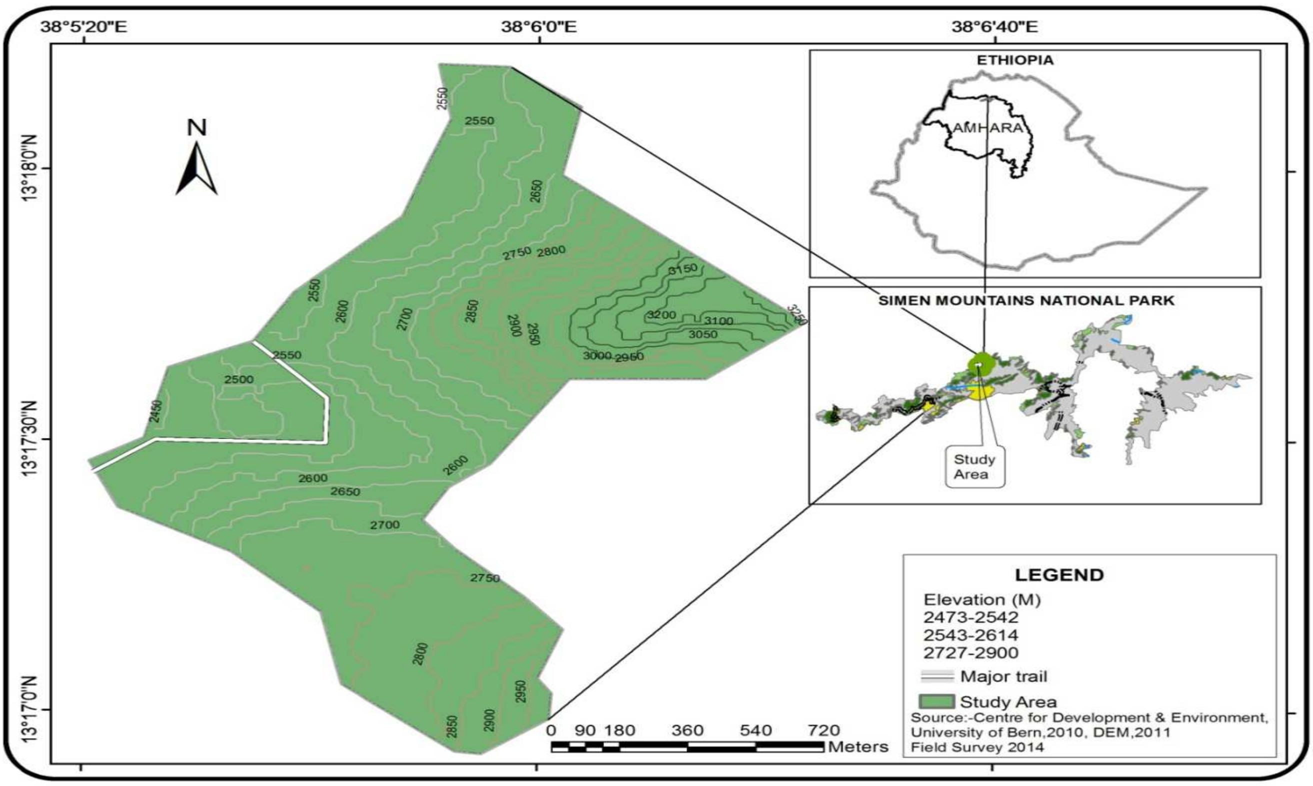

Figure 1. *Map of the study area*

2.2. Delineation of the Study Site

Delineation of the forest boundaries was the first step in forest carbon stock measurement. The boundary of the study forest area was delineated by taking geographic coordinates with GPS at each turning point. The GPS points that were taken from the study site to indicate each sample plots were recorded.

2.3. Sampling Techniques on the Field

Simple random sampling method was used to take samples. Sample plots were laid along line transects based on altitudinal variation of the study area. A randomly sampling plot of (10 m x 20 m) in each site was established. To reveal the tree composition and biomass, all live trees with a diameter ≥ 5 cm were recorded as indicated by [12]. The diameter was measured at breast height (DBH, 1.3 m height from the ground) to estimate biomass and the size class distribution of trees in a sampling plot. DBH was measured by using tree measuring tape. Trees with multiple stems connected near the ground were counted as single individuals and bole circumference was measured separately. Tree height was recorded by using measuring clinometers. The methodology and procedures used to estimate carbon stocks were simple step by step procedures using standard carbon inventory principles and techniques [12]. Procedures were based on data collection and analysis of carbon accumulating in the above ground biomass, below-ground biomass, leaf litter, and soil carbon of forests using verifiable modern methods.

2.4. Stratification of the Study Area

Stratification was done in the forest in order to take accurate data from the field as well as to maintain the homogeneity of the area. Altitude was the major parameter to classify the study area. The strata were defined at each elevation, starting from the bottom to the top of the mountain. Based on altitudinal variation, the study site was stratified into three zones namely: lower (2473-2542 m), middle (2543-2614 m) and higher (2615-2900m). Slope gradient was the second parameter to classify the area. Therefore, slope classes classified into lower (0-10%), middle (>10-20%) and higher (>20%). Aspect was also another parameter that was considered in the study forest and classified in to four classes: N (North), S (South), E (East), W (West).

2.5. Field Measurements

Sample plots (10m x20m) were laid through stratified random sampling method with nine transect lines in the various qualitatively classified biomass levels to account for the largest variability in the biomass range. Ground inventory data of tree parameters i.e., DBH and height of the trees were collected.

2.5.1. Vegetation Data Collection and Identification

The estimations of above and below ground carbon depend on the above ground biomass of living tree species. To estimate the above ground biomass all tree species within selected sample plots DBH ≥ 5cm were identified and recorded. Trees with multiple stems at 1.3 m height were treated as a single individual and DBH of the largest stem was taken. Plant identification was done by using Flora of Ethiopia and Eritrea.

2.5.2. Field Carbon Stock Measurement

The major activities of carbon measurement during the field data collection were above-ground tree biomass, below-ground biomass, leaf litter, and soil organic carbon measurements. Detailed methods are explained under the following sub headings.

(i). Above Ground Biomass (AGB)

The above ground biomass consists of all living vegetation above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The DBH (at 1.3m) and height of individual trees greater than or equal to 5cm and DBH were measured in each sampling plots.

(ii). Litter Biomass (LB)

The leaf litter is defined as all dead organic surface material on top of the mineral soil. A quadrate with a size of 1 m × 1 m was established to sample litters. In each sample plots a total of five small quadrates were laid four at the corner and one in the center to minimize heterogeneity. The litter samples were taken in sub quadrate of (1 m × 1 m) along diagonal from one corner to the other and then the leaf litters within the 1m^2 sub plots were collected. Laboratory analysis: The 100 gram sub sample fresh weights were sampled from the five sub-samples collected from each quadrant which were mixed homogenously and then taken to laboratory and oven dried at 105^{o}c.

(iii). Soil Organic Carbon (SOC)

Soil samples were collected from the field with five sub-plots within each major plot. The Samples were dug using core sampler with a diameter of 5 cm and the depth of the soil in which that took the sample was 30 cm. Mixing of soils was done properly by taking equal amount of soil from each sub plots to make a composite in order to make homogeneity. After organizing the samples in such a way, the samples were taken to Wondo Genet College of forestry and Natural resources for laboratory analysis. In the laboratory, soils are prepared and oven dried at 105^{o}c for 24 hours to remove the soil moisture so as to determine the percentage of organic carbon. Finally, the bulk density and soil organic carbon were determined after getting percentage of organic carbon.

2.5.3. Estimation of Carbon Stocks in Different Carbon Pools

(i). Estimation of Above Ground Carbon Stock (AGC)

As defined by [13]; allometric equation as a statistical relationship between key characteristic dimensions of trees that are fairly easy to measure, such as DBH or height, and other properties that are more difficult to assess, such as above ground biomass. The equation developed by [14], was used to calculate the above ground biomass as given below:

$$AGB= 34.4703 - 8.0671(DBH) + 0.6589(DBH2) \quad (1)$$

Where, AGB is above ground biomass, DBH is diameter at breast height.

(ii). Estimation of Below Ground Carbon Stock (BGC)

Below ground biomass estimation is much more difficult and time consuming than estimating aboveground biomass [15]. Roots play an important role in the carbon cycle as they transfer considerable amounts of Carbon to the ground, where it may be stored for a relatively long period of time. As indicated by [10], standard method for estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., root to shoot ratio value of 1:5 is used. The equation is given below:

$$BGB = AGB \times 0.2 \quad (2)$$

Where, BGB is below ground biomass, AGB is above ground biomass, 0.2 is conversion factor (or 20% of AGB).

(iii). Estimation of Carbon Stocks in Dead Wood

The allometric equation confirmed in REDD methodology (2009) was used to estimate the amount of biomass in standing dead wood.

$$BSDW = \Sigma_{i=0}^{n} 1/3\ (D/200)^2\ h*s \quad (3)$$

Where, biomass is expressed in kg,

h = length (m), D = tree diameter (cm) and

s = specific gravity (g cm-3) of wood. The specific density is estimated at 0.5 g cm^{-3} as default value, but can be around 0.8 for dense hard woods and around 0.3 for very light species in tropical regions [16].

The carbon content in dead wood is calculated by multiplying total biomass of dead wood with the [17] default carbon fraction of 0.47.

(iv). Estimation of Carbon Stocks in the Litter Biomass

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

$$LHGB = \frac{Wfield}{A} * \frac{Wsub_{sample(dry)}}{Wsub_{sample(fresh)}} * \frac{1}{10{,}000} \quad (4)$$

Where: LB = Litter biomass (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). The carbon content of vegetation is surprisingly constant across a wide variety of tissue types and species. [18] noted that Carbon content of biomass is almost always found to be between 45 and 50% (by oven dry mass). In many applications, the carbon content of vegetation is estimated by simply taking a fraction of the biomass by multiplying 0.5.

C= 0.5* LB Where C= is carbon content by mass, and LB= is oven-dry biomass.

Therefore, total carbon content of litter (ton/ha) =Total dry litter biomass* carbon fraction

$$CL = LBM \times \%\ C \quad (5)$$

Where, CL is total carbon stocks in the litter in ton/ha,

%C is carbon fraction determined in the laboratory (Pearson *et al.,* 2005).

(v). Estimation of Soil Organic Carbon (SOC)

The carbon stock of soil was done by using the following formula which is recommended by [12] from the volume and bulk density of the soil.

$$V = h \times \prod r^2 \quad (6)$$

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 [12]. More over the bulk density of a soil sample was calculated as follows:

$$BD = Wav,\ dry/V \quad (7)$$

Where, BD is bulk density of the soil sample per, Wav, 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 [12].

$$SOC = BD * D * \%\ C \quad (8)$$

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 (%).

2.5.4. Estimation of Total Carbon Stock Density

The total carbon stock is calculated by summing the carbon stock densities of the individual carbon pools of the stratum using the [12] formula. Carbon stock density of a study area:

$$CT = AGC + BGC + LC + SOC \quad (9)$$

Where, CT = Total Carbon stock for all pools (ton/ha), AGC=above ground carbon stock (ton/ha), BGC= below ground carbon stock (ton/ha), LC=litter carbon stock (ton/ha) and SOC= soil organic carbon (ton/ha). The total carbon stock was then converted to tons of CO^2 equivalent by multiplying it by 44/12, or 3.67 as indicated by [19].

3. Data Analysis

After the data collection was completed, data analysis of various carbon pools measured in the forests were accomplished by organizing and recording on the excel data sheet. The data obtained from DBH, diameter, height of each species, field weight (W_w), fresh weight-(FW) and dry weight (W_{dry}) of LHG and soil were organized by excel 2007 and analyzed using and MINITAB software version 16. DBH data was arranged in classes ≤10, >10-20, >20-30, >30-40 and >40 for applying appropriate model of biomass estimation equation. The relationship between each parameter was tested by descriptive statistics. Differences at the 95% (α=0.05) confidence interval was used to see the significance differences.

4. Results

4.1. 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 upper and middle parts of altitude have low to moderate carbon stocks in above ground biomass. 318.8174, 258.247 and 240.6356 ton/ha carbon stocks were recorded at the lower, middle and upper altitude respectively.

Similar trend was shown in below ground biomass in which 63.76, 51.65 and 51.64 ton/ha 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 middle and upper parts. But this is not very much significance at 95% confidence interval (F= 0.618, P= 0.543) in AGC and (F=0.618, P=0.543) in BGC stocks. It is also the same in the case of litter carbon stock and SOC. With significance difference at α=0.059 (F=0.991, P=0.378) in litter carbon stock and (F=0.653, P=0.525) SOC stocks**.** The litter and SOC carbon stock were higher in the lower parts of altitude and low in the upper altitude. 243.943, 240.3293 and 240.1949 ton/ha 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 (243.943 ton/ha), followed by the middle (240.329 ton/ha) and the upper altitudinal gradient (240.194 ton/ha).

4.2. Carbon Stocks of Different Pools Along Slope Gradient

The slope gradient was also a second factor which affects the carbon stocks of different pools in the studied forest. Above ground biomass and below ground biomass and their consecutive carbon stocks were found to be low in hilly areas of the forest due to the fact that no more vegetation cover were found there. The carbon stock of the middle slope gradient was moderate in both above ground carbon and below ground carbon stocks and higher in the upper slope gradient in both pools. 316.172, 260.355 and 187.128 ton/ha carbon stocks were recorded at the lower, middle and upper slope gradient respectively in above ground carbon stocks. Similar trend was also shown in below ground biomass in which 63.234, 52.071 and 37.426 ton/ha carbon stocks were recorded in the lower, middle and higher slope classes respectively with highest value found at the lower of slope classes followed by the middle and upper slope classes. But this was not statistically significance at α=0.05 (F= 0.169, P= 0.845) in above ground biomass and (F=0.169, P=0.845) in below ground biomass. At the same in the case of dead wood, litter carbon stock and SOC, there was no significance difference at α=0.05. The litter carbon stock was higher in the lower slope classes and low in the higher slope classes with its value arranged 0.020, 0.0171 and 0.017 ton/ha in the lower, middle and higher slope gradient respectively. The carbon stock in the soil pool was higher in lower slope classes and lower in the upper slope classes with moderate carbon stocks in the middle slope classes. 246.417, 244.453 and 240.974 ton/ha stocks of carbon were recorded in the lower, middle and upper slope classes respectively in the soil pool. However for dead wood carbon stock higher carbon stock in higher slope class (1.466 ton/ha) with lower in the lower slope class (0.290) and moderate stock in the middle slope class (0.421ton/ha).

Table 1. *Mean biomass and carbon stocks (t ha-1) in different carbon pools along altitudinal range*

Altitude class	Altitude range (m)	No of Plots	AGC	BGC	LC	DWC	SOC	Total carbon (ton/ha)
Upper	2615-2900	17	240.635	51.6494	0.459	0.016	240.195	542.582
Middle	2543-2614	19	258.247	48.1271	0.255	0.017	240.329	550.73
Lower	2473-2542	18	318.817	63.7635	0.896	0.021	243.943	627.014

Table 2. *Carbon stocks in different pools with respect to slope gradient*

Slope Class	Slope Range (%)	No of Plots	AGC	BGC	LC	DWC	SOC	Total carbon (ton/ha)
Upper	>20	22	187.128	37.426	0.017	1.466	240.974	487.396
Middle	>10-20	23	260.355	52.071	0.017	0.421	244.453	557.005
Lower	0-10	9	316.172	63.234	0.02	0.29	246.417	625.877

Table 3. *One-way ANOVA results with altitude gradients*

gradient	Carbon pools	F-value	P-value
Altitude	AGC	0.618	0.543
	BGC	0.618	0.543
	DWC	3.339	0.043
	LC	0.991	0.378
	SOC	0.653	0.525

**Bold values are significant at α=0.05 (95%)

Table 4. *One-way ANOVA results with altitude gradients*

gradient	Carbon pools	F-value	P-value
Slope	AGC	0.169	0.845
	BGC	0.169	0.845
	DWC	1.107	0.338
	LHGC	0.54	0.586
	SOC	0.077	0.926

5. Discussion

5.1. Storage of Biomass in Different Pools

The maximum above ground biomass per plot was 1795.64 ton/ha and the minimum was 162.10 ton/ha. The average biomass stock recorded in above ground biomass was 576.36 ton/ha. The results are more or less similar to the previous researches of above ground biomass of afromontane forest which were 567.2 ton/ ha [20] and 591.00 ton/ ha [21] while it was highly larger than Humbo forest of Wolaita Zone [22]. The average above ground biomass observed from these three location was 574.89 ton/ha. The global above ground biomass in tropical dry and wet forests ranged between 30-275 ton/ha and 213-1173 ton/ha respectively as indicated by [23], which is lower than the above ground biomass of Tara Gedam forest.

In this study, the differences in biomass and carbon accumulation among plots could be largely due to differences in the growth rates of plants as indicated by [24]. Litter constitutes an important flux of soil organic Carbon. The forest litter consisted of a relatively high number of trees, although the density varies among samples and species; in densely populated trees few litters were found due to the closeness of plants each other makes their litter not fall down [25]. The Carbon stocks in the litter of the study forest ranged from 2.6–3.8 ton/ha which were comparable to those reported for tropical seasonal rainforests (1.4 ton/ha) carbon [26] and tropical secondary forest at the Makiling Forest Reserve in the Philippines (1.9 ton/ha) [27]. On the other hand, the litter carbon varies on other tropical forests (2.6-3.8 ton/ha) as reported by [28]. The relatively low quantities of Carbon stored in litter carbon stock in the studied forest may be due to the high decomposition rate as reported in a 10-year study by [29] and Seasonal Wild fire distraction in some part of the forest and caring number of cattle during the winter that affect the litter carbon stock directly in the area.

The average values of soil organic carbon in the study area was 242.507 ton/ha, which was similar to the Carbon density estimates of Afromontane Rain Forests of the Eastern Arc Mountains which were found to be between 252 and 581 ton/ha as indicated by [30, 31]. The distribution of Carbon stocks in each sample plot of the study forest is known to vary due to the presence of different tree species, soil nutrient availability, climate, and topography and disturbance regime [32]. This indicates that, the higher soil organic carbon in the soil could sequester more CO_2. The bulk density of the soil in this study was found to be 0.78 g/cm^3 minimum value and 0.999 g/cm^3 maximum value with an average value of 0.93 g/cm^3. The presence of low bulk density in the soil indicates that the soil has high potentials to accumulate large amount of organic matter in it [32].

5.2. Carbon Stocks of Different Pools Along Altitudinal and Slope Gradient

Most of the time altitudinal and slope gradient were the factors that affect the storages of carbon in different pools. As observed, [33] a strong effect of slope on the SOC stock of a subalpine forest in the Olympic Mountains of Washington state. The carbon stock of the study forest was highest at the lower altitudinal range followed by the medium and lowest at higher altitude of the mountain. This is due to the decreasing of layer of large DBH trees at higher altitudinal range of the forest site and the layer of large DBH trees increases towards the lower altitudinal ranges naturally and trees and shrub deforestation was also higher in upper altitude. Especially, altitudinal variation has an impact on AGC, BGC and SOC stock because of its influence on soil water regime [34]. Similarly the carbon stock of the study forest was increased as the degree of slope gradient decreased. This is due to the inclined arrangement of the study forest that affects both forest biomass and soil nature of the area. Most steep areas were covered by lower plants (grasses, herbs and bushes) which have lower biomass and carbon relatively.

6. Conclusion

The study conducted in low land forest of Simen Mountain National Park showed that the forest contains moderately diversified plant species. A total of twenty different species of plants were collected, of which *Erica arborea* was the dominant in density and *Buddeleia polystachya* was the least dominant in the study site. Based on DBH and height class distribution the forest has a bit different trends observed in both classes. The densities of tree species decreases as the height class increases but For DBH, it has an irregular pattern. This implies that, the predominance of small sized tree and shrub species in the lower classes than in the upper classes. The analysis of these two parameters in the study forest indicated that higher percentage of number of tree species in the lower than in the higher height frequency classes. The carbon stocks of the study site shows a variation among the plots due to the presence of higher biomass in some plots and small biomass in other plots. The average carbon stock of the different carbon pools of this study was almost similar with most researches done in tropics and Ethiopia. The ANOVA result showed that at 95% confidence interval, the carbon stocks in the different carbon pools (AGC, BGC, DWC, LHGC and SOC) were different due to environmental factors (altitude and slope). The lower parts of altitude class carbon stock potential were higher in all pools (except for the DWC pool which is significant for most carbon pools) while the upper and medium parts of altitude had low to moderate carbon stock. This is due to the fact that there were dense vegetation cover in the lower altitudinal range and the presence of favorable conditions in this part. DWC was higher in higher altitude and low to moderate in medium and lower altitude. This is because the higher altitude part of the forest was under less nutrient and different environmental factors like landslide and erosions that facilitate dead wood accumulation. At same time the litter and soil carbon stocks were higher in the lower parts of altitude and slope with lower in the higher altitude due to the presence of large decides forest and by the nature of the lower part to receive the medium and higher feeds to down. The carbon stock of the higher slope gradient was lower in all four pools (AGC, BGC, LHGC, and SOC) and higher to moderate stock in lower and medium slope gradients. This is because the better density of the study forest was found in lower and medium slope area due to the presence of stable environmental conditions better relative disturbance. But DWC was higher in higher slope because environmental pressure is high in this range which affects plant life span.

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