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Original Research

Forest Carbon Stocks in Woody Plants of Mount Zequalla Monastery and It's Variation along Altitudinal Gradient: Implication of Managing Forests for Climate Change Mitigation

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Abstract

Carbon sequestration through forestry has the potential to play a significant role in ameliorating global environmental problems such as atmospheric accumulation of GHG's and climate change.The present study was undertaken to estimate forest carbon stock along altitudinal gradient in Mount Zequalla Monastery forest. Systematic sampling methods were used to collect data from seventy 10 m x 20 m rectangular plots. The area was dominated by *Juniperusprocera* tree species. The mean carbon stock per hectare was 237.2, 47.6, 6.5 and 57.6 ton for above ground biomass, below ground biomass, litter biomass and soil respectively. The mean total carbon stock in Mount Zequalla Forest was 348.8 t ha-^{1}. The statistical analysis for carbon stock variation in the different carbon pools through altitudinal gradient showed a significant variation with exception for soil organic carbon stock. The amount of carbon stock in above and below ground biomass showed increasing pattern with increasing altitude whereas litter and soil organic carbon stocks showed decreasing pattern with increasing altitude.Overall this study points out Mount ZequallaMonastery forest has the potential to sequester plenty of CO_2 with a considerable variation along altitude. Thus, it has paramount importance to give conservation priority to the forests to achieve climate change mitigation aspiration especially through forest carbon sequestration mechanism.

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INTRODUCTION

Global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide, and on measuring carbon absorbed by and stored in forests, soils, and oceans. One option for slowing the rise of greenhouse gas concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests.

Concern about global warming has resulted in investigation of innovation methods that can be used for ameliorating greenhouse gasses effect (IPCC, 2000; IPCC, 2007; Penman *et al.,* 2003). Methods for capturing carbon dioxide are one of the primary global focuses (IPCC*,* 2007). Carbon sequestration is defined as the process or mechanism of capturing and securely storing carbon dioxide (greenhouse gas) from the atmosphere (IPCC, 2000). There are a number of techniques under investigation for sequestering carbon from the atmosphere. These include ocean sequestration where-by carbon is stored in the oceans through direct injection or fertilization, geologic sequestration in which natural pore spaces in geologic formations serve as reservoirs for long-term carbon dioxide storage, and terrestrial sequestration where by a large amount of carbon is stored in soil and vegetation (IPCC, 2000).

The Kyoto Protocol recognized the importance of forests in mitigating the greenhouse gas emissions (i.e. carbon dioxide, methane and others). Forests and soils are potential sinks for elevated CO_2 emissions and are being considered in the list of acceptable offsets (UNFCCC, 1997). Sustainable forest development and forested landscape expansion is one of the key approaches for reducing atmospheric carbon concentration. It is a safe, environmentally acceptable, and cost-effective way to capture and store substantial amounts of atmospheric carbon. The concurrent development of tradable carbon credits provides financial incentives for considering carbon storage in forest management decisions (Siry *et al*., 2006).

Carbon sequestration from atmosphere can be advantageous from both environmental and socioeconomic perspectives. There are evidences from several studies in Ethiopia and other countries. The environmental perspective includes the removal of CO_2 from the atmosphere (Yitebitu Moges *et al*., 2010), the improvement of soil quality (Zewdu Eshetu, 2000), and the increase in biodiversity (Batjes and Sombroek, 1997); while socioeconomic benefits include increased yields (Sombroek *et al*., 1993), monetary incomes from potential carbon trading schemes (McDowell, 2002), normalizing droughts through its potential for creating atmospheric condensation making cloud seeding, as well as reducing flood hazards and increasing ground water recharge by increasing water infiltration through soil columns.

The potentials of forestry are intriguing. There is widespread belief now that forests can be used to reduce the costs for slowing climate change. Although sequestration through forestry does have limitations, it is generally agreed that large amounts of carbon could be sequestered utilizing existing technology (IPCC, 2001).

However, Ethiopia is lacking periodic inventory data of forests and carbon stocks, and this makes the country fail to develop sustainable forest management planning that attracts climate finances. Carbon stock evaluation in mountain forest like Mt Zequalla Monastery (also known as Mount Chuqala) helps for managing the forests sustainably from the economic and environmental points of view for the welfare of human society beside their aesthetic, spiritual, and recreational value. Various scholars also agreed on the urgency and importance of studying and documenting the vegetation resources of Ethiopia, among others, Teshome Soromessa *et al.* (2004); Ensermu Kelbessa and Teshome Soromessa (2008); Teshome Soromessa *et al.* (2011); Fekadu Gurmessa *et al*. (2011 and 2012); Adugna Feyissa *et. al.* (2013); Teshome Soromessa (2013); Teshome Soromessa and Ensermu Kelbessa (2013a and 2013b); Teshome Soromessa and Ensermu Kelbessa (2014); Mohammed Gedefaw *et. al.* (2014) are some of them. However, no study has been conducted in Mt Zequalla Monastery forest that has been intended at evaluating carbon sequestration potential of this forest. Therefore, this study was undertaken to estimate the carbon stock potential of Mt Zequalla Monastery forest in relation to altitudinal gradients using integrated approach of different techniques for ground 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 Area

The study was conducted in Oromia National Regional State in Eastern Shewa Zone, in Mount Zequalla Monastery forest. It is 74 km east of Addis Ababa. Mt Zequalla is a volcanic cone that raises to 3000 m.a.s.l. Geographically it is located between $38^0$42' - $38^0$55' E longitude and $8^0$28'N to $8^0$35' N latitude. Situated on the western edge of the Rift Valley, it forms an important land mark as it can be seen for miles around in this section of the Rift Valley. It covers an area of 9600ha. The forested area inside the crater is estimated to 197 ha.

Vegetation Survey

Diameter and Height measurement

Altitude, slope and aspect in each study plots were recorded using altimeter, clinometer and compass. Height of each tree species were measured by using Haga hypsometer. The DBH and height of all tree species having diameter ≥ 5cm in the study site were measured as follows: Diameter (at 1.3 m above the ground unless there is abnormality) of all living trees (woody plants) were measured using diameter tape. Trees with multiple stems at 1.3 m height were treated as a single individual and DBH of the largest stem was taken (Kent and Coker, 1992). Trees with multiple stems or fork below 1.3 m height were treated as a single individual, with identification code placed on. Trees on a slope area were measured on the uphill side.

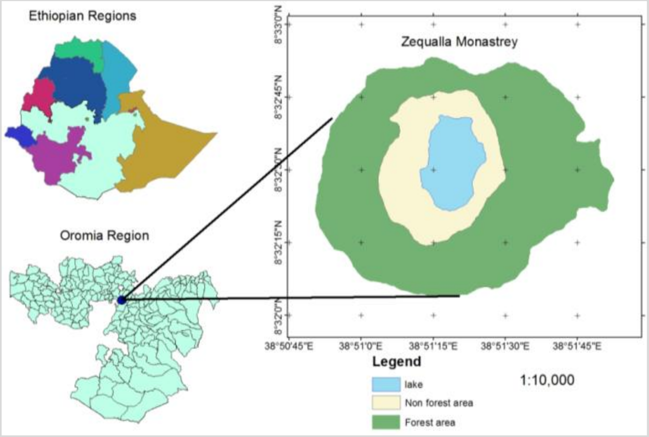

Figure 1: Location map of the study area

Species Identification

Vegetation data were collected by recording the scientific and vernacular names of the woody species in the sampling plot. Plant specimen was collected for every plant species, pressed and dried. Plant species were identified and checked at the National Herbarium, Addis Ababa University.

Field Data Collection

Simple step-by-step procedures by using standard forest and carbon inventory guide lines and techniques was used to estimate carbon stocks in the study area. The following procedures were used.

Delineation of Project Boundaries

The first step in forest carbon measurement is delineation of the project boundaries (Bhishma*et al.*, 2010). The spatial boundaries of the study area was clearly defined and properly recognized to facilitate accurate measurements. GPS coordinate points were used for boundary delineation for this study.

Sampling Method

A systematic transect sampling technique was take up in this study. Before a transect was laid, a reconnaissance survey was made across the forest in order to obtain an impression in site conditions and physiognomy of the vegetation, collect information on accessibility and to identify sampling sites. Following a reconnaissance survey, the altitudinal range of the forest was determined from GPS reading and transects were laid from the lowest altitude to the highest altitude. Using the GPS navigation system seventy sample plots were laid along line transects from the bottom of the mountain to the top of the mountain with 50 m interval each within the transect line. Twelve transects were laid with an interval at 200 m between the transect line. The sample plots were laid 100 m away from border to avoid edge effect.

Shape and Size of the Plots

Forest carbon measurement can be carried out in both rectangular and circular plots. Even though, both rectangular and circular plots are applied in most of the forest carbon measurements, rectangular plot is more advantageous and recommended for the study area. This is because rectangular plots tend to include more of within-plot heterogeneity, and thus be more representative than the circular plots of the same area (Brown, 1997; Hairiah *et al.,* 2001). In this study, sample plots of size 10 x 20 m (200 m^2) were used for vegetation sampling. In each plot, trees with a DBH of ≥ 5 cm were measured for DBH and height. A total of seventy sample plots were laid to sample the vegetation.

Field Carbon Stock Measurement

Above Ground Tree Biomass (AGTB)

The DBH (at 1.3m) and height of individual trees greater than or equal to 5cm DBH were measured in each permanent rectangular plot (200 m^2) using, diameter tape starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice. Each tree was recorded individually, together with the scientific and vernacular names. According to Karky and Banskota (2007) and MacDicken (1997) trees on the border must be included if >50% of their basal area falls within the plot and excluded if <50% of their basal area falls outside the plot. In addition, trees overhanging into the plot are needs to be excluded, but trees with their trunks inside the sampling plot and branches outside were included.

Dead Litter

Litter samples were collected in five rectangular sub plot of 1 square meter in size inside the main sample plot (200m^2) which was established at the four corners and one at the center of each plot. All the litter within the 1 m^2 sub plots were collected and weighed. 100 gm of evenly mixed sub-samples were brought to the laboratory to determine oven dry mass from which total dry mass and carbon fraction was calculated. Dead wood was not measured in the forest due to the nonexistence of dead wood within the sample plots.

Soil Organic Carbon (SOC)

Soil organic carbon was determined through samples collected from the default depth of 30 cm as prescribed by the IPCC (2006). Soil samples were collected from the five sub-plots used for litter sampling. Near the center of each plot and/or sub-plot five pits of up to 30 cm in depth were dug to best represent the study area in all plots. Samples were collected using core sampler with 5 cm diameter and radius, of which bulk density were calculated from a volume of 98.125 gm/cm^3. 100 gm of evenly mixed soil samples from the five sub plots was brought to the laboratory, and then carbon content was determined in the laboratory using Walkley-Black Method.

Data Analysis

The collected data was organized and recorded on the excel data sheet. The quantitative structure analysis was made using Microsoft excel of 2007 and SPSS software version 20 from the data (DBH, length, diameter, height of each species fresh weight and dry weight of litter and soil). Biomass of each tree species in all sample plots was analyzed using data from diameter class distribution. Analysis of variance (one-way ANOVA) was used to determine statistical significance differences of carbon stocks along altitudinal gradients for each carbon pools. Altitude was divided in to three different classes: lower (2828-2878m), middle (2879-2941 m) and higher (>2942-3011m).Differences at the 0.05 level were reported as significant.

Data analysis for Inventory Data

Estimation of Carbon in Different Carbon Pools

Estimation of Above Ground Tree Biomass (AGTB)

The selection of the appropriate allometric equation is a crucial in estimating aboveground tree biomass (AGTB). Bhishma *et al.* (2010) defined allometric equation as a statistical relationship between key characteristic dimension(s) of trees that are fairly easy to measure, such as DBH or height, and other properties that are more difficult to assess, such as above-ground biomass. They permit an estimate of quantities that are difficult or costly to measure on the basis of a single (or at most a few) measurement.

There are different allometric equations that have been developed by many researchers to estimate the above ground biomass. These equations are different depending on type of species, geographical locations, forest stand types, climate and others (Negi *et al*., 1988; Baker *et al.,* 2004; Brown *et al.,* 1989). Therefore, the application of these equations to the study area is an advantageous in a view of cost and time.

The equation used for the present study was a model developed by Brown *et al., (*1989). Appropriate criterion for this model fits with the present study.

$$Y= 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \text{ …….. (equ.1)}$$

Where, Y is above ground biomass, DBH is diameter at breast height.

Estimation of Below Ground Biomass (BGB)

Below ground biomass estimation is much more difficult and time consuming than estimating aboveground biomass (Geider *et al.,* 2001). According to MacDicken (1997), standard method for estimation of below ground biomass can be obtained as 20% of above ground tree biomass i.e., root-to-shoot ratio value of 1:5 was used. Similarly, Pearson *et al.* (2005) described this method as it is more efficient and effective to apply a regression model to determine belowground biomass from knowledge of biomass aboveground. Thus, the equation developed by MacDicken (1997) to estimate below-ground biomass was used. The equation is given below:

$$BGB = AGB \times 0.2 \text{ …………………………….. (equ.2)}$$

Where, BGB is below ground biomass, AGB is above ground biomass, 0.2 is conversion factor (or 20% of AGB).

Then the tree biomass was converted into C by multiplying the above ground tree biomass by 0.5 (MacDicken, 1997; Brown 2002).

Biomass C stock = Biomass x 0.5 Biomass carbon stock was then converted in to CO_2 equivalent as follows:

$$CO_2eq = \text{biomass C} \times 3.67$$

Estimation of Carbon Stocks in the Leaf Litter Biomass

The forest floor, or litter layer, is defined as all dead organic surface material on top of the mineral soil. Some of this material will still be recognizable (for example, dead leaves, twigs, dead grasses and small branches) and some will be unidentifiable decomposed fragments of organic material. In addition dead wood with a diameter of less than 10 cm is included in the litter layer. The following formula was used to determine litter carbon stock of the study area which is developed byPearson *et al.* (2005).

Laboratory Analysis

The total dry weight was determined in the laboratory after oven drying of the sample for 48 hours at 650^{o}C using dry ashing method as per Allen *et al.* (1986). Oven-dried samples were taken in pre-weighed crucibles. The samples were ignited at 550^{o}C for one hour in muffle furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated.

$$LB = \frac{\text{Wfield}}{\text{A}} * \frac{\text{Wsub \_sample (dry)}}{\text{Wsub \_sample (fresh)}} * \frac{1}{10{,}000} \ldots\ldots\ldots\ldots\ldots \text{(equ.3)}$$

Where:LB = Litter (biomass of litter t ha^{-1}); W $_{\text{field}}$ = 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), andW sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

Carbon Stocks in Dead Litter Biomass

$$C_L = \text{LB} \times \% \text{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(equ.4)}$$

Where, C_L istotal carbon stocks in the dead litter in t ha^{-1} % C is carbon fractiondetermined in the laboratory (Pearson *et al.,* 2005).

Estimation of Soil Organic Carbon

To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample. For convenience and cost-effectiveness, it is advised to sample at a constant depth, maintaining a constant sample volume rather than mass. Soil was sampled at constant depth of 30 cm. The carbon fraction of the sub-sample was measured in the laboratory using Walkley-Black method. In the present study the carbon stock density of soil organic was calculated from the volume and bulk density of the soil which was developed by Pearson *et al.* (2005), as follows.

$$V = h \times \pi\ r^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(equ.5)}$$

Where, V is volume of the soil in the core sampler augur in cm^3, h is the height of core sampler augur incm, 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:

$$BD = \frac{\text{Wav , dry}}{\text{V}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(equ.6)}$$

Where, BD is bulk density of the soil sample per, $W_{\text{av, dry}}$ 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).

$$SOC = BD * d * \% \text{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(equ.7)}$$

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 (%)

Total Carbon Stock Density

The carbon stock density was calculated by summing the carbon stock densities of the individual carbon pools of that stratum using the following formula (Sundquist*et al.,* 2010). Carbon stock density of a study area was calculated as follows:

$$C_{\text{density}} = C_{AGB} + C_{BGB} + C_{\text{Lit}} + SOC \ldots\ldots\ldots\ldots\ldots \text{(equ.8)}$$

Where, C $_{\text{density}}$ =Carbon stock density for all pools [ton ha^{-1}], C $_{\text{AGTB}}$ =Carbon in above -ground tree biomass [t C ha^{-1}], C_{BGB}= Carbon in below-ground biomass [t C ha^{-1}], C $_{\text{Lit}}$= Carbon in dead litter [t C ha^{-1}] and SOC = Soil organic carbon.

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

RESULTS

Carbon Stock across the Four Carbon Pools

In the present study, the largest carbon stock was covered by above ground biomass which accounts averagely 68.03% out of the four carbon pools. This carbon stock was principally derived from the forest biomass. 16.3% of the carbon storage was in organic soil carbon pool. The least amount of carbon was stored in litter carbon pool (2.24%) followed by below ground pool (13.6%). Therefore the carbon stock value of the study site in different carbon pool showed different storage capacity. Table 1illustrates the amount of carbon stocks in terms of percentage for above ground and below ground biomass, litter biomass and their carbon stocks and soil organic carbon.

Table 1: Mean biomass, carbon stocks and percent biomass in the different carbon pools (AGB: Above ground biomass; AGC: Above ground carbon; BGB: Below ground biomass; BGC: Below ground carbon; LB: Litter Biomass; LC: Litter carbon; SOC: Soil organic carbon).

Total sample plots	AGB (%)	BGB (%)	LB (%)	AGC	BGC	LC	SOC
70	81.47%	16.29%	2.24%	68.03%	13.6%	1.83%	16.3%
Mean (t/ha)	475.51	95.1	13.08	237.75	47.6	6.49	57.62

The principal carbon stock was covered by above ground biomass which accounts averagely 68.03 % out of the four carbon pools. This carbon stock was principally derived from the forest biomass. 16.3 % of the carbon storage was in organic soil carbon pool. The least amount of carbon was stored in litter biomass (2.24%) followed by below ground pool (13.6%). Therefore the carbon stock value in the study site for different carbon pools showed different storage capacity.

Carbon Stock and Elevation

Above and Below Ground Carbon Stock along Altitudinal Gradient

Altitude is one of the key physiographical gradients which had significant impacts on the different carbon pools (above ground, below ground, litter and soil). In this study the value of the above ground biomass increased as the elevation increased. The mean above ground biomass for the lower class was 596.52 ton per hectare and 677.71 ton per hectare and 834.2 t per hectare for the middle and higher class respectively (Table 2). The mean carbon stock was 298.26 ton per hectare 338.86ton per hectare and 471.1 ton per hectare for the lower, middle, and higher altitudinal class respectively.

Below ground biomass and carbon stock shows similar pattern with that of the above ground, showing increasing trend with increasing altitude. The mean largest and lowest BGB and BGC wasfound in higher altitude class (166.84 and 83.42t ha-^{1}) and lower altitude class(119.3 and 59.8 t ha-^{1}), respectively (Table 2) with a significant variation in both above and below ground carbon stock within the altitude classes (F= 5.022, P= 0.009).

Litter Carbon Stock along Altitudinal Gradient

The litter biomass and carbon stock react in a different way to the altitudinal gradient as compared to that of above and below ground carbon stock. As shown below (Table 3) the litter biomass and carbon stock decreases as the elevation increases. The lowest litter biomass and its carbon was large in higher altitude 7.89 and 3.71ton/ha, respectively and highest was recorded on the lower altitude 23.12 and 10.87 ton/ ha and the difference was statically significant (F= 23.179, *P*= 0.000).

Soil Organic Carbon Stock along Altitudinal Gradient

The soli organic carbon also follows similar pattern with that of litter carbon. As the altitude increased the soil organic carbon tends to decrease (Table 4). Higher altitude had stored the lowest SOC stock with mean carbon value of 52.9 ton/ ha showing decreasing trend with an increase in altitude like that of the litter carbon density, but the differences was not statically significant (F= 0.034, P= 0.967).

Total Carbon Density along Altitudinal Gradient

The maximum total carbon density was recorded in higher altitude class (611.63 t ha-1) whereas lower altitude class had the lowest value (428.71 t ha-^{1}). Thus, the total carbon density of study site showed increasing trend along altitudinal gradient (Table 5). The total carbon stocks of each carbon pools in different altitude classes of the study area were completed by summing all the mean values of each pool the within specified altitude classes.

Table 2: Mean biomass and carbon stock (t ha-^{1}) in above and below ground biomass along altitudinal gradient.

Altitudeclass	AGB(ton/ha)	AGC(ton/ha)	BGB(ton/ha)	BGC(ton/ha)
Lower	596.52	298.26	119.3	59.8
Middle	677.71	338.86	135.54	67.77
Higher	834.2	471.1	166.84	83.42

Table 3: Mean litter biomass and carbon stock (t ha-^{1}) along the altitudinal gradient.

Altitudeclass	LB(ton/ha)	LC(ton/ha)
Lower	23.12	11.56
Middle	9.25	4.62
Higher	7.89	3.94

Table 4: Mean soil organic carbon stock (t ha-^{1}) along the altitudinal gradient.

Altitudeclass	SOC(ton/ha)
Lower	59.06
Middle	58.78
Higher	52.9

Table 5: Total carbon stocks (t ha-^{1}) along the altitudinal gradient.

Altitude classes	AGC(ton/ha)	BGC(ton/ha)	LC(ton/ha)	SOC(ton/ha)	Total carbon stock(ton/ha)
Lower	298.26	59.8	11.56	59.06	428.71
Middle	338.86	67.77	4.62	58.78	470.03
Higher	471.1	83.42	3.94	52.9	611.36

Table 6: Values of significance for one-way ANOVA between the altitudinal gradients for AGC, BGC, LC and SOC stock.

Gradient	Carbon pool	F-value	*P*-Value
Altitude	AGC	5.022	0.009
	BGC	5.022	0.009
	LC	23.179	0.000
	SOC	0.034	0.967

DISCUSSION

According to different literature, global pattern above ground biomass in tropical forests ranged between 213-1173 t ha-^{1} (Murphy and Lugo, 1986). Above ground biomass in Amazonian Brazil forests ranged between 290-495 t ha-^{1} (Alves *et al.,* 2010) cited in (Getachew Tesfaye, 2007). According to Murphy and Lugo (1986) the above ground biomass value ranges between 30-273 t ha-^{1} and 213-1173t ha-^{1}. The average biomass estimated in the present study was greater than the value indicated by IPCC (IPCC, 2007); nevertheless, this result is comparable to those reported for the global above ground carbon stock in tropical dry and wet forests that ranged between 13.5-122.85 t ha-^{1} and 95-527.85 t ha-^{1}, respectively (Murphy and Lugo, 1986). Also it is relatively comparable with the value reported for Egdu forest (Adugna Feyissa *et al.,* 2013. The higher carbon stock in above ground biomass in the study site could be related to the higher tree dimension in the plantation forested area and existence superior protection in the area from human and animals interference as well as better strategies has been implemented by the Monastery officials due to the assumption that the area is religious.

Below ground biomass had similar pattern with that of the above ground biomass due to the fact that it is 0.2 times (20%) of above ground biomass. It had a similarity with the above mentioned studies because of the fact that it was derived from above ground carbon (Mesfin Sahle, 2011).

According to Brown and Lugo (1982) litter fall in dry tropical forests range between 2.52- 3.69 t ha-^{1}/ year. While comparing with other studies, the mean carbon stock in litter biomass in the studied forest was twice greater than those reported from Egdu Forest (Adugna Feyissa *et al.,* 2013) and dry tropical afromontane forests (Getachew Tesfaye, 2007). The variation could be due to different factors like rate of decomposition which is governed by climatic factor like temperature and moisture. Also the amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate (Fisher and Binkly, 2000). Since the study area is composed of old growth stand litter fall intensity also increased in the area in addition some part of the forested area is covered by dense tree species like *Arundinariaalpina,* which contributes a lot in intense litter fall amount within the forested patch.

In present study the average bulk density of soil investigated in Mt Zeqaulla forest was 0.79 gm/cm^{3}. The lowest and the highest were 0.43 gm/cm^{3} and 1.33 gm/cm^{3} respectively. SOC stock for different forest types of Kolli hills in India ranges from 63.37 to 273 t ha-^{1} and the average SOC stock was 96.05 t ha-^{1} (Ramachandran *et al.,* 2007). While comparing with other studies, the mean carbon stock of soil organic pool in Mt Zeqaulla Monastery Forest was almost less than by half from those reported from Menagasha Suba State Forest (Mesfin Sahile, 2011) and selected church forests in Addis Ababa (Tulu Tolla, 2011). This could be due to the existence of low soil organic matter, relatively lower range of bulk density and different factors like slope, low temperature of the area (that plays a great role in decomposition process) within the study site.

Table 7: Comparison of carbon stock (t ha-^{1}) of the present result with other studies.

	AGC	BGC	LC	SOC	Total
Mount Zequalla Forest	237.19	47.56	6.49	57.62	348.86
Egdu Forest	278.08	55.62	3.47	277.56	614.73
MenagashaSuba Forest	133	26.99	5.26	121.28	286.53
Selected Church Forests	122.85	25.97	4.95	135.94	289.71

Effects of Environmental Factors on Carbon Stock

Altitude, slope and aspect play a key role in determining the temperature regime of any sites. Within one elevation, cofactors like topography, aspect, inclination of slope and soil type affect the forest composition (Shank and Noorie, 1950). Many environmental factors (e.g. temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity) change systematically with altitude. Therefore, altitudinal gradients are among the most powerful ‘natural experiments’ for testing ecological and evolutionary responses of biota to environmental changes (Cui *et al.,* 2005; Fang *et al.,* 2004; Korner, 2007).As mountainous regions cover about 24% of total global land area (UNEP-WCMC (United Nations Environment Programme–World Conservation Monitoring Centre) 2002) and there have been rapid climate changes in mountain regions during the past few decades (IPCC (Intergovernmental Panel on Climate Change, 2007), understanding the shifts in forest carbon storage and allocation along altitudinal gradients in mountain regions will help us better predict the response of regional and global carbon balance to future climate change.

In the present study it was demonstrated that the mean above and below ground biomass carbon stock showed increasing pattern with escalating altitude significantly ($P<0.05$). Some studies in other parts of the world the results of above and below ground tree biomass decline with an increase in altitude (Luo *et al*., 2005, Leuschner *et al*., 2007; Moser *et al*., 2007; Zhu *et al*., 2011), but although it has been reported Similar study to the present study results in moist temperate valley slopes of the Garhwal Himalaya of India (Gairola *et al.,* 2011) and in tropical Atlantic moist forest in Brazil by Alves*et al.* (2010), in central Amazonian forest (de Castilho *et al.,* 2006). In the present study above ground and below ground carbon was correlated with altitude i.e. both stocks increased as the elevation increases with a significance *P*-Value of 0.009.

Soil is the most effective sequestration reservoir for carbon in many ecosystems because of the long turnover time of soil organic matter compared with most plant tissues, and because of less inter-annual variability or disturbance-driven losses (Lal, 2004). Globally, SOC density increased with precipitation and clay content and decreased with temperature (Jobbagy and Jackson, 2000), which has been confirmed on regional and local scales (Wang *et al.,* 2004; Yang *et al.,* 2007). Though SOC concentration in the present study was low due to low amount of precipitation and lower temperature (due to privileged elevation in the area there will be lofty pressure in the study area in turn decreases temperature of the location by creating high wind pressure in the surroundings). This study detected an overall decreasing pattern for SOC stocks with increasing altitude (decreasing temperature) significantly (P>0.05,). Because SOC pool size is mainly determined by C output (decomposition), which generally decreases with increasing altitude (Garten and Hanson, 2006). However, SOC stock in the studied forests was not significantly correlated to altitude (P=0.967), even though an overall decreasing trend with an increasing altitude noticed.

Similarly, litter carbon density exhibited decreasing trends along the altitudinal gradient. This could be related to gradual decrease in temperature and decomposition as the elevation increased. The decreasing pattern in litter carbon density in the present study is due to decline in litter fall quantity and decomposition with increasing altitude (Zhang *et al.*, 2008). Because of different factors affecting carbon density in the three components (vegetation, litter, and soil), total ecosystem carbon density was highly variable across biomes, especially in temperate and boreal forests (Pregitzer and Euskirchen, 2004).

All in all the total carbon accumulation did not show a clear pattern along with altitude, as vegetation, soil, and litter carbon density exhibited distinct patterns along the this gradient. These Different ecosystem components (vegetation, detritus, and soil) have different carbon turnover times and may respond to environmental factors quite differently, thus playing different roles in carbon sequestration (Pregitzer and Euskirchen, 2004). Therefore, a shift in carbon partitioning among ecosystem components along an altitudinal gradient may imply a possible change in carbon storage and allocation and thus carbon sequestration capacity in response to future climate change in mountain regions, in addition to the already documented rapid shifts in plant distribution with climate change (Kelly and Goulden, 2008).

CONCLUSION

In general based on the results it could be concluded that Mount Zequalla Forest has the potential to sequester plenty of CO_2 with a considerable variation along altitude gradients.This further revealed that the carbon pool components of forest ecosystem may respond to altitude differently and plays an important role in knowing possible change in carbon stock and thus carbon sequestration capacity in response to future climate change. Consequently, it has paramount importance to give conservation priority to the study site forests to achieve climate change mitigation aspiration especially through forest carbon sequestration mechanism, ever since prevention of deforestation and promotion of afforestation have often been cited as strategies to slow down global warming. Enhancing C sequestration by increasing forested land area (e.g. plantation forests) has been suggested as an effective measure to mitigate elevated atmospheric CO_2 concentrations and significant potential for C storage in tree biomass with an estimated mean value of 64 CMg ha$-^1$.

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