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Comparative investigation of biomass carbon reserve under different management system in church and natural forests: Implications for mitigation of climate change impact

Tekola Aschalew, Tolera Motuma, Tamirat Teshome

ABSTRACT

Forests are crucial for carbon storage and play a significant role in mitigating climate change. In Ethiopia, churches and monasteries have historically contributed to the planting, protection, and conservation of forests. This study investigates and compares biomass carbon reserves in church-managed forests and natural forests in the Bale Zone of Oromia Regional State. A systematic inventory was conducted, involving three parallel transect lines, each 90 meters long, with a total of sixty 20×20 meter plots divided equally between the two forest types. Measurements of tree height and diameter were taken for each species. Results showed significant differences in biomass carbon levels, with monastery forests demonstrating higher above-ground biomass (159 t/ha) and below-ground biomass (42 t/ha) compared to natural forests (105 t/ha and 27 t/ha, respectively). The total carbon biomass density was also greater in monastery forests (328.9 t/ha) than in natural forests (251 t/ha). These findings underscore the role of church and monastery forests in conserving biodiversity and employing traditional knowledge for effective forest management. In contrast, state-managed natural forests often face challenges due to inadequate management and local perceptions of them as open-access resources. The study concludes that the management approaches of monastery and church forests significantly influence their biomass potential, highlighting their importance for climate change mitigation.

Keywords: Algometric, Biomass, Carbon, Climate Change and Forest.

1. INTRODUCTION

Ethiopia is facing severe challenges of climate change impact due to low adaptive capacity, its geographic exposure and complexity, low income, and great reliance on climate sensitive economic sectors particularly of agriculture and pastoralist areas (FAO, 2016). The impact of climate change in manifested in annual rainfall pattern that is becoming increasingly erratic and varying temperature and precipitation negatively affecting agriculture sector and as a result droughts and floods are becoming frequent phenomena. The primary drivers are rapid deforestation and forest degradation contributed to depletion of natural forest (Leley et al., 2021).

Population growth is the main under lying factor which has resulted in extensive forest clearing for agricultural use, over grazing, and exploitation of the existing forest for fuel wood, fodder, and construction materials needs (Solomon et al., 2018). Hence, the forest area of Ethiopia has been reduced from 40% a century ago to an estimated of 11.40% today FAO, (2015) with significant environmental degradation. Forests are the main carbon reserve in the terrestrial ecosystem for mitigation of climate change Gebeyehu et al., (2019), according to FAO, (2015), the forest cover of Ethiopia declined from 13.78% to 11.40% from 1990 to 2015 due to widespread deforestation and forest degradation.

The average annual deforestation rate was about 1%, high compared to other sub-Saharan African countries The aboveground forest biomass carbon pools of tropical forests in their natural condition contain more carbon per unit area than any other land cover type (Yadav et al., 2022). The aboveground carbon storage in natural forests is higher than in any other vegetation (Negi et al., 2003). The Ethiopian Orthodox Tewahido Churches and monasteries have a long history of planting, protecting and conserving of trees (Assefa et al., 2013). Churches and monasteries are serving as in situ conservation and hot spot sites for biodiversity resources, mainly indigenous trees and shrubs of Ethiopia, which in turn give prestige for the religious sites.

As a result, these forests are sanctuaries for different organisms ranging from microbes to large animals, which have almost disappeared elsewhere (Khosravi and Sharafatmandrad, 2023). Ethiopian Orthodox Tewahido churches in particular have a long experience in conserving and protecting flora and fauna in their respective compounds. It had a cumulative knowledge of thousands of years, experiences of many people, wisdom of the spirit mediums, the wise council of elder's institutions in managing and conserving resources outliers (Sola, 2014). The escalating effects of climate change are driving the need for effective carbon sequestration strategies in forest ecosystems (Amanuel et al., 2019).

Church forests, recognized for their distinctive management methods and cultural importance, serve as a viable alternative to natural forests, which face different degrees of human impact (Tesfaye et al., 2022). Nevertheless, comprehensive data comparing biomass carbon reserves between these two distinct management systems is currently lacking (Siyum, 2020). Understanding how these forests contribute to carbon storage is vital for formulating effective climate change mitigation strategies (Belay et al., 2014). While individual studies on biomass carbon reserves in natural forests exist, there is a scarcity of comparative analyses specifically focusing on church forests versus natural forests (Mildrexler et al., 2020).

Previous research has not sufficiently explored how different management systems (e.g., church-managed versus naturally occurring) influence biomass carbon storage (Aneseyee, 2016). There remains a gap in understanding the broader ecological implications of biomass carbon reserves in these forests and how they relate to climate resilience (Waring et al., 2020). Hence the objective is to investigate and compare the biomass carbon reserves in church forests and natural forests to determine their respective contributions to carbon sequestration and analyze the specific management practices in church forests and natural forests and their influence on biomass carbon storage

2. METHODOLOGY

Description of the Study Area

This study was conducted in the Southeastern part of Ethiopia, Oromiya regional state Bale zone Goba woreda about 445 km far from Addis Ababa. It is located between a latitude and longitude of 7 0 1' North and 39059' East. The altitude ranges from 2743 to 4200 m.a.s.l with the cold (Dega) climate. The rainy season is from the end of May until early November. The annual total rainfall of the study area ranges between 600 - 1400mm, while the annual mean minimum and maximum temperatures of Goba town are 5 and 22°C respectively. The soil type in the study area is Vertisols.

Sampling design

Reconnaissance survey was conducted to observe the overall situation of the area, where the area was delineated using GPS to determine the required number of transect lines of the study. Systematic sampling methods was employed then the transect line were established based on the size and shape of the forests, three transect line was aliened systematically, distance between the transect line and the plots were 90m on the adjacent two forest types. The monastery forest was about 36.3 ha while the adjacent natural forest is 41.5 ha and both forests are found within the same agro ecological zone. Sixty sample plots were laid at the center of the transect line in each study forest. The size of the plots for tree inventory was (20 m × 20 m; 400m2).

Vegetation Data Collection and Identification

All trees with a diameter ≥ 5 cm were recorded following the methods and procedures of (Pearson et al., 2005; Pearson et al., 2007). The diameter was measured at breast height (DBH, 1.3 m height from the ground) used to estimate biomass and the size class distribution of trees in a sampling plots. DBH were measured by using caliper and tree heights were measured by using Sunnto hypsometer. Plant identification was conducted in the field following Azene, (1993) useful trees and shrubs for Ethiopia species identification manual

Estimation of carbon stocks in different carbon pools

Estimation of above ground tree biomass (AGTB)

Algometric equations of Chave et al., (2014) were used to estimate of forest carbon stocks for biomass carbon. This model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors

AGB= 0.0673× (PD2H) 0.976…………………………………………… (*eq.1*)

Where AGB= above ground biomass in Kg

P = Wood density of each tree species in g cm3 and it was obtained from global wood density database (UNFCCC, 2011)

D= diameter at breast height in cm

H= height in m

Estimation of Below Ground Biomass (BGB)

According to IPCC, (2006) estimation of below ground biomass can be obtained as: On average BGB is 0.26 % of AGB. The equation is given below:

BGB = AGB × 0.26 ………………………………………………………………… (*eq.2*)

In order to calculate both AGB and BGB, the biomass stock density were attained in Kg m2 by dividing the sum of all individual weights (in Kg)by the area of sampling plot. The value converted to ton/ha by multiplying it by 10. AGB was converted to tree AGC stock (Mg ha-1) using a carbon fraction of 0.47. While multiplication factor 3.67 (44/12) was used to estimate CO2 equivalent (Pearson et al., 2007).

Estimating of carbon in Litter Biomass Sampling

The leaf litter is defined as all dead organic surface material on top of the mineral soil. Samples that have ≥2.5cm diameter of all dead and dried leaves, twigs, branches and fruit pods an area of 1m by 1m (1m2) were collected, weighted and recorded on the field then 100 g of composited samples taken for laboratory analysis placing in a labeled bags.

According to Pearson et al., (2005), estimation of the amount of biomass in the leaf litter was calculated by:

$LB = \frac{wfield}{A} * \frac{Wsub_{sample(dry)}}{Wsub_{sample(fresh)}} \frac{1}{10,000}$………………………………………………….(*eq.3*)

LB = Litter (biomass of litter ton/ha).

W field = Weight of wet field sample of litter sampled within an area of size 1m2 (g).

A = Size of the area in which litter were collected (ha).

W sub-sample, dry = Weight of the oven-dry sub-sample of litter taken to the laboratory to

determine moisture content (g), and W sub-sample, fresh = Weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

A composited 100g of fresh weight was oven dried at 70℃ for 24 hours to determine dry to fresh weight ratios (Ullah and Al-Amin, 2012)

Once the litter biomass is obtained, then Carbon stock in dead litter biomass was calculated by using the following formula.

LC = LB × 0.37 ……………………………………………………………………………… (eq.4)

Where, LC is total carbon stocks in the dead litter in ton/ha, 0.37 is carbon fraction IPCC, (2006), LB is oven dry mass of litter biomass.

Soil Sampling

A total of 60 composite soil samples were collected from 0-20 and 20-40 cm depth for Soil carbon concentration analysis. Samples were collected from the four corners of every second plots using auger. A 250 g of composited samples taken for laboratory analysis placing in labeled bags. All soil samples were analyzed at Wondo Genet College of Forestry and Natural Resources laboratory. Soil carbon concentration was analyzed using standard method, by Walkey-Black procedure (a wet combustion of organic matter with a mixture of potassium dichromate and sulfuric acid and residual potassium dichromate titrated against ferrous sulfate) (Jackson, 1967; Reeuwijk, 2002).

The carbon stock of soil used the following formula which is recommended by (Aynekulu et al., 2011).

SOC = *(C /100) * P * D *(1- frag /100)**100..(*eq. 5*)

Where: SOC = soil organic carbon stock (t C/ha-1).

C = Soil organic carbon concentration of soil fines (fraction < 2 mm) determined in the laboratory (%, g kg-1)

P = Soil bulk density (g /cm3)

D = Depth of the sampled soil layer (cm)

Fragment = % volume of coarse fragments/100

100 is used to convert the unit to convert unit to t C/ ha-1

Note: SOC is determined on the fine soil fraction (< 2 mm) and the bulk density should be corrected for the proportion of the soil volume occupied by coarse fragments (> 2 mm)

Soil bulk density Sampling

A total of 60 Soil samples were collected from 0-20 and 20-40 cm for soil bulk density analysis. Samples were collected from the center of every second plots using modified cylindrical cores (20) cm height and 6 cm diameter) for calculating the volume and density of oven dry mass of soil samples. The bulk density samples were oven-dried at 105 °C for 24 h and weighed (Pearson et al., 2005). The collected sample were labeled and inserted in to individual plastic bag and sent to Wondo genet college of forestry and natural resources laboratory. Then the following formula was used to calculate the soil bulk density (Pearson et al., 2005).

V = h * π r2 … ……………………..……………………………………...……………. (*eq.6*)

Where, V is volume of the soil in the core sampler in cm3h is the height of core sampler in cm, and r is the radius of core sampler in cm.

Bulk density:

BD (gm/cm3) = (oven dry weight of the soil) / (volume of the core) ….………………… (*eq.7*)

Data Analyses

The vegetation data of DBH, height and frequency of each species, fresh weight and dry weight of soil were organized and analyzed by using excel 2010 and using of statistical package software (SPSS 16.0 version).

3. RESULTS AND DISCUSSION

Five tree species were identified and recorded in the studied dry afromontane forest, the dominant tree species are *Juniperus procera* (68%) followed by *Olea africana* (18 %), *Maytenus arbutifolia* (6 %), *Hagenia abyssinica* (4%), *Rosa abyssinica* (3%) respectively. Table 1 shows result for a total of 948 trees that were recorded with the average number of count per hectare in Tekle-Haymanot Monastery Forest and Adjacent Natural Forest with the total numbers of trees recorded in monastery and Adjacent natural forest were (525) and

(423) respectively. The total species count in church forest (525) is higher than in natural forest (423), suggesting that the forest church management system may be more effective in promoting overall biodiversity across these specific species.

The significant differences in species populations between the two systems suggest that management practices play a critical role in the health and diversity of forest ecosystems. The forest church systems can enhance the growth of certain species (e.g., Junipers procera and Olea africana). The specific management practices which free of any human interventions in THMF contribute to the higher numbers of certain species that could provide insight for improving conservation strategies in other natural forests. The result also indicates that Junipers procera showed most notable difference is in the population which is significantly higher in church forest (375) compared to natural forest (272). This suggest that the forest church management system is more conducive to the growth of this species, possibly due to specific management practices including free of deforestation and degradation that favor its propagation.

Similarly, the result indicates that Olea africana in similar trends are seen where church forest (96) outperforms than natural forest (74). It indicates that the forest church environment supports better conditions for this species as well. Maytenus arbutifolia interestingly in natural forest has a higher species count (34) compared to church forest (24). It indicates that while the forest church excels in certain species, the natural forest may offer more suitable conditions for this particular species. Hagenia abyssinica showed a slight advantage for church forest (23) over natural forest (17), which again points to better management strategies or conditions in the forest church. Rosa Abyssinia in natural forest shows a higher presence (26) compared to church forest (7), indicating that the natural forest might provide a more favorable environment for this species under disturbed ecological setting.

Our study indicates that church forests have good conservation and protection in good practices than the natural forests which are open for the community and liable to potential forest degradation. This is due to continuous use for fuel and construction material needs. The forest degradation in the natural forest was caused by the community involvement in fuel wood collection, felling of trees for construction material. According to the study by Mesfin, (2011), indigenous forest management practices which were made in line with its sustainability has manifested that church and monastery has immense religious and cultural knowledge in forest management practices and its believers that have developed over generations through experiences.

The previous studies conducted at similar biomes at Meskele Gedam Dry Afromontane Forest Dagnachew, (2016) and Menagasha Suba State Forest have supported the results obtained in our present study that church forest has better mamagment practices than natural disturbed forest. Similar findings were recorded in Tara Gedam Forest by Mohammed et al., (2014) and Church Forest. They showed the difference in management systems of church and natural forest that may be from types of species, geographical location tree size and density per ha and forest management.

Table 1 Total recorded species in monastery and adjacent natural forest

Study site	***Junipers procera***	***Olea africana***	***Maytenus arbutifolia***	***Hagenia abyssinica***	***Rosa abyssinica***	**Total**
THMF	375	96	24	23	7	525
ANF	272	74	34	17	26	423
Sub Total	647	170	58	40	33	948

Where THMF (Tekle-Haymanot monastery forest) and ANF (Adjacent natural forest)

Result in Figure 1 shows that the average above ground and below ground biomass of the forest in the monastery 340 ± 63 t/ha-1 and 88 ± 16 t/ha-1 respectively while that of the adjacent natural forest is 224 ± 64 t/ha-1 and 58 ± 17 t/ha-1, respectively. This difference in aboveground and belowground biomass between the monastery and adjacent natural forest is statistically significant (P = 0.000*). The minimum and maximum AGB and BGB value of Monastery Forest were 235 and 500 t/ha-1, 61 and 130 t/ha-1 while that of the adjacent natural forest is 130 and 489 t/ha-1,34 and 122 t/ha-1 respectively. The mean value of Litter biomass in the Monastery Forest were 0.040 ± 0.006 t/ha-1 while that of 0.034 ± 0.008 t/ha -1 respectively. This difference in litter biomass between monastery and adjacent natural forest is statistically significant (P =0.003).

Result in our study show that AGB appears to be the most productive under both management systems, which might be due to favorable environmental conditions or soil quality and less human intervention. The results highlight the importance of selecting appropriate management system to maximize biomass production. Scaling up the best practice of sustainable forest management in THMF treatment is beneficial for increasing biomass yield, especially in the AGB. The comparison between different forest management systems of (THMF vs. ANF) within the same site shows that THMF generally results in higher biomass than ANF, particularly in the AGB. The tallest bar represents AGB THMF, indicating the highest biomass production among the groups, at over 150 tons/ha.

AGB in ANF is also relatively high, but significantly lower than AGB THMF, with biomass around 100 tons/ha. The remaining groups (BGB-THMF, BGB-ANF, LB-THMF, and LB-ANF) show significantly lower biomass levels compared to the primary species. Notably, both LB-THMF and LB-ANF have biomass values below 30 tons/ha, indicating a marked reduction in biomass reserves in these groups. The error bars in our result provide insight into the variability and uncertainty of the biomass measurements. The significant differences in biomass among the study sites and treatments suggest that both environmental factors (site characteristics) and management practices (treatments) play a crucial role in biomass production.

Research has shown that managed forests like church forest in Ethiopia often exhibit higher AGB and BGB compared to natural forests due to optimized conditions and reduced human interference. For instance, studies in various forest types have consistently reported that management practices can enhance biomass accumulation significantly. Some studies have reported that natural forests can sometimes match or exceed the biomass of managed forests under certain conditions, particularly in regions with rich biodiversity and optimal environmental conditions. This suggests that while your findings are valid, they may not universally apply across all forest types (Solomon et al., 2018).

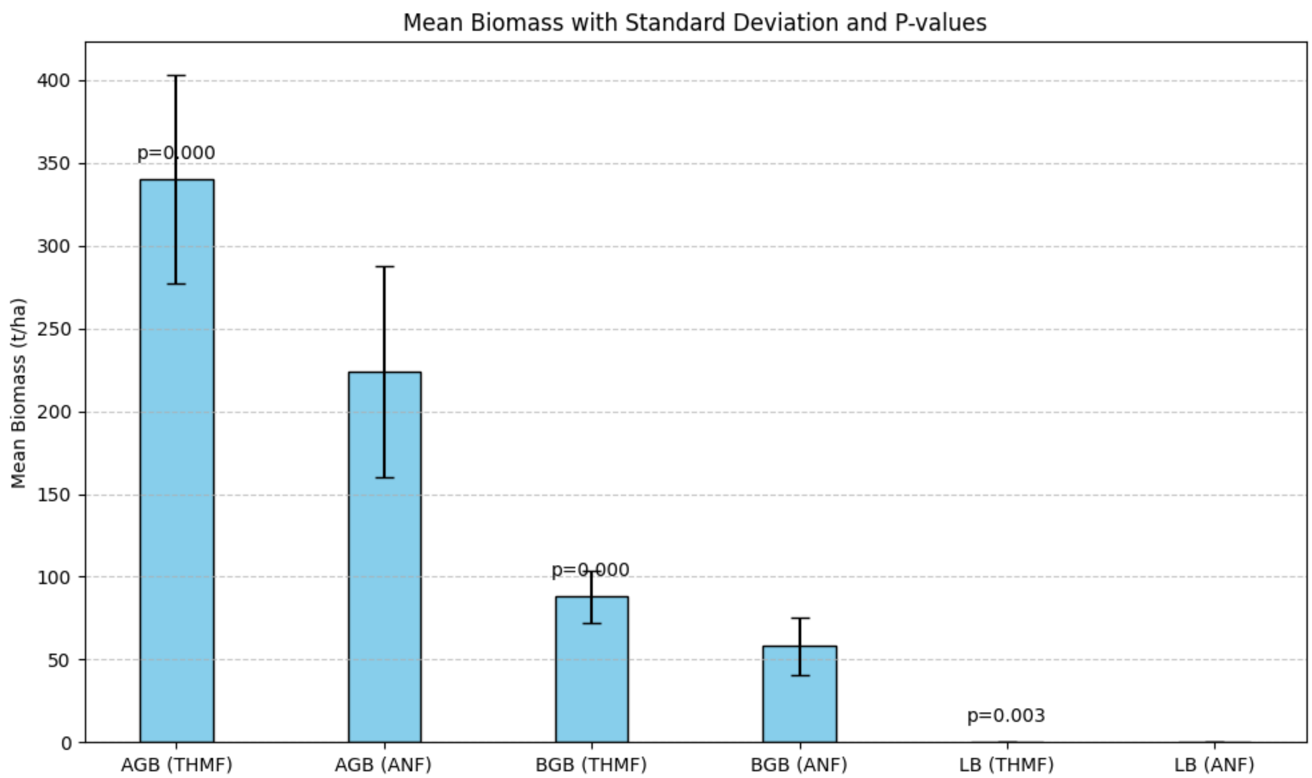

Figure 1 Show the (Above ground biomass, below ground biomass and litter biomass) and THMF and ANF (Tekle-Haymanot monastery forest and Adjacent natural forest).
Where AGB, BGB, LB (Above ground biomass, below ground biomass and litter biomass) and THMF and ANF (Tekle-Haymanot monastery forest and Adjacent natural forest).

Result of our study in Table 2 show that the biomass carbon estimates for the Tekle-Haymanot Monastery Forest (THMF) and the adjacent natural forest (ANF) provide critical insights into the ecological health and carbon storage potential of these areas. The data includes above-ground biomass carbon (AGBC), below-ground biomass carbon (BGBC), and litter biomass carbon (LBC). Above-Ground Biomass Carbon (AGBC) in THMF: The mean AGBC is 159 ± 30 t/ha, with a minimum of 105 t/ha and a maximum of 235 t/ha.

The P value of 0.000 indicates a statistically significant difference. ANF: The mean AGBC is 105 ± 29 t/ha, with a minimum of 61 t/ha and a maximum of 220 t/ha.

Result of our study in Table 2 shows the significant difference in AGBC show ($P < 0.001$) suggests that THMF has a higher capacity for carbon storage compared to ANF. This is be attributed to better management practices, higher species diversity, or more favorable growth conditions in THMF. The higher AGBC in THMF indicates its potential role in climate change mitigation through enhanced carbon sequestration. Below-Ground Biomass Carbon (BGBC) in THMF: The mean BGBC is 42 ± 7.78 t/ha, with a minimum of 29 t/ha and a maximum of 61 t/ha. Result of our study in Table 2 show The P value of 0.000 indicates a statistically significant difference where the ANF which exhibits the mean BGBC 27 ± 7.97 t/ha, with a minimum of 12 t/ha and a maximum of 57 t/ha.

The significant difference in BGBC ($P < 0.001$) further supports the findings the forest type for AGBC, indicating that the root systems of most tree species in THMF are more developed. This can enhance soil stability and nutrient uptake, contributing to the overall health and resilience of the forest ecosystem. Result of our study in Table-2 show Litter Biomass Carbon (LBC) in THMF: The mean LBC is 0.015 ± 0.002 t/ha, with a minimum of 0.01 t/ha and a maximum of 0.024 t/ha. The P value of 0.005 indicates a statistically significant difference forest type in ANF: The mean LBC is 0.013 ± 0.003 t/ha, with a minimum of 0.01 t/ha and a maximum of 0.02 t/ha. The significant difference in LBC ($P < 0.01$) suggests that the forest types in THMF have a slightly higher litter biomass, which can improve soil fertility and moisture retention.

This forest type is beneficial for the forest's health and can support a diverse range of flora and fauna. As stated by Yitebitu et al., (2010), the different types of models used for biomass estimation have impact on the value of carbon estimated in a given forest. The tree parameters used to calculate the biomass of the forest in the current study were DBH, basic Wood Density and Height. On the other side, the previous studies used only tree DBH to estimate the biomass of the corresponding forests. For example, the model used for estimating aboveground carbon stock of Tara Gedam Forest Mohammed et al., (2014) was AGB= 34.4703 - 8.0671(DBH) + 0.6589(DBH2). This model excludes wood density and total height of trees, but the present study uses the model developed by (Chave et al., 2014).

Table 2 Average biomass carbon stocks in monastery and adjacent natural forest in Goba district, southeastern Ethiopia.

Biomass	Study site	Mean	Min	Max	P value
AGBC	THMF	159±30 t/ha-1	105 t/ha-1	235 t/ha-1	0.000*
	ANF	105±29 t/ha-1	61 t/ha-1	220 t/ha-1	
BGBC	THMF	42±7.78 t/ha-1	29 t/ha-1	61 t/ha-1	0.000*
	ANF	27±7.97t/ ha-1	12 t/ha-1	57 t/ha-1	
LBC	THMF	0.015±0.002t/ha-1	0.01 t/ha-1	0.024 t/ha-1	0.005
	ANF	0.013±0.003t/ha-1	0.01 t/ha-1	0.02 t/ha-1	

Result in Table 3 shows that total CO2 Equivalent (CO2e) for the forest types in THMF exhibiting 1207 t/ha and ANF: 921.2 t/ha. The CO2e values align with the TCD findings, demonstrating that the forest types in THMF not only stores more carbon but also translates that into significant CO2 equivalent storage. This finding underscores the importance of conserving and managing forest species in THMF to leverage its carbon sequestration potential.

The mean carbon stock in litter pool of the present study was 0.015 t/ha-1 less than the previous studies by Meskele Gedam Dry Forest Dagnachew, (2016), Menagasha Suba State Forest Mesfin, (2011), Selected Church Forest and also less than (2.1 t/ha-1, IPCC, 2006), studies done by supports our finding that the amount of litter fall and its carbon stock of the forest types can be influenced by the forest vegetation (species, age and density) and climate. Similarly, the tree stands in the forest area were relatively not densely populated and this could result in low amount of litter fall. The reason for the small carbon stock of litter in the present study minimum stem per hectare and basal area contributes very low litter biomass carbon and probably due to high run off occurred and might cause for small carbon account in this pool.

Table 3 Total mean carbon stock and its % share in monastery and adjacent natural forest

Total plot 60	AGBC t/ha-1	BGBC t/ha-1	LBC t/ha-1	SOC t/ha-1	TCD t/ha-1	Co2e t/ha-1
THMF	159	42	0.015	127.9	328.9	1207
% Share	48.3	12.8	0.004	38.9	100	-
ANF	105	27	0.013	119	251	921.2
% Share	41.8	10.7	0.005	47.4	100	-

Result in Table 4 shows the calculated Pearson correlations as strong relationships between the biomass components in the two forest sites. The result implies that management practices for forest species or environmental conditions affecting biomass in one site may similarly influence the other. A high positive correlation (0.950) indicates that as AGBC increases in THMF, it also tends to increase in ANF. The significant p-value (0.000) suggests that this correlation is statistically significant. Similarly, a strong positive correlation (0.900) between BGBC in THMF and ANF indicates that both sites exhibit similar trends in below-ground biomass carbon. The p-value again supports the significance of this finding. The correlation for LBC is also high (0.950), indicating a strong relationship between litter biomass carbon in both sites. The p-value of 0.005 confirms its statistical significance.

Table 4 Biomass component correlation

Biomass Component	Correlation Coefficient (r)	P Value
AGBC	0.950	0.000
BGBC	0.900	0.000
LBC	0.950	0.005

Result in Table 5 indicates the soil organic carbon for both types forest management system from soil depth 0-20 cm SOC: THMF: 67.9 ± 13.6 t/ha (Min: 49 t/ha, Max: 89 t/ha) ANF: 61 ± 13 t/ha (Min: 33 t/ha, Max: 82 t/ha). The mean SOC in the 0-20 cm layer is higher in THMF compared to ANF, indicating a more robust organic matter accumulation in the managed forest. The higher maximum value in THMF (89 t/ha) suggests that certain areas within this site may have particularly favorable conditions for organic carbon storage. Result in Table 5 indicates 20-40 cm SOC: THMF: 60 ± 9.4 t/ha (Min: 42 t/ha, Max: 74 t/ha) ANF: 58 ± 14.3 t/ha (Min: 31 t/ha, Max: 81 t/ha) The SOC at this depth also shows a slightly higher mean in THMF than in ANF, although the difference is less pronounced than in the top layer.

Result in Table 5 shows the variation in maximum SOC values between the two sites again indicates potential differences in soil management and organic matter input. The total SOC: Forest types in THMF exhibited 127.9 t/ha, while the forest species in ANF exhibited 119 t/ha Overall, the forest species in THMF exhibits a greater total SOC compared to ANF. This finding highlights the effectiveness of the forest species in THMF in sequestering organic carbon, potentially due to better soil management practices, vegetation cover, and nutrient cycling processes. The p-values for the SOC measurements are 0.24 for the 0-20 cm layer and 0.8 for the 20-40 cm layer. These values suggest that there are no statistically significant differences between the SOC levels of the forest species types in THMF and ANF at both depths.

Result in Table 5 also shows p-value greater than 0.05 typically indicates that any observed differences could be due to random variation rather than true ecological differences. The results indicate that forest species in THMF has higher mean SOC levels than ANF, the differences are not statistically significant. This might imply that both forests are functioning effectively in terms of carbon storage, but forest species in THMF have a slight advantage, possibly due to more intensive management practices that enhance soil health. The lack of significant differences could also suggest that both sites are subjected to similar climatic and environmental conditions that govern SOC accumulation. Factors in forest types such as vegetation type, soil texture, and microbial activity are critical in influencing SOC levels.

Additionally, the higher variability in SOC in forest species of ANF's (evidenced by its wider minimum and maximum ranges) may reflect differences in natural processes, such as decomposition rates or root biomass, which can lead to uneven organic matter distribution. The result shows the forest species in THMF tend toward higher SOC. It is beneficial to examine additional ecological parameters, such as soil microbial activity, plant diversity, and land-use history, to understand the underlying mechanisms driving SOC dynamics in these environments. Furthermore, long-term monitoring of SOC changes in both sites would provide insights into their roles in carbon sequestration and climate change mitigation.

The total carbon density of Tekle-Haymanot monastery forest was 328.9t/ha-1, it was higher than that of adjacent natural forest which has 251 t/ha-1, its Co2e result was 1207 and 921.2 t/ha-1 respectively. As compared the total carbon density of the present study was lower than the previous studied by Tara Gedam Forest (Mohammed et al., 2014). This result probably the study area forest characterized lower tree size and tree density and also proportional with Meskele Gedam Dry Afromontane Forest Dagnachew, (2016), Menagasha Suba State Forest Mesfin, (2011) and Selected Church Forest in Addis Ababa.

The present study result shown that Tekle-Haymanot monastery forest have high carbon storage than the adjacent natural forest therefore monastery forest was high potential to decrease the rate of enrichment of atmospheric CO2 concentration and play an important role on climate change mitigation. Church and Monasteries play a great role on indigenous and religious knowledge in forest management practices; this shows that there is a good store of indigenous forest management practices in the church, monastery and its believers that have developed over generations through experiences.

Table 5 Mean, min, max and total soil organic carbon stocks in monastery and adjacent natural forest in Goba district, southeastern Ethiopia

Study site	0-20cm SOC	Min	Max	20-40cm SOC	Min	Max	SOC Total
THMF	67.9±13.6t/ha1	49 t/ha-1	89t/ha-1	60±9.4 t/ha-1	42 t/ha-1	74 t/ha-1	127.9 t/ha-1
ANF	61±13 t/ha1	33 t/ha-1	82t/ha-1	58±14.3 t/ha-1	31 t/ha-1	81 t/ha-1	119 t/ha-1
P Value	0.24	-	-	0.8	-	-	-

4. CONCLUSION AND RECOMMENDATION

Findings of the present study indicated that the forest species in Tekle-Haymanot Monastery Forest has significantly higher total above-ground and below-ground carbon stocks compared to the adjacent Natural Forest. The cultural and religious practices associated with the monastery have played a crucial role in conserving these resources, attributing spiritual significance to the forest, soil, and water. Monastery and church forests serve as vital repositories for both faunal and floral diversity in Ethiopia, particularly for endangered and endemic species, providing essential tree seeds for conservation efforts. The comparison of carbon stock estimations among various components above ground, below-ground, litter, and soil organic carbon highlights the ecological importance of these forests.

The present study identified that total above and belowground carbon stocks were higher in the Tekle-Haymanot Monastery Forest than the Adjacent Natural Forest respectively. The total carbon stock of Tekle-Haymanot monastery Forest also was higher than that of adjacent natural forest. Religion and cultural practices have contributed in the conservation of resources through the attribution of spiritual powers to forest, soil, water, and etc. Monastery and church forests are very important repositories for both faunal and floral resources of Ethiopia, especially for endangered and endemic species as sources of tree seeds for the conservation of these species.

This study shows the result of comparison of carbon stock estimation (above ground, below ground, litter and soil organic carbon) between the Tekle-Haymanot Monastery and the Adjacent Natural Forest. On the basis of the study and its major findings, the following conclusions are drawn. Incentive and recognition should be given for monastery and church forests; it will initiate the church leaders and believers for further natural resource development and management activities. Monastery and church forests are excellent centers of learning and research and they are ideal sites for studies on vegetation history, ecology, taxonomy and also it plays a great role on climate change mitigation therefore the Government and any concerned body should be given a great emphasis on protection and management of monastery forests from forest degradation and deforestation.

Findings of the present study has indicated that church forests are the potential carbon reserves which can benefit the community and church for benefiting from the carbon payment scheme. The comparative analyses of the present study indicated that the church forests are well managed and conserved by the church community so that they have high potential for climate change mitigation in controlling the macro climate of the area. Our study provide incentives and recognition for monastery and church forests to encourage church leaders and communities to engage in further natural resource development and management activities.

It advocates that the utilization of monastery and church forests as centers for learning and research. They are ideal for studies related to vegetation history, ecology, and taxonomy, and play a significant role in climate change mitigation. Our findings also emphasize the protection and management of monastery forests to prevent degradation and deforestation. Government and stakeholders should prioritize these areas to enhance their conservation. So that it encourages the development of carbon payment schemes that allow church communities to benefit economically from the carbon reserves within their forests. This can provide financial incentives for maintaining and enhancing forest health.

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Author Contributions

Mr Aschalew Tekola has done all laboratory analysis and statistical thesis write up analysis, Dr. Motuma was contributed all the advisory work and dr teshome tamirat the reviewing and preparation of the draft article

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

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Data and materials availability

All data associated with this study are present in the paper.

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