



Comparative analysis of biomass and soil carbon stock estimation of Gambo forest and its adjacent parkland agroforestry, Negele Arsi woreda, Ethiopia

Abera Batu¹ & Hanbesa Hashim^{2*}

¹Negelle Arsi Town Land and Environmental Protection Office, P. O. Box 24, Negelle Arsi, Ethiopia

²College of Natural Resource and Environmental Science, Oda Bultum University, P. O. Box 226, Chiro, Ethiopia

Abstract

While forests and agroforestry (AF) systems are essential for climate change mitigation, there is a lack of comparative analysis of carbon stocks in Gambo forest and an adjacent parkland AF. Current study biomass carbon measurements and comparisons fill that gap. All land-use categories have 20 plots. Tree height and DBH were measured for those with a DBH ≥ 5 cm. To collect litter and soil samples (at 30 cm depth), each plot comprises five 1m $\times$ 1m quadrats: four at the corners and one in the middle. Gambo forest conserved more carbon than nearby parkland AF, but the differences in AGC (137.78 vs. 61.74 t/ha) and BGC (35.84 vs. 12.35 t/ha) were not significant ($p < 0.05$). However, the forest had significantly higher ($p < 0.05$) litter (4.16 t/ha) and SOC (208.09 t/ha) than parklands (1.85 and 134.02 t/ha). The two land uses differ greatly in mean total carbon. Ancient, huge trees with large DBH, complex, multi-layered canopies, and diversified tree structures increase vertical and horizontal space and plant biomass density, storing more carbon in natural forests. Both land use patterns have great carbon sequestration potential, requiring integrated, proactive actions to minimize deforestation and protect forests.

Copyright © 2026 STAR Journal, Wollega University. All Rights Reserved.

Article Information

Article History:

Received: 07-04-2026

Revised: 13-08-2026

Accepted: 28-09-2026

Keywords:

Biomass carbon stock, natural forest, parkland AF, soil organic carbon

*Corresponding
Author:

Hanbesa Hashim

E-mail:

hanbesah@gmail.com

INTRODUCTION

Climate change is a global problem, which is the result of increased greenhouse gas (GHG) concentration, mainly carbon dioxide (CO₂) from different land-use changes (Tadesse et al., 2019). Forests are critical for mitigating atmospheric GHG levels because they sequester substantial carbon (C) within their parts as biomass and soil under them (Jose, 2009). Conversely, deforestation in tropical areas is a major issue, responsible for roughly twenty-five percent of net annual CO₂ inputs and about 10% of nitrous oxide (N₂O) emissions.

Consequently, forests and AF are essential for carbon stock and local climate regulation (Kothandaraman et al., 2020). While carbon storage capacity varies depending on the specific land use, with natural forests typically holding the highest stocks (Tadesse et al., 2019), AF is also a promising approach for boosting atmospheric carbon sequestration, especially in developing countries (Manaye et al., 2019). These systems help mitigate GHGs by storing carbon in both soil and AGB, though their carbon storage potential is limited (Kuyah et al., 2012).

A Peer-reviewed Official International Journal of Wollega University, Ethiopia

Statement of problem

Ethiopia's plant life is highly diverse, spanning from lowland shrublands to dense tropical rainforests (Wang et al., 2019). Despite this rich biodiversity, the country faces severe deforestation and forest loss, which is driven primarily by the conversion of wooded areas into small- and large-scale agricultural lands (FAO, 2020). Forest degradation in Gambo forest is primarily driven by a combination of local socio-economic challenges and weak institutional oversight (Masha et al., 2024). Rapid population expansion forces smallholder farmers to encroach upon forest margins to meet rising food demands (Habtamu et al., 2018). Simultaneously, a scarcity of alternative energy sources makes charcoal production a primary means of securing immediate household income, establishing a strong financial motivation to exploit vulnerable indigenous tree species. These damaging practices are intensified by significant institutional changes (Masha et al., 2024). Ultimately, this loss of forest cover elevates atmospheric carbon dioxide levels, accelerating global climate change (Manaye et al., 2019). Rising global emphasis on climate mitigation and carbon trading highlights the necessity of precise carbon stock assessment and comparison across land uses, including natural forests and AF systems. So, biomass carbon stock estimation of forests with AF is essential. Accurate biomass

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26-41

estimations of forest and AF are very important for evaluating the role of carbon sequestration and supporting climate policy. In this context, comparative analysis of the carbon dynamics of Gambo Forest and adjacent parkland AF is crucial for sustainable tree management and resilience.

Research questions

1. What are the biomass and soil carbon stocks of Gambo forest and its adjacent parkland AF?
2. What are the differences in biomass and SOC carbon sequestration capacity between the two land uses?
3. What are the differences in plant species composition across the two land-use types that would lead to variations in biomass carbon stocks?

MATERIALS AND METHODS

Study area description

Location

This study was undertaken in Gambo Forest and its nearby parkland AF in Ashoka Kebele. It is situated in Negelle Arsi woreda, Ethiopia. The study area is located at the latitude $6^{\circ} 50''$ - $7^{\circ} 38''$ N and longitude $38^{\circ} 40''$ - $39^{\circ} 06''$ E (Figure 1) and at an elevation ranging from 2100 to 2450 m with an area of 661.92 ha. It is located 240 km south of Addis Ababa and 14 km from Negelle Arsi town.

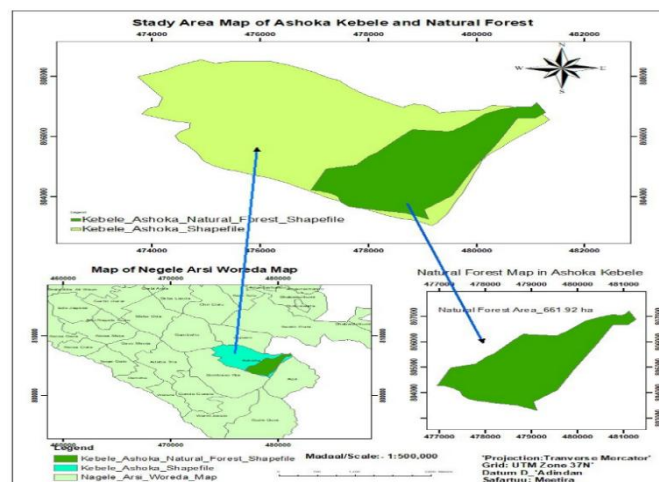


Figure 1. Location map of the study area

Climate, soil, and plant type

The study area is characterized by a warm climate with a primary rainy season from July to October and a shorter season from May to June. According to Tolera et al. (2008), the site has a mean annual rainfall of 1200 mm and an average temperature of approximately 20°C. This area is experiencing rapid degradation despite being dominated by ecologically and economically significant tree species. Primary species included in the area are *Rapanea melanophloeos*, *Hagenia abyssinica*, *Juniperus procera*, and *Podocarpus falcatus* (Tolera et al., 2008).

Sampling design and techniques

Carbon stock was estimated using simple random sampling, with 20 sample plots established for each land-use type. Rectangular plots (20 m x 10 m for natural forest and 50 m x 100 m for Parkland AF) were used due to their reported superiority in capturing heterogeneity compared to square or circular shapes (Hairiah et al., 2001). Plot sizes vary based on vegetation growth patterns within each specific land use. For instance, natural forests feature dense, crowded plant populations, whereas parkland agroforestry (AF) systems contain large, widely scattered trees (Hauck et al., 2023). Natural forests also share consistent environmental conditions over short

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26-41

distances, meaning smaller samples can accurately reflect the broader landscape. In contrast, small sample plots in parkland systems might miss trees entirely or measure a single massive tree, failing to represent the farm as a whole (Hauck et al., 2023). Furthermore, natural forests have lower spatial heterogeneity relative to their area because trees grow in dense clusters or continuous distributions. Parkland AF systems exhibit extreme spatial heterogeneity due to intentional row arrangements, boundary plantings, or wide intercropping gaps. Because trees are highly scattered or restricted to narrow bands, small plots risk capturing extreme outliers, such as hitting a dense cluster or missing trees entirely (Hauck et al., 2023). To manage this significant spatial variance and establish a reliable baseline, the plot size must be scaled up substantially. Ultimately, Ashoka kebele was chosen for this study because of its close proximity to the Gambo forest and the presence of parkland AF. Each tree in a plot was identified and recorded by its local name (Afan Oromo) with the help of elders, and its scientific name was identified from the book of Tesemma (2007), "Useful Trees and Shrubs for Ethiopia." Soil samples (bulk density (BD) and soil organic carbon (SOC)) and litter were collected from 1 m x 1 m subplots located at the four edges and center of each plot, employing an 'X' pattern as indicated in Figure 2.

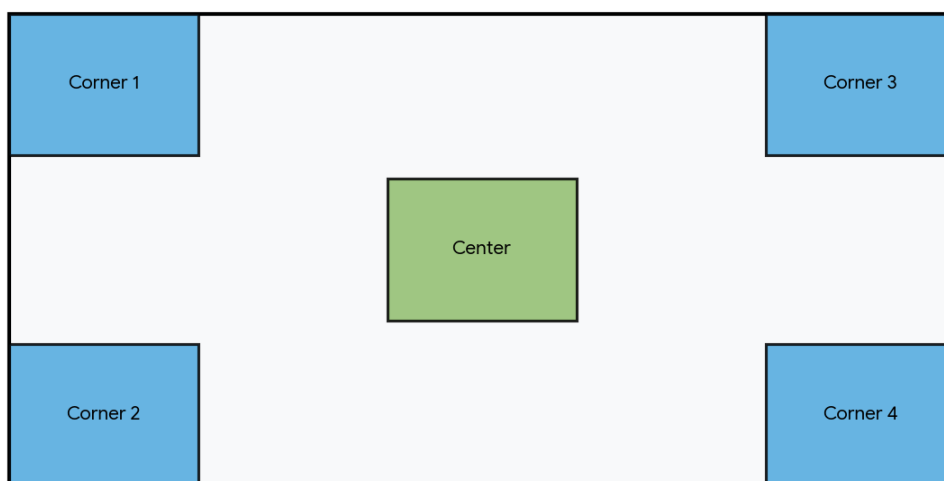


Figure 2. Soil and litter Sample plot design for study area

Method of data collection

Field data measurement

Above-ground biomass (AGB) estimation was conducted by measuring all trees within the sample plots that exhibited a diameter at breast height (DBH) of 5 cm or greater (measured at 1.3 m above ground level). Tree diameters were determined using calipers or diameter tapes for larger specimens, while heights were recorded with a hypsometer. For branching individuals, stems dividing above 1.3 m were treated as a single tree, whereas those forking below this height were cataloged as separate individuals. Finally, wood basic density values were sourced from the 2017 Ethiopian Forest Reference Level report submitted to the UNFCCC.

The soil samples were taken at a thirty-centimeter depth using an auger (Negash and Starr, 2015). The soil and litter samples collected from the four corners and at the center of large sample plots. The samples were mixed to make a representative sample of 100 g of litter and soil. Then the sample was brought to the laboratory for litter biomass analysis and SOC. Additionally, 200 g soil samples were collected from the same quadrant for bulk density analysis using a 10 cm length, 3.4 cm diameter core sampler, which was carefully inserted to prevent compaction (Roshetko et al., 2007). The soil sample for SOC was oven-dried at 105°C for 48 hours to remove moisture content and determine SOC, while the litter was oven-dried at 75°C for 24 hours. For bulk density, soil samples were oven-dried at 105°C for 24 hours (Pearson et al., 2007).

Data analysis

Above ground and below ground biomass estimation

To estimate biomass carbon storage, this study utilized allometric models, applying a 50% carbon fraction as recommended by FAO (2020). AGB was estimated using the pant-tropical model by Chave et al. (2014), using wood density (wbd in g/cm³), diameter at breast height (dbh, cm), and

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26-41
height (ht in m). This model was chosen for its accuracy across diverse climatic zones and natural forest types. AGB (above-ground biomass in kg/tree) is calculated.

$$AGB = 0.0673x(dbh^2xhtxwbd)^{0.976} \quad (1)$$

The equation developed by Kuyah et al. (2012) was used to estimate biomass of trees in parkland AF systems.

$$AGB = 0.225x(dbh)^{2.341}x(wbd)^{0.73} \quad (2)$$

We selected this equation due to its applicability to agricultural settings and its alignment with the environmental characteristics of our study location.

Due to the high cost and labor-intensive nature of direct measurement, below-ground biomass (BGB) was estimated as 20% of the above-ground biomass (AGB) for both land uses, following Gibbs et al. (2007).

$$BGB = 0.2xAGB \quad (3)$$

Litter biomass carbon estimation

The litter samples were brought to Wondo Genet College of Forestry and Natural Resources (WGCNFR) for laboratory analysis.

Litter dry biomass was calculated as follows:

$$LDM = \frac{\text{subsample dry mass} \times \text{Fresh mass of the whole sample}}{\text{subsample fresh mass}} \times \frac{1}{10000} \quad (4)$$

The expansion factor to hectares was converted by using the expansion factor = 10,000 m²/area of plot (m²).

$$LC = LDM \times \% C \quad (5)$$

Where LC was the total carbon stock in litter in t/ha, and % C was the carbon fraction determined in the laboratory according to Pearson et al. (2007).

The percentages of ash and organic carbon were calculated as

$$\% Ash = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad (6)$$

$$\% C = (100 - \% Ash) \times 0.5 \quad (7)$$

Percentage carbon content was estimated as 50% of OM according to Berhe et al. (2013).

Where: W1–Weight of crucible, W2–Weight of the oven-dried ground sample and crucible, and W3–Weight of ash and crucible

Soil data analysis

Once transported to the WGCENR, soil samples were treated with hydrochloric acid (HCl) to eliminate inorganic carbon. The soil organic carbon (SOC) content was then measured using the Walkley and Black (1934) wet oxidation technique, incorporating a correction factor of 1.33 to compensate for incomplete carbon oxidation.

Bulk density (g/cm^3) and soil organic carbon (t/ha) were determined as follows:

$$BD = (\text{Oven} - \text{dry weight of the soil}) / (\text{Volume of core sampler}) \quad (8)$$

$$SOC = BD \times \text{depth}(\text{cm}) \times \% C \times 10^{-1} \quad (9)$$

Where BD is bulk density, SOC is soil organic carbon, & 10^{-1} is a unit factor between study areas ($10^{-9} \text{ mg Mg}^1 \times 10^8 \text{ cm ha}^{-1}$).

Estimation of total carbon stock

Total carbon stock was determined by adding together the densities of each individual carbon pool.

$$TC = AGC \times BGC + LC + SOC \quad (10)$$

To evaluate differences in soil and biomass carbon between the forest and parkland AF systems, we conducted an independent samples t-test. We performed all statistical analyses using SPSS version 20.

RESULTS AND DISCUSSION

Table 1

The mean (t/ha) carbon stock in Gambo natural forest and its adjacent parkland AF

Land use categories	AGC	Std. error	BGC	Std. error	LC	Std. error	SOC	Std. error
Natural Forest	137.78	51.87	35.82	13.49	4.16	0.31	208.08	10.14
Parkland AF	61.74	6.07	12.35	1.21	1.85	0.08	134.02	14.23
p-value		0.17		0.11		0.001		0.001

Results

Above- and below-ground carbon stock

The AGB carbon storage was found to be greater in Gambo forest (137.78 t/ha) than in adjacent Parkland AF (61.74 t/ha) (Table 1 and Figure 3). The AGB carbon storage in Parkland AF was only 44.81% of the total found in the adjacent Gambo forest (Table 1). Similarly, the Gambo forest in the study area sequestered higher BGC (35.82 t/ha) than Parkland AF (12.35 t/ha) (Table 1 and Figure 3). Gambo Forest BGC was greater than adjacent parkland AF by more than 50% (Table 1). Even though the above-ground biomass and below-ground biomass carbon stock of Gambo forest were greater than its adjacent parkland AF, this difference was not statistically significant at $p < 0.17$ and $p < 0.11$, respectively (Table 1 and Appendix 1).

Litter and soil organic carbon

Litter carbon stocks and soil organic carbon (SOC) densities varied significantly between the studied land-use types. Specifically, the Gambo forest retained a significantly greater proportion of litter carbon at 69.22% (4.16 t/ha) compared to the adjacent Parkland AF system, which held only 30.78% (1.85 t/ha) ($p < 0.001$) (Table 1). Similarly, the Gambo forest exhibited a 55.27% higher SOC density (208.08 t/ha) than the Parkland AF (134.02 t/ha), representing a statistically significant difference ($p < 0.001$) (Table 1 and Appendices 4 and 5).

The total carbon stock in the Gambo forest was significantly higher at 385.84 t/ha, compared to

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26-41
209.97 t/ha in the adjacent parkland agroforestry system ($p < 0.011$). This huge difference shows that keeping natural forests safe stores a lot more carbon than turning land into farming areas (Table 2).

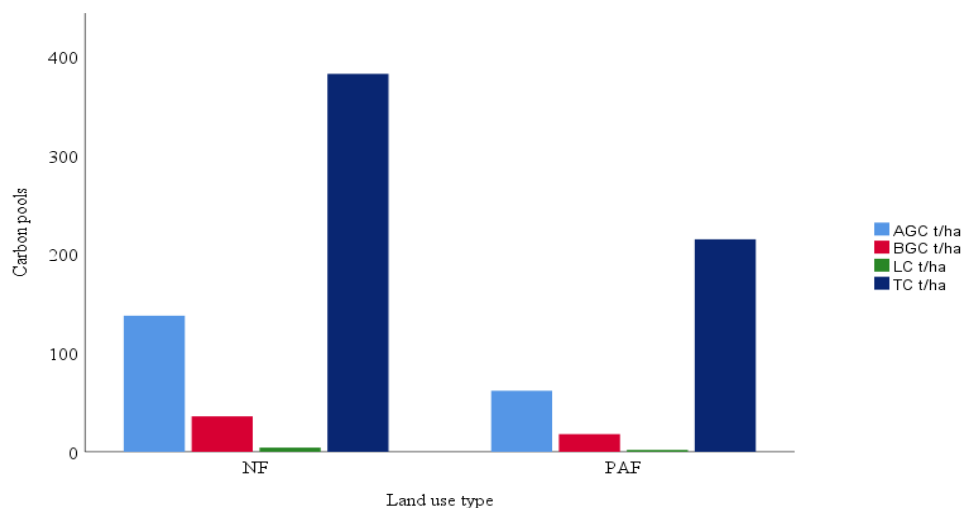
Table 2

Total carbon (TC) stock of study land uses

Land use stands	Mean (t/ha)	Standard error
Natural Forest TC	385.84	63.00
Parkland AF TC	209.97	12.88
P-value		0.011

In the natural forest, the total carbon stock is distributed among soil organic carbon (SOC) at 53.93%, above-ground biomass (AGB) at 35.71%, below-ground biomass (BGB) at 9.28%, and leaf litter biomass at 1.08%. A comparable distribution pattern was observed in the parkland agroforestry (AF) system, where soil, AGB, BGB, and leaf litter accounted for 63.83%, 29.40%, 5.89%, and 0.88% of the carbon pool, respectively.

Consequently, both land-use types followed an identical hierarchy in carbon storage capacity, with the largest reservoir found in the soil, followed sequentially by AGB, BGB, and leaf litter. Furthermore, consistent with our hypothesis, Figure 3 illustrates that the Gambo natural forest consistently maintained higher carbon stocks across all evaluated pools compared to the adjacent parkland (AF).

**Figure 3.** Carbon pools for each land use type

Discussion

Above ground and below ground Carbon stock

Above-ground carbon (AGC) stocks were evaluated across two distinct land-use types, with Gambo forest demonstrating significantly higher values compared to the adjacent parkland AF

system. Correspondingly, because below-ground carbon (BGC) was derived from AGC, the natural forest also exhibited higher BGC levels than the parkland AF. The Gambo forest exhibits greater biomass carbon than the parkland AF system due to its increased species diversity, higher stem

density, reduced disturbance, and a greater abundance of taller trees with larger diameters at breast height (DBH). Conversely, the lower carbon stocks in the parkland system are driven by anthropogenic pressures, including livestock grazing, fuelwood collection, and charcoal production. Livestock grazing, in particular, degrades vegetation and compacts soil, which severely hinders biomass carbon accumulation (Omoro et al., 2013; Habtamu et al., 2018). Furthermore, these discrepancies in carbon storage are influenced by distinct management practices, species composition, richness, basal area, and tree density per hectare. Natural environmental factors such as moisture, elevation, and temperature also foster stable, self-regulating conditions that maximize resource use and long-term organic matter storage, ultimately giving old-growth natural forests a significant advantage in total biomass over managed agroforestry systems (Ekka et al., 2026).

Environmental changes driven by altitude and elevation gradients significantly alter forest biomass across the studied plots (Feyissa et al., 2013). Within the study's 2100 to 2450-meter elevation range, colder temperatures at higher points suppress tree metabolism, photosynthesis, and decomposition, resulting in less living biomass than in warmer, lower areas. Biomass distribution is also regulated by localized moisture and temperature differences (Feyissa et al., 2013). Plots featuring moderate temperatures and high moisture support dense, large-diameter trees that maximize biomass. In contrast, plots suffering from moisture stress exhibit restricted growth and lower overall biomass.

The AGC stocks recorded in this study area were lower than those documented for both the Tara Gedam forest in Northwestern Ethiopia (Gedefaw et al., 2014) and the Chilimo Gaji forest in Central Ethiopia (Siraj, 2019).

Litter carbon stock

As shown in Appendices 2 and 3, litter carbon pools varied across land uses, with higher levels in

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26-41
the Gambo forest compared to the adjacent parkland AF. This disparity is likely due to lower litter accumulation in the parkland AF, resulting from human disturbances such as pruning branches and collecting fallen leaves for firewood, which are common local farming techniques (Negash and Starr, 2015). Conversely, the protected status of the Gambo forest resulted in less human disruption, enabling higher litter accumulation (Gatew et al., 2025).

Soil Organic Carbon stock

The SOC levels in the Gambo forest exceeded those in the adjacent parkland AF, as detailed in Appendices 4 and 5. This elevated SOC is primarily driven by a higher accumulation of litter biomass in the forest compared to the parkland system (Gibbs et al., 2007). In contrast, the lowest SOC levels occurred in AF, a trend directly linked to minimal organic matter inputs. Additionally, variations in SOC across different forest sites may stem from differing climatic and environmental conditions unique to each area (Negash & Starr, 2015).

Total Carbon Stock

With a total carbon stock of 385.82 t/ha, the Gambo forest in this study exhibits higher carbon sequestration levels than those reported for the Egdu forest (Feyissa et al., 2013) and Ziba and Anshirava forest (Gelaw et al., 2025) in Ethiopia (Table 3). The current study forest's total carbon stock was also greater than the carbon stock of the Gardula forest, southwestern Ethiopia (Gatew et al., 2025). However, the total carbon stock of the current study was less than that of the study conducted in Arba Minch Ground water Forest (Melese et al., 2014) (Table 3).

Comparatively, the 209.97 t/ha potential recorded in the parkland AF system adjacent to Gambo forest is substantially greater than figures from similar systems. For instance, it is notably higher than the 49.35 t/ha found in Silte woreda (Semere et al., 2024), the 59.65 Mg/ha in Minjar Shenkora (Tsedek et al., 2021), and the 122.6 t/ha observed in the Siaya region of Kenya (Henry et al., 2009).

Variations in carbon stocks across different studies are primarily driven by stand age, species composition, biodiversity, and forest management (Chave et al., 2014). Additional variables such as localized microclimates, ecological disturbances, and fuelwood harvesting also alter these estimates. Furthermore, discrepancies in biomass carbon data among these cited studies may often be due to methodological differences, including the choice of allometric equations, wood density values, minimum tree size thresholds, and inventory

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26-41
sampling designs (Chave et al., 2014). For instance, natural forests generally demonstrate more rapid growth and higher biomass accumulation than parkland agroforestry systems, resulting in more effective carbon sequestration over identical periods. Conversely, parkland systems experience continuous human disturbances, such as pruning, charcoal production, and fuel wood collection, which depress their carbon storage potential.

Table 3

Comparison of biomass carbon stock (t/ha) of the present study with other studies

Study place	AGC	BGC	TC
Natural Forest (this study)	137.78	35.82	385.84
Arba Minch Ground water Forest(Melese et al., 2014)	414.70	83.48	583.26
Egdu Forest (Feyissa et al., 2013)	278.0	55.62	333.7
Ades forest(Kassahun et al., 2015)	259.165	52.19	311.35
Ziba Forest (Gelaw et al., 2025)	-	-	140
Anshirava Forest (Gelaw et al., 2025)	-	-	226
Gardula Forest (Gatew et al., 2025)	-	-	271.57
Parkland AF (this study)	61.74	12.35	209.97
Parkland AF (Semere et al., 2024)	-	-	49.35
Parkland AF (Tsedeke et al., 2021)	-	-	59.65
AF in Keniya (Henry et al., 2009)	-	-	122.6

AGC= Above-ground carbon, BGC = Below-ground carbon, and TC = Total carbon.

CONCLUSION

Trees and forests play a crucial role in combating climate change by absorbing atmospheric carbon and storing it in their biomass for a long period of time. A current study in the Gambo forest demonstrated that the forest's total carbon stock (385.84 t/ha) is significantly higher than that of the adjacent parkland AF system (209.97 t/ha), highlighting how different land-use types vary in their carbon storage capacities. However, both systems contribute substantially to climate change mitigation; they both deserve better management and protection. These insights indicate that prioritizing forest conservation alongside enhanced AF practices can successfully boost carbon sequestration. Nevertheless, this study was restricted to a small geographic area and a few sample plots due to time and budget limitations, which may have impacted the

broader scalability of these carbon estimates across the wider Ethiopian highlands.

Recommendations

Based on the current study, the following actions are recommended:

Protect both land uses: Although the natural forest holds a larger carbon stock, adjacent agroforestry systems also sequester significant amounts of carbon. The local government should implement conservation efforts for both.

Implement financial incentives: The local government should establish Payments for Ecosystem Services (PES) programs to financially reward farmers who conserve natural forests and implement agroforestry practices.

Abera & Hanbesa

Encourage community management: The government should promote Participatory Forest Management (PFM) to actively involve and motivate local communities in managing agroforestry practices for carbon sequestration.

Coordinate multi-level conservation: Coordinated, integrated actions across all organizational levels are essential to mitigate deforestation and safeguard existing trees and forests within the study area.

Expand future research: Further comprehensive carbon stock estimation studies should be conducted by increasing both the geographic coverage and the number of sample plots in the region.

CRediT Author Statement

Abera Batu: Conceptualization, Data curation, Investigation, Formal analysis, and **Hanbesa Hashim:** Methodology, Supervision, writing the original draft, Validation.

Declaration of Competing Interest

The authors declare that there are no institutional, financial, or personal conflicts of interest related to this study.

Ethical Approval

Not applicable

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request and in compliance with institutional and ethical data-sharing guidelines.

Acknowledgements

The authors are highly grateful to Mr. Adem Dewid for his valuable help in mapping the study area. We also express our appreciation to the field owners for their cooperation and permission to conduct data collection on their farms.

REFERENCES

Berhe, L., Assefa, G., & Teklay, T. (2013). Models for estimation of carbon sequestered

Sci. Technol. Arts Res. J., July–Sep, 2026, 15(3), 26–41 by *Cupressus lusitanica* plantation stands at Wondo Genet, Ethiopia. *Southern Forests: A Journal of Forest Science*, 75(3), 113–122. <https://doi.org/10.2989/20702620.2013.80551>

Chave, J., Réjou-Méchain, M., Búrquez, A., et al. (2014). Improved Allometric Models to Estimate the Above-ground Biomass of Tropical Trees. *Global Change Biology*, 20, 3177–3190. <https://doi.org/10.1111/gcb.12629>.

Ekka, P., Saikia, P. (2026). Ecological attributes and tree biomass along urbanisation and elevation gradients in Ranchi, eastern India. *Discover Cities* (3), 30. <https://doi.org/10.1007/s44327-026-00212-4>

FAO. (2020). Global Forest Resources Assessment Main report. Rome. <https://doi.org/10.4060/ca9825en>

Feyissa, A., Soromessa, T., and Argaw, M. (2013). Forest Carbon Stocks and Variations along Altitudinal Gradients in Egdu Forest: Implications of Managing Forests for Climate Change Mitigation. *Science, Technology and Arts Research Journal*, 2(4), 40–46. <https://doi.org/10.4314/star.v2i4.8>.

Gatew, S., Zerihun, M. (2025). A Comparative Assessment of Carbon Stock Potential and Regeneration Status Between Natural and Plantation Forests in Southwest Ethiopia, *International Journal of Forestry Research*, 1597106, 14. <https://doi.org/10.1155/ijfr/1597106>

Gedefaw, M., Soromessa, T., 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, 101–107. <https://doi:10.4314/star.v3i1.16>.

Gelaw, F.A., Soromessa, T., Feyisa, S.T. et al. (2025). Biomass carbon stock dynamics: effects of disturbances and consequences for soil properties in the dry evergreen Afromontane forests of the Choke Mountain ecosystem, Ethiopia. *Discover Sustainability* (6) 528. <https://doi.org/10.1007/s43621-025-01368-6>

- Gibbs, H., Brown, S., Niles, J. and Foley, J. (2007). Monitoring and Estimating Tropical Forest Carbon Stocks: Making REDD a Reality. *Environment Research Letter*, 2(4), 045023.
<https://doi.org/10.1088/1748-9326/2/4/045023>.
- Habtamu, A, Hmelkot, M, and Engistie, T. (2018). Monitoring of Husbandry Practices and Harnessing of Working Equines in Hulet Eju Enese District, East Gojjam, Amhara Regional State, *Ethiopia*. (6)11. 437-446.
<https://doi.org/10.5829/idosi.ajh.2018.01.09>
- Hairiah, K., Sitompul, SM., Noordwijk, M. and Palm, C. (2001). Methods for Sampling Carbon Stocks Above and Below-ground. *International Centre for Research in Agroforestry*. Bogor, Indonesia,
<http://www.icraf.cgiar.org/sea>
- Hauck, M., Csapek, G., & Dulamsuren, Ch. (2023). The significance of large old trees and tree cavities for forest carbon estimates. *Forest Ecology and Management*. 546, 121319.
<https://doi.org/10.1016/j.foreco.2023.121319>.
- Henry, M., P. Tittonell, R.J. Manlay, M. Bernoux, A. Albrecht, B. Vanlauwe. (2009). Biodiversity, carbon stocks and sequestration potential in above-ground biomass in smallholder farming systems of western Kenya, *Agriculture, Ecosystems & Environment*, 129 (1–3), 238–252.
<https://doi.org/10.1016/j.agee.2008.09.006>.
- Gedefaw, M., Soromessa, T., 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), 101–107.
<https://doi.org/10.4314/star.v3i1.16>.
- Jose. (2009). Agroforestry for ecosystem services and environmental benefits: an overview, *Agroforestry Systems*, 76(1), 1–10, 2009.
<https://doi.org/10.1007/s10457-009-9229-7>.
- Kassahun, K., Soromessa, T., & Belliethathan, S. (2015). Forest Carbon Stock in Woody Plants of Ades Forest, Western Hararghe Zone of Ethiopia and its Variation along
A Peer-reviewed Official International Journal of Wollega University, Ethiopia
- Sci. Technol. Arts Res. J.*, July –Sep, 2026, 15(3), 26-41
- Environmental Factors: Implication for Climate Change Mitigation. *Journals & Books Hosting (International Knowledge Sharing Platform)*, 5(21), 96–109.
<http://iiste.org/Journals/index.php/JNSR/article/view/27126>
- Kothandaraman, S., Dar, J.A., et al. (2020). ecosystem-level carbon storage and its links to diversity, structural and environmental drivers in tropical forests of Western Ghats. India, *Scientific Reports* 10, 13444.
<https://doi.org/10.1038/s41598-020-70313-6>.
- Kuyah, S., Dietz, J., Muthuri, C., Jamnadass, R., Mwangi, P., Coe, R., & Neufeldt, H. (2012). Allometric equations for estimating biomass in agricultural landscapes: I. Above-ground biomass. *Agriculture Ecosystems & Environment*, 158, 216–224.
<https://doi.org/10.1016/j.agee.2012.05.011>
- Manaye, M., Negash, M., Alebachew M. (2019). Effect of degraded land rehabilitation on carbon stocks and biodiversity in the semi-arid region of Northern Ethiopia, *Forest Science and Technology* 15 (2), 70–79.
<https://doi.org/10.1080/21580103.2019.1592787>.
- Melese, B. W., Kelbesa, E., Soromessa, T. (2024). Forest Carbon Stocks in Woody Plants of Arba Minch Ground Water Forest and its Variations along Environmental Gradients. *Science, Technology and Arts Research Journal* 3(2),141.
<https://doi.org/10.4314/star.v3i2.18>
- Masha, M., Bojago, E., Belayneh, M., Tadila, G., Abera, A. (2024) Quantifying forest degradation rates and their drivers in Alle district, southwestern Ethiopia: *Implications for sustainable forest management practices*, *Geomatica*, 76 (2), 1195-1036.
<https://doi.org/10.1016/j.geomat.2024.100009>.
- Negash, M., Starr, M. (2015). Biomass and soil carbon stock of indigenous agroforestry systems on the south-eastern Rift Valley escarpment, *Ethiopia Plant Soil*. 393, 95–107.
<https://doi.org/10.1007/s11104-015-2469-6>

- Omoro, L. M. A., Starr, M., Pellicka, P. K. E. (2013). Tree biomass and soil carbon stocks in indigenous forests in comparison to plantations of exotic species in the Taita Hills of Kenya. *Silva Fennica*, 47(2), 935. <https://doi.org/10.14214/sf.935>
- Pearson, T., Brown, S. and Birdsey, R. (2007). *Measurement Guidelines for the Sequestration of Forest carbon*. Northern Research Station, Department of Agriculture, Washington. <http://www.nrs.fs.fed.us>
- Roshetko, J.M., Lasco, R.D., Angeles, M.S.D. (2007). Smallholder agroforestry systems for carbon storage. *Mitigation and Adaptation Strategies for Global Change* 12(2), 219–242. <https://doi.org/10.1007/s11027-005-9010-9>
- Semere, M., Tadesse, C., Abebe, T., Cherinet, A. & Gebreyesus, M. (2024). Comparative Carbon Stock Potential of Selected Indigenous Agroforestry Systems (AFSSs) in Silte Wereda, Southern Ethiopia. *East African Journal of Forestry and Agroforestry*, 7(1), 134-145. <https://doi.org/10.37284/eajfa.7.1.1868>
- Siraj, M. (2019). Forest carbon stocks in woody plants of Chilimo-Gaji Forest, Ethiopia: Implications of managing forests for climate change mitigation. *South African Journal of Botany*, 127, 213–219. <https://doi.org/10.1016/j.sajb.2019.09.003>
- Tadesse E, Abdulkedir A, Khamzina A. (2019). Contrasting species diversity and values in home gardens and traditional parkland agroforestry systems in ethiopian subhumid lowlands. *Journal of forestry*, 10, 266. <https://doi.org/10.3390/F1003-0266>
- Tesemma, B. A. (2007). *Useful trees and shrubs of Ethiopia: Identification, propagation and management for 17 Agro climatic Zones*. World Agroforestry Centre, East Africa Region, Nairobi, Kenya. <https://www.landscapealliance.org/knowledge/publication/33459/>
- Tolera, M., Asfaw. Z., Lemenih, M. Karlun, E. (2008). Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. *Agriculture Ecosystems & Environment* 128(1-2), 52-58. <https://doi.org/10.1016/j.agee.2008.05.001>
- Tsedek, E. R., Dawud, M. S., and Solomon M. (2021). Assessment of carbon stock potential of parkland agroforestry practice: the case of Minjar Shenkora; North Shewa, Ethiopia. *Environmental Systems Research* 10(1). <https://doi.org/10.1186/s40068-020-00211-3>.
- Wang, S, B.H. Boru, A.W., Njogu, A.C. Ochola, G., Hu, Y., Zhou, Q. (2019). Floristic composition and endemism pattern of vascular plants in Ethiopia and Eritrea. *J. Systematics and Evolution*, 58 (2019), 33-42. <https://doi.org/10.1111/jse.12527>
- Walkley, A. and Black, I. A. (1934). An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. *Soil Science*, 37 (1), 29-38. <https://doi.org/10.1097/00010694-193401000-00003>.

APPENDICES

Appendix 1

Above ground and below ground biomass carbon of study area

plot no	NF		PAF	
	AGC t/ha	BGC t/ha	AGC t/ha	BGC t/ha
1	10.05954	2.615482	39.0617	7.81234
2	213.1639	55.42262	22.49543	4.499086
3	16.93409	4.402863	100.5991	20.11982
4	60.66282	15.77233	69.84003	13.96801
5	3.936525	1.023497	21.46592	4.293184
6	7.278619	1.892441	72.35354	14.47071
7	59.48546	15.46622	72.51924	14.50385
8	17.39758	4.52337	100.6785	20.1357
9	12.51887	3.254905	50.51205	10.10241
10	237.9628	61.87033	30.17432	6.034864
11	1016.788	264.3649	56.01836	11.20367
12	67.16209	17.46214	103.6296	20.72592
13	252.7922	65.72597	53.28176	10.65635
14	237.9628	61.87033	85.15096	17.03019
15	24.24013	6.302433	51.72885	10.34577
16	327.0487	85.03267	39.1825	7.8365
17	14.3834	3.739685	100.2829	20.05658
18	11.94994	3.106985	45.75028	9.150056
19	157.8886	41.05105	36.376	7.2752
20	6.286039	1.63437	83.71472	16.74294
Av.	137.7951	35.82673	61.74078	12.34816

Appendices 2

Data Sheet Litter Sampling natural forest

Plot number	FW(g)	SSFW(g)	DW	LDM	%OM	%OC	LC
P-1	516	100	84.75	0.060884956	85.80706	56.76809	3.456322648
P-2	468	100	90.17	0.051901963	77.05404	51.69134	2.682882014
P-3	714	100	77.5	0.092129032	77.35612	51.86655	4.778415058
P-4	510	100	81.8	0.062347188	80.86142	53.89962	3.360489756
P-5	506.8	100	71.34	0.07104009	84.36963	55.93439	3.973584084
P-6	432	100	76.74	0.05629398	81.16607	54.07632	3.044171259
P-7	590.4	100	80.66	0.073196132	75.69102	50.90079	3.725740939
P-8	720	100	66.62	0.108075653	79.39314	53.04802	5.7331994
P-9	702	100	79.27	0.088558093	85.59824	56.64698	5.0165485
P-10	436.8	100	75.57	0.057800715	83.85291	55.63469	3.215724837
P-11	428.4	100	81.24	0.052732644	83.61821	55.49856	2.926585808
P-12	526.4	100	83.8	0.062816229	83.60958	55.49356	3.485896179
P-13	738	100	74.43	0.099153567	82.27233	54.71795	5.425479927
P-14	596.4	100	72.69	0.082047049	82.31944	54.74528	4.491688677
P-15	433.2	100	85.02	0.050952717	81.65031	54.35718	2.76964601
P-16	444	100	79.48	0.03528912	83.09067	55.19259	3.083229738
P-17	516	100	88.5	0.058305085	84.20476	55.83876	3.255683634

P-18	933.6	100	67.73	0.137841429	90.05837	59.23385	8.164878541
P-19	687.2	100	74.18	0.092639525	91.68636	60.17809	5.574869702
P-20	654.4	100	77.9	0.084005135	92.5287	60.66665	5.09631011
				0.074929215			4.163067341

Appendices 3

Data Sheet Litter Sampling Parkland AF Litter Data

plot number	FW(g)	SSFW(g)	DW	LDM	%OM	%OC	LC
P-1	345	100	69.56	0.0239982	93.40028	54.17216	2.68680207
P-2	202	100	72.6	0.027823691	92.85644	53.85674	1.498493317
P-3	275	100	67.73	0.040602392	91.05837	52.81385	2.144368633
P-4	301	100	72.95	0.041261138	92.64825	53.73599	2.217208086
P-5	260	100	61.89	0.042010018	88.1297	51.11523	2.147351721
P-6	270	100	66.35	0.040693293	90.86812	52.70351	2.144679382
P-7	234	100	70.47	0.033205619	91.60242	53.1294	1.764194636
P-8	250	100	79.17	0.031577618	92.25325	53.50689	1.689620121
P-9	266	100	88.16	0.030172414	92.31842	53.54468	1.615572241
P-10	260	100	64.09	0.040567951	91.39534	53.0093	2.150478702
P-11	257	100	79.01	0.032527528	92.83767	53.84585	1.751472402
P-12	278	100	76.62	0.036282955	91.74883	53.21432	1.93077277
P-13	254	100	88.97	0.028548949	93.19272	54.05178	1.543121515
P-14	228	100	75.47	0.02173536	94.0872	54.57058	1.648614316
P-15	264	100	79.87	0.02108568	94.24448	54.6618	1.80677541
P-16	271	100	74.6	0.036327078	92.63943	53.73087	1.951885492
P-17	245	100	81.13	0.030198447	92.80853	53.82895	1.62555069
P-18	314	100	82.16	0.038218111	92.25364	53.50711	2.044940669
P-19	243	100	78.86	0.030814101	93.74772	54.37368	1.675476064
P-20	140	100	77.62	0.018036589	94.21942	54.64726	0.985650142
				0.034586488			1.851151419

Appendices 4

Soil organic carbon for natural forest

plot no	BD(gm/cm3)	D(cm)	%OC	SOC
P-1	0.4765072	30	11.66688	166.78
P-2	0.61267232	30	9.714624	178.56
P-3	0.71201728	30	11.38925	243.28
P-4	0.58074848	30	11.11344	193.62
P-5	0.74384128	30	11.52346	257.15
P-6	0.73677552	30	9.01824	199.33
P-7	0.43131712	30	10.28851	133.13
P-8	0.7606976	30	11.29939	257.86
P-9	0.58860048	30	10.17408	179.65
P-10	0.786552	30	11.6567	275.06
P-11	0.50527152	30	10.01894	151.87
P-12	0.5696496	30	10.11898	172.93
P-13	0.66924	30	9.477696	190.29
P-14	0.61240816	30	13.02912	239.37
P-15	0.54174848	30	10.45594	169.93
P-16	0.63815856	30	8.259552	158.13

P-17	0.58555744	30	11.70374	205.60
P-18	0.49531248	30	18.82483	279.73
P-19	0.47144656	30	18.19584	257.35
P-20	0.36485488	30	23.03578	252.14
Av.				208.09

Appendices 5

Soil organic carbon for park land AF

Plot no	BD(gm/cm3)	D(cm)	%OC	SOC
P-1	0.459	30	10.88941	149.79
P-2	0.657503299	30	11.75392	231.85
P-3	0.659772598	30	5.76973	114.20
P-4	0.42556811	30	6.79552	86.76
P-5	0.488722864	30	8.581248	125.82
P-6	0.291492528	30	5.76973	50.45
P-7	0.44612383	30	9.412416	125.97
P-8	0.316360701	30	8.25446	78.34
P-9	0.285544768	30	10.62195	90.99
P-10	0.55961232	30	19.0944	320.56
P-11	0.408693466	30	11.99366	147.05
P-12	0.689436888	30	9.120384	188.64
P-13	0.516323085	30	10.17619	157.63
P-14	0.506448496	30	4.300096	65.33
P-15	0.477041725	30	10.55808	151.10
P-16	0.410926163	30	15.63568	192.75
P-17	0.487466645	30	8.19936	119.91
P-18	0.410926163	30	8.918208	109.94
P-19	0.717796592	30	3.571776	76.91
P-20	1.027157237	30	3.132672	96.53
Av.				134.0268871

Appendix 6

Basic Wood Density of Species in the study area

Scientific Name of species	WBD (g/cm3)
<i>Allophylus abyssinicus</i>	0.491
<i>Apodytes dimidiata</i>	0.61
<i>Bersama abyssinica</i>	0.671
<i>Buddleja polystachya</i>	0.4
<i>Cassipourea malosana</i>	0.673
<i>Celtis africana</i>	0.76
<i>Croton macrostachyus</i>	0.56
<i>Dombeya torrida</i>	0.588
<i>Ekebergia capensis</i>	0.58
<i>Fagaropsis angolensis</i>	0.7
<i>Ficus sycomorus</i>	0.422

<i>Hagenia abyssinica</i>	0.56
<i>Juniperus procera</i>	0.54
<i>Maesa lanceolata</i>	0.676
<i>Maytenus arbutifolia</i>	0.713
<i>Millettia ferruginea</i>	0.738
<i>Nuxia congesta</i>	0.512
<i>oncoba spinosa</i>	0.647
<i>Pittosporum viridiflorum</i>	0.633
<i>Podocarpus falcatus</i>	0.52
<i>Polyscias fulva</i>	0.44
<i>Premna schimperi</i>	0.658
<i>Prunus africana</i>	0.85
<i>Rapanea melanophloeos</i>	0.732
<i>Schefflera abyssinica</i>	0.491
<i>Schefflera volkensii</i>	0.405
<i>Schrebera alata</i>	0.79
<i>Syzygium guineense</i>	0.74
<i>Vepris dainellii</i>	0.7

Appendix 7

Picture captured by authors during data collection



A. DBH measurement in AF



B. DBH measurement in Gambo natural Forest



C. 1m by 1m plot for litter and soil sampling



D. soil sampling