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RESEARCH

Carbon stock estimation of Jiga dry afromontane forest of Jabitehnan District, Amhara National Regional State, northwestern Ethiopia

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Background: Forests are crucial for maintaining carbon balance, as they function both as carbon sources and as sinks that absorb carbon dioxide (CO_2) from the atmosphere, thereby helping to mitigate climate change. Forest ecosystems store over 80% of all terrestrial above ground carbon and more than 70% of soil carbon. A systematic sampling method was used to collect vegetation data. A total of 50 plots, each with 400 m^2 (20 m × 20 m), were established along eight lines transect to estimate the carbon stock of the forest. Litter, herb, and grass samples were collected from the four corners and the center of each main sample plot using subplots measuring 2 m × 2 m (4 m^2). The collected samples were weighed in the field to determine their fresh weight, and a 100 g composite sub-sample was taken from each plot for further analysis. The soil samples were collected from four corners and the center of each plot at a depth of 30 cm. All the collected plant species were identified in Debre Markos University Biology Department Herbarium Room.
Results: The mean above ground biomass and carbon stock stored in tree species per plot were 712.51 and 334.88 ton ha^{-1}, respectively. The mean biomass and carbon stock in the litter carbon stock of Jiga Forest were 2.68 ton ha^{-1} and 1.26 ton ha^{-1}, respectively. The mean soil organic carbon of Jiga forest was 248.06 ton ha^{-1}.
Conclusions: The carbon stock assessment of Jiga Forest exhibits a high mean above ground biomass and carbon stock due to its rich species composition and the presence of mature, large diameter trees.

Keywords: biomass, carbon stock, climate change

Introduction

Forests are crucial for maintaining carbon balance, as they function both as carbon sources and as sinks that absorb carbon dioxide (CO_2) from the atmosphere, thereby helping to mitigate climate change. Forest ecosystems store over 80% of all terrestrial above ground carbon (AGC) and more than 70% of soil carbon. In Ethiopia, forest resources hold approximately 2.76 billion tons of carbon, equivalent to about 10 billion tons of CO_2 in above ground biomass (AGB) (Moges et al. 2010).

The release of CO_2 into the atmosphere is a leading cause of climate change and global warming, as it raises atmospheric temperatures and threatens life on Earth. However, this impact can be mitigated by forests, which serve as significant carbon sinks. Through the process of photosynthesis, trees absorb CO_2 from the atmosphere and convert it into carbohydrates, storing carbon in their tissues. As trees grow and their biomass expands, they continue to sequester carbon, contributing to the development of various plant parts and helping to regulate the global carbon cycle (Missanjo et al. 2015).

Ecological studies are essential for understanding the status of the forest and developing a plan for conservation action (Vivero et al. 2005). Therefore, conducting a study on the carbon stock of the forest is essential to develop a plan for the wise use of forest resources and their conservation in an efficient way. In west Gojjam Zone, different studies, such as Birhanu et al. (2018) on Amoro Forest, Mekonnen and Wassie (2022) on Wonjeta St Micheal Church Forest has been conducted regarding floristic composition and vegetation structures, but there is a limited study in Jiga Forest. The absence of previous studies in the study area regarding carbon stock estimation is the main reason

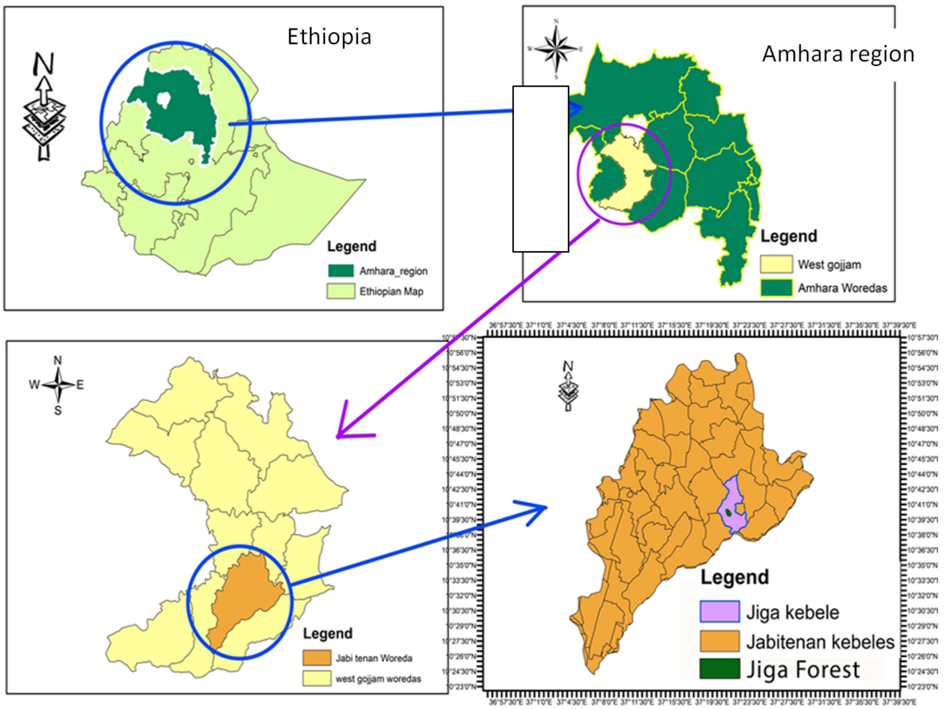

Fig. 1 The map of Jiga Forest in Jabitenan District.

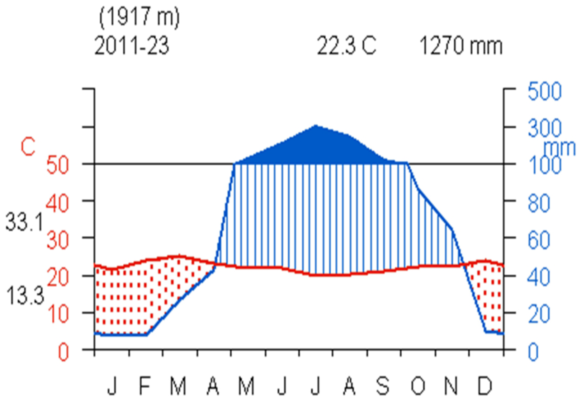

Fig. 2 Clima diagram of the study area.

Fig. 3 Partial view of plant community of Jiga Forest.

for this scientific study.

Materials and Methods

Description of the study area

The study was conducted in Jiga Forest located in Jabitehnan District, west Gojjam Zone, Amhara National Regional State, which is situated between 10°40′33″N and 37°23′18″E with the altitudinal range between 1,795 and 1,856 m a.s.l. The district town Jiga is about 372 km North of Addis Ababa and 185 km South of Bahir Dar, the capital of Amhara Regional State, and about 14.4 km southeast of the zone capital Finote Selam (Fig. 1).

Climatic data for the study area were obtained from the National Meteorology Service Center in Bahir Dar, covering a thirteen-year period (2011–2023). The district receives an average annual rainfall of 1,270 mm. The area experiences a prolonged rainy season from May to October, with peak rainfall occurring between June and September, while only light rainfall is recorded from December to February. The mean minimum and maximum temperatures are 13.3°C and 33.1°C, respectively, with an overall mean annual temperature of approximately 22.3°C (Fig. 2).

Sampling technique

A systematic random sampling technique was employed for the collection of vegetation and environmental data. In this approach, the first plots were laid randomly from the base of forest after the first plots the sample plots were taken at a fixed interval starting from the base to the top of the forest and the distance between each plot is 20 m distance and 50 meters separating each transect that does not coincide with any pattern in the vegetation due to either to the properties of plants themselves or to some regularly distributed environmental control (Kent 2012). A total of 50 plots were collected from the forest (Fig. 3).

Carbon stock estimation

To estimate the forest carbon stock, the diameter at breast height (DBH) and height of all trees and shrubs within systematically selected sample plots measuring 20 m × 20 m (400 m^2) were recorded. In this study, DBH was measured only for woody species with a DBH greater than 5 cm, while individuals with a DBH less than 5 cm were not measured. DBH and height measurements were taken using a measuring tape, starting from the plot edges and moving inward. Trees with multiple stems above breast height were recorded as a single individual (Pearson et al. 2005).

Litter, herbs, and grasses sampling

Litter, herbs, and grasses samples are collected from four corners, and the center of main sample plot subplots which has 2 m × 2 m (4 m^2) were collected, weighed, and recorded as field wet weight on the field, and 100 g of evenly mixed sub-samples for each plot were taken to Debre Markos Soil Fertility Improvement Laboratory to determine dry biomass and percentage of carbon.

Soil sampling

The soil samples were collected from four corners and the center of each plot from a depth of 30 cm and mixed, and a composite sample of 100 g from each plot was taken to Debre Markos Soil Fertility Improvement Laboratory for soil carbon analysis. For the bulk density determination of soil, a core sampler was used to collect soil samples to calculate bulk density.

Carbon stock analysis

The total carbon stock of the forest was analyzed by calculating aboveground live biomass, dead tree biomass, below ground biomass (BGB), and litter biomass (Pearson et al. 2005). The AGB and BGB were converted to carbon stock densities after multiplication with the IPCC (2006) default carbon fraction of 0.47.

AGB was calculated using a previously published allometric equation using an important parameter of height and DBH used for estimating tree biomass and carbon stock (Brown et al. 2004). In this research, allometric models were selected because preference was given to equations using DBH and tree height, which is easily measurable and strongly correlated with biomass.

$$AGB = 0.0673*(\rho D^2H)^{0.976}$$

Where: AGB = above ground biomass in kg
ρ = specific wood density in g cm^{-3}
D = stem diameter at breast height
H = total height of tree in meter

BGB of woody plant species was analyzed from the relationship of its AGB. BGB is estimated to be 20% of the AGB (Brown 1997).

$$BGB = AGB \times 0.2$$

Where: BGB = below ground biomass in kg
AGB = above ground biomass in kg

To analysis litter, herbs and grasses 100 g of mixed subsamples of fresh weight were oven dried at 105°C for 24 hours. The oven-dried samples were ground and 20 g samples were combusted in pre-weighted crucibles in the furnace at 550°C for two hours to ignite then, the cooled crucibles with ash were weighted to determine the percentage of organic carbon in the litter using the loss on ignition method following Tilahun (2018). The weight loss is assumed to be proportional to the amount of organic carbon contained in the sample.

$$LB = \frac{Dry\ weight}{Fresh\ weight} \times \frac{\text{W field}}{\text{A}}$$

Where: LB - litter biomass, W field - weight of fresh sample of litter sampled within an area of size 1 m^2, A – area of sample in ha

To determine Soil Organic Carbon field moist soil was dried in an oven at 105°C for 24 hours in the laboratory, and re-weighted to determine moisture content and dry bulk density. To estimate the percentage of organic carbon, samples were analyzed. Organic matter is converted to organic carbon using the factor SOC = SOM × 0.58 (Pribyl 2010).

Where: SOC = soil organic carbon, SOM = soil organic matter

The carbon stock density of soil organic carbon was calculated from the volume and bulk density of the soil.

$$V_{of\ soil\ in\ core\ sampler} = \pi r^2 h$$

$$BD = \frac{mass\ of\ ovendry\ soil}{volume\ of\ soil}$$

$$SOC = BD * d * \%\ C$$

Results

Carbon stock of Jiga Forest

AGB and carbon stock of Jiga Forest

The mean AGB and carbon stock stored in tree species per each plots were 712.51 and 334.88 ton ha^{-1}, respectively. The minimum and maximum carbon density per plot were

Table 1 Above ground biomass (AGB) and carbon stock of top ten species Jiga Forest

No	Species	AGB (ton ha^{-1})	BGB (ton ha^{-1})	AGC (ton ha^{-1})	BGC (ton ha^{-1})
1	*Cordia africana*	6,368.4	1,274.0	2993.2	598.6
2	*Ficus vasta*	45,935.0	9,187.0	21,589.4	4,317.9
3	*Teclea nobilis*	463.5	92.7	217.8	43.6
4	*Ficus sur*	3,207.5	641.5	1,507.5	301.5
5	*Combretum collinum*	996.0	199.2	468.1	93.6
6	*Croton macrostachyus*	764.8	153.0	359.5	71.9
7	*Albizia schimperiana*	2,040.1	408.0	958.9	191.8
8	*Phoenix reclinata*	106.7	21.3	50.2	10.0
9	*Vernonia amygdalina*	36.1	7.2	16.9	3.4
10	*Dracaena steudneri*	18.8	3.8	8.9	1.8

BGB: below ground biomass; AGC: above ground carbon; BGC: below ground carbon.

0.84 and 1,172.1 ton ha^{-1}. The minimum and maximum AGB per plot were 1.79 and 2,493.08 tons per ha respectively. The AGB of woody species varied among the plant species the highest AGB per tree was obtained from a tree species having the highest DBH value for instance *Ficus vasta, Cordia africana, Albizia schimperiana, Teclea nobilis, Ficus sur, Combretum collinum*, and *Croton macrostachyus*. The lowest AGB per tree was obtained from a tree species having less DBH value for instance *Vernonia amygdalina, Phoenix reclinata* and *Dracaena steudneri* and also the AGC stock of Jiga Forest showed variation among plot in which plot 14 contributed the highest AGC stock followed by plot 13 and plot 28 and the least AGC stock was obtained from plot 21 has 14.88 ton ha^{-1} (Table 1).

BGB and carbon stock of Jiga Forest

The mean BGB and below ground carbon (BGC) of Jiga Forest was 620 ton ha^{-1} and 291.4 ton ha^{-1} respectively. BGB shows direct proportionality because it is derived from AGB. Similar to AGB, the amount of BGB in this study showed variation between plots and plant species.

Litter, herbs and grasses carbon stock

Litter biomass and carbon stock of Jiga Forest have been estimated from 50 sample plots within 1 m × 1 m individual subplots. The mean biomass and carbon stock in the litter carbon stock of Jiga Forest were 2.68 ton ha^{-1} and 1.26 ton ha^{-1}, respectively. The minimum and maximum litter biomass estimation of Jiga Forest were 1.8 and 3.6 ton ha^{-1} and the minimum and maximum litter carbon stock estimation of Jiga Forest were 0.85 and 1.69 ton ha^{-1}. The CO_2 sequestration potential of Jiga Forest was obtained by multiplying the litter carbon stock of the forest by 3.67. Therefore, mean CO_2 sequestration potential of Jiga forest in the litter per plot was 4.62 ton ha^{-1} (Table S1).

Soil carbon stock

Soil test analysis of Jiga forest shows that the soil bulk density ranged from 0.50.86 g cm^{-3} to 1.22 g cm^{-3} while the average soil bulk density was 1.01 g cm^{-3} from this bulk density of the forest soil organic carbon was calculated and soil organic carbon showed that, the mean soil organic carbon of Jiga forest was 248.06 ton ha^{-1} with a minimum value of 207.01 ton ha^{-1} to the maximum of 289.17 ton ha^{-1}. The CO_2 sequestration potential of Jiga Forest was obtained by multiplying the litter carbon stock of the forest by 3.67; therefore mean CO_2 sequestration potential of Jiga Forest in soil organic matter per plot was 910.38 ton ha^{-1} (Table S2).

Discussion

AGC and BGC stock

AGB and BGB are key indicators used to assess the carbon storage capacity of vegetation, playing a vital role in evaluating the contribution of forests to carbon sequestration and climate change mitigation. AGB includes all plant biomass found above the soil surface, such as trunks, branches, and leaves, while BGB encompasses the biomass contained in root systems. The associated AGC and BGC values indicate the amount of carbon stored within these respective components of forest biomass (Misganaw et al. 2021).

The AGB of woody species varied among the plant species highest AGB per tree was obtained from a tree species having the highest DBH value for instance *F. vasta, C. africana, A. schimperiana, T. nobilis, F. sur, C. collinum,* and *C. macrostachyus.* The mean AGB and carbon stock stored in tree species per plot were 712.51 and 334.88 ton ha^{-1}, respectively. The minimum and maximum carbon density per plot were 0.84 and 1,172.1 ton ha^{-1}. The minimum and maximum AGB per plot were 1.79 and 2,493.08 tons per ha, respectively. The AGB of woody species varied among the plant species highest AGB per tree was obtained from a tree species having the highest DBH value, for instance, *F. vasta, C. africana, A. schimperiana, T. nobilis, F. sur, C. collinum,* and *C. macrostachyus.* This finding helps to prioritize those tree species having the highest DBH value for conservation and sustainable use.

The lowest AGB per tree was obtained from a tree species having less DBH value for instance *V. amygdalina, P. reclinata* and *D. steudneri* and also the AGC stock of Jiga Forest showed variation among plot in which Plots 14, 13, and 28 stored the highest carbon stocks these areas should be designated as priority conservation zones, while plots with lower carbon can be targeted for restoration and enrichment planting. The mean AGC stock stored in tree species per plot was 334.88 ton ha^{-1}. This value was compared with carbon stocks reported for other dry Afromontane forests in Ethiopia (Gebeyehu et al. 2019). The relatively high carbon stock observed in this forest is primarily attributed to the presence of larger trees with greater DBH and height, whereas forests dominated by medium-sized trees generally exhibit lower carbon storage.

The carbon stock of Jiga Forest is relatively high compared with many dry Afromontane forests in Ethiopia and Africa, but it also differs considerably from other forest biomes globally. The mean AGC stock of Jiga Forest 334.88 ton ha^{-1} is greater than values reported for some tropical dry forests, which typically range between 100–250 ton ha^{-1}, but lower than the carbon densities found in tropical moist rainforests such as the Amazon or Congo Basin, where AGC stocks can exceed 400–600 ton ha^{-1} (Pan et al. 2011; Saatchi et al. 2011). Similarly, the soil organic carbon stock of Jiga Forest (248.06 ton ha^{-1}) is higher than the global average for tropical forests 150 ton ha^{-1}, but lower than boreal forests, which may exceed 400 ton ha^{-1} due to colder climates that slow decomposition rates (Batjes 2014).

The observed differences between Jiga Forest and other global biomes can be attributed to several ecological and climatic conditions influence soil carbon storage warmer temperatures and seasonal rainfall in dry Afromontane forests promote faster organic matter decomposition compared with boreal systems, resulting in lower long-term soil carbon accumulation and disturbance history and land-use practices may also explain variation forests with a history of selective logging, grazing, or fire often show reduced biomass and carbon stocks compared with intact forests.

BGC stock of the forest is directly proportional with that of AGC stock of the forest higer AGC stock has high BGC stock which is 20% of AGC stock (Brown 1997). The mean BGB and BGC of Jiga Forest were 620 ton ha^{-1} and 291.4 ton ha^{-1} respectively.

Soil carbon stock

The mean soil organic carbon of Jiga forest was 248.06 ton ha^{-1} with a minimum value of 207.01 to the maximum of 289.17 ton ha^{-1}. This value covered 38% of the total carbon stock of the forest. This value is higher than the standard value of soil organic carbon 130 ton ha^{-1} and also higher compared with that of related study of dry afromontane forest of Gebeyehu et al. (2019) May be due to the presence of high humus and relatively slow decomposition rates under forest conditions, which favor the accumulation and long term storage of carbon in the soil.

The soil test analysis of Jiga Forest reveals critical information about soil health and its capacity for carbon storage. With an average soil bulk density of 1.01 g cm^{-3} and a mean soil organic carbon content of 248.06 ton ha^{-1}, the forest exhibits favorable conditions for ecological health and carbon sequestration. This data underscores the importance of conserving and managing the forest to enhance its contributions to carbon cycling, biodiversity, and climate change mitigation. Sustainable practices can further optimize the carbon sequestration potential of Jiga Forest, making it a vital asset in the fight against climate change.

Litter, herbs and grasses carbon stock

The litter biomass and carbon stock of Jiga Forest reveal important ecological characteristics that contribute to its role in carbon sequestration. Maintaining litter and understory vegetation contributes to soil fertility and long term carbon storage. Continued monitoring and management of these forest ecosystems are essential for maximizing their benefits in climate regulation, biodiversity support, and overall ecological health. The mean litter biomass of 2.68 ton ha^{-1} indicates a moderate level of organic material available on the forest floor, which is crucial for soil fertility, moisture retention, and habitat for various organisms. The mean litter carbon stock of 1.26 ton ha^{-1} reflects the amount of carbon stored in the litter layer. This carbon is vital for mitigating climate change, as it represents carbon that is sequestered from the atmosphere. The observed range of litter biomass from 1.8 ton ha^{-1} (minimum) to 3.6 ton ha^{-1} (maximum) suggests variability in litter accumulation, possibly due to differences in vegetation types, soil conditions, microclimates, or disturbances. Such variability can provide insights into ecological processes and the health of different forest areas.

The mean carbon stock in the litter carbon stock of Jiga Forest was 1.26 ton ha^{-1} which is lower than AGC and BGC stock of tree species and soil carbon stock of Jiga forest because high carbon stock in above ground vegetation recorded due to presence of abundant and large sized woody species (Tilahun 2018). The high carbon stock potential of trees in the forest was attributed due to the density, age, and DBH of the tree species the study conducted by Shrestha and Singh (2008) reported that the size and age of trees, could affect the carbon stock of forest ecosystem. This litter, herbs and grasses carbon stock of jiga forest is better than (Addi 2018) with its mean value 0.57 areas.

The mean carbon stock in the litter carbon stock of Jiga Forest was 1.26 ton ha^{-1} which is lower than AGC and BGC stock of tree species and soil carbon stock of Jiga forest because high carbon stock in above ground vegetation recorded due to presence of abundant and large sized woody

species (Tilahun 2018). The high carbon stock potential of trees in the forest was attributed due to the density, age, and DBH of the tree species the study conducted by Shrestha and Singh (2008) reported and lower than the litter, herbs and grasses carbon stock of (Hassen 2015) with its mean value 2.20 ton ha^{-1}.

Conclusions

The carbon stock assessment of Jiga Forest exhibits a high mean AGB and carbon stock of 712.51 ton ha^{-1} and 334.88 ton ha^{-1}, respectively, with species like *F. vasta, C. africana*, and *A. schimperiana* contributing substantially due to their large DBH values. Conversely, species with smaller DBH, such as *V. amygdalina* and *D. steudneri*, had lower carbon contributions. BGB and carbon stock, directly proportional to the above ground values, were estimated at 620 ton ha^{-1} and 291.4 ton ha^{-1}. The mean soil organic carbon stock was 248.06 ton ha^{-1}, and litter, herbs, and grasses contributed moderately, with a mean carbon stock of 1.26 ton ha^{-1}. The variation among plots and species reflects the forest's structural diversity and ecological complexity. Overall, Jiga Forest holds a high total carbon stock compared to other dry Afromontane forests in Ethiopia, although it remains lower than tropical moist forests globally due to its rich species composition and the presence of mature, large diameter trees.

Supplementary Information

Supplementary information accompanies this paper at https://doi.org/10.5141/jee.25.056.

Table S1. Total carbon stock of Jiga Forest. **Table S2.** Soil test of Jiga Forest.

Abbreviations

CO$_2$: Carbon dioxide
DBH: Diameter at breast height
AGB: Above ground biomass
BGB: Below ground biomass
AGC: Above ground carbon
BGC: Below ground carbon
LB: Litter biomass
SOC: Soil organic carbon
SOM: Soil organic matter

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Authors' contributions

All authors have made essential academic contributions to this manuscript. DZ collected and analyzed the data; YD prepared the draft of the manuscript and edited the prepared manuscript; AK revised the techniques for data collection, and critically reviewed and organized the paper sequence and HM reviewed the manuscript. All authors read and approved the final draft of the manuscript.

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Availability of data and materials

Data and supplementary materials will be available on reasonable request to corresponding author.

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Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

Addi A. The ecology, carbon stock, bee forage diversity in a moist Afromontane forest of Gesha and Sayilem districts in Kaffa zone, South West Ethiopia [PhD dissertation]. Ethiopia: Addis Ababa University; 2018.

Batjes NH. Total carbon and nitrogen in the soils of the world. Eur J Soil Sci. 2014;65(1):10-21. https://doi.org/10.1111/ejss.12114_2.

Birhanu L, Bekele T, Demissew S. Woody species composition and structure of Amoro Forest in West Gojjam Zone, North Western Ethiopia. J Ecol Nat Environ. 2018;10(4):53-64. https://doi.org/10.5897/JENE2018.0688.

Brown S. Estimating biomass and biomass change of tropical forests: a primer. FAO Forest Paper 134. Rome: FAO; 1997.

Brown S, Shoch D, Pearson T, Delaney M. Methods for measuring and monitoring forestry carbon projects in California. Arlington: Winrock International Publishing; 2004.

Gebeyehu G, Soromessa T, Bekele T, Teketay D. Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia. J Ecology Environ. 2019;43:7. https://doi.org/10.1186/s41610-019-0105-8.

Hassen N. Carbon stocks along an altitudinal gradient in Gera Moist Evergreen Afromontane forest, Southwest Ethiopia [MSc dissertation]. Ethiopia: Addis Ababa University; 2015.

IPCC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 2006. https://www.ipcc-nggip.iges.or.jp/public/2006gl/. Accessed 12 Oct 2023.

Kent M. Vegetation description and data analysis: a practical approach. 2nd ed. Hoboken: Wiley-Blackwell; 2012.

Mekonnen AB, Wassie WA. Floristic composition, structure and regeneration status of woody plants in Wonjeta St Micheal Church Forest, Northwestern Ethiopia. Research Square [Preprint]. 2022 [cited 2022 Dec 21]. Available from: https://doi.org/10.21203/rs.3.rs-2243112/v1.

Meragiaw M, Woldu Z, Martinsen V, Singh BR. Carbon stocks of above- and belowground tree biomass in Kibate Forest around Wonchi Crater Lake, Central Highland of Ethiopia. PLoS One. 2021;16(7):e0254231. https://doi.org/10.1371/journal.pone.0254231.

Missanjo E, Kamanga-Thole G, Bonongwe D. Allometric equations for estimation of above ground biomass of Eucalyptus camaldulensis in Malawi. Journal of Basic and Applied Research International. 2015;2(2):41-7.

Moges Y, Eshetu Z, Nune S. Ethiopian forest resources: current status and future management options in view of access to carbon finances. 2010. https://www.un-redd.org/document-library/ethiopian-forest-resources-current-status-and-future-management-options-view. Accessed 25 Nov 2024.

Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA, et al. A large and persistent carbon sink in the world's forests. Science. 2011;333(6045):988-93. https://doi.org/10.1126/science.1201609.

Pearson T, Walker S, Brown S. Sourcebook for land use, land-use change and forestry projects. Winrock International and the BioCarbon; 2005.

Pribyl DW. A critical review of the conventional SOC to SOM conversion factor. Geoderma. 2010;156(3-4):75-83. https://doi.org/10.1016/j.geoderma.2010.02.003.

Saatchi SS, Harris NL, Brown S, Lefsky M, Mitchard ETA, Salas W, et al. Benchmark map of forest carbon stocks in tropical regions across three continents. Proc Natl Acad Sci U S A. 2011;108(24):9899-904. https://doi.org/10.1073/pnas.1019576108.

Shrestha BM, Singh BR. Soil and vegetation carbon pools in a mountainous watershed of Nepal. Nutr Cycl Agroecosyst. 2008;81:179-91. https://doi.org/10.1007/s10705-007-9148-9.

Tilahun A. Vegetation ecology and carbon stock of Wof-Washa Forest, North Vegetation Ecology and carbon stock of Wof-Washa Forest, North Shewa Zone, Amhara Region, Ethiopia [PhD Dissertation]. Ethiopia: Addis Ababa University; 2018.

Vivero JL, Kelbessa E, Demissew S. The Red List of endemic trees and shrubs of Ethiopia and Eritrea. Cambridge: Fauna and Flora International; 2005.