Hindawi
Applied and Environmental Soil Science
Volume 2022, Article ID 8414027, 10 pages
https://doi.org/10.1155/2022/8414027

Research Article

Carbon Stock Potential across Different Land Covers in Tropical Ecosystems of Damota Natural Vegetation, Eastern Ethiopia

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Received 28 December 2021; Revised 12 April 2022; Accepted 3 May 2022; Published 31 May 2022

Academic Editor: Claudio Cocozza

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The research was carried out in Damota kebele, in the Oromia regional state of Ethiopia, to examine the carbon sequestration potentials under three land covers (i.e., farmland (FL); bushland (BL), and woodland (WL)). In the three land covers, 60 squares of 20 m × 20 m, 5 m × 5 m, and 1 m × 1 m with six horizontal transect lines were employed to gather data on tree, shrub, herbaceous, and soil, respectively. To estimate organic carbon percentage, soil parameters were collected from three soil profiles (i.e., 0–10 cm, 10–20 cm, and 20–30 cm). The results showed that MA had significantly higher above-ground carbon (AGC) with 67.9 ± 11.4 Mg ha^{-1}, whereas BL had significantly higher below-ground carbon (BGC) stocks with 16.32 ± 5.5 Mg ha^{-1}, compared to other gradients. However, FL had the lowest AGC (53.2 ± 4.5 Mg ha^{-1}) and BGC (8.04 ± 2.9 Mg ha^{-1}). FL exhibited a significantly higher SOC value than the other two land covers followed by WL. The BL 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. WL had relatively higher TC than the other gradients. But FL had the lowest TC stock. Due to a high amount of human and animal interference in FL, weak security, and law enforcement measures, it has low TC. In conclusion, FL should embrace the better ecological, policy, and socioeconomic considerations than the other land covers.

1. Introduction

The amounts of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere are now widely recognized as the principal cause of global warming. Carbon in the atmosphere accumulates at a rate of 3.5 pentagrams each year. The majority of it is due to the combustion of fossil fuels and the conversion of tropical forests to agricultural areas [1]. Increased atmospheric concentrations of so-called greenhouse gases are assumed to be the primary cause of the increase in temperature of the earth's near-surface, air, and oceans in recent decades (GHGs). CO_2 is also a major GHG that contributes to global warming. As a result, climate change has had a significant impact on the world's micro and macroclimate, including biodiversity loss, deterioration of natural vegetation, and soil loss of vital natural ecosystems and their services, as well as indigenous knowledge [2].

According to the 1997 Kyoto Protocol, which is the first major international agreement on climate change, natural vegetation plays an important role in mitigating climate change by naturally collecting carbon from the atmosphere and therefore reducing the impact of CO_2 emissions [3, 4]. Natural vegetation potentially stores more than 80% of all above-ground carbon on the planet and 70% of all organic carbon in soil [5]. On the other side, deforestation and forest degradation account for 12–20% of annual greenhouse gas emissions, more than the total amount of emissions from all forms of transportation combined [6]. Carbon storage in forest biomass decreased by an estimated 0.5 Gt per year between 2005 and 2010, according to a recent assessment, mostly due to a decline in global forest acreage [7].

Changes in land use, particularly the conversion of a natural system to a controlled one, alter the carbon balance [8]. There is also a lot of evidence that agriculture has a detrimental influence on carbon stocks [9, 10]. Agriculture, on the other hand, is one of the land use strategies that emits and sequesters CO_2. It may lose soil organic matter as a result of heavy decomposition after soil plowing, the removal of above-ground biomass during harvest, and the significant soil erosion that these activities entail [10]. Agriculture, on the other hand, can serve as an important sink if proper land use and management practices are implemented [11, 12]. After fossil fuel burning, deforestation is the second most important producer of greenhouse gases (GHG) in the tropics [13]. Forest conversion to other land uses, such as agriculture, improves decomposition and carbon removal through harvest [14–16]. The conversion of arable land to forest land, on the other hand, resulted in a significant increase (50%) in soil carbon [17, 18].

Due to Ethiopia's lack of proper adaptive capacity, the effects of climate change are causing a slew of problems. 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, and it also has a limited adaptive ability [19]. Rainfall is becoming more unpredictable as the temperature rises, and the resulting decrease in precipitation is frequently harmful to Ethiopian agriculture [20]. Droughts, which are frequently followed by soil erosion, are also becoming further common [21] 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 fuel wood, 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 CRGE's mission is to save and restore forests for economic, environmental, and carbon-storage reasons. Ethiopia recognizes the importance of natural flora and forests in mitigating global climate change as a responsible member of the world community [22].

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 [23]. Furthermore, REDD+ has the greatest chance for mitigating climate change in a poor tropical country [24]. As a result, natural forest management and enhancing their carbon stock potential is 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 [25].

Several studies in natural vegetation areas, including Ethiopian rangelands [26–28], have been conducted in various parts of the nation, with a focus on carbon stock potential [26–28]. 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. Some of the earlier studies aimed to estimate the potential for biodiversity and carbon storage in vegetation without taking into account land cover such as farmland, woodland, and bushland; others only aimed at contrasting natural forests with different ecological gradient such as elevation, slope, and aspect [29]. Land cover, on the other hand, has a considerable impact on carbon stock potential [30]. More importantly, land cover is an important environmental factor, since it influences other nonliving and living factors such as soil, temperature, landscape, and flora [31]. Therefore, there is a significant demand for information on natural forest carbon store potential in different land cover categories. As a result, such baseline data will aid in proper land use plans for large watershed areas while taking land cover into consideration.

The significance of this research is to give baseline information on vegetation's potential to mitigate climate change and its impact if existing land use is changed to policymakers, local experts, community members, and researchers. 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) stock would increase within increasing vegetation diversity decreasing soil depth [32]. The main goal of this study was to assess the carbon store capacity of Damota natural vegetation in eastern Ethiopia across different land covers.

2. Materials and Methods

2.1. Area Location. The research was conducted from 2020 to 2021 in Damota natural vegetation (DNV), East Hararghe, situated between 09° 23′ 30″ and 09°27′ 00″ N and 41° 59′ 00″ and 42° 06′ 30″ E (Figure 1). The area represents eastern Ethiopia's tropical vegetation and spans 1692 acres, with elevations ranging from 2032 to 2391 meters above the mean sea level. The climate is defined by the district agroclimatic zones. The mean annual temperature is about 21.9 C, ranging from mean minimum and maximum temperatures of 12.80°C and 31.10°C, respectively. The mean annual rainfall is 1093.8 mm $year^{-1}$, with low variation from year to year, ranging from 1011.2 mm to 1154.9 mm $year^{-1}$.

Acacia tortilis, *Acacia seyal, Acacia brevispica, Acacia nilotica, Acacia etbaica, Euphorbia adjurana,* and *Acacia bussei* species are the main components in the tropical forest of DNV. Flat to gentle slopes dominate the topography, accounting for around 85% of the entire area, while intricate valleys and deep gorges make up the remaining 15%.

2.2. Study Site Sampling. The study sites were selected using stratified purposive sampling. Three different land cover categories (i.e., treatments) were identified, namely, farmland, woodland, and bushland. The description of the land cover classes was based on the standard classes defined by the US Geological Survey [33]. The study area border was delineated using the global positioning system (GPS). Farmland, woodland, and bushland were used to classify the study location. Systematic sampling of transect by land cover categories was conducted to establish relatively homogeneous units and obtain accurate data from the fieldwork. The study region had a range of land cover, which aided in determining land cover variations as a predictor variable for carbon stock collection and measurement design.

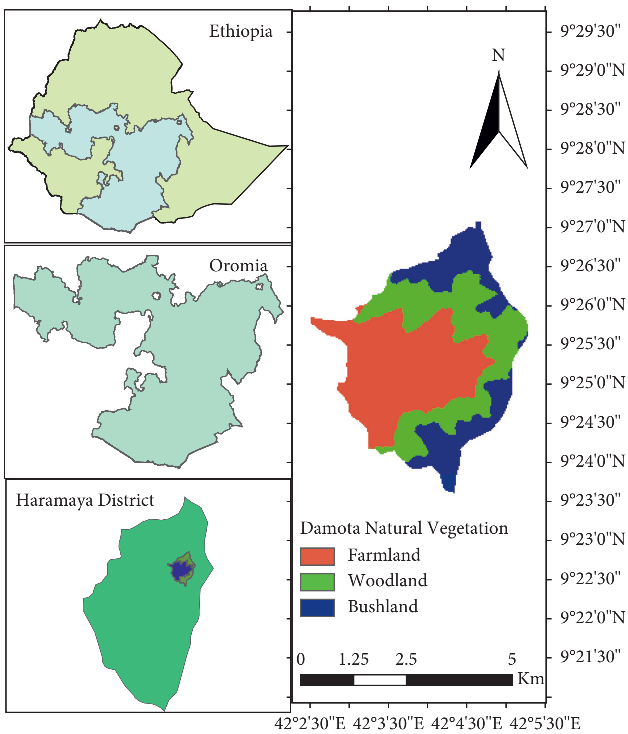

Figure 1: Damota natural vegetation map.

2.2.1. Woody Species Sampling. A total of 60 squares quadrat (20 quadrats within each land cover) along six transects lines (two transects in three land covers) were obtained at a distance of 100 meters interval systematically. Nested plots were established for sampling and gathering separate size classes of growth form. The methods included laying out 40 m^2 (20 m × 20 m) nested plots for trees and shrubs. A 1 m × 1 m plot was used at the four corners and central locations of each main 20 m × 20 m quadrat to sample herbaceous vegetation, litter, and soil sampling for SOC determination. Pieces of 1 m^2 square made of thin wood timber were used to sample GHL and soil made by the local operator.

All herbaceous vegetation in every quadrat, which includes litters, were clipped at the ground level and weighed, and a 100 g composite pattern was transferred to the laboratory, where moisture content, dry biomass, and oven-dry mass were determined by suitable laboratory methods [34, 35] to estimate the amount of carbon stocked using GHL. Litter is defined as all nonliving biomass larger than the SOM limit (recommended 2 mm) that is dead and in numerous stages of decay above organic soil [36]. Scientific nomenclature was carried out using published literature, i.e., "Flora of Ethiopia and Eritrea" [37], Useful Trees and Shrubs of Ethiopia [38], and Natural Database for Africa (NDA) Version 2 [39]. For some species that we were unable to identify directly in the field, plant specimens were collected, pressed, dried, and identified in the herbarium.

A calibrated soil auger was used to collect soil samples up to 30 cm in depth (between 0 and 10, 10 and 20, and 20 and 30 cm) [36]. A soil composite was obtained by mixing soil from 5 subquadrats of every primary quadrat to quantify organic carbon. Equal weights of every sample from all the major quadrants (400 m^2) alongside a single transect had been mixed and blended collectively in accordance to their depth, air dried, and processed via a 2 mm sieve to separate particles and gravel to form one soil sample for every soil depth alongside a transect. As a result, a total of 24 composite soil samples (3 land covers × 2 transects × 3 soil depth) were produced from a total of 60 sample squares.

The bulk density was determined using the core technique [40]. Soil bulk density determination has been performed in the center of every transect relying on their soil profile, lead-off from floor soil with a 5 cm depth and 2.5 cm diameter core sampler gently pushed into the soil to avoid compaction [35]. All samples were tagged with the square to which they belonged and taken to the lab for bulk density examination.

2.3. Carbon Stocks Estimation

2.3.1. Carbon Stock and Above-Ground Biomass. Chave et al. [41] developed allometric equations that were used to generate a reliable estimate of forest carbon reserves for AGB. The model was found to be accurate across a wide range of tropical vegetation types, with no noticeable effect from geography or environmental conditions [41, 42]. According to Henry [43], equations that incorporate several tree measurements improve the accuracy of forest biomass calculation. As a result, many studies used Chave et al.' [41] model, which appeared to be the best model for carbon inventory evaluation in Africa, based entirely on climatic conditions, DBH of trees, and wooded area type of the study region to determine biomass of tree species with a diameter of less than 5 cm [42].

$$\mathrm{AGB} = 0.0673 \times (\rho\ D2H)^{0.976}, \tag{1}$$

where AGB (kg/tree) is the above-ground biomass, H (m) stands for the tree's height, D (cm) is the breast height (1.3 m) diameter, and ρ (t.m^{-3}) is the density of wood.

Allometric equations were used for trees/shrubs with DBH of less than 5 cm and shrubs. For assessing woody carbon stocks, [44] established equations for all woody species in Ethiopia.

$$\mathrm{AGB} = (1.4277x\mathrm{DSH} + 0.0088x\,(\mathrm{DSH}\exp 3.0), \tag{2}$$

where AGB (Kg) is the above-ground biomass and DSH (cm) is the diameter at stump height (1.3 m).

50% of total tree and shrub biomass is generally 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 [45]:

$$\mathrm{AGTSCS} = \mathrm{AGTSDBM}x0.5, \tag{3}$$

where AGTSCS is the above-ground trees and shrubs carbon stocks and AGTSDBM is the above-ground trees and dry shrub biomass.

2.3.2. Calculation of Dead Woods Carbon Stock. Similarly, the allometric equation of above-ground biomass was used to evaluate the biomass of deadwood standing with branches. Because the deadwood standing has no leaves, conifer species had 5-6% subtracted, whereas broadleaved species had 2-3% eliminated [46].

$$\mathrm{BSDW} = 0.0673 \times (\rho\ D2H)^{0.976} - 5.5\%\,(2.5\%), \qquad (4)$$

where BSDW is the biomass of standing dead wood, H (m) is the tree's height, D (cm) is the breast height (1.3 m) diameter, and ρ (t.m^{-3}) is the density of wood.

2.3.3. Estimation of Carbon Stock and Below-Ground Biomass of Wood. The below-ground biomass (BGB) was computed using 20% of the above-ground biomass (AGB) [47]. By multiplying by 0.5 fractions of the default value, the biomass of stock density was transformed to carbon stock density [45].

$$\mathrm{BGB} = \mathrm{AGB} \times 0.2, \qquad (5)$$

where BGB stands for the below-ground biomass and AGB is the dry biomass of above-ground trees and shrubs.

2.3.4. Carbon Stocks Estimation in Grasses, Herbs, and Dead Litter. To analyze litter, herbs, and grasses (LHG), samples were collected from the required subsquares of each quadrat. Inside the field, fresh samples were weighed with a 0.1 g precision. Inside the box, 100 g subsamples from each relevant quadrat were labeled and brought to the laboratory. The subsamples 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, according to [46]

$$\mathrm{GHL's} = \frac{W\ \mathrm{field}}{A} \times \frac{W\ \mathrm{sub, fresh} - \mathrm{sample, dry}}{2!} \times \frac{1}{10000}, \qquad (6)$$

where GHL's (t. ha^{-1}) is the biomass of grass, herbs, and leaf litter, W_{field}/A (Kg) is the weight of a freshly sampled destructively sparkling field sample of leaf litter, herbs, and grasses inside the place of measurement, A (ha) is the dimension of the collection place for leaf litter, herbs, and grasses, Wsubsample, dry (g) is the weight of an oven-dried subsample of leaf litter, grasses, and herbs delivered to the lab to measure moisture content, and Wsubsample, fresh (g) is the weight of a sparkling subsample of leaf litter, grasses, and herbs taken to the lab to measure moisture content.

The following method was used to calculate carbon inventory in the litter and herb layer [48]:

$$C\,\mathrm{stored}\left(\mathrm{Mg\,ha^{-1}}\right) = \mathrm{Total\ dry\ weight} \times C\ \mathrm{content}. \qquad (7)$$

The carbon stock © content of the dry biomass of herbs and litters accounted for 47% of the square total dry biomass [3].

2.3.5. Estimation of Soil Organic Carbon Pool. The difference between soil total C (TSC) and soil inorganic C (SIC) concentrations, measured independently, can be used to estimate SOC content indirectly [49]. Using an inorganic carbon analyzer, this method measures SIC volumetrically [50]. STC was determined by dry combustion with a CNS analyzer at 1150°C combustion temperature and 850°C reduction temperature.

To determine SOC, field damp soil was dried for 12 hours at 105°C in a laboratory oven and then reweighted to determine dry bulk density and moisture content. We applied the WB method for SOC measurement [51]. The method consists in oxidizing the organic carbon to CO_2 by an excess of the strong oxidant $K_2Cr_2O_7$ (using Ag_2SO_4 as a catalyst), $FeSO_4$ is then used to titrate the remnant $Cr_2O\ _7^{2-}$, and the organic carbon content is estimated by the $Cr_2O_7^{2-}$ volume consumed during the reaction [52]. 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 [50]. 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 Erlenmeyer flask to keep at 60–80 ml, and unreacted $K_2Cr_2O_7$ is determined by titrating with 0.2 M $FeSO_4$. The soil organic C (SOC) content is calculated as the difference in $FeSO_4$ used between a blank and a soil solution [50].

The volume and bulk density of the soil had been used to compute the carbon inventory density of soil organic carbon [53].

$$V = H \times \pi r^2, \qquad (8)$$

where V (cm^3) is the volume of soil withinside the core sampler, H (cm) is the core sampler height which is 5, r (cm) is the radius of the core sampler, which is 2.5.

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

$$\mathrm{BD} = \frac{\mathrm{Wav, dry}}{V}, \qquad (9)$$

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

The carbon stock in soil was determined as follows:

$$\mathrm{SOC} = \mathrm{BD} \times d \times \%C, \qquad (10)$$

where SOC (Mg ha^{-1}) is the soil organic carbon stock per unit area, BD (g.cm−3) is the bulk density of soil, d is the depth to which the sample will be taken in total (30 cm), and $\%C$ is the carbon concentration (percentage) measured in the lab.

2.3.6. Total Carbon Stocks Estimation. The total woody biomass carbon inventory buildup in all land covers per square and then per hectare was calculated by combining the biomass and carbon inventories of the various pools. As a consequence, the total dry biomass was estimated by adding all biomass swimming pools for each square and using the method below to convert the average of all squares to hectare:

$$\text{Total biomass}\left(\frac{\text{Mg}}{\text{ha}}\right) = \text{AG TSDBM} + \text{BG TSDBM} + \text{HL DBM}, \quad (11)$$

where AGTSDBM (Mg ha^{-1}) is the dry biomass of above-ground trees and shrubs, BGTSDBM (Mg ha^{-1}) is the dry biomass from below-ground trees and shrubs, and GHLDBM (Mg ha^{-1}) is the dry biomass of grasses, herbs, and litters.

Using the same formula as for whole biomass, the complete carbon stock per square and per hectare was calculated.

$$\text{TCS}\left(\frac{\text{Mg}}{\text{ha}}\right) = (\text{TAGC} + \text{TDWC} + \text{TBGC} + C(\text{GHL's}) + \text{SOC}), \quad (12)$$

where TCS (Mg ha^{-1}) is the total carbon stock in total dry biomass, TAGC (Mg ha^{-1}) is the above-ground tree biomass carbon stock, TDWC (Mg ha^{-1}), dead woods carbon stock, TBGC (Mg ha^{-1}) is the total below-ground carbon stock, C(GHL's) (Mg ha^{-1}) is the carbon stock in biomass of grass, herb, and litter, and SOC (Mg ha^{-1}) is the soil organic carbon.

2.4. Statistical Analyses. For each sampling site, all data were organized as fixed factors (land covers) and random variables (sample plots). The tree DBH, tree height, fresh and dried weight of litter, and soil sample data were gathered, categorized, and compiled in excel sheets. Tree vegetation, litter, and soil carbon stocks were computed. Because each sample was taken from a normally distributed population, each sample was drawn independently of the other samples, and the variance of data in the different land covers was the same, and the influence of land cover variation on biomass carbon and SOC stock was tested using a one-way analysis of variance (ANOVA) at a 95% confidence interval.

3. Results and Discussion

3.1. Vegetation Characteristics. In Damota natural vegetation, 47 plant species from 32 genera and 21 families were collected and measured to estimate above-ground and below-ground biomass carbon. The dominant family was Fabaceae, which had 9 species. The present study showed different tree populations among the stratum with a mean density of 98 ± 12.97, 183 ± 63.47, and 298.38 ± 89.43 trees per hectare in FL, BL, and WL, respectively. In all land cover categories, the study revealed that the top three tree species, i.e., *Acacia brevispica, Acacia etbaica*, and *Acacia tortilis*, were the dominant tree species in all land cover categories.

A significant percentage of woody species was discovered in lower frequency categories, whereas a low percentage of species was identified in higher frequency classes, according to this study. This suggests that the species composition of the study sites was generally heterogeneous. WL had a higher percentage of species with a higher frequency class (17.28%) than BL and FL, which had just 11.34% and 9% of species, respectively. In the lower frequency class, BL had a higher species percent (63.22%) than FL (57.34%) and WL (45.87%). As a result, the study confirmed that each land cover categories have a significant degree of floristic heterogeneity. Among the total tree species, 10, 8, and 5% of species were observed only in WL, BL, and FL, respectively, while 25% of tree species was observed in all land cover categories (Figure 2).

Mean of species richness of species decreased nonsignificantly from the WL site through BL to FL categories, which showed that the average number of species per sampling unit was also higher in WL than in the BL and FL covers. Several tree species with large DBH class were measured in WL than in BL and FL categories. However, large numbers of trees with lower DBH class (<10) were recorded in BL than WL and FL (Figure 3).

3.2. Carbon Stock Estimation

3.2.1. Above-Ground and Below-Ground Carbon Stocks. The amount of AGC in the three land cover categories differed significantly, according to the findings (Table 1). The WL categories had the highest AGC (67.9 11.4% Mg ha^{-1}). However, FL had a significantly lower AGC, i.e., 53.2 ± 4.5 Mg ha^{-1}. This discovery indicated that the land cover categories have a significant impact on AGC, resulting in a drop in AGC as FL. The outcome was also in line with predictions [54]. Large trees are becoming more common in WL, and their manipulation by legal and illegal cutting and grazing is very limited, which is the foundation for this trend. So, such large trees in WL resulted in the accumulation of larger AGC in WL. The various vegetation in WL and biodiversity status, as well as other physical or climatic parameters (temperature, soil, humidity, and topography) and biological component changes, are likely to explain the discrepancy in similar research [55].

In terms of BGC, the three land cover categories differed significantly. BL had a substantially higher BGC than WL and FL. However, in terms of BGC, there was no significant difference between WL and FL (Table 1). The disturbance and diameter class distribution of vegetation FL were the causes of these disparities. Local people have a significant impact on the study region in FL, which is likely the source of the reduced biomass at farmland due to the extension of cultivable land and the purchase of key forest products [56]. The current examination of AGC and BGC equities confirms the findings of a previous study [26].

3.2.2. Carbon Stock of Dead Wood. In comparison to WL and BL land cover strata, the FL categories stratum had less standing and fallen dead woods, and more stumps were measured. FL gradients had lower values of dead woods and stumps, indicating that human intervention is more widespread in FL than in the other two gradients, with local men and women harvesting firewood and clear vegetation for cultivation. The total mean carbon stock from the deadwood in this study was found to be 0.71 ± 0.53 Mg ha^{-1}. The mean of deadwood carbon was 0.85 ± 0.63, 0.78 ± 0.47, and 0.52 ± 0.32 Mg/ha^{-1} for BL, WL, and FL, respectively. In

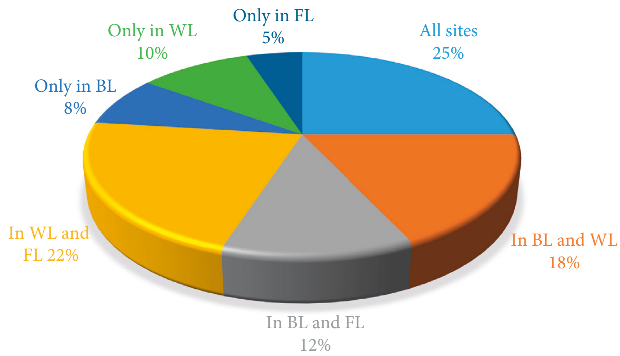

FIGURE 2: Percentages of species distribution across three land cover categories (BL, bushland; FL, farmland; WL, woodland).

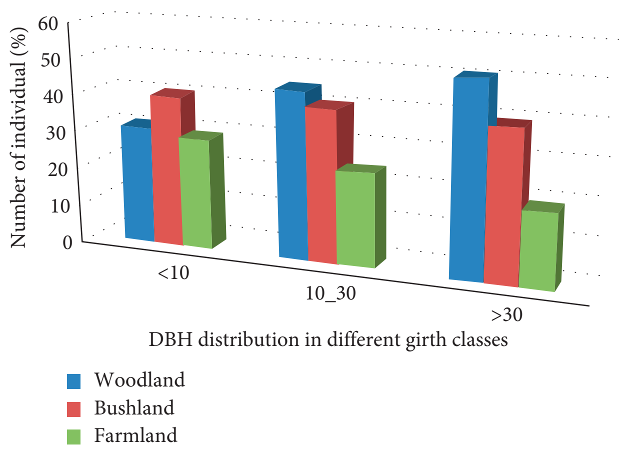

FIGURE 3: Diameter distribution of species in three altitudinal gradients.

TABLE 1: Mean ± SD of AGC, BGC, DWC, and GHL in land covers.

Gradients	Carbon pool (Mg ha^{-1})			
	AGC	BGC	DWC	GHL
FL	$53.2^{b} \pm 4.5$	$8.04^{b} \pm 2.9$	$0.52^{a} \pm 0.32$	$1.13^{a} \pm 0.36$
WL	$67.9^{a} \pm 11.4$	$10.12^{b} \pm 3.8$	$0.78^{a} \pm 0.47$	$1.57^{a} \pm 0.65$
BL	$56.4^{b} \pm 9.6$	$16.32^{a} \pm 5.5$	$0.85^{a} \pm 0.63$	$1.72^{a} \pm 0.84$
P	0.03*	0.024*	0.06	0.15

AGC, above-ground carbon; BGC, below-ground carbon; DWC, deadwood carbon; GHL, grass herbs litter; BL, bushland; FL, farmland; WL, woodland. Different letters indicate significant differences. *, **, and *** indicate significance at 5, 1, and 0.1% significance levels, respectively.

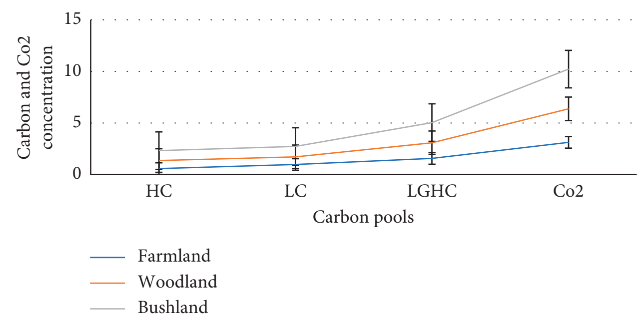

FIGURE 4: Herb and litter imply carbon stock distribution (HC, herbaceous plant carbon; LC, litter carbon; LGHC, little and herb carbon; CO_2, carbon dioxide equal GHL) (Mg ha^{-1}).

general, deadwood carbon differed insignificantly crosswise the three land cover categories as compared to other carbon pools (Table 1). The difference in dead carbon stock across the three land cover categories was attributed to the high level of human intervention in the FL categories, whereas densely populated tree species were surveyed in WL [57].

3.2.3. Carbon Stocks in Herbs and Grass Litter. Damota natural vegetation has an average GHL carbon stock of 1.47 ± 0.69 Mg ha^{-1}. BL, WL, and FL had mean GHL carbon stocks of 1.72 ± 0.84, 1.57 ± 0.65, and 1.13 ± 0.36 Mg ha^{-1}, respectively (Table 1). According to this finding, BL had a somewhat greater GHL carbon content than the other two sites. FL exhibited a lower concentration of GHL carbon than the other two, with WL acting as an intermediate between them (Table 1). The lowest GHL carbon value could be attributable to illegal grazing and grass cutting for cultural and religious holidays, as well as the collection of litter for fuel in FL categories [58]. While there was little intervention in BL, it had a greater GHL carbon content than the others. According to Gebresamuel et al. [59], land cover categories have different carbon stocks in GHL. According to this study, the GHL carbon inventory of the three land cover categories did not change significantly (Figure 4).

3.2.4. Soil Organic Carbon. The average bulk density of soil in the Damota was calculated to be 0.76 ± 0.4 g.cm^{-3} (Table 2). Bulk density of soil across land cover categories indicated that there is a significant mean difference between FL and BL; however, MA has a lower mean bulk density than FL and higher than BL insignificantly (Table 2). Across land cover categories, the carbon concentration of the soil in the research site reduces significantly from FL to BL. As a result, the carbon content of FL is much higher than that of WL and BL (Table 2). The three land cover categories had significantly different SOCs. SOC steadily diminishes as from FL to BL. As a result, FL had the highest SOC value, followed by WL. The BL, on the other hand, had significantly less SOC (Table 2). Similarly, [60] observed a decreasing pattern of SOC across different land covers. The cause for this decrease in SOC with carbon stock across land cover in Ethiopia due to greater human activities and high rate of microbial decomposition in FL facilities breakdown in FL soils [61]. Organic matter production on the soil could be encouraged by farm activities comparatively bright sunlight, which is less controlled by massive trees with a closed canopy. Human and animal intervention, on the other hand, is common in FL, which may result in the accumulation of manure and other organic material, causing rapid litter decomposition. This could be due to changes in vegetation structure and diversity throughout the land covers, resulting in different amounts of organic matter being accumulated due to high inputs from root biomass and above-ground biomass [62].

The study area's mean soil bulk density increased as the soil depth increased. Bulk density increased insignificantly from top (0–10 cm), middle (10–20 cm), and bottom (20–30 cm) soil depth (Table 3). The percentage of organic carbon, on the other hand, decreased significantly with

Table 2: Means (±SD) of soil bulk density, %carbon, and SOC land covers.

Soil parameter	Altitudinal class			Grant mean	P value
	FL	WL	BL		
BD ($g.cm^{-3}$)	$1.08^{a} \pm 0.4$	$0.63^{ab} \pm 0.2$	$0.58^{b} \pm 0.3$	0.76 ± 0.4	0.02^{*}
%C	$2.14^{a} \pm 0.7$	$1.94^{b} \pm 0.4$	$1.56^{b} \pm 0.6$	1.88 ± 0.6	0.00^{*}
SOC ($Mg\ ha^{-1}$)	$80.6^{a} \pm 18.3$	$71.6^{b} \pm 11.5$	$65.8^{b} \pm 9.7$	72.6 ± 35.7	0.02^{***}

BD, bulk density; %C, carbon percentage; BL, bushland; FL, farmland; SOC, soil organic carbon; WL, woodland. Different letters indicate significant differences. *, **, and *** indicate significance at 5, 1, and 0.1% significance levels, respectively.

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

Depth	Parameter		
	BD ($g.cm^{-3}$)	%C	SOC ($Mg\ ha^{-1}$)
0–10 cm	0.72 ± 0.6^{a}	$2.37^{a} \pm 0.92$	86.3 ± 12.8^{a}
10–20 cm	0.852 ± 0.7^{a}	$2.00^{b} \pm 0.65$	70.7 ± 9.08^{ab}
20–30 cm	$0.97.6 \pm 0.8^{a}$	$1.25^{b} \pm 0.81$	62.8 ± 11.61^{b}
P value	0.60	0.02^{*}	0.03^{*}
Grant mean	0.76 ± 0.4	1.88 ± 0.6	72.6 ± 35.7

BD, bulk density; %C, carbon percentage; SOC, soil organic carbon. Different letters indicate significant differences. * indicates significance at 5% significance level.

Table 4: Mean summary of five carbon pools and total carbon in three land covers.

Gradients	Carbon pool ($Mg\ ha^{-1}$)					
	AGC	BGC	DWC	GHL	SOC	TC
FL	$53.2^{b} \pm 4.5$	$8.04^{b} \pm 2.9$	$0.52^{a} \pm 0.32$	$1.13^{a} \pm 0.36$	$80.6^{a} \pm 18.3$	143.49
WL	$67.9^{a} \pm 11.4$	$10.12^{b} \pm 3.8$	$0.78^{a} \pm 0.47$	$1.57^{a} \pm 0.65$	$71.6^{b} \pm 11.5$	151.97
BL	$56.4^{b} \pm 9.6$	$16.32^{a} \pm 5.5$	$0.85^{a} \pm 0.63$	$1.72^{a} \pm 0.84$	$65.8^{b} \pm 9.7$	141.09
P	0.036^{*}	0.024^{*}	0.06	0.15	0.027^{*}	

AGC, above-ground carbon; BGC, below-ground carbon; DWC, deadwood carbon; GHL, grass herbs litter; BL, bushland; FL, farmland; SOC, soil organic carbon; TC, total carbon; WL, woodland.

depth. In the upper profile, the mean percent organic carbon is much higher than at lower depths (Table 3). Similarly, SOC follows a decreasing pattern from top to bottom soil with significant variation across the three soil profiles. The maximum SOC value was found in the top (0–10 cm depth) profile, followed by the medium (10–20 cm depth) profile, and the lowest SOC value was found in the lower soil profile (20–30 cm depth) (Table 3). This signifies that a large amount of SOC accumulates in the soil's top layer. Higher organic matter accumulation and decomposition activity in topsoil, which interacts heavily with surrounding plant roots and environmental elements [27, 28, 63], is the cause of this trend, which is also confirmed by the trend in the top three soil profiles [27, 28, 63].

3.2.5. Total Carbon Stock. Summing each carbon pool assessed in the research region provided the total carbon density of the tropical ecosystem. As a result, the total mean carbon density throughout the entire study site was found to be 436.55 $Mg\ ha^{-1}$. 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 51.42% of the total study site, whereas the lower carbon stock density was revealed in AGC, BGC, LHG, and DWC carbon pools with 40.65%, 7.89%, 4.24, and 2.15%, respectively. In general, the below-ground part contains a total of 59.31% and the above-ground 40.69% (Table 4). According to Chinasho et al. [29], the soil contains a greater proportion of the total carbon store in tropical ecosystems. Soils, on average, are the most significant carbon sinks in worldwide terrestrial ecosystems, holding three times as much carbon than vegetation [64]. According to most studies, soil organic carbon outnumbers above-ground carbon (carbon in vegetation). This finding is also consistent with the findings of [14, 28, 29, 65], who found that soil organic carbon provided more than 90% of the total carbon stock in the forested grassland.

The WL has the highest total carbon biomass, followed by FL (Table 4). The lowest TC biomass was found at BL. This means that the entire carbon stock pattern was humped, with the land cover indicating the peak carbon stock at the woodland categories. As a result, the WL category performed admirably in the vast majority of carbon pools [66]. This may be due to the WL high species diversity, favorable environmental circumstances, and soil characteristics. The reason for such variations may be due to the variation in different mountain vegetation. Shrub species had a higher tcarbon proportion than large trees in some areas, especially in the WL class. This makes the variation in TC higher in WL than FL and BL categories, which is relatively dominated by large trees and shrubs making the variation in TC higher than the other land covers. Most Ethiopian and international findings [66–68] have already reported a similar tendency [30].

4. Conclusion

The findings of this study demonstrated the influence of different land cover categories on carbon stock. Further research in similar settings is needed to confirm and validate the findings. The findings suggest that conservation efforts should be focused on protected area-based biodiversity conservation with ecological networks, which could improve both functional biodiversity and ecosystem services related to carbon storage, such as climate change mitigation. We evaluated above-ground carbon stocks in tropical deciduous woodland ecosystems under a variety of land cover changes in this work, taking into account the ecosystem's spatial and temporal heterogeneity. The asymmetric variance of natural resources in the measurement of ecosystem carbon stocks is highlighted by the variation in carbon storage with land cover types. Natural ecosystems, in comparison to cultivated land, conserved significant amounts of carbon, according to the findings. The findings of this study could lead to the start of a large-scale study on above-ground carbon stocks stored in soils and vegetation in Ethiopia's various land cover ecosystems to better understand the relationship between structural and functional biodiversities and ecosystem services linked to carbon storage for better ecosystem conservation and management. This suggests that stronger law enforcement and management are needed in other areas, particularly in FL, heavily impacted by unlawful human and animal activities.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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