Journal of Tropical Biodiversity and Biotechnology
Volume 07, Issue 02 (2022): jtbb69360
DOI: 10.22146/jtbb.69360

Research Article

Carbon Stock Potential of Gara Gola Natural Vegetation in East Hararghe Zone, Eastern Ethiopia

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Keywords:
Ethiopia
gola
carbon stock
natural vegetation
altitude
Submitted:
24 September 2021
Accepted:
16 April 2022
Published:
15 June 2022
Editor:
Miftahul Ilmi

ABSTRACT

This study was conducted at Gara Gola, in the Oromia regional state of Ethiopia, to examine the carbon sequestration potentials under three altitudinal gradients [i.e., Lower altitude (LA: 1500–1800 m.a.s.l.); Middle altitude (MA: 1801–2000 m.a.s.l.) and upper altitude (UA: 2001–2300 m.a.s.l.)]. A total of 60 quadrats of 20m x 20m, 5m x 5m, and 1m x 1m with six horizontal transect lines were employed to gather data on the tree, shrub, herbaceous, and soil, respectively. To estimate organic carbon percentage, soil parameters were collected from three soil profiles (i.e., 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm). The mean total carbon stock of the study area was 641.18 Mg ha-1. MA had relatively higher TC than the other gradients. But the LA had the lowest TC stock, due to a high amount of human and animal interference. The results showed that the UA had significantly higher above-ground (AGC) and below-ground carbon (BGC) stocks with 147.3±39.4 Mg ha-1 and 18.37±7.8 Mg ha-1, respectively, compared to other gradients. However, LA had the lowest AGC (66.8±8.7 Mg ha-1) and BGC (12.06±2.6 Mg ha-1). Lower altitude exhibited a significantly higher SOC value than the other two altitudinal gradients followed by MA. The UA had the lowest SOC value. SOC across the three soil profiles follows a reduction trend from topsoil depth to lower soil depth with significant variation. In conclusion, LA should embrace better ecological, policy, and socioeconomic considerations than the other gradients.

INTRODUCTION

Carbon dioxide (CO2) and other Green House Gases (GHGs) concentrations in the atmosphere are now universally acknowledged as the primary source of global warming. Carbon accumulates at a rate of 3.5 pentagrams per year in the atmosphere. The majority of it comes from fossil fuel combustion and the conversion of the tropical forest into agricultural fields (Paustian et al. 2016). Increased atmospheric concentrations of so-called greenhouse gases are assumed to be the primary cause of the increase in temperature of the earth near-surface, air, and oceans in recent decades (GHGs). CO2 is also a major greenhouse gas (GHG) that contributes to global warming. Thus, Climate change has resulted in a lot of influence on the micro and macroclimate of the world, including losses of biodiversity, degradation of natural vegetation and soil, and loss of important natural ecosystems with their services and indigenous knowledge (Alemu 2014).

Natural vegetation plays an essential part in mitigating climate change, according to the 1997 Kyoto Protocol, which is the first major international agreement on climate change, by naturally collecting carbon from the atmosphere and therefore lessening the impact of CO2 emissions (IPCC 2007a; Perschel et al. 2007). Natural vegetation potentially stores more than 80% of all above-ground carbon on the planet and 70% of all organic carbon in soil (Fauzi et al. 2017). On the other side, deforestation and forest degradation account for 12 to 20% of annual greenhouse gas emissions, more than the total amount of emissions from all forms of transportation combined (Saatchi et al. 2011). According to a recent assessment, carbon storage in forest biomass dropped by an estimated 0.5 Gt per year between 2005 and 2010, attributable primarily to a loss in worldwide forest acreage (Gebrewahid et al. 2018).

As mountain regions cover about 27.2 % of the global land area and there have been rapid climate changes in mountain regions during the past few decades (IPCC 2007a), understanding the shifts in forest carbon storage and allocation along altitudinal gradients in mountain regions will help us better predict the response of regional and global carbon balance to future climate change (Poudel et al. 2020). The above and below ground carbon stocks were increased with increasing altitude while the total carbon stock decreased with increasing altitudinal gradient (Kumar et al. 2021). The analysis of carbon stock variation of different carbon pools along the altitude of the forest showed a significant variation, whereas the above and below-ground carbon stock variation with slope, a gradient was also significant except soil organic carbon and liter carbon (Kumar et al. 2021).

Climate change consequences are also posing several issues in Ethiopia due to the country inadequate adaptive capacity. The country is vulnerable to climate change due to its remoteness and complexity, low income, and reliance on climate-sensitive economic sectors such as agriculture and pastoralism, it also has a limited adaptive ability (FAO 2016a). Rainfall is becoming more unpredictable as the temperature rises, and the resulting decrease in precipitation is frequently harmful to Ethiopian agriculture (Fonta et al. 2011). Droughts, which are frequently followed by soil erosion, are also becoming further common (Edwards 2010), due to increased deforestation and deterioration of land resources. Population growth has resulted in extensive forest loss for agricultural use, grazing, and exploitation of existing forest for fuelwood, feed, and construction materials. Ethiopia government launched the Climate-Resilient Green Economy (CRGE) in 2011 in response to the effects of climate change, such as rising average temperatures and erratic rainfall patterns. The objective of the CRGE is to protect and restore forests for economic, environmental, and carbon-storage purposes. As an accountable member of the international public, Ethiopia understands the importance of natural vegetation and forests in mitigating global climate change (Eshetu

& Hailu 2020a).

One of the four pillars of Ethiopia Climate Resilient Green Economy (CRGE) Strategy is Reducing Emissions from Deforestation and Forest Degradation (REDD+), to avoid emissions from the forest sector while absorbing greenhouse gases from other sectors to achieve a carbon-neutral economy by 2030 (Gonzalo et al. 2017). Furthermore, REDD+ has the greatest possible for mitigating climate change in a poor tropical country (FAO 2016b). As a result, natural forest management and enhancing their carbon stock potential are critical for large-scale carbon absorption and generating carbon credits to meet the CRGE strategy by increasing carbon sequestration potential and biodiversity conservation while also improving local community livelihoods (Eshetu & Hailu 2020a).

In this context, numerous researches in natural vegetation areas, including Ethiopian rangelands (Alemu 2012; Bikila et al. 2017; Tessema et al. 2017) were undertaken in various parts of the nation, concentrating on carbon stock potential. However, these investigations could not provide complete data on the country carbon stock potential. In east Hararghe, there are no detailed studies on carbon stock potential. Even some of the earlier studies aimed to estimate the potential for biodiversity and carbon storage in vegetation did not take into account ecological gradients such as elevation, slope, and aspect; others were only aimed at contrasting natural forests with different land uses such as community grazing (Chinasho et al. 2015). Ecological parameters such as elevation and slope, on the other hand, have a considerable impact on carbon stock potential (Acharya et al. 2011). More importantly, elevation is an important environmental factor since it influences other nonliving and living factors such as soil, temperature, landscape, and flora (Simegn & Soromessa 2015). Therefore, there is a significant demand for information on natural forest carbon store potential in height, aspect, and slope gradients. As a result, such baseline data will aid in good land use development for huge watershed areas, taking elevation into account.

This study will give baseline information for policymakers, local experts, community members, and researchers on the vegetation ability to mitigate climate change and its impact if the current land use is changed to another. Because the surrounding area is regarded as one of the country industrial pools, this change could happen soon. This modification will add to global GHG emissions and local climate change impacts. This study tested the hypothesis that soil organic carbon (SOC) and carbon stock would increase within creasing altitudes and soil organic carbon stock would increase with increasing natural vegetation and decreasing soil depth (Bargali & Bargali 2020). The primary goal of this study was to evaluate the carbon stock capability of Gara Gola natural vegetation across altitudinal gradients in eastern Ethiopia.

MATERIALS AND METHODS

Area Location

The research was administered within the Gara Gola Natural Vegetation within the Goro Gutu district of the Oromia regional state eastern Hararghe Zone. The district covers 531 km², accounting for about 2.35 % of the zone total area. Karamile, the capital, is 108 kilometers west of Harar. The agro-climatic zones of Goro-Gutu district are Dega (2,000-2,657 m.a.s.l), Woinadega (1,500-2,000 m.a.s.l), and Kola (1,500 m.a.s.l), which cover roughly 11, 52 and 37 % of the district total area, respectively (Figure 1). The climate is defined by the district agro-climatic zones. Agriculture (including crop and livestock production) is the people primary source of income and employment. Within the district, the average landholding per household is 0.37 hectares. Agriculture is practiced, with the most common crops being sorghum, maize, and wheat.

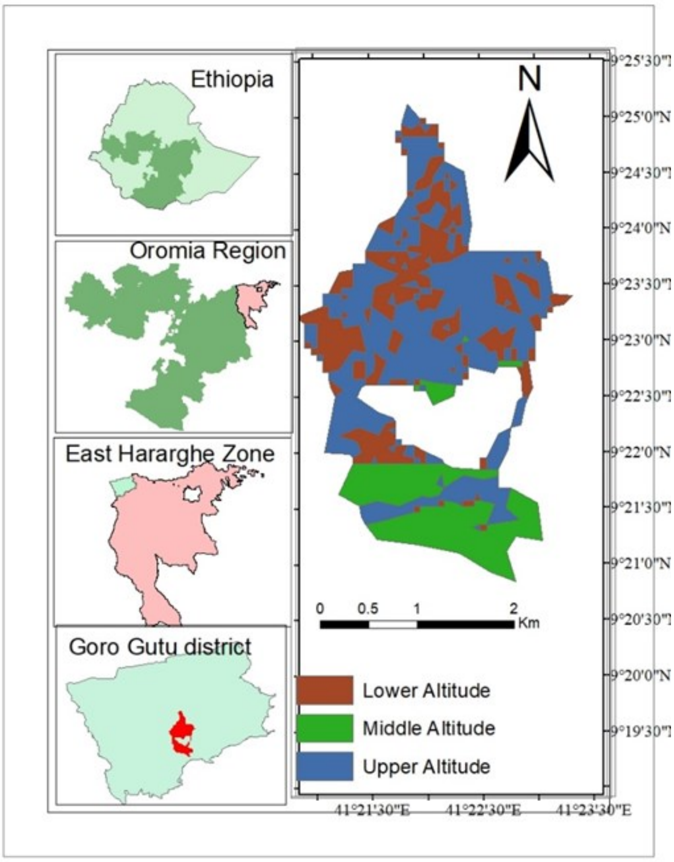

Figure 1. Gara Gola Natural Vegetation Map.

Climatic

The region is classified as a semi-arid tropical belt in eastern Ethiopia, with a sub-humid climate. The area means annual rainfall (2000-2020) is roughly 924.7 mm, according to data from a meteorological station. A bimodal rainfall distribution pattern characterizes the studied area. The local season of short rain, called Badheessa, lasts from March to May, while the main/long rainy season, known as Ganna, lasts from late June to September (Zeleke et al. 2021). The mean monthly low temperature ranges between 4.1°C in December and 16.4°C in January, though the maximum temperature ranges amid 24.5°C in December and 28.3°C in May, respectively.

The Study Area Stratification

The study area boundaries were created so that forest carbon stocks could be accurately measured and accounted for. The study area border was delineated using the Global Positioning System (GPS). Lower altitude (LA: 1500–1800 m.a.s.l), Middle altitude (MA: 1801–2000 m.a.s.l), and Upper altitude (UA: 2001–2300 m.a.s.l) were used to classify the study location. Systematic sampling of transect by altitude sections was conducted to establish relatively homogeneous units and obtain accurate data from the fieldwork. The study area had an elevational variation that helped determine the variants in elevation as a predictor variable to relate with woodland carbon stocks—sampling and measurement design.

Woody Species Sampling

Two parallel transect lines were laid at 200m intervals in each site, parallel to the stand gradient and 50m far from the edge to prevent edge outcome. In each transect line, a quadrat sized 20mx20m was established systematically for data collection of trees, 5mx5m for shrubs, and 1m x1m for Herbs, Grasses, and Litter (GHL) and samples of the soil (Yayneshet 2011; Hasen-Yusuf et al. 2013; Bazezew et al. 2015). A total of 60 quadrats along six transects lines were obtained at a distance of 100 meters (20 quadrats with three in each gradient). GPS was also used to record the latitude and longitude of each research quadrat. Nested plots were established for sampling and gathering separate size classes of growth form. The methods included laying out 40 m^2 (20 mx20 m) nested plots for trees and shrubs.

A 1m x 1m plot was erected at the four corners and central locations of each main 20m x 20m quadrat to sample herbaceous vegetation and litter (figure 2). Pieces of 1m^2 quadrat made of thin wood timber were used to sample GHL and soil made by the local carpenter. All herbaceous vegetation in every quadrat, which includes litters, were clipped at the ground level, weighed, and a 100g composite pattern was once introduced to the laboratory, where moisture content, dry biomass, and oven-dry mass had been determined the use of suitable laboratory method (Roshetko et al. 2002; Jina et al. 2008) to estimate the amount of carbon stocked using GHL. Litter is defined as all non-living biomass larger than the soil organic matter limit (recommended 2mm) that is dead and in numerous stages of decay above organic soil (IPCC 2006). Scientific nomenclature was carried out using published volumes "Flora of Ethiopia and Eritrea" (Sebsebe 1997), Useful Trees and Shrubs of Ethiopia (Bekele-Tesemma & Tengnäs 2007) and Natural Database for Africa (NDA) Version 2 (Ermias 2011). For some species that were unable to identify directly in the field, plant specimens were collected, pressed, dried, and identified in the herbarium.

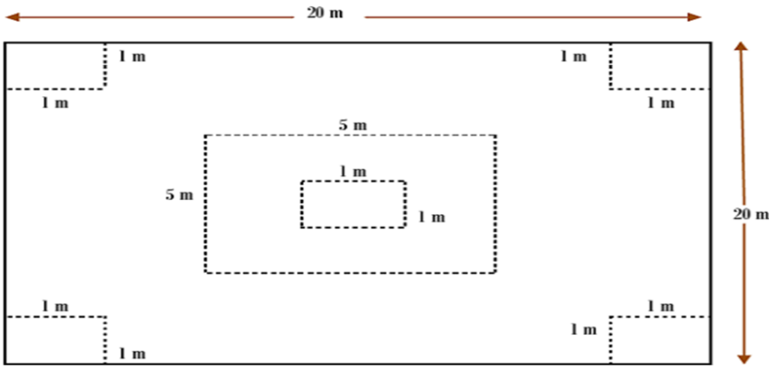

Figure 2. Position of the quadrat in the diagram. (1m x 1m for herbaceous, litter, and soil sampling; 5m x 5m for shrub sampling; and 20m x 20m for tree sampling).

A 1m x 1m plots were employed at all corners and middle places of all main quadrat for soil sampling. For SOC determination, soil samples were obtained in five 1m2 quadrats, with GHLs samples taken with a graded 30cm soil auger. A calibrated soil auger was used to collect soil samples up to 30cm in depth (between 0 up to 10, 10 up to 20, and 20 up to 30 cm) (IPCC 2006). A soil composite pattern was once created by mixing soil from 5 sub-quadrats of every primary quadrat to quantify organic carbon. Equal weights of every sample from all the major quadrants (400m^2) alongside a single transect had been mixed and blended collectively in accordance to their depth, air -dried and processed via a 2mm sieve to separate particles and gravel to form one soil pattern for every soil depth alongside a transect. As a result, a total of 24 composite soil samples (3 altitude x 2 transects x 3 soil depth) were produced from a total of 60 sample quadrats.

The bulk density was determined using the core technique (Blake 1965). Soil bulk density determination has been taken in the center of every transect relying on their soil profile, lead-off from the floor soil with a 5 cm depth and 2.5cm diameter core sampler gently pushed into the soil to keep away from compaction (Roshetko et al. 2002). All of the samples were tagged with the quadrat to which they belonged and taken to the lab for bulk density examination.

Carbon Stocks Estimation

Carbon stock and above-ground biomass

Allometric equations developed by Chave et al. (2014) were employed to provide a valid estimate of forest carbon reserves for AGB. The model was found to remain true across a wide range of tropical vegetation kinds, with no discernible consequence from geography or ecological conditions (Chave et al. 2014; Victor 2015). Equations that combine more than one tree measurement, according to Henry (2010), increase the accuracy of forest biomass calculation. As a result, many research employed the model of Chave et al. (2014), which used to be the satisfactory model for carbon inventory evaluation in Africa (Victor 2015) based totally on climatic conditions, DBH of trees, and wooded area kind of the study region to decide biomass of tree species with a diameter of much less than 5cm.

According to Chave et al. (2014), incorporating country-specific wood density into the equation improves biomass calculation substantially. As a result, Ethiopia conducted a thorough investigation to identify the most acceptable wood density estimate for the country, and data on the basic wood density of 421 indigenous and exotic tree species found in Ethiopia were gathered. The species' overall average wood density is 0.612 g/cm3. This is similar to the global average and the value for tropical Africa. (Chave et al. 2009; Reyes et al. 1992; IPCC 2006). Accordingly, in this study, I have used data on wood density from the database.

$$ABG = 0.0673 \times (WD \times DBH^2 \times H)^{0.967} \qquad \text{eq.1}$$

Whereas;
AGB= Aboveground Biomass (in kg dry matter)
H= height of the tree (in m)
DBH = Breast Height Diameter (in cm)
WD = Density of wood (g/cm3)

(Brown 1997; Inventory 2004) allometric equations were used for trees/shrubs with a DBH of less than 5 cm and shrubs. For assessing woody carbon stocks, (Inventory 2004) established equations for all woody species in Ethiopia.

$$AGB = (1.4277 \times DSH + 0.0088 \times DSH^{3.0}) \qquad \text{eq.2}$$

Whereas;
AGB (Kg) = Above-ground biomass and
DSH (cm) = Diameter at stump height (1.3m)

50% of total tree and shrub biomass used to be assumed to be the carbon inventory when converting above-ground dry biomass to carbon. As a result, the carbon store of above-ground biomass in trees and shrubs was calculated as follows (Brown 2002):

$$AGTCS = AGTSDBM \times 0.5 \qquad \text{eq. 3}$$

Whereas;
AGTSCS = Above-ground trees and shrubs carbon stocks
AGTSDBM=Aboveground trees and dry shrub biomass

Calculation of dead woods carbon stock

For fallen deadwood, De Vries formula (de Vries 1986) has been applied, estimating log volume in m3 ha^{-1}. This formula requires the length of the transect (L) and the log diameter (d) at the point of intersection.

$$V = \frac{\pi^2 \Sigma d^2}{8L} \qquad \text{eq. 4}$$

Whereas;
V = volume per hectare of deadwood

d = log diameter at the point of intersection of the transect perpendicular to the axis of the log,
L = length of the transect.

There are two decomposition classes recorded for deadwood particles: sound and rotten. If the decomposition class was missing in the data, it was assumed that the deadwood piece was sound. Because a rotten wood contains less biomass than a sound wood, the wood density of deadwood is scaled down using lower wood densities than for standing trees, as follows:

Sound deadwood biomass = volume x 90% x default WD eq. 5
Rotten deadwoon biomass = volume x 50% x default WD eq. 6

The default wood density for the species is 0.612 g/cm3, similarly as for trees, since the overall average wood density for the species is 0.612 g/cm3.

Estimation of carbon stock and below-ground biomass of woody

To estimate the BGB carbon pool default values proposed by IPCC (2006) have been applied. For biomes, a root-to-shoot ratio of 27% is applied as suggested for tropical mountain sysstems (Singh et al. 1994).

BGB = AGB x 0.27 eq. 7
Whereas;
BGB = below-ground biomass.
AGB = above ground biomass

Carbon stocks estimation in grasses, herbs, and dead litter

Samples have been gathered from the specified sub-quadrats of every important quadrat to evaluate litter, herbs, and grasses (GHLs). Fresh samples have been weighed with a 0.1g accuracy withinside the field. A hundred g sub-samples from every important quadrat were labeled inside the box and introduced to the laboratory. The sub-samples have been utilized to calculate an oven-dry-to-wet mass ratio, which was then used to convert the complete moist mass to oven-dry mass (Pearson et al. 2013).

$$\text{GHL's} = \frac{W\,field}{A} \times \frac{\text{W sub, fresh} - \text{sample, dry}}{2!} \times \frac{1}{10000} \qquad \text{eq. 8}$$

Whereas;
GHL's (t. ha-1) = Biomass of grass, herbs, and leaf litter
Wfield A (Kg),= Weight of a freshly sampled destructively sparkling field sample of leaf litter, herbs, and grasses inside a place of measurement
A(ha) = The dimension of the collection place for leaf litter, herbs, and grasses

Wsub-sample, dry (g) = weight of an oven-dried sub-sample of leaf litter, grasses, and herbs delivered to the lab to decide moisture content and

Wsub-sample, Fresh (g)= Weight of a sparkling sub-sample of leaf litter, grasses and herbs that used to be taken to the lab to take a look at moisture content.

The following method was used to calculate carbon inventory in the litter and herb layer (Lasco et al. 2006):

C stored (Mg ha^{-1}) = total dry weight x C content eq. 9

The carbon stock (C content) of the dry biomass of herbs and litters accounted for 47% of the quadrat total dry biomass (IPCC 2007b).

Estimation of organic carbon reserves in the soil

Field damp soil becomes dried in a laboratory oven at 105°C for 12 hours to evaluate SOC, then re-weighted to measure dry bulk density and moisture content material. I applied the WB method for SOC measurement (Walkley & Black 1934). The mechanism of this method is to oxidize the organic carbon in the samples to CO_2 by excessive strong oxidant $K_2Cr_2O_7$ (using Ag_2SO_4 as a catalyst), $FeSO_4$ is then used to titrated the remnant $Cr_2O_7^{2-}$, and the organic carbon content is estimated by the $Cr_2O_7^{2-}$ volume consumed during the reaction (Visconti & de Paz 2021). A calibration coefficient of 1.10 was used for oxidation efficiency. 0.1–0.5 g soil sample is treated with 5 mL 0.8 M 1/6 $K_2Cr_2O_7$ standard solution, and then mixed with 5 ml concentrated H_2SO_4 (Chen et al. 2015). The mixture is heated at 170 –180°C for 5 minutes with an oil bath furnace and cooled at room temperature. The solution is transferred into a 250 ml Erlenm eyer flask to keep at 60 –80 ml, and unreacted $K_2Cr_2O_7$ is determined d by titrating with 0.2 M $FeSO_4$. Soil organic C (SOCMWB) content is calculated from the difference in $FeSO_4$ used between a blank and a soil solution (Chen et al. 2015).

The volume and bulk density of the soil had been used to compute the carbon inventory density of soil organic carbon (Pearson 2007).

$V = H \times \pi r^2$ eq. 10

Whereas:

V(cm3) = the volume of soil withinside the core sampler.

H(cm)= core sampler height which is five.

r (cm) =radius of the core sampler, which is 2.5.

A soil sample bulk density can also be estimated as follows:

$$BD = \frac{Wav, dry}{V}$$ eq. 11

Whereas;
BD = soil sample bulk density per quadrat
Wav, dry = average air-dry weight per quadrat of the soil sample,
V (cm^3) = soil sample volume in the core sampler

The carbon stock in soil was determined as follows:

SOC = BD x d x %C eq. 12

Whereas:
SOC (Mg ha^{-1}) = Soil Organic Carbon Stock per unit area
BD (g.cm-3), = Bulk Density of Soil
d = The depth to which the sample will be taken in total (30cm) and
%C = Carbon concentration (percentage) measured in the lab

Total Carbon Stocks Estimation

Finally, by including the biomass and carbon inventory of the different pools, the total woody biomass carbon inventory accumulation in all altitudinal gradients per quadrat and then per hectare used to be computed. As a result, the total dry biomass was calculated by using summing all biomass swimming pools for each quadrat and the converting the average of all quadrats to hectares the usage of the formula below:

Total biomass (Mg ha^{-1}) = AGTSDBM + BGTSDBM + HLDBM eq. 13

Whereas;
AGTSDBM (Mg ha^{-1}) = Dry biomass of above-ground trees and shrubs
BGTSDBM (Mg ha^{-1}) = Dry biomass from below-ground trees and shrubs
GHLDBM (Mg ha^{-1}) = Dry biomass of grasses, herbs, and litters

Using the same formulae as for whole biomass, the complete carbon stock per quadrat and per hectare had been calculated.

TCS (MG ha^{-1}) = (TAGC + TDWC + TBGC + C(GHL's) + SOC eq. 14

Whereas;
TCS (Mg ha^{-1}) = total carbon stock in total dry biomass
TAGC (Mg ha^{-1}) = Aboveground Tree Biomass Carbon Stock
TDWC (Mg ha^{-1}) = Dead Woods Carbon Stock
TBGC (Mg ha^{-1}) = Total Belowground Carbon Stock
C(GHL's) (Mg ha^{-1}) = Carbon Stock in Biomass of Grass, Herb and Litter
SOC (Mg ha^{-1}) = Soil Organic Carbon

Statistical Analyses

All data was once organized as fixed factors (altitude gradients) and random variables (sample plots) for each sampling site. The collected data of tree DBH, tree height, fresh and dry weight of litter, and soil sample were recorded, organized, and compiled in excel sheets. The carbon stock of tree vegetation, litter, and soil were calculated. The influence of altitude variation on carbon stock was tested using a one-way analysis of variance (ANOVA) at a 95% confidence interval, since each sample is taken from a normally distributed population, each sample has been drawn independently of the other samples and the variance of data in the different altitude is the same. The least significant difference test was performed to separate means by using a one-way analysis of variance (ANOVA) when the result showed the presence of significant differences along an altitude gradient on biomass carbon and SOC stock. Tables and Figures have been used to present the result of descriptive and inferential statistics of the find out about.

RESULTS AND DISCUSSION

Vegetation characteristics

A total of 52 vegetation species belonging to 33 genera and 24 families were collected in Gola natural vegetation were measured for the estimation of aboveground and belowground biomass carbon. The present study showed different tree populations among the stratum with a mean density of 114±21.54, 279±109.25, and 430.66±205.36 trees per hectare in LA UA, and MA respectively. In all altitudinal gradients, the study revealed that the top three dominant tree species such as *Acacia tortilis, Acacia bussei, and Grewia schweinfurthii* were the leading dominant tree species in all altitudinal gradients by their relative dominance.

This study found a high percentage of woody species in lower frequency groups and a low percentage of species in higher frequency classes. This indicates that generally, the study sites had heterogeneous species composition. MA had more species percent with higher frequency class which are 11.33% as compared to UA and LA that had only 5.5% and 4% of species respectively. While in the lower frequency class UA had species percent (58.33%) than LA (52%) and MA (50%). As a result, the study confirms that each altitudinal gradient has a significant degree of floristic heterogeneity. Among the total tree species, 8, 7, and 6% of species were observed only in MA, UA, and LA respectively, while 30% of tree species were observed in all altitudinal gradients (Figure 3).

Mean of species richness of species decreased non significantly from the MA site through the UA to the LA gradient shows an average number of species per sampling unit was also higher in the MA than in the UA and LA gradient in Gola natural vegetation. Several tree species with large DBH class were measured in MA than LA and UA gradient. However, large numbers of trees with lower DBH class (<5) were recorded in LA than MA and UA (Figure 4).

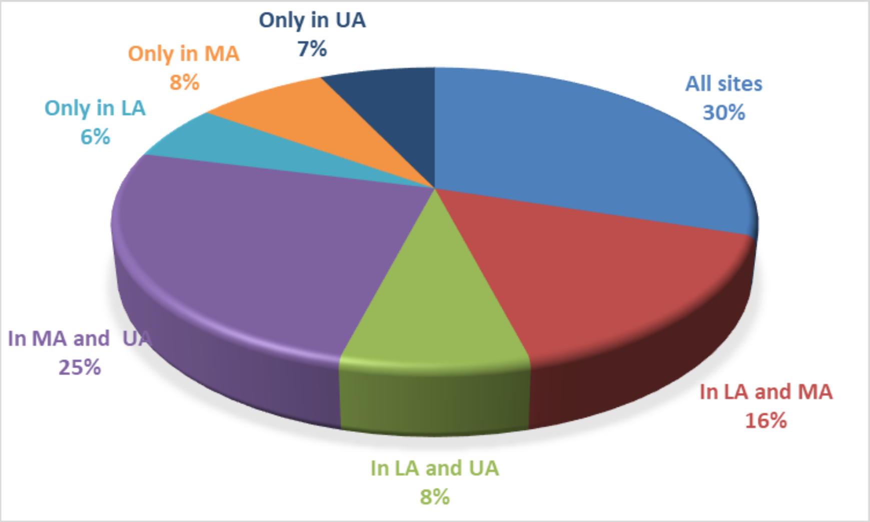

Figure 3. Percentages of species distribution across three altitudinal gradients (LA=lower altitude, MA=middle altitude land, and UA=upper altitude).

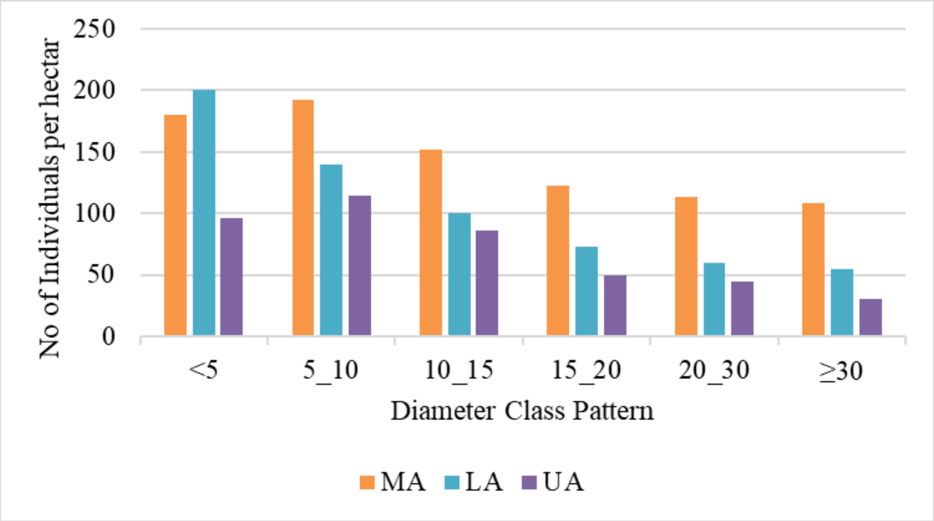

Figure 4. Diameter distribution of species in three altitudinal gradients (LA=lower altitude, MA=middle altitude land, and UA=upper altitude).

Carbon Stock Estimation

Above-ground and Below-ground Carbon Stocks

The result indicated that there is a significant difference in the amount of AGC in the three altitudinal gradients (Table 1). The maximum AGC was found in the MA gradient (85.7±19.2 Mg ha^{-1}). However, LA had s significantly lower AGC with 66.8 ±8.7. This finding demonstrated that the altitudinal gradient strongly influences AGC, which may be stated as a decrease in AGC as the altitude rises. The result is also in accordance with expectations (Gebrewahid et al. 2018). The presence of large trees increases in the MA, and their manipulation by legal and illicit cutting and grazing is rather modest, which is the basis for this trend. So, such large trees in MA resulted in the accumulationof larger AGC in UA. On the other hand, because few large individuals can account for the massive amount of carbon above and below ground, the presence of species characterized by giant individuals, and possibly due to favorable conditions for tree growth in middle altitudes. The explanation for the disparity in similar studies is likely to be the diverse vegetation in MA and biodiversity status, and other physical or climatical factors (temperature, soil, humidity, topography, and so on), biological component variations also contributed to the wide range of studies. This concept was also backed up by (Bikila et al. 2017).

The three altitudinal gradients had a significant difference in BGC. The BGC of UA was much higher than that of MA and LA.LA had also significantly lower BGC than MA and UA. However, there was no significant difference between MA and LA of BGC (Table 1). The reason for such differences was The disturbance and diameter class distribution of vegetation LA Local people have a considerable influence on the study area in LA, which is likely the source of the lower biomass at lower elevations through cultivable land expansion and the acquisition of critical forest products (Gebrewahid et al. 2018). The present study of AGC and BGC stock results was agreed with the earlier study of (Teshager et al. 2018).

Table 1. (Mean±SD) of AGC, BGC, DWC, and GHL in three altitudinal gradients.

Gradients	Carbon pool(Mg ha^{-1})			
	AGC	BGC	DWC	GHL
LA	66.8^{b} ±8.7	12.06^{b} ±2.6	0.00^{b} ±0.00	1.01^{a} ±0.45
MA	85.7^{b} ±19.2	14.93^{b} ±5.2	0.97^{a} ±0.25	1.22^{a} ±0.48
UA	71.3^{a} ±39.4	18.37^{a} ±7.8	1.26^{a} ±0.40	1.45^{a} ±0.34
P	0.042*	0.038*	0.06	0.15

AGC=above ground carbon, BGC= below ground carbon, DWC=deadwood carbon, GHL=grass herbs litter, LA=lower altitude, MA=middle altitude land, UA=upper altitude

Carbon Stock of Dead Wood

In the LA forest stratum, no standing and fallen dead woods were estimated, and more stumps were measured as compared with the MA and UA forest stratum. The absence of dead woods and stumps measured in LA gradients indicated the existence of human interference in LA is more widespread than the other two gradients, with local men and women collecting firewood. This enables the collecting of dead plants at LA more quickly. In MA and UA, dead woody plants were only found in 15 quadrants. The total mean carbon stock from the deadwood in this study was found at 0.74±0.54-Mg ha^{-1}. The mean of deadwood carbon was 0.97±0.25, 1.26±0.40Mg/ha^{-1} and 0 for MA, UA and LA respectively. In general, deadwood carbon differs insignificantly crosswise between the two altitudinal gradients as compared to other carbon pools (Table 1). The dead carbon stock variation among the three strata was happened due to the high human intervention in the LA gradient and densely populated tree species were surveyed in higher altitude gradient (Simegn & Soromessa 2015). A similar trend was observed and reported in Yegof mountain natural vegetation in North East, Ethiopia (Eshetu & Hailu 2020b).

Carbon Stocks in Herbs and Grass, Little

The mean GHL carbon stock The average GHL carbon stock of Gara Gola natural vegetation was about 1.21±0.45Mg ha^{-1}(Figure 3). LA, MA, and UA had mean GHL carbon stocks of 1.01±0.45, 1.22±0.48, and 1.40±0.34-Mg ha-1, respectively (Table 1). According to this result, UA had insignificantly higher GHL carbon than the other two locations. LA had a lower GHL carbon concentration than the other two, with MA as an intermediary between them (Table 1). The explanation for this variance could be due to unlawful grazing and grass cutting for cultural and religious holidays and the gathering of little for fuel in a lower altitudinal gradient than the others, causing it to have the lowest GHL carbon value (Eshetu & Hailu 2020). While there was little intervention in UA, it had a greater GHL carbon content than the others. According to (Zhang et al. 2008) the lack of a discernible pattern in litter carbon density in this study could be attributed to a decrease in litterfall amount and breakdown as altitude increases (Eshetu & Hailu 2020). According to (Bazezew et al. 2015; Chinasho et al. 2015; Simegn & Soromessa 2015; Abere et al. 2017) altitude variation have different carbon stock in GHL. Accordingly in this study, the GHL carbon inventory of the three altitudinal gradients did not change significantly (Figure 5).

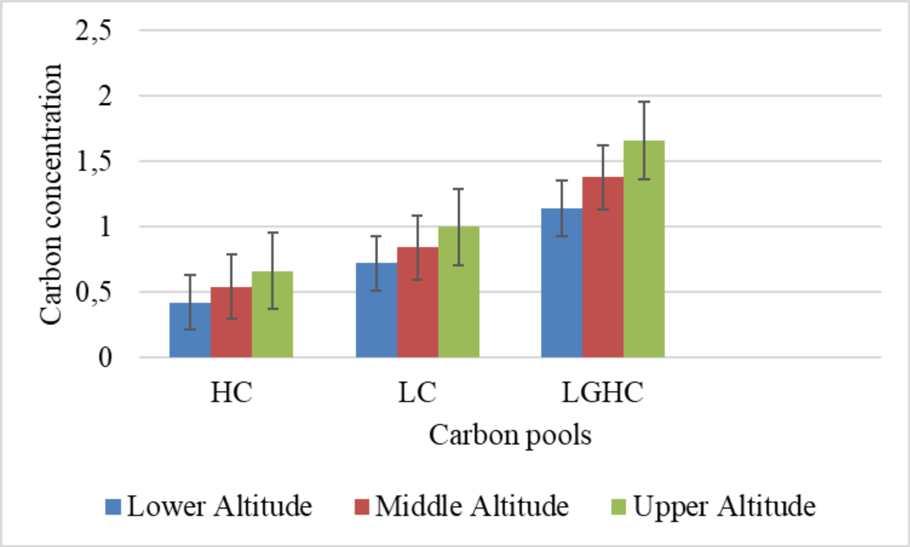

Figure 5. Herb and litter imply carbon stock distribution (HC=herbaceous plant carbon, LC=litter carbon, LGHC= little and herb carbon (Mg ha^{-1}).

Soil Organic Carbon

In the Gara Gola, the average bulk density of soil was calculated to be 0.94±0.8g.cm^{-3} (Table 2). Bulk density of soil across altitudinal gradient indicates that there is a significant mean difference between LA and UA, however, MA has a lower mean bulk density than LA and higher than UA insignificantly (Table 2). The carbon concentration of the soil in the research region significantly decreases with the increments of altitudes. As a result, in this investigation, the LA has significantly higher carbon concentration than MA and UA (Table 2). The SOC of the three altitudinal gradients differed signifi-

Table 2. Means (±SD) of soil bulk density. %Carbon and SOC across altitudinal gradients.

Soil parameter	Altitudinal class			Grant mean	P-value
	LA	MA	UA		
BD ($g.cm^{-3}$)	1.31^{a} ±0.9	0.82^{ab} ±0.4	0.73^{b}±0.2	0.94±0.8	0.013*
%C	3.23^{a} ±1.0	2.66^{b}±0.7	2.05^{b}±0.8	2.61±0.9	0.02*
SOC ($Mg\ ha^{-1}$)	140.4^{a} ±47.1	109.2^{b} ±30.1	97.3^{b} ±43.5	118.9±46.4	0.00***

BD=bulk density, %C= carbon percentage, LA=lower altitude, MA=middle altitude land, SOC=soil organic carbon, and UA=upper altitude.

cantly. SOC followed an inversely proportionate trend to the increasing altitude. As the altitude rises, SOC steadily decreases from lower to upper altitude. As a result, the LA had significantly the greatest SOC value followed by MA. However, the UA had a significantly lower amount of SOC than the (Table 2). Similarly, (Eshetu 2014; Kassahun et al. 2015; Tefera 2016) observed a decreasing pattern of SOC with increasing altitude. The cause for this decrease in SOC with altitude could be due to greater temperatures in LA facilities breakdown in lower altitude soils (Zhu et al. 2010). Organic matter generation on the soil may be aided by LA relatively intense sunlight radiation, which is less dominated by huge trees with a closed canopy. On the other hand, human and animal intervention is high in LA, which may lead to the accumulation of manure and other organic substances, resulting in rapid litter decomposition. According to (Chinasho et al. 2015; Kassahun et al. 2015; Tefera 2016), soil type, siltation as a result of soil erosion and topography, as well as leaching and runoff, may additionally produce a circumstance for such a trend, with high SOC at the decrease gradient and reducing as altitude increases. This could be due to changes in vegetation structure and diversity throughout the elevation gradient, resulting in different amounts of organic matter being accumulated due to high inputs from root biomass and above-ground biomass (Gebrewahid et al. 2018).

The mean soil bulk density of the study area increased with the depth of the soil. The mean value of bulk density from the top (0-10cm), middle (10-20cm), and lower (20- 30cm) soil profile was increased insignificantly (Table 3). On the other hand, the percentage of organic carbon significantly decreased with depth increment. The mean % organic carbon Upper profile has significantly higher than the subsequent depth. (Table 3). Similarly, SOC across the three soil profiles follows a reduction trend from top to lower soil with significant variation. The top (0-10cm depth) had the highest SOC and followed by the middle (10-20 cm depth) profile. While the lower soil profile (20-30 cm depth) had the lowest SOC value (Table 3). This means that a high amount of SOC tends to accumulate in the top layer of the soil. This trend is caused by higher organic matter accumulation and decomposition activity in topsoil as it highly interacts with the surrounding plant roots and environmental elements. (Bazezew et al. 2015; Bikila et al. 2017; Tessema et al. 2017) also confirmed such a trend in the top three soil profiles.

Table 3. Means (±SD) of BD, %C, and SOC across soil depth.

Depth (cm)	Parameter		
	BD (g.cm^{-3})	%C	SOC (Mg ha^{-1})
0-10cm	0.83±1.3^{a}	3.24^{a} ±1.0	131.2±44.6^{a}
10-20cm	0.92±0.3^{a}	2.39^{b} ±0.8	122.5±40^{ab}
20-30cm	1.08.4±0.5^{a}	2.21^{b} ±0.5	103 ±47.3^{b}
p-value	0.509	0.01*	0.04*
Grant mean	0.94±0.8	2.61±0.9	118.9±46.4

BD=bulk density, %C= carbon percentage, and SOC=soil organic carbon.

Total carbon stock

The total carbon density of the forest ecosystem was calculated by summing each carbon pool estimated in the study area. As a result, the present study revealed that the total mean carbon density of 621.94 Mgha^{-1} in the whole forest ecosystem. Biomass carbon and SOC estimation of the study area showed variation in carbon storage in different carbon pools. The highest carbon stock was estimated in SOC with 55.7% of the total forest ecosystem, whereas the lower carbon stock density was revealed in AGC, BGC, LHG, and DWC carbon pools with 35.90%, 7.2%, 0.59, and 0.35% respectively. In general, the belowground part contains a total of 64.3% and the above-ground share takes 35.9% (table 4). According to (Chinasho et al. 2015), more percentage of the total carbon store of tropical forest is located in the soil. Soils, on average, are the greatest carbon sinks in global terrestrial ecosystems, as they can hold three times as much carbon as vegetation (Schlesinger 1990). Most research suggests that soil organic carbon exceeds above-ground carbon (carbon in vegetation). This finding is also aligned with the investigation of (Girmay et al. 2008; Chinasho et al. 2015; Assaye & Asrat 2016; Bikila et al. 2017) also suggested that more than 90% of the total carbon stock was contributed from soil organic carbon in the wooded grassland.

The MA has the highest total carbon biomass, followed by the LA (Table 4). The lowest TC biomass was found at UA. This meant that the en-

Table 4. Mean summary of five carbon pools and total carbon in three altitude gradient.

Gradients	Carbon pool(Mg ha^{-1})					
	AGC	BGC	DWC	GHL	SOC	TC
LA	66.8b±8.7	12.06b ±2.6	0.00 b±0.00	1.01^{a} ±0.45	130.4^{a} ±47.1	209.8
MA	85.7 a±19.2	14.9 b ±5.2	0.97a ±0.25	1.22^{a} ±0.48	109.2^{b} ±30.1	211.4
UA	71.3b ±39.4	18.37a ±7.8	1.26a ±0.40	1.45^{a} ±0.34	97.3^{b} ±43.5	189.71
P	0.042*	0.038*	0.06	0.15	0.0*	

AGC=above ground carbon, BGC= below ground carbon, DWC=deadwood carbon, GHL=grass herbs litter, LA=lower altitude, MA=middle altitude land, SOC=soil organic carbon, TC=total carbon, and UA=upper altitude.

tire carbon stock pattern was humped, with the altitudinal gradient indicating the peak carbon stock at the intermediate altitude. As a result, in the majority of the carbon pools, the MA gradient behaved magnificently (de la Cruz-Amo et al. 2020). This may be due to the gradient high species diversity, favorable environmental circumstances, and soil characteristics. The reason for such variation may be due to the variation of vegetation structure in different mountain vegetation. Shrub species had a higher carbon proportion than large trees in some areas, especially in the MA class. This makes the variation in TC higher in MA than LA and UA class, which is relatively dominated by large trees, making the variation in TC much smaller than the other altitudinal gradients. Similarly, most findings in Ethiopia and overseas, such as (Muluken 2020; Matewos 2021; Tesema & Abera 2021) have previously reported a similar pattern (Abere et al. 2017).

CONCLUSION

The research was carried out in the natural vegetation of Gara Gola in Eastern Ethiopia. Gara Gola natural vegetation supplied about 578 Mg/ha of TC. The ABC, BGC, and SOC of the three altitudinal gradients, on the other hand, varied significantly. The UA gradient had the greatest AGC value, whereas the LA gradient had the lowest. This implies that AGC rises as altitude rises. A similar result was also got for BGC as it is derived from AGC indirectly. In contrast to AGC, the connection between SOC and altitude is inversely proportional. As a result, LA had the highest SOC, followed by MA. However, no significant differences were detected in the three altitudinal gradients for DWC and GHL carbon. In terms of DWC, only the two top altitudinal gradients were sampled. SOC contributed the most to the area's total carbon stock, followed by AGC. GHL and DWC, on the other hand, made a negligible contribution to total carbon. In most cases, the stock potential MA outperformed the others because it had greater total carbon stock values. This suggests that stronger law enforcement and management are needed in other areas, particularly in LA, heavily impacted by unlawful human and animal activities.

AUTHORS CONTRIBUTION

AH was the sole author for data curation; formal analysis; writing of original draft; writing review and editing, conceptualization; methodology; investigation, and authors read and approved the final manuscript.

ACKNOWLEDGMENTS

I want to acknowledge Haramaya University Herbaria for their helpful help with plant identification.

CONFLICT OF INTEREST

The author declares that he has no conflict of interests. The content is new and has not been published in any journal.

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