Estimating carbon storage of Biteyu forest in the Gurage Mountain Chain, Ethiopia

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1. Background

Forests are known to be an important natural brake on climate change since they play considerable roles globally as both a carbon sink and source because of their large biomass per unit area of land (Gibbs *et al*., 2007). The carbon stocks in the forests originated from the atmosphere and are accumulated in the organic matter of soils and trees. According to Lal (2010), about 500 billion tons of carbon is stored in vegetation worldwide. The carbon continuously cycles between forests and the atmosphere through the decomposition of dead organic matter (Alexandrove, 2007) and therefore, changing carbon stocks in forests can affect the amount of carbon in the atmosphere.

Tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing carbon pools (e.g. reduced impact logging), expansion of carbon sinks (e.g. reforestation, agro-forestry), and substitution of wood products for fossil fuels (Brown *et al*., 1996; Gorte, 2009). Tropical Montane forests, typically store 100-200 t C ha^{-1} only from the aboveground biomass. According to a 40-year study of African, Asian, and South American tropical forests by the University of Leeds, showed that tropical forests absorb about 18% of all carbon dioxide added by fossil fuels (NIACS, 2012). Thus, carbon storage and sequestration by terrestrial ecosystems, i.e. soil and vegetation is one of the options for reducing carbon emissions as a strategy for climate change mitigation.

The current forest cover of Ethiopia is about 12.3 million ha or 11.0 % (MEFCC, 2015). It seemed to have shown a certain increase compared to the figure (~4.0%) of forest cover in Ethiopia in the past due to mainly by the change in forest definiton (von Breitenbach, 1961, 1962). However, the natural forests in different parts of the country are still under degradation threat and the country has been experiencing the climate change effects as evidenced by the increase in average temperature, a change in rainfall patterns and heavy flooding, recurrent drought and food insecurity. These climate change impacts will affect everyone, particularly, the Sub-Saharan Africa, where countries are already vulnerable to climate variability and have the least capacity to respond. However, countries can respond and counteract to the climate change effect, partly, by designing climate change mitigation strategies. Ethiopia, as one of the countries in Sub-Saharan Africa, has a climate change mitigation potential i.e. greening the environment by planting trees and regenerating the natural forests disturbed by man.

With regard to the Ethiopian forest vegetation, many studies have been conducted, particularly, in relation to classification, floristic composition and species diversity (White, 1983; Friis, 1992; Tamrat Bekele, 1993, 1994; Sebsebe Demissew *et al*., 1996; Talemos seta *et al*., 2019). Comparatively, the country is lacking periodic inventory data of carbon stocks for national carbon accounting and for the purpose of REDD+ initiatives. Due to this and other factors, developing sustainable forest management planning which attracts carbon markets has become a great challenge for the country.

Therefore, the present study is aimed at estimating the total carbon storage and identifying the disturbance level of *Biteyu* forest ecosystem in the Gurage mountain chain of Ethiopia. The study also estimates individual's carbon stocks in soil, AGB, BGB, forest litter and quantify the distribution of carbon stock in different tree size and height classes of in forests. The findings of this study would be important for climate change mitigation, conservation and the sustainable forest management planning.

Keywords: aboveground biomass, Belowground biomass, Biteyu forest, Carbon stocks, disturbance

2. Material and Methods

2.1. Description of Biteyu Forest

2.1.1. Location

The Gurage Mountain Chain harbours patches of intact vegetation cover in a mosaic of various land use and land cover matrices. It is located at the edge of the central rift valley in Ethiopia, which is one of the environmentally susceptible areas. Biteyu Forest is one of the remnant forest patches in the Gurage mountain chain (Figure 1). The total area of the Biteyu forest is estimated to be 547 ha (SUNARMA, 2015). SUNARMA is a local NGO working on the area of Natural Resource Management. This forest patch is a remnant Dry Evergreen Afromontane Forest that was once widespread on the Central plateau of Shewa (Mekonnen Biru, 2003). This area lies between 8$_0$ 13-8$_0$14' N and 38^0 19' - 38$_0$ 20' at the edge of the western escarpment of the Central Rift Valley which is about 20 km NW of Butajira town of the Gurage zone. Biteyu forest is approximately about 130 km south of Addis Ababa. The topography of the forest is very rugged with an elevation ranging from 2200 m to 3400 m a.s.l and the slope of the forest ranges from 20 to 55 degrees. This forest covers mountain chains such as *Kechemochi*, *Gerodeaebi* and *Beiri.* Consequently, Biteyu forest drains more than forty seasonal small streams, and two perennial rivers, which merge together to form *Wegeram* River that eventually forms the *Meki* River in the western escarpment of the Central Rift Valley. Logan (1946) described that Central Ethiopia contains the majority of the soils made of volcanic origin. Two principal soil types originating from the disintegration of volcanic substrates mixed with sand and limestone, black and red soils described. The black soils appear on the plateau and in the bottom of valleys whereas the red soils on rugged and sloppy mountains (von Breitenbach, 1961). Generally, the type of the soil is luvisol (FAO, 1998).

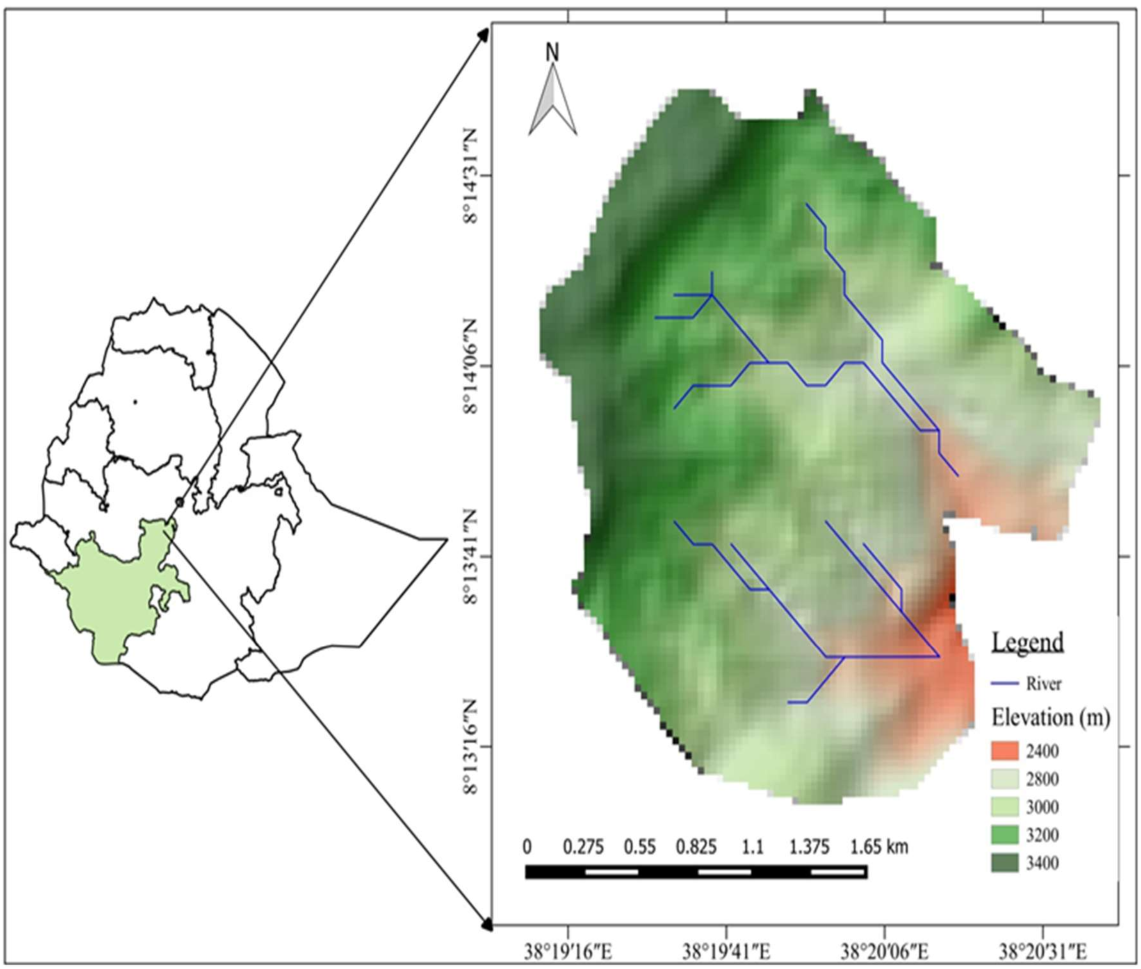

Figure 1. Location map of Biteyu forest in SNNPR of Ethiopia

2.1.2. Climate

In order to construct the climate diagram of Biteyu forest (Figure 2), 21 (1994-2015) years climate data of Butajira station was obtained from the Ethiopian Metrological Service Agency (NMSA, 2016). The mean monthly minimum temperature of the coldest month is 9.9 $_0$C and mean monthly maximum temperature of the warmest month is 27.1 $_0$C. Moreover, the mean annual temperature and mean annual rainfall of this area is 18.8 $_0$C and 1128 mm respectively. The area possess unimodal rainfall pattern by which it gets small rainfall in March and April and the highest rainfall in between May and September.

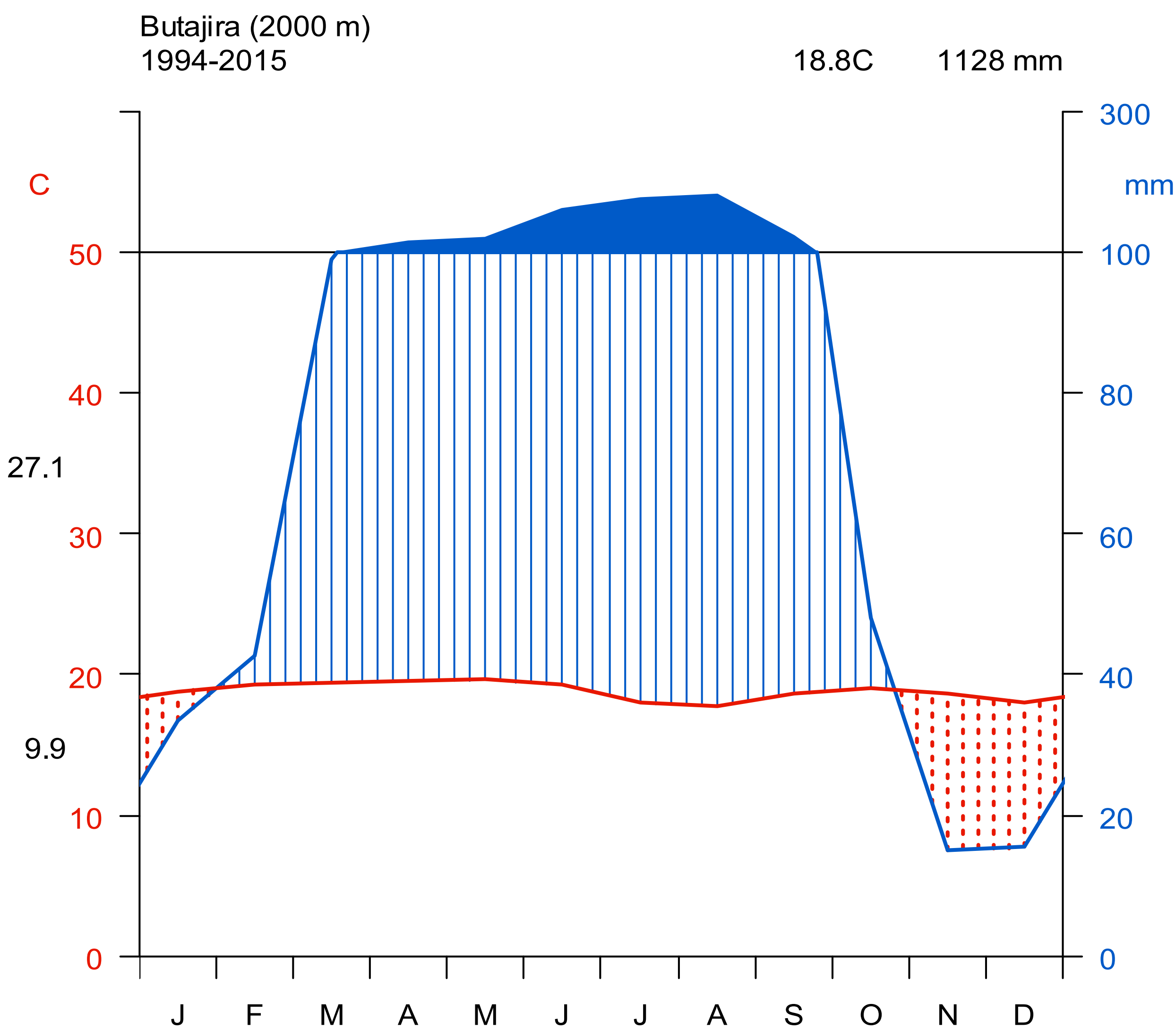

Figure 2. Climadiagram of the nearest Metreological station (Butajira town)

2.1.3. Vegetation

Biteyu forest is classified as Dry Afromontane forest (figure 3); the vegetation of the forest is characterized by indigenous species such as *Juniperus procera, Olea europaea* subsp.*cuspidata, Podocarpus falcatus* and associated woody species including *Maytenus addat, Myrsine melanophloeos*, *Olinia rochetiana, Maesa lanceolata* and others. Logging for construction purpose, fuelwood collection and agricultural expansion are the major causes for the dwindling of the vegetation. Severe trampling and heavy livestock grazing pressure were observed as the major causes of forest degradation and deforestation

Figure 3. The view of Biteyu forest

2.2. Methods

2.2.1. Sampling Technique

Systematic sampling technique was used for vegetation data and environmental data collection following Muller-Dombois and Ellenberg (1974) and Kent and Coker (1992). A total of **10** line transects were laid along elevational gradients. The transects were 500 m apart from each other. The sampling plots were 300 m apart from each other containing 5 plots each totaling 50 plots in the whole forest.

2.2.2. Plot shape and Sample size

A square or a rectangle is the most commonly adopted shape for sampling plots for vegetation types including forests, plantations, agroforestry, shelterbelt, grassland and cropland (Pearson *et al.,* 2005). Square plots were used in this study. Sampling should be carried out with statistical rigour to come up with good results. Accordingly, the first step is identifying the number of plots required to reach the desired precision in the results. Therefore, preliminary data were necessary in order to calculate the required number of plots for the desired level of precision. Preliminary data 10 randomly selected plots were collected from the Biteyu forest following Pearson *et al*. (2005). Total carbon stock from four carbon pools (AGB, BGB, soil and litter) was determined from each plot and the mean carbon stock from all the plots in the forest was used for sample size determination.

Thus, preliminary data for a single stratum was used to determine sample size using the formula:

$n = \frac{(NxS)2}{\frac{N2xE2}{t2} + NxS2}$ where, n= number of sampling units in the population, N = number of sampling units, E = allowable error, S = standard deviation, t = sample statistics from t-distribution at 95%. Based on this formula, the number of plots required from this data was 51 for the carbon estimation of the forest.

2.3. Data collection and Analysis

The level of disturbance was estimated using cattle intereference and wood stump as indicator of disturbance in the forest. The number of cattle interferences and wood stump was recorded in each plot and the mean of the numbers were calculated.

All vegetation data for the biomass and carbon determination were collected from a square plot of 900 m^2. Sub-plotting was used to separately collect data for trees, soil, herbs, grasses and forest litter. The total carbon stocks of the forest were calculated by summing up the carbon stocks of the individual pool in each study forest using the following formula.

$$C\ density = C_{ABG} + SOC + C_{BGB} + C_L$$

Where, C density = Carbon stock density for all pools for each study sample (t C ha^{-1})

C_{ABG} = Carbon stock in above ground tree biomass (t C ha^{-1})

SOC= soil organic carbon (t C ha^{-1})

C_{BGB} = Carbon stock in below ground biomass (t C ha^{-1})

C_L = Carbon stock in litter, herb and grasses (t C ha^{-1})

To estimate the above ground biomass, all tree species in sample plots with DBH $\geq$ 2.5 cm were identified and recorded. For woody species with multiple stems at 1.3 m height, all stems were measured and the averages of them were taken during data collection. Very recently, Chave *et al*. (2014) have improved their previous equations and propose a single allometric equation to estimate tree AGB across vegetation types when wood specific gravity, trunk diameter, and total tree height are available. Most of the variation was found within vegetation types, and the apparent variation among vegetation types appears to reflect small sample sizes. This interpretation is supported by the fact that the form factor (ratio of AGB divided by $\rho D^2 H$) varies weakly across vegetation types. Accordingly,

$AGB = a*(\rho D^2 H)^{b,}$ Where, coefficients a = 0.0673 and b = 0.976 and parameters, AGB (kg), ρ (g/cm3), D (cm) and H (m). This model performed well across forest types and bioclimatic conditions alternatively represented as $AGB = 0.0559*(\rho D^2 H)$.

Measurements of belowground biomass are indeed highly uncertain, and the lack of guidelines for measuring carbon stocks in forests empirical values for this type of biomass has for decades been a major weakness in ecosystem models (Pearson *et al*., 2005, 2007). Therefore, it is more parsimonious to apply regression model to determine belowground biomass from knowledge of AGB (Cairns *et al.,* 1997). Applying these equations provide relatively good estimate of below-ground biomass. This is the most practical and cost-effective method of determining biomass of roots. BGB was estimated from AGB using the relationship derived for the tropics by Cairns *et al*. (1997):

$$BGB = \exp(-1.0587 + 0.8836 \ln ABG)$$

Moreover, the soil organic carbon density for a sampling plot was estimated (Tian *et al*., 2009) as: $SOC\ (ton/ha) = OC/100 * BD * D * 10{,}000\ m^2/ha$

Where, OC (%) is the concentration/percent of organic carbon, BD (Mg/m^3) is the bulk density of soil sample, D (m) is the given soil depth. The unit metric tons per hectare were used for soil organic carbon as well as biomass carbon measurements in this study.

In addition to the above variables, the forest litter, herbs and grasses on top of the soil were included in the litter pool and have been estimated using simple harvesting technique (IPCC, 2003). A small sample plot of $1m^2$ which was established for soil sampling in four corners and the centre of the bigger plot was used to collect all materials inside the plot including herbs, grasses and litter. A well-mixed subsample was collected to determine oven dry-to-wet weight ratio to convert the total wet mass to oven dry mass, which follows the following equation:

$$Cl = \frac{W\ field}{A}\ X\ \ W\frac{subsample(dry)}{subsample(fre\quad)} * \frac{1}{10000}$$

Where: C_L= biomass of litter, herb and grasses (t ha^{-1})

W $_{field}$ = weight of fresh sample of destructively sampled within an area of size $1m^2$ (g);

W subsample (dry) = weight of the oven-dry sub-sample, and

W subsample (fresh) = weight of the fresh sub-sample taken to the laboratory (g)

The individual carbon pool and total carbon stocks were determined. Distribution of AGB in a range of DBH size classes was considered to assess the potential of the forest across its size classes. In addition, the relationship between carbon of AGB and plot level species diversty of the forest was analyzed by using simple linear regression analysis. The mean of four different carbon pools were compared and tested for the significant difference using one way ANOVA at $\alpha = 0.05$.

3. Result and Discussions

3.1. Results

3.1.1. Disturbances in the forest

As the Biteyu forest is an open accessed, it is usual to find a number of cattle and dead stump as an indicator of human disturbance in the forest (Figure 4). The cattle interference affects the forest understory from growing and recruitment. Here, the cattle interference indicates the number of livestock counted in each plot such as sheep, cows, donkeys and oxen in each plot. There was a strong negative relationship ($R^2 = 0.803$, $F_{1,\,28} = 114$, $P < 0.001$) observed between the cattle interference and altitude indicating the number of cattle recorded in each plot decreases with altitude. The mean of cattle interference in the Biteyu forest was 4.77±2.12 per ha. The mean of wood stump in the Biteyu forest was 26.67±9.37 per ha. This showed the cutting of larger trees in the forest have been a serious threat to the forest and hence leads to the forest degradation.

Figure 4. Cutting and Grazing activities in the Biteyu forest

3.1.2. Size class Distribution and Basal Area

The decreasing patterns of stem density across diameter class distribution (Figure 5) were observed in the forest which show the general trends of population dynamics (J shaped curve) but there was an interruption in the last class. The analysis showed that the smallest diameter class (2.5-10 cm) in the forests represented 37.05% of the total stem density. The diameter classes between 10 and 30 cm comprised a stem density of 41.08% in the forest. Similarly, the diameter class between 30 and 50 cm contains stem density of 15.76% for Biteyu forest. The number of individuals within the largest DBH class (>50 cm) represented only 6.09% in *Biteyu* Forest. *Podocarpus falcatus* was a tree species with the largest diameter (198.73 cm) recorded in Biteyu forest. The tree species with DBH range greater than110 cm was contributed only by *Hagenia abyssinica* and *Podocarpus falcatus* in Biteyu Forest.

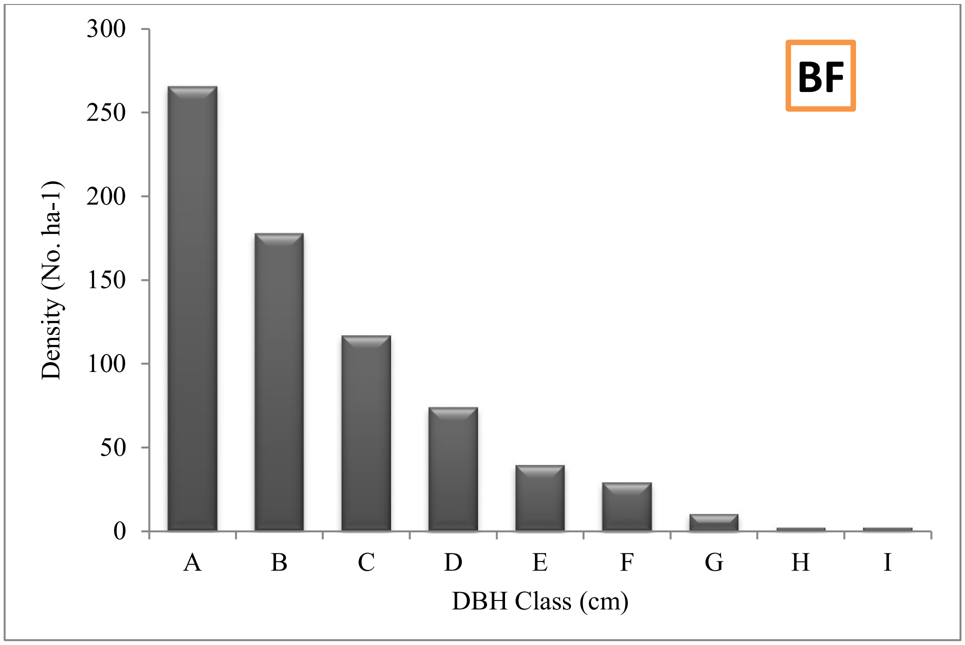

Figure 5. Size class distribution (Diameter classes: A = 2.5-10 cm, B = 10-20 cm, C = 20-30 cm, D = 30-40 cm, E = 40-50 cm, F = 50-70 cm, G = 70-90, H = 90-110, I ≥ 110).

The total basal area of the *Biteyu* forest was 41.64 m^2 ha^{-1}. The presence of high density, high frequency and high basal area indicate the overall dominance of species of the given forest. Accordingly, *Olinia rochetiana*, *Ilex mitis, Maytenus addat, Maesa lanceolata, Podocarpus falcatus, Schefflera volkensii, Olea europaea* subsp. *cuspidata, Myrsine melanophloeos and Hagenia abyssinica* were the nine most important woody species of the forest contributing to the highest proportion (87.9%) of basal area of the Biteyu forest (Table 1).

The considerable contribution of these species to the basal area of the forest is due to possession of a/ the higher density than their size/DBH in individuals of the tree species such as *Olinia rochetiana* and *Maesa lanceolata*. Many of the individuals of these two species have the lowest DBH classes and the basal area contributed by these classes is small. However, the sum of the basal area of individuals of these species is higher than individuals of the remaining seven species. b/ intermediate and high DBH classes have relatively small number of individuals per hectare such as *Ilex mitis, Maytenus addat, Podocarpus falcatus, Schefflera volkensii, Olea europaea* Subsp. *cuspidata*, *Myrsine melanophloeos* and *Hagenia abyssinica*.

Table 1. Basal Area and Density of nine most important woody species in Biteyu forest

Species	Basal Area (m^2ha^{-1})	%	Density No ha^{-1}	%
Olinia rochetiana	6.71	16.29	150.74	21.00
Ilex mitis	5.91	14.34	29.26	4.08
Maytenus addat	5.46	13.24	40.37	5.62
Maesa lanceolata	5.42	13.15	116.67	16.25
Podocarpus falcatus	4.79	11.62	63.70	8.88
Schefflera volkensii	3.39	8.22	29.26	4.08
Olea europaea subsp. *Cuspidata*	1.8	4.37	19.63	2.73
Myrsine melanophloeos	1.40	3.41	23.70	3.30
Hagenia abyssinica	1.34	3.26	24.44	3.41
Total	36.24	87.90	497.78	69.35

3.1.3. Carbon storage in the dominant tree species

Biteyu forest is characterized by having tree species with high density including *Olinia rochetiana, Maesa lanceolata, Podocarpus falcatus and Vernonia rueppellii.* However, the highest biomass carbon was stored in *Ilex mitis* with a carbon stock of 4.92±0.65 and 1.22±0.15 t ha^{-1} in AGB and BGB, respectively. This is probably because *Ilex mitis* has been frequently occurred in the study plots and having with a bit wider size class compared to its stem density. Moreover, *Maytenus addat, Olea europaea* subsp. *cuspidata, Podocarpus falcatus, Olinia rochetiana, Myrsine melanophloeos* were among the tree species with higher biomass carbon stock in Biteyu forest (Table 2).

Table 2. Carbon stock ± se (t C ha^{-1}) of above and belowground Biomass of dominant tree species.

Species Name	Carbon in AGB	Carbon in BGB
Bersama abyssinica	0.42 ± 0.2	0.076 ± 0.03
Brucea antidysenterica	0.47 ± 0.36	0.2 ± 0.16

Hagenia abyssinica	1.00 ± 0.9	0.43 ± 0.38
Ilex mitis	4.92 ± 0.65	1.22 ± 0.15
Juniperus procera	1.12 ± 0.40	0.32 ± 0.10
Maesa lanceolata	1.00 ± 0.08	0.33 ± 0.025
Maytenus addat	3.96 ± 0.49	0.995 ± 0.108
Myrica salicifolia	1.13 ± 0.37	0.325 ± 0.095
Myrsine melanophloeos	1.15 ± 0.17	0.32 ± 0.045
Nuxia congesta	0.98 ± 0.19	0.29 ± 0.09
Olea europaea subsp. *Cuspidata*	2.60 ± 0.47	0.65 ± 0.114
Olinia rochetiana	1.16 ± 0.09	0.326 ± 0.02
Podocarpus falcatus	1.80 ± 0.84	0.38 ± 0.16
Schefflera volkensii	1.45 ± 0.21	0.415 ± 0.052
Vernonia rueppellii	0.11 ± 0.02	0.04 ± 0.005

Moreover, the simple linear regression analysis between AGB carbon and plot diversity (H) in Biteyu forest showed the positive relationship but not significantly different (R^2 = 0.045, P = 0.263). However, it indicates that slight increase in plot diversity tends to increase the carbon stock of AGB even if the difference is not significant.

3.1.4. Carbon Storage in AGB across different DBH classes

The smallest carbon stock was estimated in the DBH class of 2.5-10 and 10.01-20.0 cm despite its high density (figure 6). The highest AGB carbon was estimated in the DBH > 50 cm for both forests. In Biteyu forest, the smaller size classes (DBH < 20 cm) held 61.86% of the total stems density but a very small fraction (1.6%) of the live AGB carbon density. On the other hand, the smaller size classes held 80.14% of the total stems density and 1.5% of the live AGB carbon in Boter-Becho forest. Tree species with DBH > 50 cm comprised of *Podocarpus falcatus*, *Ilex mitis, Hagenia abyssinica, Juniperus procera and Maytenus addat* among others held 58.23% of the average carbon stock in AGB of the Biteyu forest. Similarly, in Botor-Becho forest, the tree species with DBH > 50 cm accounted for 61.6% of the average carbon stock in above ground biomass. Those tree species included in this size class in Boter-Becho include *Allophylus abyssinicus, Apodytes dimidiata, Ficus sur, Hagenia abyssinica, Ilex mitis, Juniperus procera, Macaranga capensis, Olea capensis* subsp. *macrocarpa, Olinia rochetiana, Croton macrostachyus, Podocarpus falcatus, Pouteria adolfi-friedricii, Syzygium guineense* Subsp. *afromontanum, Celtis africana* among others. In Biteyu forest, only individuals with DBH > 90 cm comprised of five species *Podocarpus falcatus*, *Ilex mitis, Hagenia abyssinica, Juniperus procera and Maytenus addat* accounting for more than 75% of the average carbon stock in AGB of the Biteyu forest. Only 25% or less of the average carbon stock in AGB is comprised by all the plant species with a DBH< 90 cm in Biteyu forest. This indicates that the forest is nearly devoid of the larger trees because of the selective logging of trees for fuel, timber, and construction purpose by the nearby community as confirmed also by observation and the personal communication by the elders of the village in the study area.

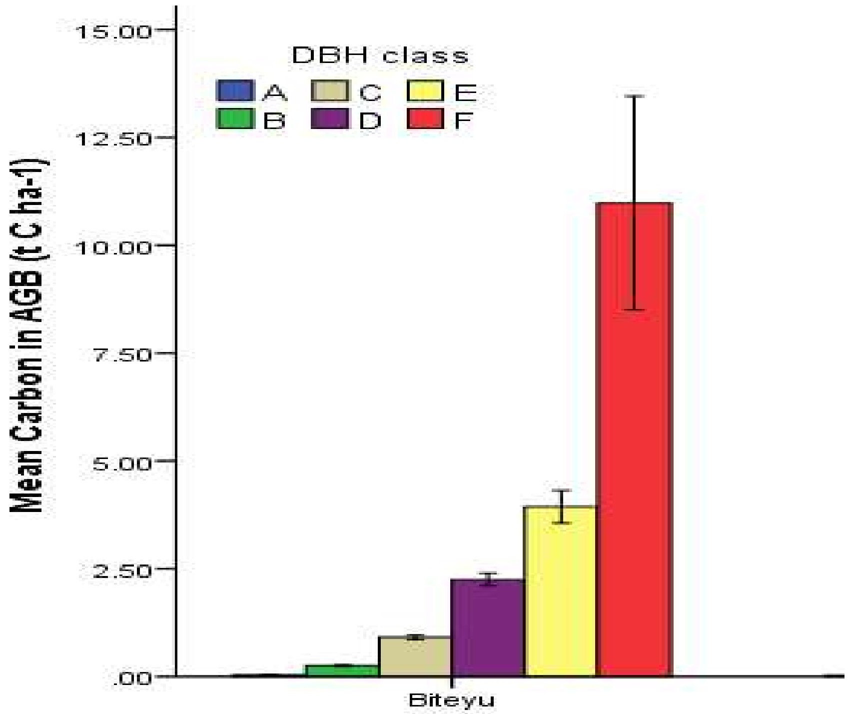

Figure 6.Mean carbon stock in AGB of Biteyu Forest (A = 2.5-10, B = 10.0-20, C = 20.0-30, D = 30.0-40, E = 40.0-50, F = >50).

3.1.5. Carbon storage in different pools of Biteyu forest

The estimates of total carbon stock in Biteyu forest was 166.67 ± 16.4 (Table 2). The estimated carbon stock in AGB and BGB in Biteyu forest was 87.13 ± 11.80 t ha^{-1} and 22.94 ± 2.84 t ha^{-1}, respectively. In Biteyu forest, the plot level variation of carbon in AGB ranges from 5.69 to 257 t ha^{-1}.

Table 2. Carbon stocks of Biteyu forests

Carbon pool	Biteyu Forest
Carbon in AGB	87.1 ± 11.80
Carbon in BGB	22.94 ± 2.84
Soil Carbon	56.37 ± 1.73
Litter carbon	0.26 ± 0.01
Total	166.67 ± 16.4

3.2. Discussions

3.2.1. Carbon stocks in Biteyu forest Ecosystem

The average total carbon stock of Biteyu forest (Table 3) from the present study was more or less similar with other studies in Ethiopia. Similar studies done in different forest ecosystems of Ethiopia showed significant difference in the amounts of total carbon stocks estimated. Abel Girma *et al*. (2014) and Tibebu Yelemfrhat *et al*. (2014) found out an average of 348.8 t ha^{-1} and 568.314 t ha^{-1} in Mount Zequalla Monastery forest and Lowland Area of Simien Mountains National Park, respectively. Similarly, Muluken Nega *et al*. (2015) and Belay Melese *et al*. (2014) found out an average of 507.29 and 583.27 t ha^{-1} in Adaba-Dodola Community forest and Arba-Minch Ground Water Forest, respectively. Hamere Yohannes *et al*. (2015) also estimated an average of 523.64 ± 29 t ha^{-1} in Gedo Forest of Oromia Regional State. Moreover, Adugna Feyesa *et al*. (2013) estimated an average of 614.72±35.79 t ha^{-1} in Egdu forest. This difference is attributed to the difference in topography, sampling type, forest type, soil characteristics, level of disturbance, and forest structure and species composition of the forest ecosystem among others.

The average total carbon stock of Biteyu forest is smaller than that of other studies done in the dry evergreen montane forest (for instance Gedo forest, Hamere Yohannes *et al*., 2015) due to the higher anthropogenic disturbance mainly selective cutting of large trees. Zhu *et al*. (2010) reported the mean total ecosystem C density of 237 t ha^{-1} (ranging from 112 to 338 t ha^{-1}) across all the forest stands in Northeast China. Of the total ecosystem carbon density, 153 t ha^{-1}, 14 t ha-

[1] and 70 t ha^{-1} was stored in vegetation biomass, in forest detritus and in soil organic matter (1-m depth) respectively. The carbon stock of forest detritus (14 t C ha^{-1}) here is much larger than the litter carbon for Biteyu (0.26) because in the forest detritus of Northeast China included standing dead trees, fallen trees, and floor material but only leaf litter and herbs were included in the sample of the present study. On the contrary, Swai *et al.* (2014) reported smaller carbon pools; the mean carbon stocks 48.37, 45.71 and 0.26 t C ha^{-1} in AGB tree species, herbs and SOC respectively in Hanang forest, Tanzania. For further information, the mean carbon stocks of different carbon pools in different Forests of the country were compared with the present study in the Table 3.

Table 3. Estimates of carbon stocks (t ha^{-1}) in different carbon pools by different authors

Authors	Forest Name	AGBC	BGBC	Soil C	Litter C
Hamere Yohannes *et al*. (2015)	Gedo Forest	281	56.1	183.69	0.41
Muluken Nega *et al*. (2015)	[a]ADCF	319.43	-	186.4	1.06
Abel Girma *et al*. (2014)	[b]MZMF	237.2	47.6	57.6	6.5
Belay Melese *et al.* (2014)	[c]AGWF	414.70	83.48	83.80	1.27
Mohammed Gedefaw *et al*. (2014)	[d]TGF	306.37	61.52	274.32	0.90
Tibebu Yelemfrhat *et al*. (2014)	[e]LLSMNPF	270.89	54.18	242.51	0.019
Adugna Feyissa *et al.* (2013)	Egdu Forest	278.08	55.62	277.56	3.47
Mesfin Sahile (2011)	[f]MSSF	133	26.99	121.28	5.26
Tulu Tolla (2011)	[g]AACF	122.85	25.97	135.94	4.95
The Present study	**Biteyu forest**	**87.13**	**22.94**	**56.37**	**0.26**
Boter Becho forest	[h]BBF	189.4	43.98	159.31	0.30

Note: [a]Adaba-Dodola Community Forest, [b]Mount Zequalla Monastery Forest, [c]Arba Minch Ground Water Forest, [d]Tara Gedam Forest, [e]Lowland Area of Simien Mountains National Park, [f]Menagesha Suba State Forest, [g]Addis Ababa Church Forests, [h]Boter-Becho forest

Biteyu forest from the present study has a mean carbon stock of 87.13 ± 11.80 t C ha^{-1} and 22.94 ± 2.84 t C ha^{-1} in above and belowground biomass, respectively. The mean total carbon stock of AGB for tropical dry forests ranged between 30-126 t C ha^{-1} (Houghton, 1999; Defries *et al.,* 2002; Brown, 1997; IPCC, 2006; Swai *et al.,* 2014) in which the carbon stock of AGB (87.13 t C ha^{-1}) in Biteyu forest from the present study is in the same range. Moreover, Gillespie *et al.* (1992) reported that dry biomass may vary from 50 to 550 t ha^{-1}and explained that the causes for this wide variation in biomass production are soil, climate, species, stand density, stand age, and management.

Biteyu forest have low stem density compared to other dry evergreen forests in the country, and it can explain the lower estimates for biomass and carbon stock as supported by other studies (Hamere Yohannes *et al*., 2015; Abel Girma *et al*., 2014; Tibebu Yelemfrhat *et al*., 2014; Mwakisunga and Majule, 2012; Munishi *et al*., 2009). The direct forward reason for this is the direct anthropogenic impact on the forest including selective logging of trees, fuel wood collection, and subsistence agriculture, grazing and browsing effect. The total AGB contributed 52.30% in Biteyu Forest. Large trees (DBH > 50 cm) contributed more than 58.23% of the average carbon stock in AGB of the Biteyu Forest. However, in Biteyu forest large trees (DBH > 90 cm) contributed more than 75% of the total AGB. Similar research carried out in the Brazilian Atlantic forest indicated that large trees contribute to 78% of the total AGB (Lindner, 2010). Moreover, a similar study in Amazon has estimated that about 1% of all the tree species account for half of the carbon locked in the vast South American rainforest. Although the region is home to an estimated 16,000 tree species, researchers found that only 182 species dominated the carbon storage process. Almost 20% of the world's terrestrial vegetation carbon stock is stored in the tropical forests of Amazonia. It is vital to the Earth's carbon cycle, storing more of the carbon than any other terrestrial ecosystem (Fauset *et al.,* 2015). However, when the biomass removal is too severe as in Biteyu Forest, regeneration ability of the trees are seriously affected resulting in a severely altered forest ecosystem as was reported in (Fauset *et al.,* 2015; MarenandVetaas, 2007).

The findings of this study showed that carbon storage and partitioning among different components of the forest and other similar forests of the country vary greatly. This variation is mainly due to the difference in forest type, species composition, forest structure, soil nutrient availability, climate, disturbance regime and topography, which was similarly reported by various scholars (Gillespie *et al.*, 1992; Yong *et al.*, 2011; Zhu *et al*., 2010; Houghton, 2005).

3.2.2. Recommendations

Based up on the results of the present study, the following recommendations as implications for forest conservations were forwarded.

Several anthropogenic disturbances such as agricultural expansion, cattle interference (grazing and browsing), selective logging for timber and house construction, and fuelwood collection reported to take place in Biteyu forest. Moreover, it was noted that the community in three villages immediately around the Biteyu forest mainly depend on the forest for their livelihood leading to continuous forest fragmentation based on personal information and observations. Therefore, there should be a need to intervene further human disturbances within the forest so that it can sustain its ecological functioning. Accordingly,

- Community education and public awareness on the use and ecosystem services of Biteyu forest should be provided by Woreda Natural Resource Management offices.
- Encouraging alternative income generating activities to enhance livelihood diversification such as poultry, modern beehives, improved crop/fruit varities should be done by the Regional and local governments.
- Woreda Agricultural and Rural development offices in consultation with NGOs should introduce multipurpose tree species in order to buffer the forest conservation zone and promote the sustainable utilization of forest resources.
- Attention should be given by the forest management authorities in order to rehabilitate, restore the degraded areas of the forest through reforestation and natural regeneration of the missing indigenous tree species such as *Podocarpus falcatus, Juniperus procera*, *and Hagenia abyssinica.*
- Communal grazing land should be allocated for the surrounding community in order to reduce grazing and browsing pressure on the forest ecosystem.
- Law enforcement should take place on exploitation of forest resources,
- A more participatory and community centred approach of forest management scheme should be promoted in the area.
- In view of carbon trading as significant climate change mitigation strategy, developing site-specific and species-specific biomass equation applicable to wide DBH classes in the country should be important for a more precise quantification of carbon stock. Ministry of Forest, Environment, and climate change and REDD+ office should be responsible for carrying out the action.
- As to the Ethiopian constitution, land belongs to the state so that the ownership of the Biteyu forest remains umbigous making the conservation effort difficult. Thus, there has to be an appropriate policy and coordinated institutional agreement with the local people in order to effectively manage and or conserve the forest and its resources in the area.

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