Journal of Agroforestry and Environment

Volume 18, Issue 2, 2025

Journal DOI: https://doi.org/10.55706/jae
Journal homepage: www.jagroforenviron.com

Carbon Stock Estimation and Human Disturbances in Dry Afromontane Forest Northwestern Ethiopia: Implications for Climate Change Mitigation

Anteneh Shibabaw Atalay

Forest and Rangeland Plant Biodiversity Research, Ethiopian Biodiversity Institute, Addis Ababa, Ethiopia

Correspondence: Anteneh Shibabaw Atalay, E-mail: antenehhshibabaw@gmail.com, Mobile phone: +251922556268

Received: 26/08/2025

Accepted: 4/11/2025

Available online: 14/11/2025

Abstract: Climate change is the most serious global environmental issue caused by excessive atmospheric greenhouse gases, primarily carbon dioxide. This study examined the carbon stock potential and the effects of human disturbances on carbon storage in aboveground biomass, belowground biomass, litter biomass, and soil. Forty plots with 20 m x 20 m systematic sampling techniques were laid out to measure the height and DBH of all woody plant species with DBH ≥ 5 cm. Additionally, 200 sub-plots, each measuring 1 m x 1 m, were established within the major plots to gather litter and soil samples. The results indicated that the mean total carbon stock and CO_2 equivalent in the Embuli Tahisasdar forest were 172.47 t ha^{-1} and 633.38 t ha^{-1}, respectively. The estimated average carbon stock in the aboveground, belowground, litter, and soil organic carbon was 43.22 ± 74.13 t ha^{-1}, 11.24 ± 19.27 t ha^{-1}, 2.49 ± 0.86 t ha^{-1}, and 115.52 ± 118.96 t ha^{-1}, respectively. The significant variations in carbon stock were observed across different altitudinal and topographic aspects for aboveground biomass, belowground biomass, litter, and soil ($P<0.05$). In conclusion, the study area serves as a significant carbon sink, contributing positively to the reduction of greenhouse gas emissions and it has the potential to generate carbon credits, offering financial benefits to the community while supporting biodiversity conservation efforts for the region's forest resources.

Keywords: Altitude; Carbon pools; Climate change; Disturbance; Forest.

INTRODUCTION

Climate change is the most global and growing concern of environmental problems facing communities (Yohannes et al., 2015). This change is due to the increasing atmospheric concentrations of human-induced greenhouse gas emissions. Greenhouse gases entered the atmosphere through anthropogenic activities and were reported as a reason for an increase in the world average temperature of approximately 0.74°C over the past century (IPCC, 2007). The estimates of projected temperature increase over the 21st century range between approximately 1.8°C and 4.9°C (IPCC, 2007). Future projections indicate that temperature increases are generally consistent with historical trends, with temperature increases over land (Kang et al., 2008).

The threats posed by climate change, such as global weather patterns change, global warming, natural disasters, ozone depletion, biodiversity loss, rising sea levels, and the existence of future human life, have led to worldwide debate and negotiations (Streck and Freestone, 2009). Addressing these concerns has centered on mitigating greenhouse gas emissions, primarily carbon dioxide, as well as quantifying the carbon sequestered and stored by forests, soils, and oceans (Girma et al., 2014). The method to delay the rise in greenhouse gas concentrations in the atmosphere and thus the potential for climate change is to increase the amount of carbon removed from and stored in forests (Girma et al., 2014).

Forests play a vital role in the global carbon cycle because they store huge amounts of carbon in vegetation and soil that exchange carbon with the atmosphere through photosynthesis and respiration (McMahon et al., 2010). Forest has a major carbon reservoir and plays an important role in climate change mitigation (Nowak and Greenfield,2020). The response of forests to alarmingly growing atmospheric carbon dioxide concentrations is critical for climate change mitigation by naturally taking carbon out of the atmosphere (IPCC, 2000). Forest ecosystems comprise 62– 78% of terrestrial carbon (Ullah and Al-Amin, 2012). The world's forests store 289 gigatons of carbon in their biomass alone, with tropical forests accounting for the largest 44% (FAO, 2010). The world's tropical forests release around 425 million tons of carbon annually (Pan et al., 2011). Deforestation and degradation of tropical forests constitute the second largest source of anthropogenic CO_2 emissions after fossil fuel combustion (Vander et al., 2009). Over fifty percent of the worldwide potential for reducing greenhouse gas emissions is attributed to the forestry sector (IPCC, 2007b). Globally, carbon storage is distributed as follows: soil organic carbon accounts for 44%, above- and belowground biomass represents 42%, deadwood comprises 8%, and litter contributes 5% (Zerihun et al. 2012). Forest soil acts as a key carbon sink, with soil organic carbon constituting a significant proportion of total ecosystem carbon stocks (Gebeyehu et al.,2019). Studies in African tropical forests reveal that up to 70% of total carbon stocks are stored in soil, emphasizing the importance of soil conservation for maintaining ecosystem function (Ryan et al.,2011).

Anthropogenic activities, including deforestation, grazing, and urbanization, significantly affect the forest carbon dynamics, as highlighted by recent studies on land-use change and its contribution to global carbon emissions (Abebe and Megento,2016). The forest resources of Ethiopia store 2.76 billion tons of carbon in the aboveground biomass (Moges et al., 2010), yet the forest area is degraded due to firewood collection, grazing, cutting, and developmental activities, resulting in substantial deforestation and degradation, impacting carbon sequestration potential and exacerbating climate change challenges (Deribew,2020).

Local carbon inventories for various tropical Afromontane forests lack quantified data on Ethiopian forest sectors (Gebeyehu et al., 2019). Carbon stock data is crucial in carbon credit programs because it allows for sustainable forest management and monitoring systems, enhancing the carbon sequestration capacity of the country's forest resources and mitigating the negative impacts of global climate change (Dibaba et al., 2019). However, most Ethiopian forests lack well-organized carbon stock data and information on how human activities influence the carbon stock potential (Muluken, et al., 2015). The carbon stock potential of the Embuli Tahisasdar's natural forest has not yet been studied. Therefore, this study aimed to (1) estimate the carbon stock potential of various carbon pools, (2) assess the variation of different carbon pools along altitudinal and topographic aspects, and (3) evaluate the impacts of human disturbance on carbon storage in the study area.

MATERIALS AND METHODS

Study Area

The research was conducted in the Embuli Tahisasdar Forest, situated in the Machakel district of the Amhara region, located approximately 330 km northwest of Addis Ababa, 237 km south of Bahir Dar, and 30 km from the western part of Debre Markos town. The forest's geographical location is between the latitudes of 10^0 28' and 10^0 29' N and the longitudes of 37^0 30' and 37^0 32' E (Fig. 1).

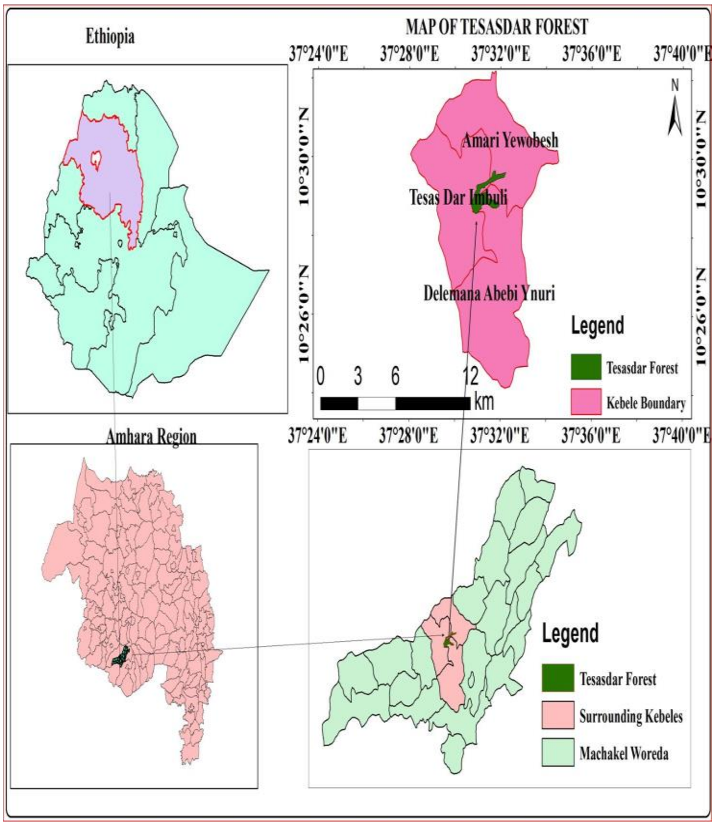

Fig. 1. Locational map of the study area

Sampling Design

A systematic sampling technique was employed to thoroughly examine the study area. Each plot was established at 100 meters intervals using a measuring tape, GPS, and a compass. The major plot was laid out 20 m × 20 m, with smaller sub-sampling units of 1m^2 used to collect saplings, seedlings, falling litter, and soil data. A total of forty major plots were surveyed, and the study area was stratified into three namely, low, mid, and high altitudes-based zones.

Data Collection

Aboveground and belowground biomass

Sampling plots had a radius of 20 meters and a total area of 400 square meters. The growth patterns of all the woody plant species were described, recorded, and measured in each sample plot. Individual trees with a diameter at breast height ≥5 cm and the height of a tree/shrub ≥1.5 m were measured. Geographic location and altitude were recorded using a Garmin GPS. The carbon pool in belowground biomass constitutes 20% of the aboveground biomass (Subedi *et al.*,2010).

Litter biomass

Leaf litter samples were collected using composite sampling methods. Two hundred litter samples were collected from forty plots, each measuring 1 m², located within the main plot. One sample was taken from the center, and four samples were taken from each corner. The wet weight of the composite samples was recorded. The

DOI: https://doi.org/10.55706/jae1833

total weight of the samples was recorded following a 24-hour drying period at 70 °C in an oven. The C fraction was also tested in a laboratory (Subedi et al.,2010).

Organic carbon in the soil

Composite soil samples were collected from all the forty plots using a 20 cm soil depth core sampler. The soil samples were taken from two layers (0– 20 cm and 20– 40 cm), and the mean values were subsequently computed. The volume of the soil sample was estimated by measuring the height and radius of the core sampler. All soil samples were stored in plastic bags, and five equal weights were gathered from each layer of every sample. A composite sub-sample of 100 g from each plot was submitted for laboratory analysis using the Walkley– Black procedure (Ebasan et al.,2016).

Estimation of carbon stock across various carbon pools

Aboveground biomass

The present research utilized the equation formulated by Chave et al. (2014), to estimate the aboveground biomass of the forest, using diameter at breast height (DBH), tree height, and wood-specific density as dependent variables.

$AGB = 0.0673(\rho HD^2)0.976$………… Equation (1)

AGB represents the aboveground biomass (kg), D denotes the diameter at breast height (cm), H indicates the height (m), and ρ signifies the basic wood density (g/cm^3).The wood density data information was obtained from the global wood density database (Zanne et al., 2009), the ICRAF,the wood density database (www.worldagroforestry.org), and the wood technology research Centre in Addis Ababa (Desalegn et al., 2012).

The carbon stock was calculated using a conversion factor of 0.47, which translates to a carbon content of 47% for aboveground biomass in tropical and subtropical forests (Subedi et al.,2010).

$AGC = AGB * 0.47$………………….. Equation (2)

where AGC is aboveground carbon, AGB is aboveground biomass

Belowground biomass

Belowground biomass is estimated at 20% of the aboveground biomass (root-to-shoot ratio) model used for tropical dry forests (Subedi et al.,2010).

$BGB = AGB * 0.20$ ……………………Equation (3)

BGB represent belowground biomass, AGB indicates aboveground biomass, 0.20 is a conversion factor

$BGC=BGB* 0.47$…………………… Equation (4)

Litter biomass

According to Pearson *et al.* (2007), the biomass present in the litter can be estimated as follows:

$$LB = \frac{Wfield}{A} * \frac{Wsub-sample\,(dry)}{Wsub-sample\,(fresh)} * \frac{1}{10{,}000} \quad \text{…Eq. (5)}$$

LB represents litter biomass, Wfield denotes the weight of the wet field sample of litter collected from an area of 1 m^2 (g), A indicates the size of the area from which the litter was collected (ha), Wsub-sample (fresh) refers to the weight of the fresh sub-sample of litter taken to the laboratory for moisture content analysis, and Wsub-sample (dry) indicates the weight of the oven-dry sub-sample of litter brought to the laboratory for moisture content determination (g).

The percentage of organic carbon stored in the litter carbon pool as a result of the dry ashing process was determined using the following method (Pearson *et al.*,2007).

$\% Ash = Wc - \frac{Wa}{Wb} - Wa * 100$. Equation (6)

$\%C = (100-Ash\%) * 0.58$………… Equation (7)

This analysis is based on the assumption of 58% carbon content in ash-free litter material. In this context, C represents organic carbon (%), Wa denotes the weight of the crucible (g), Wb indicates the weight of the oven-dried ground samples and crucibles (g), and Wc refers to the weight of ash and crucibles (g). Ultimately, the carbon content in litter was calculated in tons per hectare for each sample.

$LC= LB* \%C$…………………… Equation (8)

where, CL is the total carbon stocks in the dead litter in tons/ha, and % C is the carbon fraction determined in the laboratory (Subedi et al.,2010).

Soil organic carbon

According to Pearson *et al.* (2007), soil organic carbon was determined using the method;

$BD = Wdry/V$………..…..Equation (9)

BD represents the bulk density of the soil sample, W dry indicates the air-dry weight of the soil sample, and V represents the volume of the soil sample. The volume of the soil sample is computed as;

$V= h*\pi r^2$ …………Equation (10)

Where V = volume of the soil in the core sampler augur (cm^3), h = the height of the core sampler augur (cm), and r = radius of the core sampler (cm). Finally, soil organic carbon is calculated as follows:

$SOC = BD * D * \% C$ ………… Equation (11)

where SOC= soil organic carbon stock per unit area (ton/ha), BD is soil bulk density (g/cm^{-3}),

DOI: https://doi.org/10.55706/jae1833

D is the total depth at which the sample was taken (0-20 and 20-40 cm), and %C is carbon concentration (%) (Pearson et al., 2007).

Total carbon stock

The total carbon stock was estimated by adding the carbon stock of all individual carbon pools of the forest ecosystem (Subedi *et al.*,2010). Then converted into tones of CO_2 equivalent multiplying it by 3.67(Pearson *et al.*,2007). According to Pearson et al. (2007), the total carbon stock density was calculated as:

C_T= AGC+BGC+LC+SOC………. Equation (12)

Where CT represents the carbon stock for all carbon pools (ton/ha), AGC denotes carbon in aboveground biomass, BGC indicates carbon in belowground biomass, LC refers to carbon in dead litter, and SOC signifies soil organic carbon.

Human disturbance index

The human disturbance index in Embuli Tahisasdar Forest was evaluated by actual field observation, utilizing indicators of human activity in the field. The impacts of human activities (cutting, road construction, firewood collection, and grazing) on the forest carbon storage were assessed. The human disturbance index was calculated by summing the number of detected human impacts within the plot and dividing by the total number of disturbances which is four. The values ranged from 0 to 1, with 0 indicating no impact and 1 indicating all impacts, indicating highly impacted by human intervention (Bastos et al.,2023). The level of human disturbance was evaluated and classified into four major categories using a visual scale. Each human disturbance factors was recorded in all of the study area's sample plots. The human disturbance classifications were as follows: 1 = undisturbed (nonvisible indicators of human disturbance),2 = slightly disturbed (<20% human disturbance),3 = moderately disturbed (>20% human disturbance) and 4 = highly disturbed (>60% human disturbance) (Bisht et al.,2022).

Data analysis

Upon completion of field data collection, all field and laboratory results, including diameter at breast height measurements, plant species heights, and fresh and dry weights of litter and soil data, were compiled and summarized in an Excel spreadsheet (version 20).The major carbon pools' data were analyzed using SPSS software version 20, and one-way ANOVA was used to examine the impacts of altitudinal and topographic variation on the carbon storage potential of woody plant species.

RESULT

Floristic composition

Forty-four distinct woody plant species, including trees and shrubs, from 28 families, were recorded and identified in the Embuli Tahisasdar dry Afromontane Forest. Among these families, Fabaceae was the most dominant (17.86%). Rutaceae, Asteraceae and Rosaceae were the next dominant families and have equal percentages accounting for 10.71% each.

Biomass and carbon stock in various carbon pools

The study area had an average aboveground biomass of 86.43±148.25 tons/ha and a belowground biomass of 22.47±38.55 tons/ha, while the mean litter biomass was 0.053 tons/ha.

Table 1.The mean total carbon stock, CO_2 equivalent and percentage on different carbon pools

Carbon pools	Mean carbon stock (ton/ha)	CO_2 eqv.	%
AGC	43.22	158.61	25.06
BGC	11.24	41.68	6.52
LC	2.49	9.14	1.44
SOC	115.52	423.95	66.98
Total	172.47	633.38	100

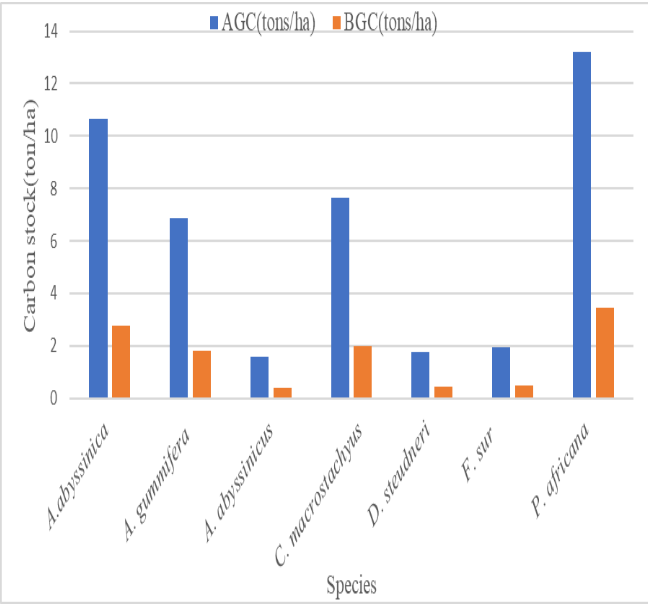

Fig.2. Estimated carbon stock potential of the top dominant woody species

DOI: https://doi.org/10.55706/jae1833

Environmental determinants of carbon stock

Altitudinal variation

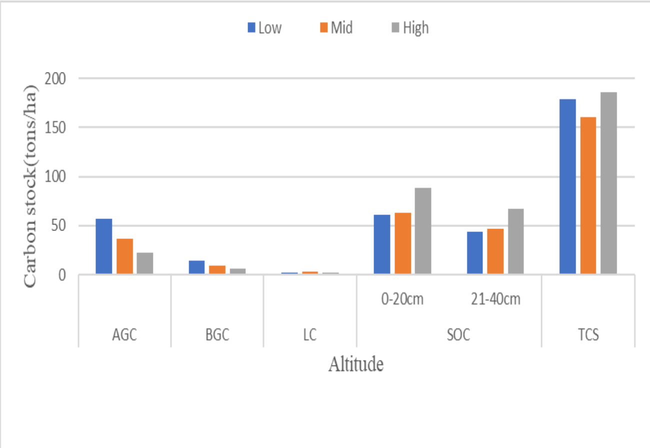

Fig.3. Mean carbon stock across various pools along the altitudinal gradient (tons/ha)

Human disturbance index

Since the study area is accessible to the public, various human disturbances can be observed. These disturbances have been categorized into four main classifications, each associated with its respective human disturbance index (HDI) values: including tree cutting, firewood collection, grazing, and the presence of road construction in the forest.

Topographic aspect

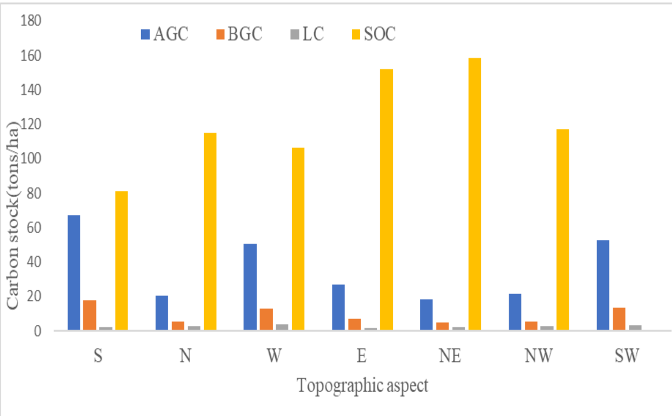

Fig. 4. Average carbon stock in various pools across topographic aspects (tons/ha)

Table.2. One way ANOVA result of environmental factors significance difference of various carbon pools

Environmental factors	**Carbon pools**	**F-value**	**P-value**
Altitude	AGC	1.086	0.348
	BGC	1.086	0.348
	LC	3.454	**0.042**
	SOC (0-20cm)	6.667	**0.007**
	SOC (20-40cm)	3.984	**0.038**
Topographic aspect	AGC	0.761	0.605
	BGC	0.762	0.605
	LC	2.699	**0.03**
	SOC (0-20cm)	3.973	**0.019**
	SOC (20-40cm)	3.462	**0.03**

*Bold values significant at α=0.05

DISCUSSION

Carbon stock in various pools

The total carbon stock of the Embuli Tahisasdar forest was 172.47 tons/ha, putting it in the lower range when compared to other studies, such as Menagesha Suba forest (286.53 tons/ha), Tara Gedam Forest (643.11 tons/ha), Ades Forest (585.4 tons/ha) and Humbo forest (225.98 tons/ha). The present result showed that mean aboveground carbon stock and belowground carbon stock was 43.47 tons/ha and 11.24 tons/ha, respectively, the lower scoring emphasizing the negative effects of deforestation, as documented in tropical forest degradation research. While the study area had a lower AGC stock, compared to Ades Forest and Tara Gedam Forest, reported significantly higher AGC stocks, reflecting effective forest management practices (Yohannes et al.,2015), it lagged in biomass carbon due to high human disturbances in the Embuli Tahisasdar forest. On the other hand, the carbon stock was mainly contributed by soil organic carbon, with a mean of 115.52 tons/ha.This finding is consistent with recent studies highlighting soil as a significant carbon reservoir in degraded forests (Abegaz,2020). The soil organic carbon in the Embuli Tahisasdar Forest was exceptionally high, surpassing the soil organic carbon levels of most Ethiopian forests, including Ashirava forest (111.43 ton/ha), Ziba forest (100.07), and Biheretsige central closed public park forest (113.55 ton/ha). This may be due to organic matter deposition, or historical soil management practices that enhanced carbon storage in the soil (Houghton,2005). Similar findings were reported by Kidanemaryam (2014) and Chinasho (2015), who noted that high levels of soil organic carbon may indicate historical accumulation or specific ecological dynamics in disturbed forests. However, the imbalance contribution of soil organic carbon to the total carbon stock underscores the decreased significance of biomass in carbon sequestration within the forest. This imbalance is a direct consequence of deforestation and other human disturbances, which have significantly decreased the forest's above ground biomass, belowground biomass, and litter biomass storage capacity (Habtamu and Elias,2022).

DOI: https://doi.org/10.55706/jae1833

Carbon stock variation in woody species

The highest carbon stock was recorded for *Prunus african* (16.7 ton/ha) followed by *Acacia abyssinica* (13.4 ton/ha), *Croton macrostachyus* (9.6 ton/ha), *Albizia gummifera* (8.6 ton/ha) and *Ficus sur* (2.4 ton/ha) compared to the other 44 identified woody species in the Embuli Tahisasdar forest (Fig.2), While *Calpurnia aurea* and *Rubus apetalus* was recorded the least carbon storage. This difference may be due to variations in species composition, as the presence of woody species with greater diameter at breast height (DBH), height, and density contributed to the greater carbon stock recorded for these species in the study area. The dominant species are an important determinant of the carbon stock of woody species in forest ecosystems (Winfree et al., 2015; McNicol et al. 2018; Padmakumar et al., 2018; Gebeyehu et al., 2019b).

Effect of altitude and topographic aspect in carbon stock

The altitudinal variation affects the biomass and carbon stock of various carbon pools in the forest ecosystem (Alves et al., 2010). Variation in altitude results in variation in the carbon stock (Leuschner et al., 2007; Kobler et al., 2019; Eshetu and Hailu, 2020). This reveals that there would be substantial variation in carbon storage as a result of a significant effect on climatic parameters (Sheikh et al., 2009). The present result revealed a weak correlation between altitude and AGC stock, as evidenced by high p-values (Table 2). These results suggested that while direct statistical relationships are not significant, other ecological processes may mediate the impacts of altitude on carbon dynamics over time (Klein,2022). The carbon stock in the present study showed significant variation throughout the altitudinal gradient in litter biomass, and soil organic carbon ($P < 0.05$). However, aboveground carbon density and belowground carbon density showed statistically insignificant variation along altitude (Table 2).

The highest above-ground biomass and below-ground biomass carbon stock was recorded in the lower altitude (Fig.3), while the lowest was recorded in the higher altitude part of the forest (Fig 3). In the current study area, it was observed that aboveground and belowground carbon stock had shown a decreasing pattern with increasing altitude. Similar findings have been reported (Chinasho et al., 2015; Simegn and Soromessa, 2015). This may be due to the present of large trees with high DBH and height that account for a large proportion of AGC and BGC at the lower altitudes of the study forest. However, this study contradicted findings reported in Mount Zequalla Monastery (Girma et al., 2014); the tropical Atlantic Forest of Brazil (Alves et al., 2010); on Mount Changbai in China (Zhu et al., 2010). Litter carbon, as shown in figure 3, exhibited minimal variation across altitudes, with nearly similar values recorded for lower, middle, and upper elevations. This revealed that factors influencing litter carbon storage, such as litterfall rates and decomposition processes, were largely uniform across altitudes. The result showed strong correlations between altitude and litter carbon stock, as evidenced by low p-values, and litter carbon stock was statistically significant (Table 2).

The highest level of soil organic carbon was recorded at the upper altitude class in the present study. Similar results have been reported in (Zhu et al., 2011). The current findings indicate that SOC stock exhibited a rising trend as altitude increased. Whereas, the lowest soil organic carbon stock was recorded at the lower altitude class of the study area due to human and animal disturbances like cropping, cutting, grazing, and less decomposition of organic matter. The reduction in soil organic carbon content with increasing soil depth can be attributed to a more conducive environment for topsoil, as well as a decline in biological activity at increased depths. This phenomenon is further influenced by the rapid decomposition of forest litter and its mixing with surface materials. Similar results were reported for tropical soils by Dinakaran and Krishnayya (2008); and Sheikh et al. (2009). The result indicated strong correlations between altitude and soil organic carbon stock, as evidenced by low p-values, and SOC was statistically significant (Table 2).

Biomass and carbon stock varied significantly along topographic aspects in Embuli Tahisasdar Forest. The highest aboveground and belowground carbon stock was recorded in the South (67.25 tons/ha) and Southwest (52.43 tons/ha) respectively, while the least was recorded in the Northeast (18.15 tons/ha) (Fig.4). Similar results were recorded by Sharma et al. (2011) and Kassahun et al. (2015) that the topographic aspect could affect biomass and carbon stock of living biomass. This variation could be attributed fluctuations in temperature, solar radiation, and intensity. Temperature can determine the length of the growing season of plants, and solar radiation can affect the rates of photosynthesis that lead to changes in biomass (Jolly et al., 2005). Radiation also affects soil moisture and temperature, affecting soil carbon storage capacity (Bayat 2011; Sharma et al., 2011; Kassahun et al., 2015). The topographic aspect has a statistically insignificant impact on the aboveground and belowground carbon of the study area ($P<0.05$). However, litter and soil organic carbon were statistically significant ($p<0.05$) (Table 2).

Effect of human disturbance on carbon storage

Carbon stock potential of Embuli Tahisasdar forest is affected by anthropogenic/human activities. The one-way ANOVA analyzed the relationships between human disturbance indices and different carbon pools as shown in table 2. The result revealed a strong correlation between litter biomass and soil organic carbon along human disturbance in the study area (Table 2). Even though, the correlations between disturbance levels and AGC stock was weak, as evidenced by high p-values. These results suggested that while direct statistical links are not significant, other ecological processes may mediate the impacts of human activities on carbon dynamics over time (Klein,2022). Variation in forest carbon among sites, which

DOI: https://doi.org/10.55706/jae1833

might lower the statistical power of analyses and possibly hide the direct effects of human disturbances. Nevertheless, broader trends highlight the cumulative effects of anthropogenic pressures on the forest ecosystems (Chazdon,2008).

Implications for climate change mitigation

Forests are the biggest terrestrial reservoir for atmospheric carbon because they remove CO_2 from the atmosphere and store it in the soil, litter, trees and other organic matter (Mwakisunga and Maule, 2012). Estimating the amount of forest biomass is very important for monitoring and estimating the amount of carbon that is lost or emitted during deforestation and gives information about the forest□s potential to sequester and store carbon in the forest ecosystem. Hence, estimating the forest carbon stock is mainly important to assess the magnitude of carbon exchange between the forest ecosystem and the atmosphere (Vashum and Jayakumar, 2012). In addition, it can help us to measure the carbon stocks which will help to understand the current status of carbon stocks and also derive the near future changes in the carbon stocks (Muluken et al., 2015). Finally, it provides important information to determine the changes in carbon stocks as required by the UNFCCC and forestry projects for mitigating carbon emissions like REDD+.

Forest conservation and management is a promising strategy to increase carbon storage in the forest ecosystem. Conservation of dominant woody species plays a significant role in a better long-term guarantee of ecosystem services of climate change mitigation (Mensah et al., 2016a; Mewded and Lemessa, 2020). Benefits obtained from forest-based carbon offset initiatives include biodiversity and natural resources conservation, watershed protection, sustainable livelihood enhancement, and local and global climate stability (Royal Society, 2001). The enhancement of the carbon sequestration and the conservation of existing carbon stocks in tropical forests ecosystem could be a strategy to improve carbon storage and thus, contributing in mitigate climate change.

CONCLUSION

Embuli Tahisasdar forest plays a significant role in carbon sequestration and has the potential to generate carbon credits thus, contributing to climate change mitigation. The largest proportion of carbon stock is contributed by soil organic carbon pool, followed by the above-ground, below-ground, and litter carbon pools, respectively. The highest carbon stock was recorded for *Prunus africana* followed by *Acacia abyssinica* and *Croton macrostachyus*. The highest above-ground and below-ground carbon stock was recorded at the lower altitude class. Carbon stock of woody species in the study area was varying along altitudinal and topographic aspect. The above-ground and below-ground biomass and carbon stock were decreased with increasing altitude. Whereas, soil organic carbon increases as the altitude increases. Woody species type, altitude, topographic aspect and human disturbances significantly affect the biomass and carbon stock which is recommended to take into account these determinant factors in considering a certain dry Afromontane Forest for carbon sequestration potential for climate change mitigation measures.

Accurate quantitative data on carbon stock would serve as an essential input for carbon trading and inform forest management practices from the perspectives of carbon storage and conservation. Furthermore, carbon estimates derived from primary data would enhance the carbon inventory, contributing to a more comprehensive assessment of total greenhouse gas emissions in the country for both national and international reporting.

Acknowledgement

I would like to thank Alene Gebyaw and Desyibelew Wale, a field technician from the Debre Markos Soil Laboratory Center, for assisting us during soil data collection and analysis. My special thanks go to Asresie Mekonnen, Befekadu Mewded, Sissay Alemu, Debeli Chala, and Tewodros Misganaw researchers from Ethiopian Biodiversity Institute for their field data collection and technical advice. I also extend our gratitude to the Ethiopian Biodiversity Institute for logistic and financial support for field data collection.

Conflict of Interest

There are no conflicts of interest declared by the authors.

REFERENCES

Abebe, M.T.; Megento, T.L. The city of addis ababa from ‘Forest city to urban heat island: Assessment of urban green space dynamics. J. Urban Environ. Eng. 2016, 10, 254– 262.

Abegaz, A.; Tamene, L.; Abera, W.; Yaekob, T.; Hailu, H.; Nyawira, S.S.; Da Silva, M.; Sommer, R. Soil organic carbon dynamics along chrono-sequence land-use systems in the highlands of Ethiopia. Agric. Ecosyst. Environ. 2020, 300, 106997.

Alves, L. F., Vieira, S. A., Scaranello, M. A., Camargo, P. B., Santos, F. A., Joly, C. A., & Martinelli, L. A. (2010). Forest structure and live aboveground biomass variation along an elevational gradient of tropical Atlantic moist forest (Brazil). *Forest ecology and management*, *260*(5), 679–691.

Asrat, F., Soromessa, T., Bekele, T., Kurakalva, R. M., Guddeti, S. S., Smart, D. R., & Steger, K. (2022). Effects of Environmental Factors on Carbon Stocks of Dry Evergreen Afromontane Forests of the Choke Mountain Ecosystem, Northwestern Ethiopia. *International Journal of Forestry Research*, *2022*. https://doi.org/10.1155/2022/9447946

Ayalew, A., Bekele, T., and Demissew, S. (2006). The Undifferentiated Afromontane Forest of Denkoro in the Central Highlands of Ethiopia: A Floristic and

Structural Analysis. Sine *Ethiopia Journal of Science,* 29(1): 45– 56.

Bastos, J.R.; Capellesso, E.S.; Vibrans, A.C.; Marques, M.C.M. Human impacts, habitat quantity and quality affect the dimensions of diversity and carbon stocks in subtropical forests: A landscape-based approach. J. Nat. Conserv. 2023, 73, 126383.

Bayat AT (2011) Carbon stock in an Apennine beech forest. MSc thesis. University of Twente Bazezew, M. N., Soromessa, T., & Bayable, E. (2015). Carbon stock in the Adaba-Dodola community forest of Danaba District, West-Arsi zone of Oromia Region, Ethiopia: An Implication for Climate Change Mitigation. *Journal of Ecology and the Natural Environment*, *7*(1), 14-22.

Bhishma P., Subedi, Pandey, S.S., Pandey, A., Rana, E.B., Bhattarai, S., Banskota, T.R., Charmakar, S. and Tamrakar, R., (2010). Forest Carbon Stock Measurement: Guidelines for measuring carbon stocks in community-managed forests. Asia Network for Sustainable Agriculture and Bioresources, Federation of Community Forest Users, *International Centre for Integrated Mountain Development, Katmandú, Nepal*. 69p.

Bisht, S.; Bargali, S.S.; Bargali, K.; Rawat, G.S.; Rawat, Y.S.; Fartyal, A. Influence of Anthropogenic Activities on Forest Carbon Stocks-A Case Study from Gori Valley, Western Himalaya. Sustainability 2022, 14, 16918.

Chave, Jérôme, Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. C.,Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, *20*(10), 3177– 3190. https://doi.org/10.1111/gcb.12629

Chazdon, R. L. (2008). Beyond deforestation: restoring forests and ecosystem services on degraded lands. *science*, *320*(5882), 1458-1460.

Chinasho, Alefu. (2015). Carbon Stock in Woody Plants of Humbo Forest and Its Variation along Altitudinal Gradients: The Case of Humbo District, Wolaita Zone, Southern Ethiopia.” *International Journal of Environmental Protection and Policy* 3(4): 97.

Deribew, K.T. Spatiotemporal analysis of urban growth on forest and agricultural land using geospatial techniques and Shannon entropy method in the satellite town of Ethiopia, the western fringe of Addis Ababa city. Ecol. Process. 2020, 9, 46.

Desalegn, G., Teketay, D., Gezahgne, A., & Abegaz, M. (2012). Commercial Timber Species in Ethiopia: Characteristics and Uses A handbook, for forest ‘ Industries, Construction and Energy Sectors, Foresters and Other Stakeholders.

Dibaba, A., Soromessa, T., & Workineh, B. (2019). Carbon stock of the various carbon pools in Gerba-Dima moist Afromontane Forest, South-western Ethiopia. *Carbon balance and management*, *14*(1), 1-10.

Dinakaran, J., & Krishnayya, N. S. R. (2008). Variations in type of vegetal cover and heterogeneity of soil organic carbon in affecting sink capacity of tropical soils. *Current science*, 1144-1150.

Ebasan, M.S.; Aranico, E.C.; Tampus, A.D.; Amparado, R.F. Carbon stock assessment of three different forest covers in Panaon, Misamis Occidental, Philippines. J. Bio. Env. Sci. 2016, 8, 252– 264. Available online: http://www.innspub.net (accessed on 23 January 2024).

Eshetu EY, Hailu TA (2020) Carbon sequestration and elevational gradient: the case of Yegof mountain natural vegetation in North East, Ethiopia, implications for sustainable management. Cogent Food Agric 6:1733331

FAO. (2010). Global Forest Resource Assessment. Country Report, Ethiopia, Rome.

Gebeyehu, G., Soromessa, T., Bekele, T., & Teketay, D. (2019). Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia. *Journal of Ecology and Environment*, *43*(1), 1-18.

Gedefaw, M, Soromessa T., and Belliethathan,S. (2014). Forest Carbon Stocks in Woody Plants of Tara Gedam Forest: Implication for Climate Change Mitigation.” *Science, Technology and Arts Research Journal* 3(1): 101.

Girma, A, Soromessa T., and Bekele,T. (2014). Forest Carbon Stocks in Woody Plants of Mount Zequalla Monastery and It s Variation along Altitudinal Gradient: Implication of Managing Forests for Climate Change Mitigation.” *Science, Technology and Arts Research Journal* 3(2): 132.

Habtamu, M., & Elias, E. (2022). Role of urban forests for Carbon emission reduction in Addis Ababa: A review. *Journal of Ecosystem & Ecography*, *12*(2), 316.

Houghton, R.A. Aboveground Forest biomass and the global carbon balance. Glob. Change Biol. 2005, 11, 945– 958.

IPCC. (2000). Land Use, Land-Use Change, and Forestry. Cambridge University Press, Cambridge, UK, pp. 996.

IPCC. (2006). Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Buendia L. Publicado por: IGES,

IPCC. (2007a). IPCC Fourth Assessment Report on Climate Change. *Intergovernmental Panel on Climate Change*, (November).

IPCC. (2007b). Highlights from Climate Change 2007. The Physical Science Basis. In: Summary for Policy Makers: Contribution of Working Group I to the Fourth Assessment Report of the IPCC, pp. 545-552 (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., eds.). Cambridge University Press, Institute of Terrestrial Ecology, Edinburgh.

IPCC. (2014). It provides an integrated view of climate change as the final part of the IPCC. IPCC‟s Fifth Assessment Report (AR5).

Jolly W, Dobbertin M, Zimmermann N, Reichstein M (2005) Divergent vegetation growth responses to the

2003 heat wave in the Swiss Alps. Geophys Res Lett 32: L18409. https://doi.org/10. 1029/2005GL023252.

Kang, S. M., I. M. Held, D. M. W. Frierson, and M. Zhao, (2008). The response of the ITCZ to extratropical thermal forcing: Idealized slab-ocean experiments with a GCM. *Journal of Climate*, 21(14), 3521– 3532.

Kassahun Kidanemariam, Teshome Soromessa, Satishkumar Belliethathan, and Kidanemariam. 2015. Forest Carbon Stock in Woody Plants of Ades Forest, Western Hararghe Zone of Ethiopia and Its Variation along Environmental Factors: Implication for Climate Change Mitigation." *Journal of Natural Sciences Research www.iiste.org ISSN* 5(21): 96– 109. www.iiste.org.

Klein, L.J. Urban Forests for Carbon Sequestration and Heat Island Mitigation. 2022. Available online: https://elib.dlr.de/187233/1/Paper_2022_KDD_AI4GoodWorkshopUrbanForests4CO2SequestrationAndHeatIslandMitigation.pdf (accessed on 18 December 2023).

Kobler J, Zehetgruber B, Dirnböck T et al (2019) Efects of aspect and altitude on carbon cycling processes in a temperate mountain forest catchment. Landscape Ecol 34:325– 340

Leuschner, C., Moser, G., Bertsch, C., Röderstein, M., & Hertel, D. (2007). Large altitudinal increase in tree root/shoot ratio in tropical mountain forests of Ecuador. *Basic and Applied Ecology*, *8*(3), 219-230.

McNicol IM, Ryan CM, Dexter KG et al (2018) Aboveground carbon storage and its links to stand structure, tree diversity and foristic composition in south-eastern Tanzania. Ecosystems 21:740– 754

McMahon, S. M., Parker, G. G. and Miller, D. R. (2010). Evidence for a recent increase in forest Meseret, H.; Eyasu, E. Role of Urban Forests for Carbon Emission Reduction in Addis Ababa:A review. Civ. Environ. Res. 2022, 12, 316.growth. Proceedings of the National Academy of Sciences. Science107: 3611– 3615.

Mensah, S., Veldtman, R., Assogbadjo, A. E., Glèlè Kakaï, R., & Seifert, T. (2016). Tree species diversity promotes aboveground carbon storage through functional diversity and functional dominance. *Ecology and evolution*, *6*(20), 7546-7557.

Mewded, B., & Lemessa, D. (2020). Factors affecting woody carbon stock in Sirso moist evergreen Afromontane Forest, southern Ethiopia: implications for climate change mitigation: B. Mewded, D. Lemessa. *Environment, Development and Sustainability*, *22*(7), 6363-6378.

Moges, Y., Z. Eshetu, and S. Nune, (2010). Ethiopian Forest Resources: Current Status and Future Management Options because of Access to Carbon Finances. Literature Review for Ethiopian Climate Research and Networking and the United Nations Development Program. Addis Ababa, Ethiopia.

Moser G, Bertsch C et al (2007) Large latitudinal increase in tree root/shoot ratio in tropical mountain forests of Ecuador. Basic Appl Ecol 8:219– 230.

Muluken, N. B., Teshome, S., & Eyale, B. (2015). Carbon stock in Adaba-Dodola community forest of Danaba District, West-Arsi zone of Oromia Region, Ethiopia: An implication for climate change mitigation. *Journal of Ecology and The Natural Environment*, *7*(1), 14– 22. https://doi.org/10.5897/jene2014.0493

Nowak, D.J.; Green field, E.J. The increase of impervious cover and decrease of tree cover with in urban areas globally (2012– 2017). UrbanFor.UrbanGreen.2020,49,126638.

Padmakumar B, Sreekanth N, Shanthiprabha V et al (2018) Tree biomass and carbon density estimation in the tropical dry forest of Southern Western Ghats, India. iForest 11:534

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, A.D., Piao, S., Rautiainen, A., Sitch, S., Hayes, D., 2011. A large and persistent carbon sink in the world s forests. Science 333 (6045), 988– 993.

Pearson, T.R., Brown, S.L. and Birdsey, R.A., (2007). *Measurement guidelines for the sequestration of forest carbon*. US Department of Agriculture, Forest Service, Northern Research Station.

Ryan, C.M.; Williams, M.; Grace, J. Above- and belowground carbon stocks in a miombo woodland landscape of mozambique. Biotropica 2011, 43, 423– 432.

Sharma, C. M. *et al*. (2011). Variation in Carbon Stocks on Different Slope Aspects in Seven Major Forest Types of Temperate Region of Garhwal Himalaya, India." *Journal of Biosciences* 36(4): 701– 8.

Sheikh, M.A., Kumar, M., Bussmann, R.W. (2009). Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and management* 4:6.

Simegn, T. Y., & Soromessa, T. (2015). Carbon stock variations along altitudinal and slope gradient in the forest belt of Simen Mountains National Park, Ethiopia. *American Journal of Environmental Protection*, *4*(4), 199-201.

Streck and Freestone. (2009). Legal Aspects of Carbon Trading. Kyoto, Copenhagen. London, United Kingdom: Oxford University Press.

Subedi, B.P.; Pandey, S.S.; Pandey, A.; Rana, E.B.; Bhattarai, S.; Banskota, T.R.; Charmakar, S.; Tamrakar, R. Forest Carbon Stock Measurement: Guidelines for Measuring Carbon Stocks in Community-Managed Forests. 2010.

Tefera, M., & Soromessa, T. (2015). Carbon stock potentials of woody plant species in Biheretsige and Central Closed Public Parks of Addis Ababa and its contribution to climate change mitigation. *Carbon*, *5*(13).

Ullah, M.R. and Al-Amin, (2012). Above- and below-ground carbon stock estimation in a natural forest, Bangladesh, *Journal of Forest Science,* 58 (8): 372– 379.

Van der Werf G. R., D. C. Morton R. S. DeFries, J. G. J. Olivier, , P. S. Kasibhatla, R. B., Jackson, G. J. Collatz,

DOI: https://doi.org/10.55706/jae1833

and J. T. Randerson, (2009). CO2 emissions from forest loss. National Geoscience*,* 2: 737– 738.

Winfree R, FoxWilliams WJNM et al (2015) Abundance of common species, not species richness, drives delivery of a real-world ecosystem service. Ecol Lett 18:626– 635

Wolde, B. M., Kelbessa, E., & Soromessa, T. (2014). *Original Research Forest Carbon Stocks in Woody Plants of Arba Minch Ground Water Forest*. *7522*(June), 141– 147.

Yohannes, Hamere, Teshome Soromessa, and Mekuria Argaw. (2015). “Carbon Stock Analysis Along Altitudinal Gradient in Gedo Forest : Implications for Forest Management and Climate Change Mitigation.” 4(5): 237–44.

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., ... & Chave, J. (2009). Global wood density database.

Zerihun Getu, Tadesse Woldemariam and Winston Adams. 2012. Forest Carbon Stock Assessment Manual for EDD+ in Ethiopia.

Zhu, J., Hu, H., Tao, S., Chi, X., Li, P., Jiang, L., &

Fang, J. (2017). Carbon stocks and changes of dead organic matter in China's forests. *Nature Communications*, *8*(1), 151.

DOI: https://doi.org/10.55706/jae1833