Carbon Storage of Selected Church Forests in Northern Ethiopia: Implication for Climate Change Mitigation

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Research

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Abstract

Background

Forests are known to play an important role in regulating the global climate. Therefore, it serves as natural sink of CO_2 to mitigate climate change. Churches and monasteries have a long history of planting, protecting and conserving of trees. This study was conducted on selected church forests, with the objectives of estimating of the carbon stock and its variation along the altitudinal gradients. In light of this, primary data collection was done by field inventory and secondary data was collected from different sources. In order to collect vegetation data particularly above ground biomass (AGB), a total of 64 plots each with the size of 20 m x 20 m at an interval of 100 m, were laid along the established transects at 200 m apart. For litter and soil sample collection, five sub-quadrants 1 m x 1 m were established at four corners and center of every quadrant. Composite method was also used for litter and soil sampling. Data analysis of various carbon pools measured in the forests were analyzed on the excel data sheet and R software.

Result

Results revealed that the total mean carbon stock density of church forests was 133.14 t/ha with aboveground biomass carbon of 24.73 t/ha and belowground biomass carbon 6.41t/ha, litter biomass carbon of 1.80 t/ha and soil carbon stock 100.19 t/ha.

Conclusion

The result of this study showed that altitude has no significant impact on carbon pools. Overall, this study may increase knowledge on the study site and show contributing of church forests for climate change mitigation.

Introduction

Nature provides goods and services that contribute to improving a good quality of life and human well-being (Díaz et al., 2018). But the effective functioning of these services is compromised when ecosystems are under pressure by habitat change, land use change, overexploitation, invasive alien species, pollution, and climate change (Carvalho *et al.*, 2014; Lipton et al., 2018).

Climate change is the single biggest environmental crisis facing Earth, which may lead to unfathomable humanitarian disasters (Mal et al., 2018).

Sacred Natural Sites (SNS) are portions of land or water that hold spiritual significance for specific communities (Wild et al., 2008). They are often hotspots of cultural as well as biological diversity (Verschuuren et al., 2010). These include sites which have been physically altered by those who hold them to be sacred due to burial grounds or constructions of monuments which are known as semi natural sacred sites, or those that have been less actively altered, such as areas that are preserved and set aside due to their spiritual significance (Jeanrenaud, 2001; Bhagwat & Rutte, 2006; Anthwal et al., 2010).

According to Wild et al., (2010) SNS are as nodes of resilience, restoration and adaptation to climate change, as offer opportunities for building landscape connectivity networks and recovering ecologically sound, because they form important refugee for biodiversity and maintain a dynamic cultural fabric in the face of global change.

There are many SNS around the world, as diverse as the countries and cultures which they represent (Bhagwat & Rutte, 2006; Dudley et al., 2009; Finlay & Palmer, 2003). As a result, these groves are represented globally with different names and purposes, such as church forests, fetish forests, and sacred forests (Ormsby and Ormsby, 2010; Cardelús et al., 2012). They are found all over the world including Japan, Morocco, India, Ghana and Ethiopia (Cardelús et al., 2012; Cardelús et al., 2013).

In Ethiopia there are more than 35,000 Orthodox Churches in which most of them own forests (Wassie *et al.*,2010). The forests are also called sacred groves being kept for the past many hundred years through the strong biblical basis, theological thoughts, religious belief and commitment of the communities (Wassie, 2002). The churches and monasteries of the Ethiopian Orthodox Tewahido church (EOTC) are often surrounded by small natural forest characterized by a high floral and faunal diversity with many indigenous and rare species (Wassie, 2007; Cardelús et al., 2013), as the Church has a long history of planting and protecting trees around churches.

The global importance of forest ecosystem emphasizes the need to accurately determine the amount of carbon stored in different forest ecosystem, because carbon stock assessment is an important step in carbon accounting and consideration of land use options and strategies to promote carbon sequestration (Ribeiro et al., 2013). The major carbon pools to be measured in forest carbon estimation are plant biomass (above and below ground), soil organic carbon (SOC), litter, herbs, and grass (LHG) and dead wood (Subedi et al., 2010).

According to Tola (2011), the contribution of church forests to the reduction of atmospheric CO_2 concentration can be estimated by computing both above and below-ground biomass in selected church forests. Therefore, this study has been conducted to estimate the carbon stock (storage) of these church forests by survey of forest stand measurement and by quantifying the carbon stock in above and below ground: dead litter and soils organic carbon, which are known potential pools for carbon sink.

Materials And Methods

Description of the Study Areas

The study was carried out in Abune Aregawi Debere Bereket Church, and Montogera Estifanos Church Forest in Amhara Regional state and in Mai- Anbesa Kidane Miheret Monastery, and Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest in Tigray Regional State as the geographical context within which the research questions were explored. Each of the church forests is described separately as follows.

Abune Aregawi Debere Bereket Church Forest

Geographical location

Abune Aregawi Debere Bereket Church Forest is found in South Gondar Zone of Amhara region, particularly in Fogera woreda with an area of 21.8 ha. It is located at 37°49'E to 37° 98'E of longitude and 11° 67'N to 12°04' N of latitude. The altitude of Fogera woreda ranges from 1783 to 2410 m.a.s.l. (meter above sea level). Woreta is the capital of the district and is found 625 Km from Addis Ababa and 55 Km from the Regional capital, Bahir Dar. The woreda is bordered on the north by Limo Kemekem; Dera by, south, on the west, by Lake Tana and on the east, by Farta.

Climate

Metrological data from 1986-2019 obtained from Ethiopian National Meteorology Agency (ENMA) of the nearest station (wereta) was extracted, analyzed and presented in climate diagram (Figure 2). The average annual rainfall is about 1454 mm, while the annual mean temperature also varies from 10.6°C to 30.3°C. Rain fall is mono-modal, June to September being the rainy season.

Topography, Soil and Land use

Agro ecologically, the woreda is classified as ‘weina dega’ (mid land). As the Woreda Agricultural Office indicated the soil type of the woreda is categorized as 65% black soil (vertisol), 20% brown soil, 12% red soil, 3% gray soil.

The land use/cover of Fogera woreda is dominated by agricultural land, 69.9% of the total land mass within woreda is allocated to agriculture, Grazing land 14.59%, and Forest land 4.67 %. (Secondary information from wereda Agricultural Office).

Montogera Estifanos Church Forest

Geographical location

Montogera Estifanos Church Forest is found in the Amhara Regional State with an area of 7.5 ha. LiboKemkem wereda is one of the districts located in south Gondar at the North West part of Ethiopia. The town of the district is located 645 kilometers from Addis Ababa to the North and 85 kilometers from the regional city of Bahir Dar to the North. It is located at 37°57'E to 37° 96'E of longitude and 11° 96'N to 12°36'N of latitude. The wereda is bordered in the North, by Semien Gondar Zone; in the South, by Fogera Woreda; in the West, by Lake Tana, and in the East, by be Belesa Woreda. The elevation of the woreda ranges from 1783 to 2410 m.a.s.l as of the woredas agricultural office.

Climate

Metrological data from 1986-2019 obtained from ENMA of the nearest station (Addis zemen) was extracted, analyzed and presented in climate diagram (Figure 4). The study area has mean annual rainfall which is 1347 mm. The mean annual temperature of the study area ranges from 8.7- 32°C.

Topography, Soil and Land use

The agro-climatic zone of the Woreda consists 81.1% of Woinadega, and 18% of Dega, and 0.9% of kolla. LiboKemkem is characterized by plain, mountainous, ups and downs, depression and swampy areas which account 42%, 21%, 30%, 1% & 6% respectively. The soils of the study area are categorized as 60% brown soil, 22% red soil, 15% black soil and 3% gray soil. A survey of the land in this district shows that 39.9% of the total land mass within the woreda is allocated to agriculture. Grazing land, 14.3%; Forest land, 4.6 %, and others 41.5% (secondary information from wereda Agricultural Office).

Mai- Anbesa Kidane Miheret Monastery Forest

3.1.3. Geographical location

Mai- Anbesa Kidane Miheret Monastery Forest is found in Enderta, a district found in south eastern Administrative Zone of Tigray Regional State in Ethiopia with area of 33 ha. It is located at 785 km of North of Addis Ababa, the capital city, and geographically laid on 13º 24' to 13º 64' North Latitude and 39º 27' to 39º 74' Eastern Longitude and altitude in the area ranges from 1400m to 1800m. It shares borders with Wukro to the north, DeguaTemben to the west, afar region to the east, and HintaloWajirat to the south.

Climate

Metrological data from 1987-2019 obtained from ENMA of the nearest station (Mekele airport) was extracted, analyzed and presented in climate diagram (Figure 6). It is also characterized by rainfall of 575 mm per annum, and the minimum and maximum temperature is 8.9°C and 27 °C respectively.

Topography, Soil and Land use

Agroecology greater portion of Enderta lies in the midland agro-ecological zone. The landscape is mostly plain and hills, with bush vegetation. Its soil type is dark reddish brown and dark black clays and other types.

Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest

Geographical location

Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest is found in Hintalo Wajirat woreda on the south eastern zone of Tigray with an area of 16.9 ha. It is located 745 km north of the capital Addis Ababa and 38 km South of Mekelle, the capital of Tigray region. Geographically, it is positioned between 39°27' to 39°81' E (Latitude) and 12°88' to 13°41' N (Longitude) and the altitude of the district ranges from 1550 to 3400 meters above sea level. It is bordered by Enderta woreda on the north, Raya Azebo woreda to the south, the Afar region to the east, and Endamehoni and Alaje woredas to the west.

Climate

Metrological data from 2005-2020 obtained from ENMA of the nearest station (Hewane) was extracted, analyzed and presented in climate diagram (Figure 8). The study area has mean annual rainfall which ranges from 184 mm and the mean temperature estimate ranges from 7.3 to 29.5 °C.

Figure 8 Climate diagram of the nearest station (Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest) (Data source: ENMA).

Topography, Soil and Land use

Agro ecology of the district is Kolla (22.5%), Weina-Dega (63.75%), and Dega (13.75%). in Hintalo-Wajirat the soil compositions are vertisols, cambisols and fluvisols. The central part of the district is mostly characterized by black soil with cracking nature dominated by clay particles (Relief society of Tigray, 2000 in Mohammed, 2006).

Data Types and Sources of the study

This study was relying both on primary and secondary data. Secondary data was obtained through review relevant literature from libraries and internet including resource materials such as journals, annual reports, books, workshop proceedings and district reports. Primary data was also obtained through field measurement on necessary parameters that are used to estimate carbon stock of the study area.

METHODOLOGY

Delineation of Study Area

The initial step activities such as observing the study site area in order to get the ways and to record GPS points for boundary delineation of this study sites was done. Then after, the GPS points that were taken from each study site to indicate each sample plot were recorded.

Sampling design

For this study sampling plots of square shape which have dimensions of 20 m ×20 m was formed. In each site, sample plots were laid out along 100m ground distance, using a measuring tape, GPS and compass. The boundaries of the main plots were marked, then altitude, latitude and longitude data were recorded from the centre of each main plot. Inside larger plots (20 m × 20 m plot), five 1 m × 1 m sub-sampling units (four at the corners and one center of main plot) were located for fallen litter and soil sampling. The number of sample plots varied from site to site depending on the area of the church and to different existing conditions of the study area like vegetation coverage, availability of litter within the study sites.

Methods of data collection

Inventory of trees

For this study, to estimate the carbon stock of each study site, the species having DBH equal to or greater than 5 cm was considered, since in carbon stock measurement the minimum diameter is often 5 cm DBH as recommended by IPCC (2006) and (Pearson, 2007)

All trees having DBH greater than or equal to 5 cm and height at 1.3m were measured by using diameter tape and hypsometer. In cases where trees branched at or below the breast height, diameter was measured separately for each branch and quadrat. Diameter at each stem was measured separately for trees with multiple stems connecting near the ground. A tree with multiple stems at 1.3 m height was treated as a single individual.

Litter sampling

The Litter samples were collected from 1 m × 1m quadrat sub-plots in each plot. All the litter inside within 1 m^2 quadrat sub-plots of each main plot were collected, weighed and recorded and placed in a plastic bag and labeled to which sample plot it belongs. Then field wet weight was recorded and taken to laboratory to determine the litter biomass. The total dry weight was determined in the laboratory after oven drying of the sample at 70 °C for 24 hours to determine moisture content from which the total dry mass is calculated (Ullah & Al-Amin, 2012; Negash & Starr, 2015).

Oven- dried samples were taken in pre-weighed crucibles. The samples were ignited at 550°C for one hour in muffle furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated. Finally, carbon in leaf litter t ha^{-1} for each site was determined.

Soil sampling

The soil samples for soil carbon determination were collected from sample plots laid for litter sampling. In each sub-quadrat one composite soil sample was taken using core sampler auger at depth of 30 cm from the four corners and center of plots. The bulk density (BD) of the soil samples were collected by using a core sampler. Soil organic carbon was determined in the laboratory following Walkley-Black Method (1934). In the laboratory, soil samples were dried at 105 °C for 24 hours to remove the soil moisture and to determine the percentage of organic carbon as well as the bulk density (Pearson *et al.,* 2005). The soil organic carbon was calculated according to Pearson *et al.*, (2005).

Carbon stock estimation

Aboveground biomass carbon stock estimation

To estimate the AGB carbon, the total height and perimeter at breast height of all living stems ≥5 cm DBH within each plot was measured and identified them to the species level. Then, the aboveground biomass

(AGB) was estimated using allometric equations.

The generic allometric equations developed by Chave *et al.*, (2014) was considered a suitable equation to estimate above ground biomass in a tropical forest. Since this model performed well across forest type and bioclimatic conditions of pan-tropical areas, this study used this model to determine the AGB; the equation is given below (Chave *et al.*, 2014).

$AGB = 0.0673 *(WD * DBH^2 * H)$ ^ 0.976 ———————————— *(equ.1).*

Where: AGB = above ground biomass (in kg dry matter) WD = wood density (g/cm3) DBH = diameter at breast height (in cm) H = total height of the tree (in m).

Accordingly, the carbon content of tree vegetation in the study area was estimated by following IPCC (2006) which recommended the use of 47% (conversion factor: 0.47) for estimations of carbon concentration for aboveground biomass of tropical and subtropical forests

C = 0.47* AGB. ………………………………………………….. *(Equ.2).*

Belowground biomass carbon stock estimation

To estimate the carbon stock of belowground biomass, the methodology proposed by IPCC (2006), that is the application of a root to shoot ratio method was used.

The equations that have been used to calculate the belowground biomass is given below:

BGB = AGB* 0.26 ————————————————————— *(equ.3).*

Where BGB is belowground biomass, AGB is aboveground biomass; 0.26 is the conversion factor (or 26% of AGB). The biomass of stock density was converted to carbon stock density by multiplying default value of 0.47 carbon fraction (IPCC, 2006).

C = 0.47* BGB. ………………………………………………….. *(Equ.4).*

Estimation of Carbon in the Litter Biomass

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

$$LB = \frac{Wfield}{A} * \frac{Wsub\_sample(dry)}{Wsub\_sample(fresh)} * \frac{1}{10,000}$$ ……………………………… *(equ.5)*

Where: LB = Litter (biomass of litter t ha^{-1})

W_{field} = weight of wet field sample of litter sampled within an area of size 1 m^2 (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).

The percentage of organic carbon storage from the dry ash in the litter carbon pool was calculated as follows (Allen *et al.,* 1986)

%Ash = $wc - wa / wb - wa * 100$ ………………………………………… *(Equ.6)*

%C = (100 − Ash %) $*$ 0.58 ……………………………………………… *(equ.7)*

This is by considering 58% carbons in ash-free soil material.

Where, C = organic carbon (%), Wa = the weight of the crucible (g), Wb = the weight of oven dried grind samples and crucibles (g), Wc = the weight of ash and crucibles (g). Finally, carbon in litter t/ha for each sample was determined.

Carbon stocks in dead litter biomass

CL = LB × % C………………………………. *(Equ.8)*

Where CL is total carbon stocks in the dead litter in t ha^{-1}, % C is carbon fraction determined in the laboratory (Pearson *et al.,* 2005).

Estimation of Soil Organic Carbon

The carbon stock density of soil organic carbon was calculated as recommended by Pearson *et al.* (2005) from the volume and bulk density of the soil.

V = h p r^2 **…………………………………….** *(Equ.9)*

Where V is volume of the soil in the core sampler augur in cm^3, h is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm (Pearson *et al.,* 2005). More over the bulk density of a soil sample can be calculated as follows:

BD = ……………………………………. *(Equ.10)*

Where BD is bulk density of the soil sample per, $W_{av, dry}$ is average air-dry weight of soil sample per the quadrant, V is volume of the soil sample in the core sampler auger in cm^3 (Pearson *et al.*, 2005).

SOC = BD * d * % C ……………………………………. *(Equ.11)*

Where, SOC= soil organic carbon stock per unit area (t ha^{-1}),

BD = soil bulk density (g cm^{-3}),

D = the total depth at which the sample was taken (30 cm), and

%C = Carbon concentration (%)

3.4.5. Total Carbon Stock Density (TCSD)

The total carbon stock density of each site was calculated by adding the carbon stock densities of the individual carbon pools using the formula (Pearson *et al.,* 2005).

Carbon stock density of a study area:

$C_{density} = C_{AGB} + C_{BGB} + C_{Lit} + SOC$………………………. *(Equ.12)*

Where: $C_{density}$ = Carbon stock density for all pools [ton ha^{-1}]

C_{AGTB} = Carbon in above -ground tree biomass [t C ha^{-1}]

C_{BGB} = Carbon in below-ground biomass [t C ha^{-1}]

C_{Lit} = Carbon in dead litter [t C ha^{-1}]

SOC = Soil organic carbon

The total carbon stock was then converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson *et al*., 2007).

Results

Forest carbon stocks at each church forest

Carbon stock of Montogera Estifanos Church Forest

The result revealed that mean above ground biomass, carbon stock stored, and corresponding CO_2 equivalent were 125.03, 58.76 and 215.66 ton/ha, respectively. The minimum and maximum carbon density with values of 5.06 and 129.34 ton/ha were estimated respectively. Accordingly, minimum and maximum of 18.57 and 474.68 ton/ha CO_2 equivalents were stored in above ground biomass. The result revealed that mean below ground biomass, carbon stock, and corresponding CO_2 equivalent in the forest were 32.51, 15.28 and 56.07 ton/ha, respectively. The minimum and maximum carbon density with the value of 1.32 and 33.63 ton/ha were estimated respectively. Accordingly, minimum and maximum of 4.83 and 123.42 ton/ha corresponding CO_2 equivalents were stored in below ground biomass. The result showed that mean litter carbon stock and corresponding CO_2 were 2.37 and 8.69 ton/ha respectively. In the soil carbon pool, the result showed that mean soil organic carbon stock contained in it was 76.52 ton/ha. Accordingly, minimum and maximum of 178.40 and 396.16 ton/ha with mean of 280.82 corresponding CO_2 equivalents were stored in the soil.

Total mean carbon stock (ton/ha) of Montogera Estifanos Church Forest which is the sum of AGC, BGC, litter, and soil organic carbon (ton/ha) was 152.93 ton/ha. The corresponding minimum and maximum value of CO_2 equivalents were 206.17 and 897.23 ton/ha, with a mean of 561.24 respectively.

Carbon stock of Woji Abune Aregawi Debere Bereket Church Forest

The result revealed that mean above ground biomass, carbon stock stored and corresponding CO_2 equivalent were 71.19, 33.46 and 122.79 ton/ha, respectively. The minimum and maximum carbon density with values of 4.69 and 87.71 ton/ha were estimated respectively. Accordingly, minimum and maximum of 17.20 and 321.90 ton/ha CO_2 equivalents were stored in above ground biomass. It was observed that mean below ground biomass, carbon stock and corresponding CO_2 equivalent in the forest were 18.51, 8.70 and 31.93 ton/ha, respectively. The minimum and maximum carbon density with the value of 1.22 and 22.80 ton/ha were estimated respectively. Accordingly, minimum and maximum of 4.47 and 83.69 ton/ha corresponding CO_2 equivalents were stored in below ground biomass. The result showed that mean litter carbon stock and corresponding CO_2 were 2.16 and 7.96 ton/ha respectively.

In the soil carbon pool, the result showed that mean soil organic carbon stock contained in it was 86.33 ton/ha. Accordingly, minimum and maximum of 145.74 and 569.53 ton/ha with mean 316.85 of corresponding CO_2 equivalents were stored in the soil.

Total carbon stock (ton/ha) of Woji Abune Aregawi Debere Bereket Church Forest which is the sum of AGC, BGC, litter, and soil organic carbon (ton/ha) was 130.66 ton/ha. The carbon stocks in the plots were ranged in the minimum value of 46.79 ton/ha and

maximum values of 269.47 ton/ha forest zone. The corresponding minimum and maximum value of CO_2 equivalents were 172.37and 988.95ton/ha, with a mean of 453.60 respectively.

Carbon stock of Mai-Anbesa Kidane Miheret Monastery Forest

The result revealed that mean above ground biomass, carbon stock stored, and corresponding CO_2 equivalent were 12.00, 6.00 and 22.03 ton/ha respectively. The minimum and maximum carbon density with values of 0.07 and 55.79 ton/ha were estimated respectively. Accordingly, minimum and maximum of 0.27 and 204.76 ton/ha CO_2 equivalents were stored in above ground biomass.

The result revealed that mean below ground biomass, carbon stock, and corresponding CO_2 equivalent in the forest were 3.12, 1.47 and 5.38 ton/ha, respectively. The minimum and maximum carbon density with value of 0.02 and 13.64 ton/ha were estimated respectively. Accordingly, minimum and maximum of 0.07 and 50.4 ton/ha corresponding CO_2 equivalents were stored in below ground biomass.

The result showed that mean litter carbon stock and corresponding CO_2 were 1.33 and 4.90 ton/ha respectively.

In the soil carbon pool, the result showed that mean soil organic carbon stock contained in it was 121.90 ton/ha. Accordingly, minimum and maximum of 335.28 and 562.84 ton/ha with mean of 447.38 corresponding CO_2 equivalents were stored in the soil.

Total mean carbon stock (ton/ha) of Mai-Anbesa Kidane Miheret Monastery Forest which is the sum of AGC, BGC, litter, and soil organic carbon (ton/ha) was 130.71 ton/ha. The corresponding minimum and maximum value of CO_2 equivalents were 337.48 and 829.17 ton/ha, with a mean of 479.69 respectively.

Carbon stock of Emba Kidest Arsema Mekane Andinet Monastery Forest

The result revealed that mean above ground biomass, carbon stock stored and corresponding CO_2 equivalent were 1.50, 0.71 and 2.59 ton/ha respectively. The minimum and maximum carbon density with values of 0.27and 1.60 ton/ha were estimated respectively. Accordingly, minimum and maximum of 0.99 and 5.85ton/ha CO_2 equivalents were stored in above ground biomass. The result revealed that mean below ground biomass, carbon stock and, corresponding CO_2 equivalent in the forest were 0.39, 0.18 and 0.64ton/ha, respectively. The minimum and maximum carbon density with value of 0.07 and 0.41ton/ha were estimated respectively. Accordingly, minimum and maximum of 0.24and 1.44ton/ha corresponding CO_2 equivalents were stored in below ground biomass. The result showed that mean litter carbon stock and corresponding CO_2 were 1.33 and 4.90 ton/ha respectively. In the soil carbon pool, the result showed that mean soil organic carbon stock contained in it was 116.01ton/ha. Accordingly, minimum and maximum of 316.46 and 462.57 ton/ha with mean of 425.76 corresponding CO_2 equivalents were stored in the soil.

Total mean carbon stock (ton/ha) of Emba Kidest Arsema Mekane Andinet Monastery Forest which is the sum of AGC, BGC, litter, and soil organic carbon (ton/ha) was 118.24 ton/ha. The corresponding minimum and maximum value of CO_2 equivalents were 320.28 and 473.86 ton/ha, respectively with a mean of 433.89 ton/ha.

The total mean carbon storage of this forest was calculated as 133.14-ton $ha^{-1.}$

The potential of each study sites in carbon stocks vary from site to site due to their area coverage and structure vegetation composition of the tree/shrub species.

Study sites	AGC	BGC	LC	SOC	TOTAL
Woji Abune Aregawi Debere Bereket Church Forest	33.46	8.70	2.16	86.33	130.66
Montogera Estifanos Church Forest	58.76	15.28	2.37	76.52	152.93
Mai-Anbesa Kidane Miheret Monastery Forest	6.00	1.47	1.33	121.90	130.71
Emba Kidest Arsema Mekane Andinet Monastery Forest	0.71	0.18	1.33	116.01	118.24
Mean	24.73	6.41	1.80	100.19	133.14

Table 1. The means value of the carbon stock in all study sites.

Based on the result, Figure 9 shows the carbon stock potentials of Mai- Anbesa Kidane Miheret Monastery Forest and Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest were higher than other sites by soil organic carbon stock amount, but the carbon stock of the sites were lower than the rest of the study sites in both AGC and the BGC stocks. Therefore, Montogera Estifanos Church Forest has higher carbon stock compared to the rest of the study sites while Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest had low carbon stock.

Carbon stock along altitude

In the present study area, the different carbon pools such as carbon stock in above and belowground of trees, LHGs and carbon in soil were distributed along the altitudinal gradient but there was no statistically significant variation of carbon stock in carbon pools along an altitudinal gradient.

As shown in Table 2, it was noted that there is significant variation in aboveground and belowground carbon stock among sites. But the variation of aboveground and belowground carbon stock along altitude is statistically insignificant at 95% confidence interval (Table 2)

In the same way, there was no significant variation in the mean total carbon stock density of LHGs in the study sites. (Table 2)

Similarly, Despite the presence of mean soil carbon stock density variation in altitudinal classes, there was no statistically significant differences ($p>0.05$) along altitudinal gradient (Table 2)

Gradient		Carbon stock		
Site	AGC	BGC	LC	SOC
F-value	8.762	16.587	2.105	6.898
P-value	7.63e-05 ***	1e-07 ***	0.111	0.000804 ***
Altitude				
F-value	1.058	0.022	0.731	0.744
P-value	0.308	0.883	0.396	0.393921

Table 2 Summarized results of two-way ANOVA relation between carbon pools with altitude and site

Discussions

The studied forest patches were endowed and characterized by important woody and shrub species in the Northern Ethiopia. They are one of the very few remaining dry afromontane church forests located in the Northern Highlands of Ethiopia. Besides, the type of plant species observed and identified in the sites were dominant and important woody species that could be used for ecological benefit of the country at large.

According to Brown, (1997), the above ground carbon stock is 47 t/ha for tropical dry forest and 36 t/ha for sub-Saharan African countries while, according to IPCC (2006) assessment, 126 t/ha was reported for tropical dry forest and 72 t/ha for open sub-Saharan African countries. Similarly, Houghton (1999) recorded 55 t/ha carbon for tropical dry forest and 30 t/ha carbon for open forest in sub- Saharan African countries. The average above ground carbon in the present study (24.73 t/ha) was smaller than the value indicated above.

Similarly when compared with other studies, the mean carbon stock in above and belowground biomass of the present study was significantly lower than the result of Sekele-Mariam Dry Evergreen Montane forest (Asersie Mekonnen and Motuma Tolera, 2019), Abiyu, & Tulu Tolla, Selected Church Forests (2013,2011 respectively). The BGC has similar pattern with that of the aboveground values due to the fact that it is 0.26 times (26%) of the aboveground results. This disagreement on carbon stock of the forest site is probably due to variations in age of the trees, management of the forests, the allometric model used. regional variability in soil, topography, existing species height, and DBH range of trees that few large individuals can account for large proportion of the plots above and below ground carbon (Brown & Lugo, 1982).

According to Brown & Lugo, (1982) litter fall in dry tropical forests range between 2.52–3.69 t ha^{-1} $year^{-1}$. On the other hand, mean biomass carbon stock in LHGs for tropical dry forests was 2.1 t/ha as reported by IPCC (2006). The finding of the present study was less compared to values reported above. Mean carbon stock of litter biomass obtained in this study was also lower than Selected Church Forests

(Tola, 2011), but was higher than the result of Sekele-Mariam Dry Evergreen Montane Forest (0.02-ton ha^{-1}) reported by Asersie Mekonnen and Motuma Tolera, (2019), and selected church forests (0.9 ton/ha) reported by Abiyu, (2013). The reason for litter carbon differences may be due to factors such as rate of decomposition (which is governed by climatic factor like temperature and moisture), the forest vegetation type (species, age and density), land cover types and climate (Binkley & Fisher, 2013). Furthermore, the variation might have happened due to the difference in forest management practices of the church forests.

Soil organic carbon plays a vital role in the global carbon cycle and C pools (Sundarapandian & Subbiah, 2015). According to Luke (2018), the average soil organic carbon in Ethiopia ranges from 94 to 133 ton/ha. On the other hand, the IPCC default values are 31 to 130 ton/ha for different tropical soils (IPCC, 2006). This result obtained from the present study was consistent with the studies mentioned above. This finding was more or less similar with the findings reported by Abiyu, (2013, Asersie Mekonnen and Motuma Tolera, (2019) and Tola, (2011). The contribution of SOC stock was higher than the total biomass contribution.

Forests are one of the crucial ecosystem components that play a great role for temporary and long-term carbon storage, but the forest biomass and carbon is highly disturbed by environmental factors such as altitude (Alves et al., 2010, Asner et al., 2014 and Fentahun *et al.*, 2017).

The maximum of AGC (t/ha) were found in the Montogera Estifanos Church Forest. The variation may have been occurred due to tree diameter and height. This implies that the higher carbon stock in above-ground biomass in the study site could be related to the higher tree DBH in the church forest. According to Slik *et al.*, (2013) bigger trees have a significant role on the variability in carbon stocks. This is also supported by Gibbs *et al.*,(2007) who reported bigger trees with higher diameter storing the largest density of carbon within biomass. Another study suggested that the large-sized tree leads to the increase of carbon stocks while the smaller size classes held contributed to a small fraction of the live AGC (Getaneh *et al.*, 2019).

SOC is determined by the solar radiation, ground vegetation, biomass content and microbial activities and so on. One aspect of the organic carbon pool that remains poorly understood is its vertical distribution in the soil and accompanying relationship with climate and vegetation (Jobbágy & Jackson, 2000). The increase in temperature leads to the increase in production and decomposition. In addition to that, high altitude plants have large roots to shoot ratio, which results in higher carbon concentration in soil (Yang et al., 2009). Soil organic carbon has been shown to increase with increased clay contents (Jobbágy & Jackson, 2000) because clay dominated soils are capable of higher SOC storage compared to course textured sandy soils due to stabilizing effects by soil macro aggregates and associated iron oxides on soil organic matter (Six *et al.*,2000). These might be the reason for the variation in the SOC content in the study sites.

Generally, the carbon pool of the study sites did not show significant variation along altitudinal gradient as aboveground carbon, belowground carbon, litter carbon and soil organic carbon. The reason for such might be due similar species composition and the topographical nature where the study sites located throughout the altitudinal gradient of the forest.

Conclusion And Recommendation

Carbon stock study of forests is crucial to show forest potential and role to mitigate climate change.

Mean carbon stock density obtained for the entire church forests was 133.14 ton/ha. Although Carbon stock in the study sites were relatively low compared to similar church forests in the country, the characteristics of plant communities in the study area present good carbon stock especially, in soils and woody biomass. On top of that, there was tremendous capacity for the study area to store carbon and act as carbon sink if properly managed.

Differences in carbon storage among studied church forests reflect variation in a number of factors, such as tree community physiognomic characteristics, composition and soil properties. DBH is the most significant factor for large aboveground biomass storage in Mantogera church forest. Mean carbon stock in the respective pools showed that soil carbon pool was the highest, followed by above ground biomass while litter was lower in carbon stock.

In this study, aboveground, below ground, and soil carbon pools density litter carbon pool was not significantly different along altitudinal gradients.

Abbreviations

AGC———————————— Aboveground carbon

AGB———————————— Above-ground biomass

ANOVA————————— Analysis of Variance

BGB———————————— Below ground biomass

C——————————————— Carbon

DBH- ———————————— Diameter at breast height

EOTC- ——————————— Ethiopian Orthodox Tewahido church

IPCC- ———————————— Intergovernmental Panel on Climate Change

LB—————————————— Litter Biomass

LC———————————— Litter Carbon

LHG——————————— Litter, herbs, and grass

SNS————————————— Sacred Natural Sites

SOC———————————— soil organic carbon

Declarations

Availability of data and materials

Data are available on request from the authors only based on logical requests

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Authors' contributions

kehali has written the paper and has done the analysis. Teshome Soromessa has reviewed the paper, helped to write. Abeje Eshete has reviewed the paper, edited grammar. The authors read and approved the final manuscript

Ethics declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Figures

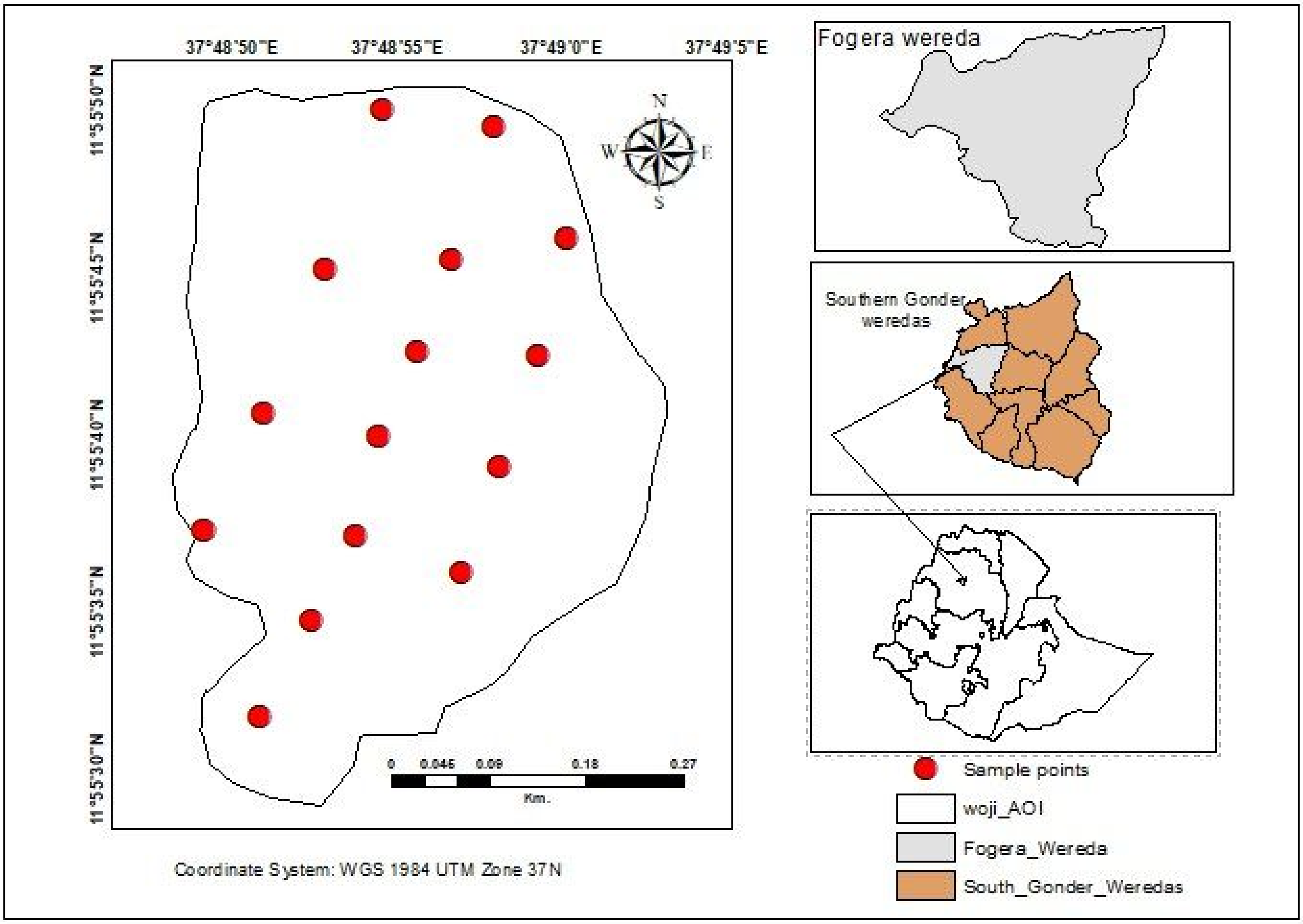

Figure 1

Map of Ethiopia showing the study area (Abune Aregawi Debere Bereket Church Forest)

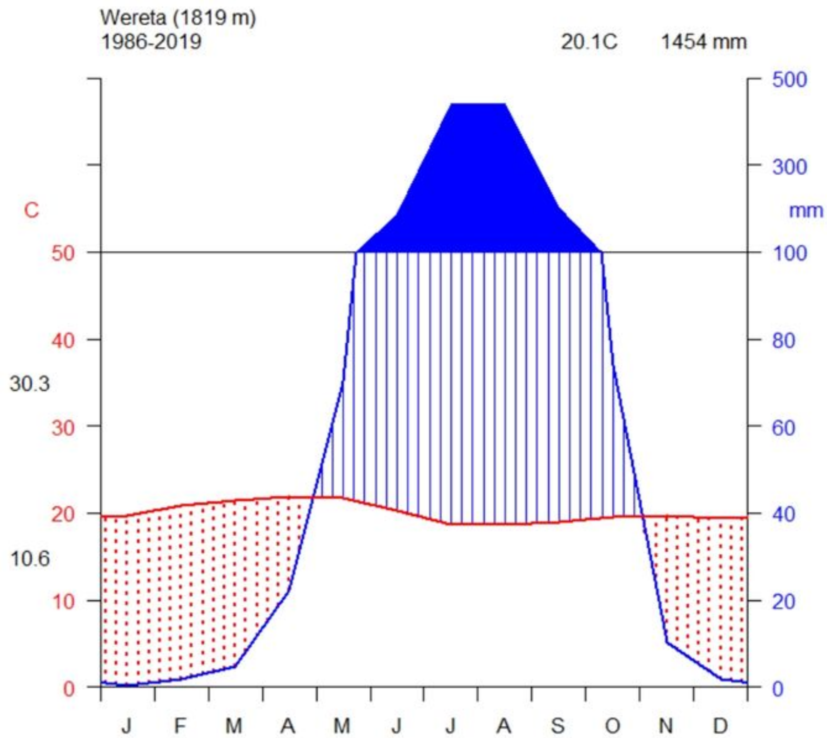

Figure 2

Climate diagram of the nearest station (Abune Aregawi Debere Bereket Church Forest) (Data source: ENMA)

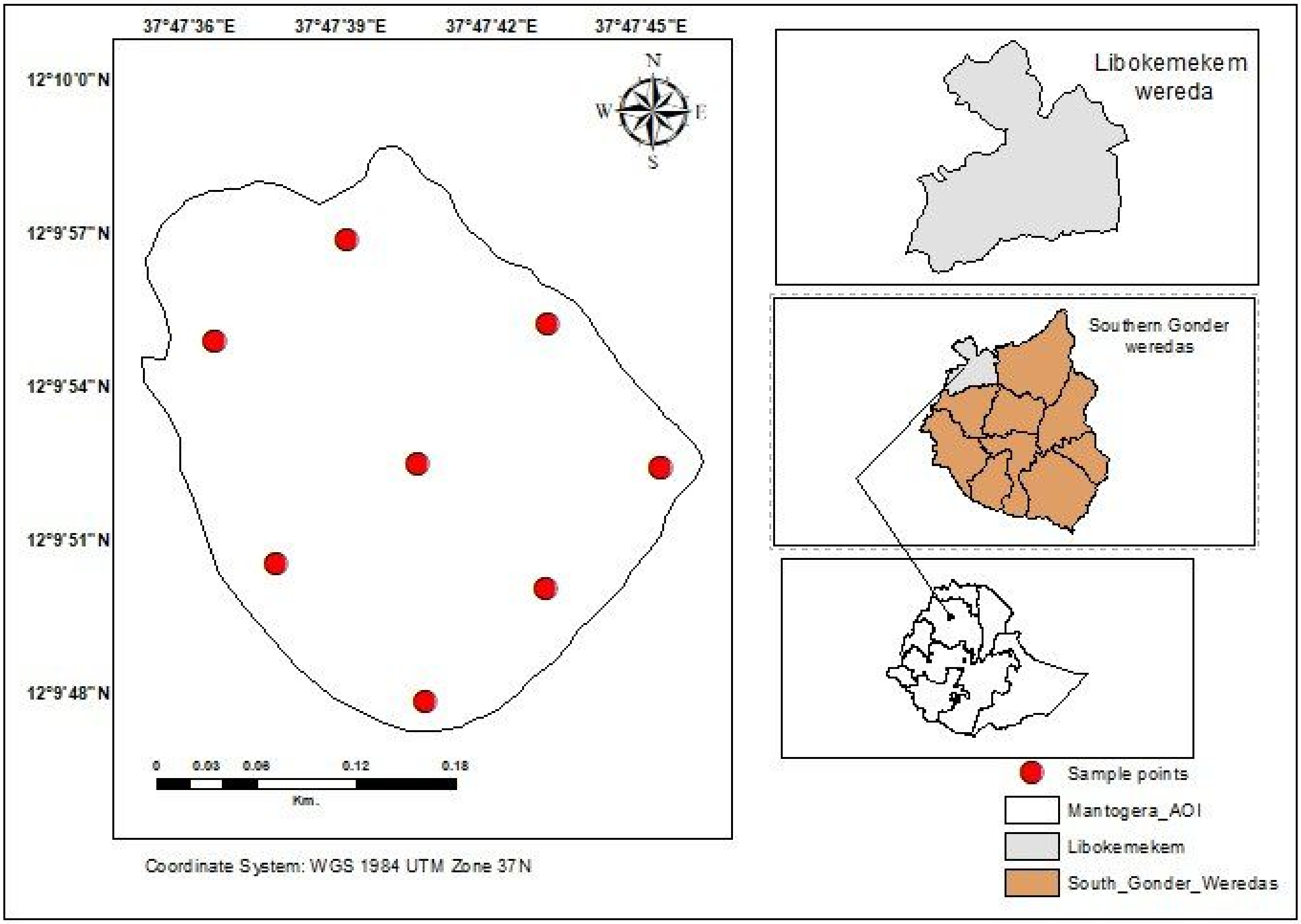

Figure 3

Map of Ethiopia showing the study area (Montogera Estifanos Church Forest)

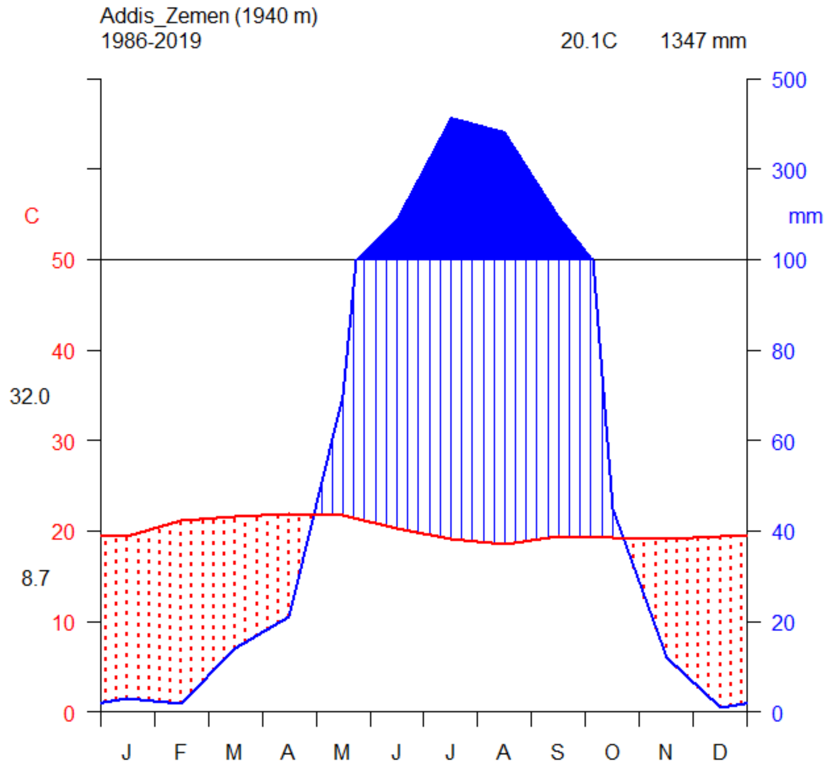

Figure 4

Climate diagram of the nearest station (Montogera Estifanos Church Forest)

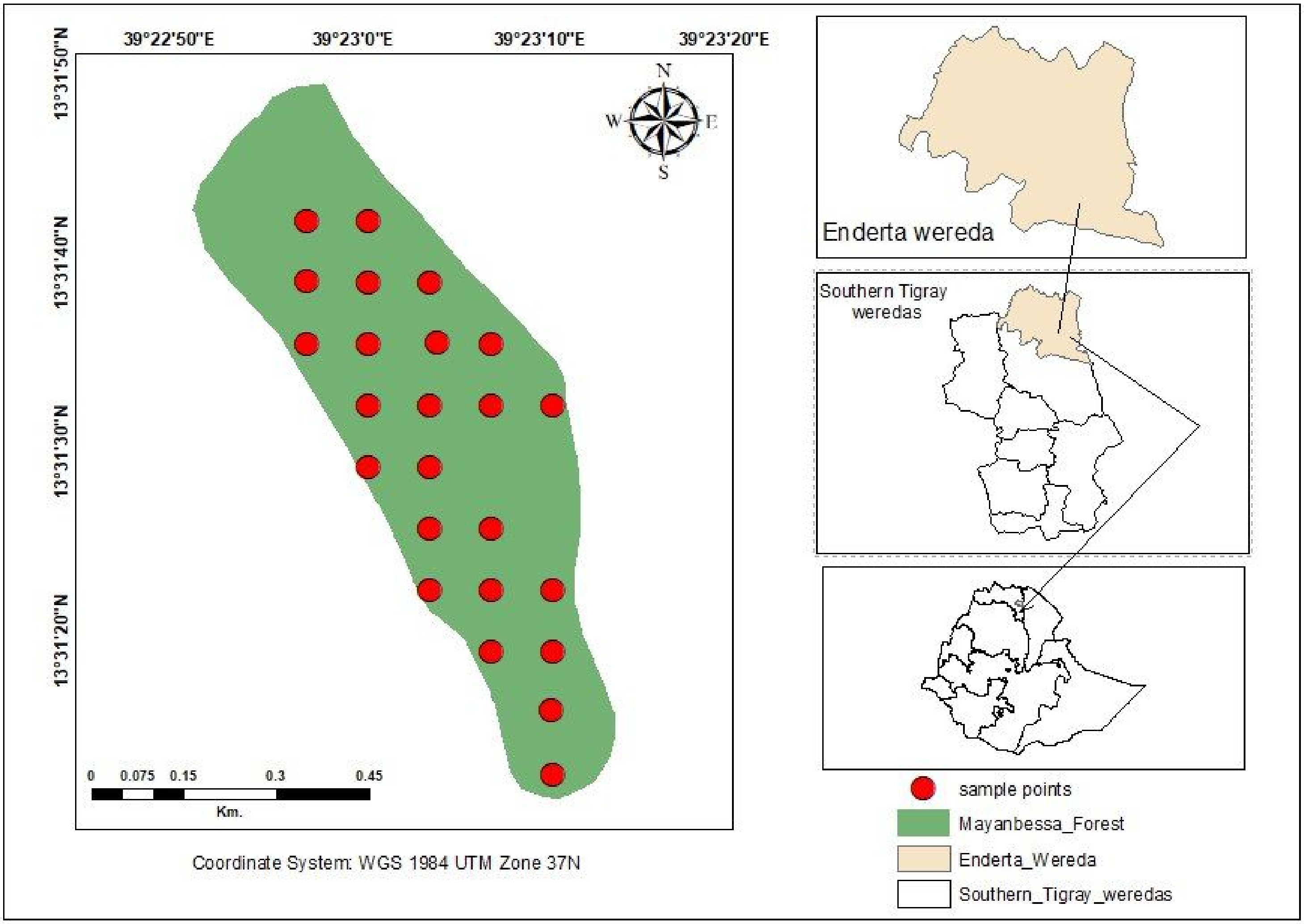

Figure 5

Map of Ethiopia showing the study area (Mai- Anbesa Kidane Miheret Monastery Forest).

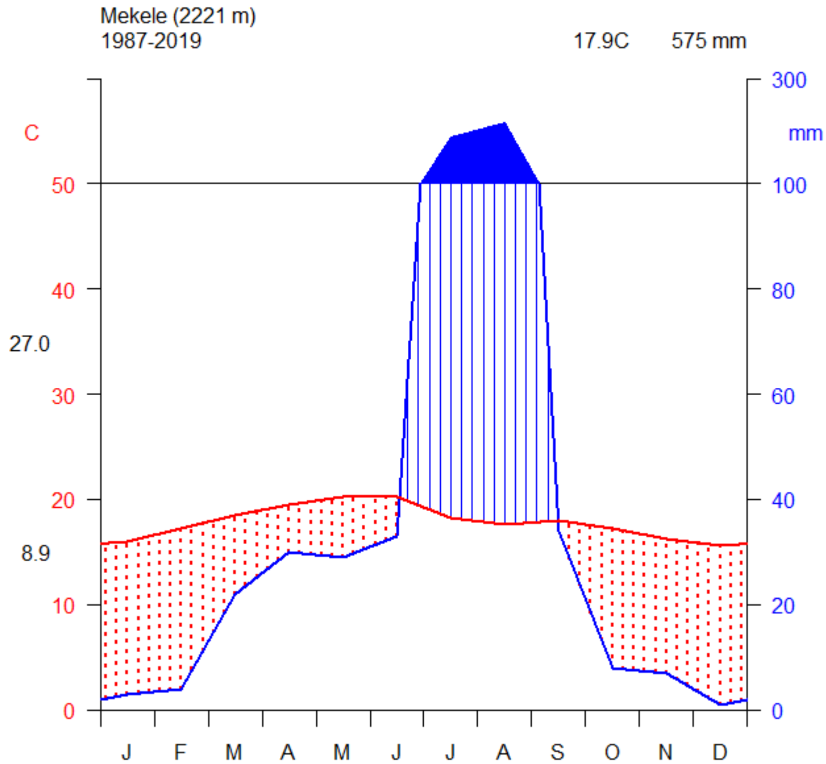

Figure 6

Climate diagram of the nearest station (Mai- Anbesa Kidane Miheret Monastery Forest) (Data source: ENMA)

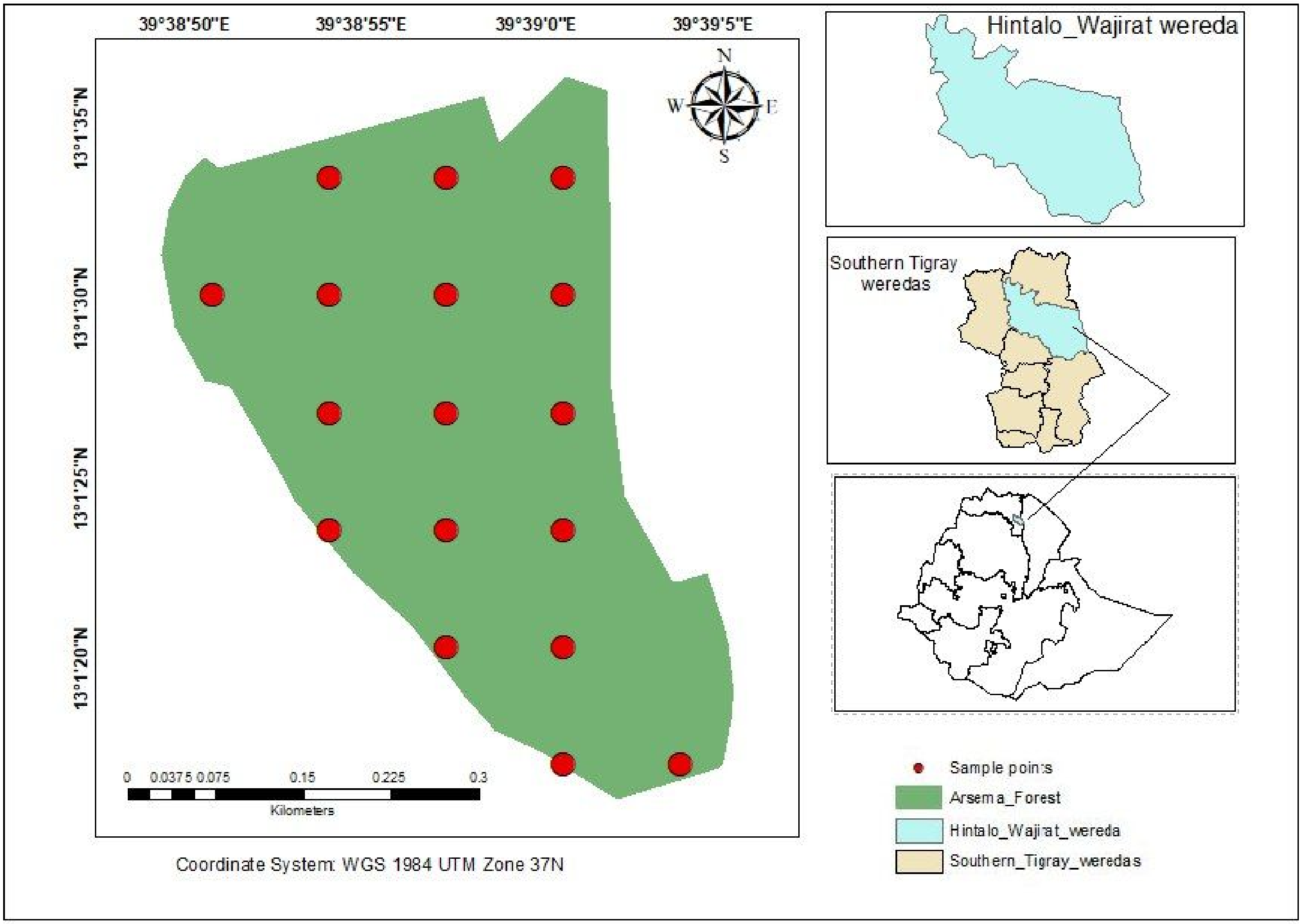

Figure 7

Map of Ethiopia showing the study area (Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest)

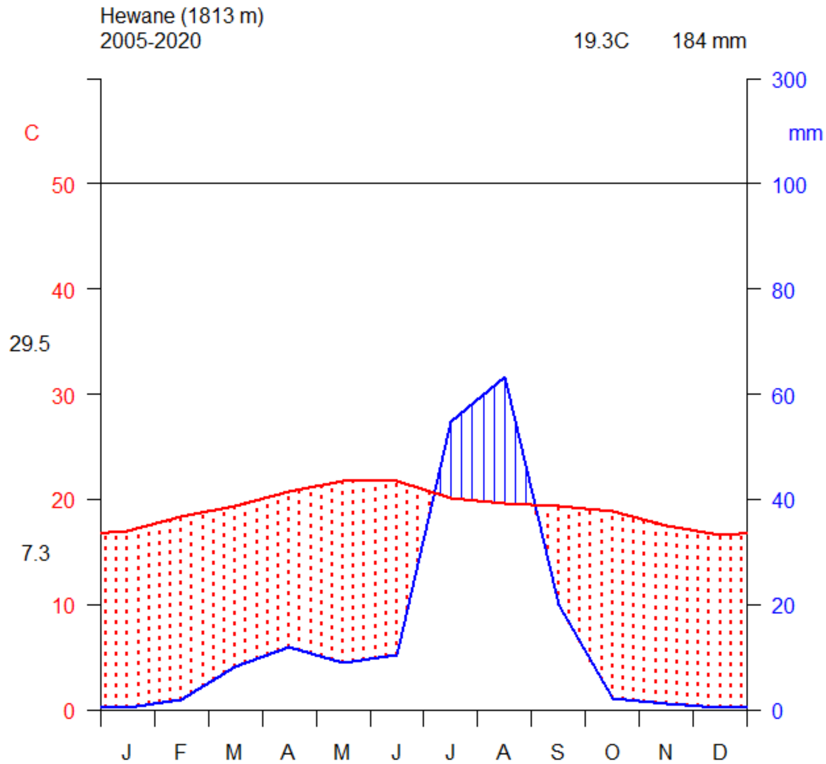

Figure 8

Climate diagram of the nearest station (Emba Kidest Arsema Mekane Kidusan Andinet Monastery Forest) (Data source: ENMA).

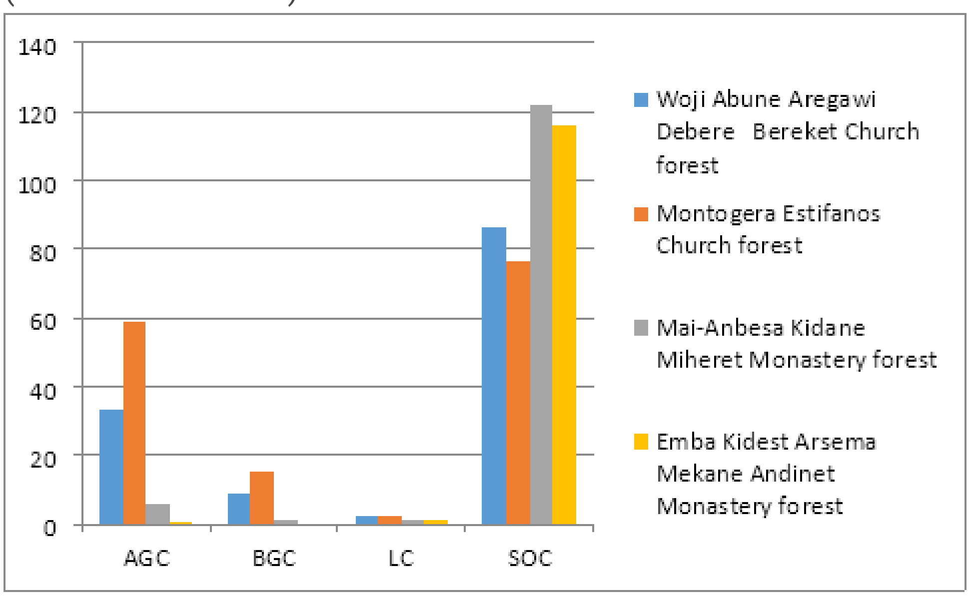

Figure 9

Total carbon stocks in study sites