Carbon storages and sequestration potentials of Sulula Mofa Forest Northern Ethiopia: Implications of managing forests for climate change mitigation

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Abstract

Forests provides various services and particularly, playing an incredibly greater role in balancing the global carbon balance and mitigating climate change by sequestering CO_2 and storing organic carbon from the atmosphere. The overall objective of this study was intended to investigate the Carbon stock and CO_2 sequestered potentials, along altitudinal, slope and aspect gradients of woody species of Sulula Mofa Forest, Northern Ethiopia. Systematic sampling technique was used to collect data from the three carbon pools. A total of 42 sample plots with size 400m^2 for Tree pool, small plots with a size of 1m^2 for Litter pool and Soil data collected from five sub-plots within each major plot and a diameter of > 5cm and at the depth up to 30cm land surface. DBH of woody species were measured in each major sampling plot at DBH ≥ 1.3m & the diameter at DBH ≥ 5cm. The biomass of woody species was estimated using the non destructive allometric equation, while appropriate laboratory procedures were used in the analysis of litter and soil biomass. A total of 54 woody plant species categorized into 50 genera and 33 families were recorded and identified. The total carbon stock and CO_2 sequestration potentials of the woody species were estimated to 1121.14 t/ha & 4114.59 t/ha respectively, of which tree pools (658.55), Soil pools (315.88) and Litter pools (146.71). In the study forest, 92.59% of carbon stored and CO_2e sequestered were contributed by the following ten woody tree species of the study forest; *Ficus sur, Juniperus procera, Cupressus lusitanica, Eucalyptus globulus, Acacia abys*sinica, *Croton macrostachys, Erythrina abyssinica, Olea europaea subsp. cuspidata, Cordia africana* and *Pteroloblum stellautm* with their descending order. Plots in the south and west part of the forest had more species diversity, greater carbon stocks and CO_2 sequestration potentials. Plots at the middle and upper altitudes assessed had more species diversity. It can be concluded that the study forest contributes high carbon stock, better sequestration potential and plays a role in climate change mitigation. Thus, we suggests that, stakeholders should adopt effective forest conservation measures and get benefit from the bio-carbon fund from their activity (CDM of the Kyoto Protocol); as financial incentives to improve foresters' Livelihoods.

1. Background

Tropical forests play a key role in climate change mitigation by sequestering and storing carbon from the atmosphere. Forests and soils are potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets (UNFCCC, 2017). Forest ecosystems are known in storing the highest proportion of terrestrial carbon (Beyene et al., 2018) and play a significant role in the global carbon cycle.

Forests are playing a great role in mitigating climate change (Siraj, 2019; Vieira et al., 2004), serving in soil and water conservation (FAO, 2014), providing habitat for terrestrial biological diversity (MEA, 2005) and enhancing the livelihood of poor people (Siraj & Zhang, 2018). Forests containing up to 80% of the total above-ground terrestrial C and 40% of the below-ground C, hence having a critical role in the global C cycle (Justine et al., 2015).

Different scholars were estimated Africa's and Ethiopia's carbon stock. African forests constitute 21% of the global total carbon stock of forest biomass and had the ability to sequester up to 630 kg of carbon per hectare per year (Katerere et al., 2009). Africa's carbon stock was estimated (in TgC/year) to 613 of forest Biomass, 43 of Dead wood, 6 of Litter and 83 of Soil carbon stored and estimated as a total of 745 (Pan *et al.*,, 2011). Africa Total forest Area was 527 Mha, with a total Carbon density (Mg/ha) of Vegetation was 99, Soil was 120 and having a total Carbon stored (Pg) was 52 and 63 respectively (Hui *et al.*, 2015).

Ethiopia has one of the largest forest resources in the horn of Africa which covers 11.40% in 2015 (FRA, 2015) and has a good potential in mitigating climate change (FAO, 2010). The forests resources of Ethiopia stored 2.76 billion tons of carbon which equivalent to 10 billion tonnes of CO_2 in the AGB and the SOC pool in Ethiopia was 14 billion tonnes of C/year which were about an investment of $150 M/year (Shiferaw, 2013). Ethiopia contributes 0.27% of global emissions and was ranked 163 out of 181 countries, the 22nd most vulnerable country and the 31st least ready country (Benzie, 2016).

The studies made on the biomass of trees in Ethiopia is very limited and even the available studies have focused on small diameter ranges and on limited species including Eucalyptus and Acacia trees (Muluneh & Worku., 2022; Siraj, 2019; Fantu et al., 2010; Bazezew et al., 2015). Ethiopia is endowed with natural vegetation where floristic and fauna life forms dynamic ecosystems.

There is great interest in assessing forest carbon stock (Djomo *et al.*, 2016) and therefore, it is considered as the global issue and large scale CO_2 emission reductions are required with strict limits on each country to what level carbon is absorbed to mitigate climate change (Condit, 2008). In Ethiopia, there are inadequate data in the form of carbon accumulation records or databank to assess the carbon sequestration potential of different forests (Muluneh & Worku., 2022; Siraj, 2019). Forests are a current focus for action since they play an important role in mitigating climate change by naturally taking carbon out of the atmosphere through photosynthesis process (Watson et al., 2000).

Hence, the assessment of carbon storages and sequestration potentials of the study forest has not been studied. Therefore, the present study attempted to provide scientific information by quantifying the total carbon stored through examining the forest AGB carbon, BGB carbon; LB carbon and SOC carbon stock potential and the total sequestration of the study forest the key role forest play a in climate change mitigation.

2. Materials and Methods

2.1. Study Area Description

2.1.1. Geographical Location

The study was conducted at Dessie-Haik District which is located in South Wollo Zone, North-East part of Amhara region, Ethiopia (Fig. 1**)**. The District Haik city, at around lake Haik, is found 30km away from zone administration, Dessie city and 454km away from regional capital, Bahir Dar and 431km away from the capital city of Ethiopia, Addis Ababa. It shares immediate boarders in the North with Ambassel Woreda, in the South with Dessie zuria woreda, in the East with Worebabo Woreda and in the west with Kutaber and Ambassel Woreda. The Woreda has a total area of 44030hectaresand subdivided into nineteen rural and five small urban kebeles. Altitude of theWoreda ranges from 1488-2900m.a.s.l (Seid, 2013). The woody species of Sulula-Mofa forest is, a mixed type of natural and plantation forest starting from the *Derg* Regime, is found in Kebele 01 and 08 is approximately positioned at latitude 11^0 23'07"-11^0 23' 53"N and 39 ^{0}67'10" -39 ^{0}68 '80"E longitude.

2.1.2. Climate

The study region is characterized by a semi-arid climate and which has warm-humid summers and cold-dry winters and the minimum temperature in January and the maximum temperature is in June (Hurni, 1998). Major seasonal rainfall patterns in Ethiopia symbolized as a bimodal rainfall patterns with spring and summer rains and short dry season during the early summer, particularly in June. The mean annual precipitation ranges from 1000-2200mm and More than 80% rainfall occurs between July and September (Soromessa & Kelbessa, 2013). It has '*Dega'* (13%); '*Weina Dega'* (72%) and '*Kolla'* (15%) agro ecological zones. It has '*Dega'* (13%); 'Weina Dega' (72%) and '*Kolla'* (15%) agro ecological zones. It has an average annual rain fall is1030mm and an average temperature of 21^oc per annum (Seid, 2013).

2.1.3. Geology and Soils

In the central plateau including Sulula Forest, basalt constitutes the main rock types that are chemically and mineralogicaly uniform in composition (Soromessa & Kelbessa, 2013). The soils in Wollo plateau including Sulula Forest area are reddish brown, gravelly and shallow at higher altitudes, while at lower sites they tend to become dark-grey and deep; whereas soils in the surrounding low plains are vertisol, black soils with characteristic high clay content (Tesfaye et al., 2016). Among the six soil groups of Ethiopia the study area is classified to the plateau soil region and the soils are derived from basaltic and other volcanic rocks. The soils are mainly red lateritic soils or black vertisol soils. They are usually fertile and highly affected by Over cultivation, over grazing and some other human interference (Soromessa & Kelbessa, 2013).

2.1.4. Vegetation Cover

The study forest is a type of Dry Evergreen Afromontane Montane Forest type. The study forest grouped under Dry single-dominant Afromontane forest with a canopy of several strata occurring between (2200–2800 meters) ranges of altitude usually dominated by Tid/Gatira *(Juniperus procera)* followed by Weira/Ejersa (*Olea europaea* subsp. *cuspidate)*, Grar *(Acacia abyssinica)and* in some parts dominated by Asta *(Erica arboreal)* (Friis *et al*., 2010).

The total forest cover of the region estimated as 12,884km^2, that is, about 8.2% of the total land area. Including bush lands, it is about 21,783km^2, which is about 13.85% and the Percentage of forest cover in South Wollo zone were estimated as Natural forest 0.13%, Woodlands 0.25%, Plantation 0.7%, Riverine 0.02% and the Sum total of zonal forest cover were 1.1% (Mulatie *et al*., 2016).

2.1.5. Land Use Types and Economic Activity

It is the most populous area in Amhara region with total population 152,891. Out of the total land cover, 15937 ha are used for crop production, 736 ha for grazing, 14308 ha forest and bush land, 3800ha water body and 1000ha are wasteland. The average land holding per household is estimated as 0.5ha (Seid, 2013).

The Amhara region census data in 2007 (unpublished) showed that; Tehuledere Woreda had total population of 117,877 from which 14,745 were living in urban areas and 103,132 in rural areas.

The people of the study area are the largest chat (*Catha edulis)* cultivators of in Northern part of Ethiopia and economically supported from Oranges and papaya are often sold in the local markets located in Haik city and markets in neighboring areas such as Dessie town, Kombolcha city, Weldia, Kobo city, Afar region, Alemata city and Mekkele, Tigray.

2.2. Data collection

2.2.1. Reconnaissance survey

Reconnaissance survey was carried in the study area in order to have general overview of the forest so as to estimate the position, number and length of transects to be laid across the forest. Permanent plot navigation was carried out by loading sample plot locations onto the GIS and Auto CAD for partitioning. Sample plots, Altitudes, Latitudes, Altitude (Elevation), Aspects (Northing, Easting) and Slope degrees of the study forest were navigated in the study area by using WGS84 Mobile Topographer Applicability software. Center points of all plots were marked permanently and the GPS points saved, printed and the points loading to Google Earth to permanently map the study forest. The sketch of the plot center references, their distances and bearings to the center were recorded and shown on the inventory form.

Topographer applications was used to measure slope Degree (Azimuth) to obtain horizontal distances and heights of trees distance and other distance measurements using table of slope correlation form. Then, the main work of Carbon measurement of AGB, BGB, Litter Biomass and Soil Biomass were measured using formula.

2.2.2. Sample Size determination

The sample size must be adapted to the tree diversity of the stand; the more variability there is within a forest stand, the bigger the number of trees sampled should be and Sample size determination depends on the vegetation type, logistics, manpower and cost (Dietz & Kuyah, 2011). In order to determine statistically sufficient sample size, the following sampling technique was employed in the study forest (Table 1). Using WGS 84 Topographer Applications 93

UTM points were taken from different parts of the forest area, loaded them to Google Earth, the study forest demarcated and partitioned to 209 plots of 20mx20m (400m^2) size each with a distance of 120m from the plot centers. Then, Randomly 42 sample quadrats (a total sampled area of the study forest was 42x400m^2 equal to16800m^2 or 1.68ha) were taken from the forest and the number of trees and shrubs species per plot was counted and recorded on spread sheet forms. The number and area of major sample plots, each having an area of 400 m^2 was determined after calculating and observing the forest cover. The design of the sampling Units in the field were used plot stratified sampling technique with purposive sampling and the sampling design were created with the following stages:

The boundary of plot (a population) on the map that was surveyed and determined as 3,000,000m^2 (300hectare) areas of polygon demarcated Using WGS 84 Topographer Applications of 93 UTM (Universal Transverse Mercator Coordinate System) points.

Table 1
The sequences of steps in sample determination:

1st	**The map scale used determined as: – 1: 1000.**
2nd	The broad population (L) which were surveyed Determined as:- L = 3km2 = 3,000,000 m2 = 300 ha
3rd	The Area of sample plots (l) that were used determined as:- l = 0.04ha
4th	The population size (N) Determined as:- N = L/l = 300ha/0.04ha = 7500 plots
5th	The Intensity of sampling (IS) that were used determined as:- IS (Taking around 5–10% of N); N = 5.6%
6th	The number of sampling plots (n) that were done determined as:- n = N/IS = 7500ha *5.6/100 = 42 plots
7th	5 small plots (1m *1m = 1m2) for soil data (ns) in each plot and determined as:- Qs = n * 5 = 42plots *5 = 210 small plots.

2.2.3. Stratification of the Study Area

Stratification was done in the study forest in order to take accurate data from the field as well as to maintain the homogeneity of the study area. Altitude was a major parameter to classify the study area. The strata were defined at each 100 m elevation, starting from the lower to the higher altitude of the study forest area. Therefore, based on altitudinal variation, the study site was stratified into three zones namely: higher class (2559-2727m), middle class (2390-2558m) and lower class (2220-2389m) having cluster distribution of sample plots 26.19%, 50% and 23.81% in their respective order. Starting from 100m into the forest land; 2220m was measured as a lower altitude because the forest starts at this altitude value and 2727m was considered as an upper altitude due to the boundary of the study area stopped at 2800m height at mount Mofa.

Slope gradient was the second parameter to classify the study forest. The classification of the study area by slope was similar with classifications based on altitude starting from the starting point to ending point of samples (forest) (Gadow et al., 2012). Accordingly, slope classes were classified into lower class (1-100^0), middle class (101–250^0) and higher (251–343^0) and each were subdivided in to two slope degrees. Aspect was also another parameter that was considered in the study forest and classified in to eight classes: N (North), NE (Northeast), NW (Northwest), S (South), SE (Southeast), SW (Southwest), E (East)and W (West) having proportion plots of 11.9%, 4.76%, 4.76%, 19.1%, 4.76%, 11.9%, 19.1% and 23.82% respectively. Plots slope or inclination (%) and aspect were recorded using World Geodetic System (WGS 84 Mobile Topographer Applicability a type of the Global Positioning System, GPS), respectively. Environmental variables include altitude and geographical locations (latitude and longitude) of each sample quadrat were measured clustered (using WGS 84 Mobile Topographer Applicability (Cell Phone Galaxy A10) having an accuracy of ≤ 5m.

The field data was collected using field formats and all validated field data were entered into computerized data bases of SPSS, ArcGIS, Microsoft Excel, Auto CAD, Plant Finder Mobile Applications and Mobile Topographer Applicability software version 9.3.2 surveying tools which uses GNSS (Global Navigation Satellite System)receiver for useful data collection, data outputs all graphs and data analysis (Appendix 4).

2.3. Data type and sources

2.3.1. Above ground Biomass Data Collection

The above ground biomass consists of all living woody plant species above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The DBH (at ≥ 1.3m) & the diameter at DBH ≥ 5cm and DBH were measured in each sampling plots. AGB were calculated using defined allometric equation as a statistical relationship between key characteristic dimensions of trees for Dry Afromontane forest type of our study as of AGB is above ground biomass, D is the DBH diameter at breast height and tree height using (R^2 Adjusted = 0.67, for n ≥ 32, Tree size ; diameter ≥ 5cm at the tree height ≥ 1.3m and form factor f = 0.42) as expressed, the assumption that 50% biomass (on a dry weight basis) is carbon is well accepted (Bhishma *et al.*, 2010). The biomass stock density of a sampling plot is converted to carbon stock densities by default carbon fraction of 0.47, as the dry biomass contains 47% organic carbon in the tropical and sub-tropical region. So, for our study, the measured biomass was converted to carbon units by taking 50% of the AGB to AGC (Walker *et al*., 2015).

2.3.2. Below Ground Biomass Carbon Stock Data Collection (BGB)

Standard method for estimation of BGB can be obtained as 20% of above ground tree biomass (root to shoot ratio value of 1:5 was used). BGB was calculated by considering 20% of the AGB (MacDicken, 1997). The biomass stored was converted to carbon stock by multiplying 0.5 fraction of default value (Sarah *et al*., 2015). Roots play an important role in the carbon cycle as they transfer considerable amounts of Carbon to the ground, where it may be stored for a relatively long period of time (Geider et al., 2001).

2.3.3. Litter Biomass Data Collection

The Litter Biomass (LB) is defined as all dead organic surface material on top of the mineral soil (Karberg *et al*., 2008). A total of 210 small plots with a size of 1m×1m ($1m^2$) were established and litters samples were collected from 42 plots taking average weight of litters of 100g. In each sample plots a total of five small quadrates were laid, four at the corner and one in the center to minimize heterogeneity. The litter samples were taken from sub quadrate of ($1m^2$) along diagonal from one corner to the other and then the leaf litters within the $1m^2$ sub plots were collected. 100g of Litter Biomass (LB) sub sample of fresh weights will be sampled from the five sub-samples from each quadrant and can be mixing homogenously then it were taken to Wollo University Chemistry Laboratory and oven dried at 105^{o}c for laboratory analysis of LB.

2.2.6. Soil Data Collection

Soil data was collected using core sampler having a diameter of 5cm and from the depth of up to 30cm land surface. In this study Soil Organic Carbon (SOC) samples were collected from the field with five sub-plots within each major plot following Justine et al., (2015). Mixing of soil samples were done properly by taking equal amount of soil from each sub plots to make about 100g of composite sample in order to make homogeneity. All samples were labeled to which plot they belong and brought to Wollo University Chemistry laboratory for analysis. In the laboratory, soils were prepared and oven dried at 105^{o}c for 24 hours to remove the soil moisture so as to determine the percentage of organic carbon. Finally, the bulk density and soil organic carbon were determined after getting percentage of organic carbon.

2.3. Biomass and Carbon Stock Analysis

2.3.1. Above Ground Biomass Analysis (AGB)

The above ground biomass consists of all living woody plant species above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The DBH (at ≥ 1.5m) & the diameter at DBH ≥ 5cm and DBH will be measured in each sampling plots. AGB was calculated using defined allometric equation as a statistical relationship between key characteristic dimensions of trees for Dry Evergreen Afromontane forest type as given below (Bhishma *et al.*, 2010):

$$\text{AGB}= 34.4703 \text{ - } 8.0671(\text{D}) + 0.6589(\text{D2}) \ldots\ldots (1)$$

Where; AGB is above ground biomass, D is the DBH diameter at breast height

2.3.2. Below Ground Biomass Analysis (BGB)

Roots play an important role in the carbon cycle as they transfer considerable amounts of Carbon to the ground, where it may be stored for a relatively long period of time (Geider et al., 2001). Standard method for estimation of BGB can be obtained as 20% of above ground tree biomass (root to shoot ratio value of 1:5 is used). The equation is given below (Kent & Coker, 2014):

$$\text{BGB} = \text{AGB} * 0.275 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where; BGB is below ground biomass, AGB is above ground biomass, 0.2 is conversion factor (or 27.5% of AGB).

2.3.3. Litter Biomass Analysis (LB)

Estimation of the amount of litter biomass will be calculated by using the following equation (Pearsonet al., 2007):

$$\text{LB} = \frac{\text{W field}}{\text{A}} * \frac{\text{W subsample (dry)}}{\text{W subsample (fresh)}} * 110{,}000\ldots\ldots\ldots (3)$$

Where; LB = Litter biomass (in ha^{-1}); W field = Weight of wet field sample of litter that will be sampled within an area of size $1m^2$ (in g); A = Size of the area in from which litter will be collected (in ha); W sub-sample (dry) = Weight of the oven-dry sub-sample of litter that will be taken to the laboratory to determine moisture content (in g), and W sub-sample (fresh) = Weight of the fresh sub-sample of litter that will be taken to the laboratory to determine moisture content (in g).

The Carbon content of biomass is almost always found to be between 45–50% (by oven dry mass) and the carbon content of vegetation will be estimated by simply taking a fraction of the biomass multiplying by a default number of 0.5 (Karberg *et al.*, 2008).

$$C= 0.5* LB \ldots\ldots\ldots (4)$$

Where; C = is carbon content by mass, 0.5 is default carbon fractionand LB = is oven-dry biomass. Therefore, total carbon content of litter LB (t ha^{-1}) = Total dry litter biomass multiplying by carbon fraction.

$$LC = LBM * \%C\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where; CL is total carbon stocks in the litter in t ha^{-1}, %C is carbon fraction that will be determined in the laboratory.

2.3.4. Soil Carbon Stock Data Analysis (SOC)

The carbon stocks of soil were done by using the following formula from the volume and bulk density of the soil which is recommended by (Pearson et al., 2007).

$$V = h * \pi r^{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where; V is volume of the soil in the core sampler in cm^3, h is the height of core sampler in cm, and r is the radius of core sampler in cm. More over the bulk density of a soil sample will be calculated by using following formula:

$$BD = \frac{Wav\ , dry}{V}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where; BD is bulk density of the soil sample per, Wav, dry is average air dry weight of soil sample per quadrant, V is volume of the soil sample in the core sampler auger in cm^3using formula (Pearson et al., 2007):

$$SOC = BD * D * \%\ C \ldots\ldots\ldots\ldots\ldots (8)$$

Where; SOC = soil organic carbon stock per unit area (t ha^{-1}) BD = soil bulk density (gcm^{-3}), D = the total depth at which the sample was taken (30cm), and %C = Carbon concentration (%)

The total carbon stock density in the studying forest (SF) will be converted to tons of CO_2 equivalent and multiplying it by 44/12 or 3.67 of the molecular weight ratio of CO_2 to O_2 in order to understand the climate change mitigation potential of the study area using the formula below at the end of the analysis (Pearson et al., 2007).

$$CT = AGC + BGC + LC + SOC\ldots\ldots\ldots\ldots\ldots (equ.9)$$

Where; CT Total Carbon stock for all pools (ton/ha), AGCabove ground carbon stock, BGCbelow ground carbon stock, LC litter carbon stock and SOC (t/ha).

2.4. Statistical Analysis of Carbon Stocks

The data analysis of different carbon pools of the study forest was measured and organized by arranging and recording the data on the excel data sheet. The data that obtained from the study site such as DBH, height of each species, wet weight, fresh weight and dry weight of litter and soil carbon will be analyzed using Statistical Package for Social Science (SPSS) software version 23. In order to apply appropriate models for biomass estimation, the height and diameter data were arranged in classes and the environmental factors were classified in different sections for similar pattern analysis. Based on these classifications, the DBH and height of trees were categorized into five classes: 0–10, 11–20, 21–30, and 31–40 and > 40. Differences at the 95% ($\alpha = 0.05$) confidence interval will be used to see the significance differences.

Correlation of the various carbon pools with one another will be tested using Pearson's product moment correlation coefficient and P value between Carbon pools and environmental gradients of slope and altitude to observe the correlations between AGBC, BGBC, LBC, DWBC and SOC using SPSS23software output(Pearson et al., 2007).

3. Results and Discussion

3.1. Estimations of Biomass and Carbon Stock Pools of SF

3.1.1. Estimations of AGB, AGC and CO_2e

The result revealed that, the total above ground biomass, carbon stored and CO_2 equivalents in the study forest were 1033.02, 516.51 and 1895.6 t/ha respectively. The maximum total biomass analyzed, carbon stored and CO_2 captured within in their order of AGB, AGC and CO_2equivalents estimated by five most important woody species as: *Ficus sur* (240.13, 120.07&440.64), *Cupressus lusitanica* (96.79, 48.39 & 77.61), *Eucalyptus globulus* (74.95, 37.48 & 137.54), *Juniperus procera* (67.04, 33.52&123.01) and *Acacia abyssinica* (47., 23.7 39&86.97). Accordingly, the result indicates that, 92.59% of AGB, AGC and CO_2 equivalents were contributed by the following ten woody tree species of the study forest; *Ficus sur, Juniperus procera, Cupressus lusitanica, Eucalyptus* *globulus, Acacia abys*sinica, *Croton macrostachys, Erythrina abyssinica, Olea europaea subsp. cuspidata, Cordia africana* and *Pteroloblum stellautm* with their descending order.

The results are more or less similar to the previous researches of Afromontane Forests; like the study in Siemen mountain national forest (Simegn et al., 2014), the average biomass stock recorded in above ground biomass was 576.36 t/ha. The result at Humbo State forest (Chinasho et al., 2015), 225.98 t/ha average carbon stocked was estimated.

The study at Chilimo forest (Mehari *et al*., 2019), reported the aboveground biomass for the sampled woody species *Juniperus procera* were contribute184.62t/ha carbon stock. In comparable, *Ficus sur* were top contributor of carbon stocked estimated to 240.13t/ha in the current study (Table 2).

Table 2
Height, Circumference, DBH, total BA and species mean BA of SF.

Average Height	**AH = Total H/Total Individuals**	**13634.6m/5272**	**2.59m**
DBH	DBH = C/π = 51330/3.14	16347.13cm	163.47m
Basal Area	BA = $(DBH/2)^2$ * 3.14	5244.27m	97.12m
Total BA	BA = pi*$(DBH)^2$/4*1.68	3.14* $(163.47)^2$/4*1.68	12486.38m^2/ha
Species Mean BA	Total BA/ Number of species	12486.38m^2/ha/54	231.23m^2/ha

3.1.2. Estimations of BGB, BGC and CO_2e

The result of study forest indicated that, the mean total below ground biomass, carbon stocked and CO_2 equivalents of the forest were 284.08, 142.04 and 521.29t/ha. Accordingly, the result indicates that, the highest BGB, BGC and CO_2 equivalents were contributed and stored by 10 woody tree species of the study forest were *Juniperus procera, Cupressus lusitanica, Eucalyptus globulus, Acacia abyssinica, Ficus sur, Olea europaea subsp. Cuspidata, Cordia africana, Erythrina abyssinica, Croton macrostachysand Pterolobium stellatum* with their descending order (Table 3).

Table 3:- Top 10 woody species of those highest contributors of biomass and carbon stock in SF.

Code	Species name	AGB	AGC	ACO_2	BGB	BGC	BCO_2	TB	TC	TCO_2
1	*Ficus sur*	240.13	120.07	440.64	66.04	9.22	33.83	85.47	42.74	156.84
2	*Cupressus lusitanica*	96.79	48.39	177.61	26.62	3.14	11.52	29.1	14.55	53.39
3	*Eucalyptus globulus*	74.95	37.48	137.54	20.61	13.31	48.84	123.41	61.7	226.45
4	*Juniperus procera*	67.04	33.52	123.01	18.43	0.09	0.34	0.84	0.42	1.56
5	*Cordia africana*	48.45	24.23	88.91	13.32	6.52	23.92	60.42	30.22	110.89
6	*Acacia abyssinica*	47.39	23.7	86.97	13.03	10.31	37.82	95.56	47.79	175.36
7	*Erythrina abyssinica*	36.11	18.06	66.27	9.93	0.07	0.27	0.69	0.34	1.25
8	*Pterolobium stellatum*	27.84	13.92	51.08	7.65	0.09	0.32	0.82	0.41	1.49
9	*Croton macrostachys*	27.39	13.69	50.26	7.53	0.07	0.25	0.64	0.32	1.17
10	*Olea europaea subsp cupsidata*	22.82	11.41	41.87	6.28	0.18	0.65	1.63	0.82	3
Total		755.65	377.83	1386.62	207.8	103.9	381.32	963.43	481.77	1767.93
Total Tree Pool								963.46	481.73	1767.95
Number of species								54	54	54
Species' Mean								17.84	8.92	32.74

As the current study analysis revealed, the maximum carbon stock of above ground Biomass, Carbon stored and CO_2 sequestered were seen with values of AGB, AGC and CO_2 equivalents respectively in the next five plots 7 (1901.51, 950.75&3489.27t/ha) plot 42 (1684.86, 3091.73&842.43t/ha), plot 20 (1672.16, 836.08&3068.41 t/ha) plot 6 (1598.98, 799.49 & 2934.13 t/ha) and plot 35 (2911.41, 793.3 & 1586.6 t/ha). Below Ground Biomass, Carbon Stocked and CO_2 Sequestered followed that almost the same pattern of above ground carbon pool as it is derived taking 50% of AGC. Whereas, the minimum with above ground and accordingly, minimum in below ground was estimated in the region of plots 13, 11, 22, 12 and 10in their respective order of Biomass, Carbon stock and it's CO_2eq (Fig. 2).

3.1.3. Estimations of LB, LC and CO_2e

The Carbon content of biomass is almost always found to be between 45–50% (by oven dry mass) and the carbon content of vegetation will be estimated by simply taking a fraction of the biomass multiplying by a default number of 0.58 (Karberg *et al*., 2008). The result provided information on that the total Litter, Herb and Grass (LHGs) LB, LC and CO_2equivalents with the mean values of LB, LC and CO_2equivalents were 6.69, 293.42 and 1076.85t/ha respectively.

As the result analyzed from the current study, the maximum carbon density of Biomass, Carbon stocked and CO_2 Sequestered within LB (5.58, 115.55 &424.06t/ha) was estimated in the region of plots 38 in their respective order of LB, LC and its CO_2eq. Whereas, the minimum record (1.09, 28.29 &103.81t/ha) was estimated in the region of plots 15 respectively (Appendix 2).

3.1.4. Estimations of SOM, SOC and CO_2e

The result indicated that, the total soil SOM, SOC and CO_2equivalents were (13.6, 315.88 & 1159.27t/ha) respectively. As seen in (Table 3), the maximum Soil Biomass, Carbon stocked and CO_2 Sequestered with (11.05, 229.68 &842.92t/ha) was estimated in the region of plots six and thirty two. On the contrary, minimum values in soil (5.52, 141.86 & 520.62t/ha) was estimated in the region of plots one in their respective order of Soil Carbon stock and its CO_2 equivalents (Table 4).

Table 4
Top 12 plots for Total Tree, Litter and Soil Pool biomass, carbon Stocks and CO_2 sequestration potentials of SF.

Plot	AGB (%)	AGC (t/ha)	CO_2 Equivalent	BGB (%)	BGC (t/ha)	CO_2 Equivalent	LB	LC	CO_2 Equivalent	SOMC (%)	SOC (t/ha)	CO2 Equivale
7	1901.51	950.75	3489.27	522.92	261.46	959.55	2.55	57.54	211.18	7.25	175.11	642.64
42	1684.86	842.43	3091.73	463.34	231.67	850.22	4.74	117.55	431.4	8.98	203.08	745.29
20	1672.16	836.08	3068.41	459.84	229.92	843.81	3.62	81.46	298.95	8.29	192.52	706.56
6	1598.98	799.49	2934.13	439.72	219.86	806.88	4.47	99.55	365.34	11.05	229.68	842.92
35	1586.6	793.3	2911.41	436.31	218.16	800.64	5.39	121.4	445.53	8.98	203.08	745.29
38	1471.39	735.69	2700	404.63	202.32	742.5	5.26	122.23	448.57	7.94	186.93	686.03
8	1465.44	732.72	2689.09	403	201.5	739.5	2.2	42.4	155.6	6.9	168.88	619.79
21	1443.75	721.88	2649.29	397.03	198.52	728.55	4.4	79.8	292.88	7.94	186.93	686.03
41	1441.79	720.9	2645.68	396.49	198.25	727.56	3.61	76.17	279.53	7.25	175.11	642.64
25	1398.92	699.46	2567.03	384.7	192.35	705.93	4.25	97.36	357.3	8.29	192.52	706.56
39	1381.58	690.79	2535.19	379.93	189.97	697.18	5.58	115.55	424.06	8.29	192.52	706.56
24	1347.2	673.6	2472.12	370.48	185.24	679.83	4.48	112.22	411.85	7.25	175.11	642.64
Total	43386.99	21693.49	79615.12	11931.42	5965.71	21894.16	167.30	3667.77	13460.71	340.06	7896.94	28981.7
Plots	42	42	42	42	42	42	42	42	42	42	42	42
Average	1033.02	516.51	1895.60	284.08	142.04	521.29	6.69	146.71	538.43	13.60	315.88	1159.27

3.1.5. Estimations of Total Carbon Stock in SF

The mean total biomass (TB) stored in the study forest was estimated to 1337.4 ± 353.64 t/ha (1033.02 ± 277.37, 284.08 ± 76.28, 6.69 &13.60t/ha) in the order of above ground, below ground, litter and soil Carbon pools. Whereas, the total Carbon stored (TC) and sequestered in the study forest were estimated to 1121.14 ± 176.82t/ha (516.51 ± 138.68, 142.04 ± 38.14, 146.71 &315.88t/ha) in the order of above ground, below ground, litter and soil Carbon pools respectively where the Litters had the lowest.

Accordingly, the current study forest's CO_2equivalents (TCO_2) from the atmosphere for its purpose of making organic carbon by sequestrations in the study forest were estimated to 4114.59 ± 648.94t/ha (1895.6 ± 508.98, 521.29 ± 139.97, 538.43 &1159.27) in the order of Carbon pools of above ground, below ground, litter and soil Carbon pools per 1.68 ha of plot areas.

The results reported from Banja forest (Abere et al., 2017), were total carbon stock of the forest was 639.87t/ha whereas trees pools store 406.47 t/ha, litter pools were stored 2.58 t/ha and soil 230.82 t/ha. Another study report from Wof Washa forest (Ayalew, 2018), provide carbon stock data by different carbon pools as: 51% were contributed by aboveground vegetation, 34% of carbon stock by the soil and 15% was contributed by Litters and below ground pools. The result from Sulula Mofa Forest study compared with other 5 previously published carbon stock and CO_2 sequestration forest researches in Ethiopia and indicated as it had approximately similar results. Meanwhile, Sulula Mofa forest nearly similar to Simien Mountains National Park (Simegn et al., 2014) in the tree pool and the litter pool; the total carbon density and CO_2 equivalents were nearly similar toHumbo Forest(Chinasho et al., 2015).The study in Woody Plants of Mount Zequalla Monastery revealed that total carbon stock and CO2 sequestration were estimated to 348.91 and 1280.50 t/ha respectively (Girma et al., 2014).The current forest study was dissimilar to Church Forests(Tura, 2013) in both carbon stock contribution and CO_2equivalents(Table 5).

Table 5
Biomass, Carbon density and CO_2 equivalent comparison of SF with other previous forest studies.

Study Forests		Carbon Pools (t/ha)						
		Biomass	AG C	BGC	LC	SOC	TC	TCO_2
Simegn et al., (2014)		-	270.89	54.18	0.02	242.51	567.59	2083.07
Tura, (2013)		-	122.85	24.57	4.95	135.94	288.31	1058.09
Chinasho et al., (2015)		-	112.93	46.05	53.07	617.3	829.36	3043.72
Sahle, (2011)		-	133	26.99	11.5	121.28	292.77	1074.47
Girma et al., (2014)		-	37.2	47.6	6.49	57.62	348.91	1280.5
Muluken *et al.*, (2014)			277.78	41.65	1.06	186.4	506.89	1860.29
Gedefaw et al., (2014)		-	306.36	61.27	0.9	274.32	642.85	2359.27
Sulula Mofa Forest (Current study)	Total Carbon Stock	1337.4	516.51	142.04	146.71	315.88	1121.14	4114.59
		± 353.64	± 138.68	± 38.14			± 176.82	± 648.94
	Species Mean Contribution	24.77	9.57	2.63	2.72	5.85	20.76	76.21

As the above five study forest comparison revealed; that the current study forest seen as the most important forest in sequestering CO_2 and stocking carbon. Sulula Mofa Forest had the nearest minimum value of 421.93t/ha CO_2 sequestration potential differences (1070.87 ± 648.94t/ha CO_2equ.) with Humbo Forest (Chinasho et al., 2015).

3.1.6. Biomass and Carbon Stock Contribution in SF

As the result revealed, the total carbon contribution of all pools (t/ha), the percentage contribution were estimated in Tree pools (58.74%) Litter pools (13.09%) and Soil pools (28.17%) of CO_2 sequestration. From the result, it was dedicated that, tree pool had greater CO_2equivalents in the study forest (Table 6).

Table 6
Total Carbon stocks of four carbon pools in SF.

Total Carbon Stock in each Carbon Pools					
Carbon Pools		Total Biomass (t/ha)	Total Carbon (t/ha)	Total CO_2 Equivalents (t/ha)	
				Total CO_2	Percent
Tree Pool (58.74%)	Above Ground	1033.02	516.51	1895.6	46.07%
	Below Ground	284.08	142.04	521.29	12.67%
Litter Pool		6.69	146.71	538.43	13.09%
Soil Pool		13.60	315.88	1159.27	28.17%
Mean		1337.4	1121.14	4114.59	100%

3.2. Factors Affecting Carbon Stocks of SF

In the current study Forest, three environmental factors (altitude, slope and aspect) which affect forest carbon stock were investigated, observed and analyzed that their effect had higher correlation on the carbon pools. More visibly, altitude and aspects provide a clear picture of effect on tree species diversity, Carbon stock density and sequestration potentials of the study forest. Generally, plots in the middle class altitude had more tree species diversity and greater values of biomass, carbon stock and CO_2 equivalents.

3.2.1. Carbon Stock along Altitudinal Gradient

The different carbon pools such as carbon stock and CO_2 sequestered in above and below ground of trees, Litters and carbon in soil were distributed along the altitudinal gradient and the carbon stored was varied among carbon pools and middle class plots had about 50% carbon density and CO_2equivalents than upper and lower class altitudinal gradients in each (having nearly equivalent proportionality) Tree, Litter and Soil pools.

Due to the altitudinal gradient, the values of different carbon pools varied. The middle altitudinal class had the highest carbon pool with an average carbon density of 517.14t/ha, whereas the lower altitudinal class had the lowest carbon pools with the recorded value of 230.16t/ha. The middle class was in between the two and had the value of 54.49 t/ha. The CO_2equivalents of middle, upper and lower altitude classes were estimated to 1897.89, 1016.22and 844.68t/ha respectively.

The total CO_2equivalents of 4485.1 ± 370.51t/ha and a mean value of each plot were estimated to 106.79 ± 8.82 t/ha (Table 7).

Table 7
Carbon Stock Density and CO_2 Equivalents along Altitudinal Classes in SF.

Pool	Biomass				Carbon Stocked				CO_2 Sequestered			
	UC	MC	LC	Total	UC	MC	LC	Total	UC	MC	LC	Total
Above Ground	123.21	226.09	134.47	483.77	61.61	113.05	67.23	241.89	226.09	414.88	246.75	887.72
Below Ground	67.77	124.35	73.95	266.08	33.89	62.18	36.98	133.04	124.36	228.19	135.7	488.25
Litter Pool	120.19	251.19	100.87	472.25	60.09	125.6	50.43	236.12	220.54	460.94	185.09	866.58
Soil Pool	242.63	432.63	151.03	1222.1	121.32	216.32	75.52	611.05	445.23	793.88	277.14	2242.55
Total Mean	553.8	1034.27	460.32	2444.2	276.9	517.14	230.16	1222.1	1016.22	1897.89	844.68	4485.1
				± 1106.8				± 100.96				± 370.51

3.2.2. Carbon Stock along Slope Gradient

In relation to the effect of slope classes in the study forest, plots found around slope degree ≥ 250^0 had higher estimated total biomass, carbon density and CO_2equivalents. Plots in slope class ranged from 151^0-200^0 observed with the lowest tree diversity, carbon stocks and CO_2equivalents. It was also observed that, plots in the south and west were more diversified and had greater carbon stocks and CO_2 equivalents (Table 8).

Table 8
slope effects of carbon stock density and CO_2 sequestered in SF.

Slope	Number of plots	Biomass	Carbon Stocked	CO_2 Eq.
Slope ≤ 50	8	177.13	201.58	739.81
Slope 51–100	6	147.06	158.01	579.91
Slope 101–150	4	118.02	101.72	373.3
Slope 151–200	2	46.93	36.13	132.58
Slope 201–250	8	153.58	164.06	602.1
Slope > 250	14	219.72	287.24	1054.17
Total	42	862.45	948.74	3481.87
		± 474.95	± 172.4	± 632.72

3.2.3. Carbon Stock along Aspect Gradient

It was processed and estimated that, plots in the south and west was more diversified and had greater carbon stocks and CO_2equivalents. North eastern parts of the sample plots observed with lowest in species diversity, higher DBH, shorter height, lower carbon stock density and smallest CO_2equivalents(Table 9).

Table 9
Mean Carbon stocks (t/ha) and CO_2 Eq along Aspect Classes in SF.

Aspect Class	Total Biomass	Total Carbon	Total CO_2 equivalents
N	1232.62	366.85	801.39
NE	569.53	169.50	370.28
NW	776.44	231.08	504.81
S	2646.13	787.54	1720.39
SE	781.81	232.68	508.30
SW	1357.99	404.16	882.90
E	2382.04	708.94	1548.70
W	2083.44	620.07	1354.56
Total	7041.67	2095.73	4578.18
	± 5704.27	± 974.59	± 463.59

3.2.4. Comparison between Different Carbon Pools in SF

At the global level, 19% of C in the earth's biosphere is stored in plants and 81% in the soil and about 31% of C is stored in the biomass and 69% in the soil (Nabuurs et al., 2007). Organic C stored in the world's soils is about 1100-1600Pg, more than twice the C in living vegetation (560Pg) or in the atmosphere (750Pg) (Justine et al., 2015). Soil is a good source of C pool and, thus, a C sinks (Kimble et al., 2014). SOC sequestration is a major sink for atmospheric CO_2, with the global soil C pool (1550Pg) being three times greater than the biotic pools (560Pg) and twice the atmospheric C pool (760Pg) (Lal, 2008). Soils play a key role in global C pool, resulting in storage of ~ 75% of terrestrial C (FAO, 2010).

In the study forest, from total carbon stocks were 1121.14 t/ha and CO_2sequestration potentials of the study forest were estimated 4114.59 t/ha. Tree pools in the above and below ground were the largest, soil pool were the second whereas litter pool was the least contributors for carbon stock (658.55, 315.88 and 146.71 respectively) and total CO_2 equivalents of 4114.59 t/ha having values of, (2416.89, 1159.27 and 538.43 t/ha)CO_2 equivalent values of tree,soil and litter pool respectively (Fig. 3 and Appendix 11).

3.3. The Role of Forests in Carbon Stock and Climate Change Mitigation

GHG emissions could rise by 25–90% by 2030 relative to 2000 and the Earth could warm by 3°C (Suppiah et al., 2007). Emissions estimated a median global temperature that will increase from post-2030 of 2.7°C to 3.5°C by 2100 (Magnan *et al.*, 2016).

Forests are thought to offer a mitigation strategy to reduce global warming and store over half of the carbon residing in terrestrial ecosystems (Hui *et al.*, 2015). Forests sequester and store more carbon than any terrestrial ecosystem by storing more than 80% of all terrestrial above ground carbon and more than 70% of all soil organic carbon (Assefa et al., 2013). It was pointed out that, forest ecosystems are regarded as the largest terrestrial carbon pool that have an average biophysical mitigation potential of 5,380Mt $CO_{2/}$year until 2050 (Suppiah et al., 2007).

Different literature indicates the carbon estimation for Ethiopia and a carbon density of 101 t/ha for high forests in Ethiopia reported by (Brown, 1997), 2.5Bt in 2005 reported by (Sisay & Mungatana, 2009), and 867Mt by (Gibbs *et al.*, 2007). Ethiopia has committed to reduce its carbon emissions by 255Mt CO_2eq/year by 2030 (NSFDP, 2018).The Amhara region total Carbon stock of the Forest (Mg/ha) was estimated 35.4 and Percentage of forest cover in South Wollo zone were estimated as total forest cover of 1.1% and an approximated 1.43Mg/ha CO_2eq/year (Sisay, 2017) (Table 11).

Table 11
-Different study estimations data of Carbon Stock and CO_2 equivalents in the past 40 years.(Multiple numbers in one cell are estimates from different sources)

Country	Estimations of Carbon Stock and CO_2 Reduction potential in the Years (Mt = million tone)			
	1993–2010		2011–2020	
	Carbon Stock	CO_2 eq. Sink	Carbon Stock	CO_2eq. Sink
World	4017Tg (Pan *et al.*, 2011)	14742.4Tg	1146Pg(Hui *et al.*, 2015)	4206Pg
Africa	219Pg (Katerere et al., 2009)	115Pg	745Mt (Pan *et al.*, 2011)	2734Mt
Ethiopia	141Mt (Sisay, 2017)	518t/ha	867Mt (Gibbs *et al.*, 2007)	3182Mt
Amhara Region	35.4Mg/ha (Sisay, 2017)	129.92Mg/ha	19.1Mt (Kibruyesfa, 2017)	690.1Mt
South Wollo	0.39Mg/ha (Sisay, 2017)	1.43Mg/ha	0.21Mt/ha	0.77Mt/ha
Sulula Mofa Forest were estimated			(0.0011Mt/ha) or 1121.14 t/ha	(0.0041Mt/ha) or 4114.59 t/ha

3.4. Trading Carbon Credits and Its Potential to Improve Livelihoods

Forests and soils are potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets and they are environmentally acceptable and cost-effective way to capture and store large amounts of atmospheric carbon (UNFCCC, 2017).

Forest carbon activities of further potential for a triple benefit: climate change mitigation, community development and biodiversity conservation; therefore, Forest and Soil managements make efforts to capture all the three (Virgilio & Marshall, 2009). Developing countries are more vulnerable to climate change because a large proportion of their population directly depends on agricultural and natural ecosystems for their livelihoods (Mujuru, 2014). Forest and Soil management strategies therefore become an important C mitigation approach through mitigation measures involving both CO_2e reduction and increasing C sinks (Suppiah et al., 2007).

A tradable carbon credit offers financial incentives for considering carbon storage in forest management decisions (Quere *et al.*, 2018). Carbon sequestration by Ethiopian forests has the potential to contribute to the Ethiopian well-being in two ways. First, sequestration of carbon in forests, thereby, slowing the rate of climate change and second, the potential to gain foreign income (MEFCC, 2017). Ethiopia put as of the world's lowest emitters of GHG emissions; however, most vulnerable country and the least ready country (CCPE, 2018). Developing countries will require $28-67B in funds to enable adaptation to climate change in 2030 as estimated by (UNFCCC, 2007).

Bottom-up regional studies show that forestry mitigation options have the economic potential at costs up to 100 US$/t$CO_2$eq to contribute 1.3-4.2GtCO_2eq/year (average 2.7GtCO_2eq/year) in 2030. About 50% can be achieved at a cost under 20 US$/t$CO_2$-eq (around 1.6Gt$CO_2$/year) with large differences between regions. Global top-down models predict far higher mitigation potentials of 13.8GtCO_2eq/year in 2030 at carbon prices less than or equal to 100 US$/t$CO_2$eq (Nabuurs et al., 2007).

The current study, in Sulula Mofa Forest, was estimate and predicts the mitigation potentials to 4114.59 tCO_2 equivalents per hectare of the forest. Based on the global top-down and bottom-up regional model of the 2030, Sulula Mofa Forest could contribute forestry mitigation options having justified and predicted economic potential of the study forest at costs from $\geq$ 82292 US$ up to $\leq$ 411459 US$ per year carbon prices and it would be financial incentives to improve Livelihoods for the surrounding community. It is proved that there is interaction between the local community and a state forest (Lalisa *et al.*, 2009).

4. Conclusion and Recommendations

4.1. Conclusion

The total carbon stock density contribution of SF estimated to 1121.14 t/ha from the 3 carbon pools as: Tree pools (658.55), Soil pools (315.88) and Litter pools (146.71) and the forest's potentials of CO_2 sequestration was estimated to a total of 4114.59 t/ha as of Tree pools (2416.89), Soil pools (1159.27) and Litter pools (538.43). From the result, it was dedicated that, soil pools had greater carbon stock density and higher sequestration potential in the study forest.

This study affirms that different environmental variables (altitude, slope and slope aspect) affect woody tree species diversity and total carbon stocks and CO_2 equivalents in the study forest as each carbon pool shows variation along these environmental gradients. Southern and south western parts of Trees, Litters and soils counted for higher carbon contribution along these environmental gradients. It can be concluded that Sulula Mofa Forest contributes high carbon stock, better sequestration potential and plays a role in climate change mitigation. There is interaction between the local community and directly with Global carbon Budget.

4.2. Recommendations

Thus, We suggests that, stakeholders should adopt effective Forestry conservation measures and get benefit from the bio-carbon fund from the clean development mechanism (CDM) of the Kyoto Protocol as financial incentives to improve foresters' Livelihoods.

Declarations

Ethics approval and consent to participate

Prior oral informed consent was obtained from the local communities as well as from all individual participants.

Consent for publication

The authors have agreed to submit and approved the manuscript for submission.

Availability of data and materials

Data will be available on request

Competing interests

The authors declare no conflict of interest related to this paper

Author Contributions

HY designed the study, collected and analyzed the data. SM identified the plants, and wrote the manuscript. All authors read and approved the final manuscript.

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Figures

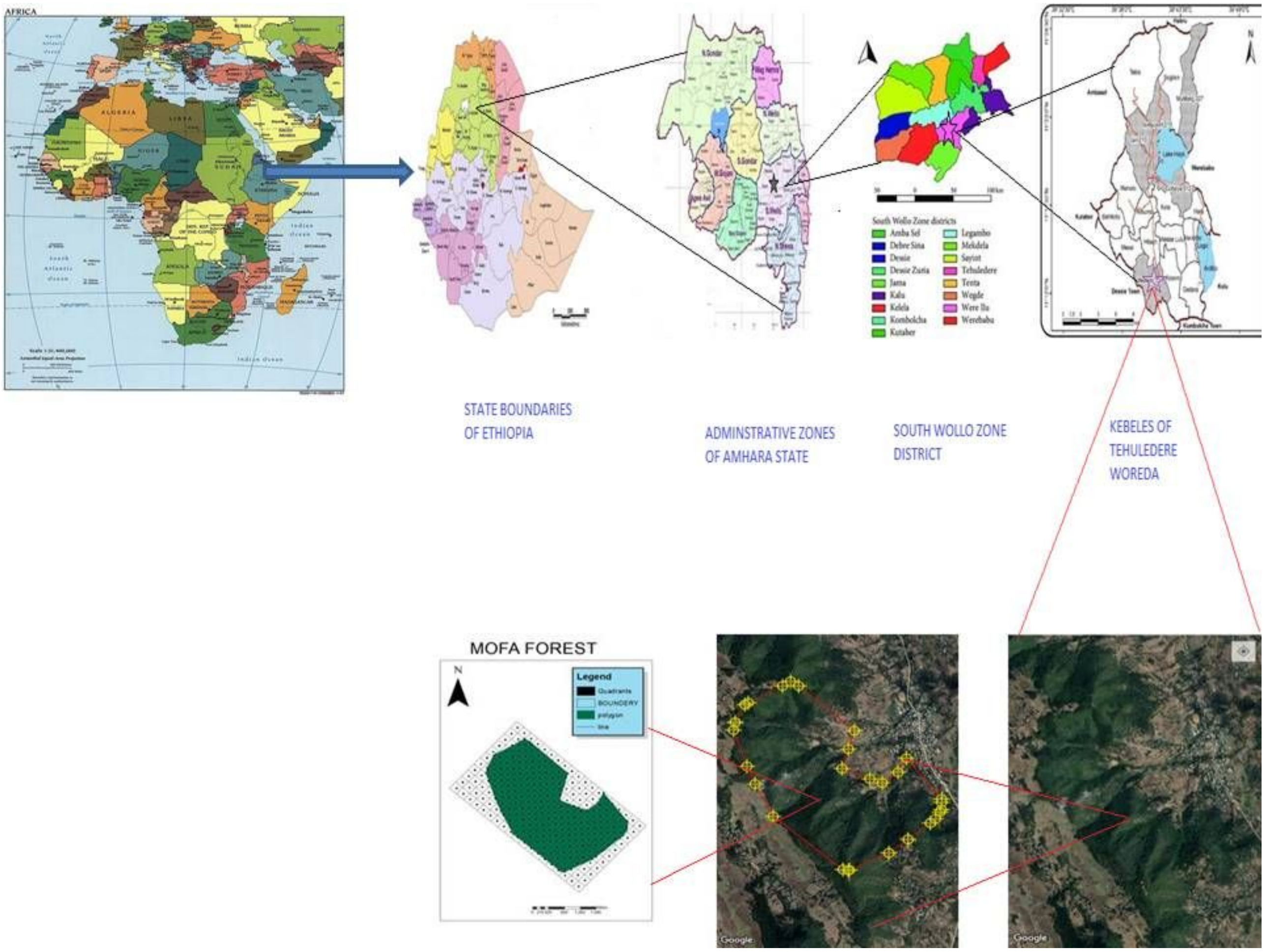

Figure 1

Map of Ethiopia and Study Site (Sulula Mofa Forest).

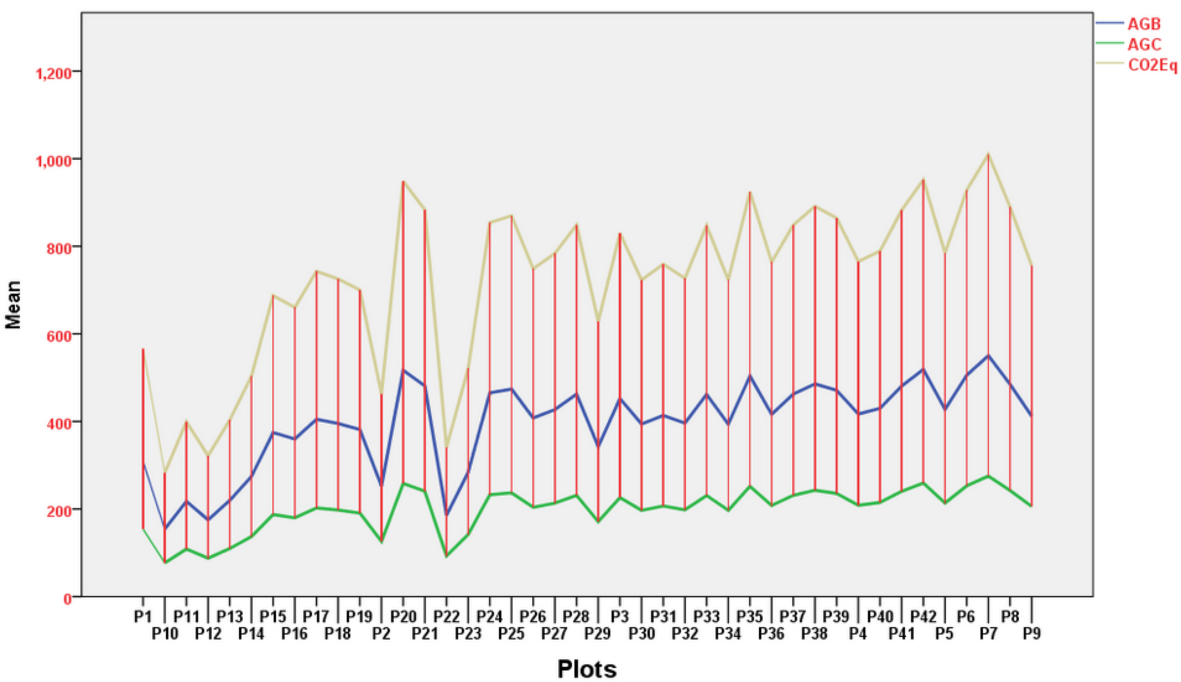

Figure 2

Mean Total above Ground Biomass, Carbon and its CO_2eq per plots.

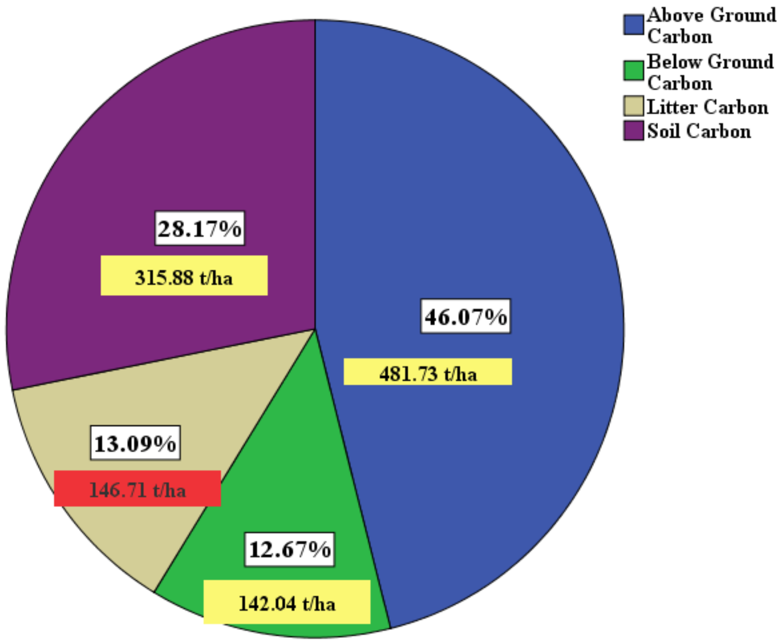

Figure 3

Percent (%), Contribution Comparisons between different carbon pools in SF.