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Research Article

Effects of Elevations on Carbon Stocks of Kella Natural Forests in Konso Zone, Southern Ethiopia

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Abstract

Different anthropogenic and biophysical factors can affect woody species diversity and carbon stocks along the elevation gradients. This study, thus, was conducted to evaluate the impact of elevation on carbon stock potential in Kalla forest, Konso zone, Sothern Ethiopia. The study was undertaken along three elevation gradients, namely, low (LE) (1,605-1,690 m), middle (ME) (1,691-1,775 m) and high (HE) (1,776-1,860 m) elevations. A total of 60 sample plots (20 m x 20 m) were systematically laid down along the elevation gradients at interval of 200 m between transects and 50 m between sample plots. In each main plot a 5 sub plots (four from corners and one at the center) with 1 m x 1m were used to collect litter and soil samples. A total of 120 soil samples for soil chemical analysis and 120 samples for bulk density determination were taken separately. The total ecosystem carbon stocks (biomass plus soil, 0-60 cm) were significantly different ($p < 0.05$) across the three studied elevations. The LE showed higher ecosystem carbon stock (301.8 ± 171.6 t C ha^{-1}) than ME (255.6±88.2) and HE (190.8± 58.2). The SOC stock (0 - 60 cm depth), standing biomass and litter accounted for 90.8 %, 6.6 % and 2.6% respectively in the LE whereas 93.0 %, 5.1 % and 1.9 % in the ME and. 92.1%, 6.3% and 1.6% in the HE. *Juniperus procera* and *Euphorbia tirucalli* contributed altogether 81 % of the total biomass carbon stocks in the LE and both species shared 60 % in the ME whereas *Euclea racemosa* and *Juniperus procera* accounted for 48% of the total biomass carbon stock in HE. The total above ground biomass carbon stocks were significantly correlated with the species diversity. Finally, this study affirms that elevation affect woody species diversity and total carbon stocks in Kalla forest, Sothern Ethiopia.

Keywords: Biomass, Carbon stock, Elevation range, Woody species diversity

1 Introduction

The reductions of emission from deforestation and forest degradation by managing the existing forests sustainably bring financial and technical incentives from industrialized nations to developing countries through REDD+. To tap this opportunity, accurate and consistent data that meet international standards while creating favorable policy environment are the most important requirements (IPCC 2006).

In effect, reliable estimates of biomass, liter and soil carbon are needed to understand the contribution of forests to reduce atmospheric carbon dioxide. Measuring and estimating carbon stocks and changes in various pools are very important for carbon trading (Yitebitu et al. 2010). This calls researchers to direct their interests to quantify forest carbon stocks following standardized carbon stock accounting method. Currently the demand of reliable information regarding forest carbon stock both at national and global levels is growing (Genene et al. 2013).

However, several environmental factors such as temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity changes systematically with altitude affect the biomass productivity in forest ecosystem. An altitudinal gradient is among the most powerful ‘ ‘natural experiments’ ’ for testing ecological and evolutionary responses of biota to environmental changes (Fang et al. 2005). Although changes in species composition and distribution, biodiversity and community structure along altitudinal gradients have been well documented in the past few decades (Fang et al. 2005), the altitudinal patterns of carbon storage and partition among components (vegetation, detritus and soil) of forest ecosystems remain to be poorly studied (Fang et al. 2005).

Besides, in Ethiopia, as one of the country in the tropics, little is known about inter site and temporal variability of forest biomass compared to other parts of the tropics (Chave et al. 2001; Abel Girma et al. 2014). Periodic forest inventories and monitoring in the country are lacking even though they are most useful in order to evaluate the magnitude of carbon fluxes between aboveground biomass (AGB) and the atmosphere. Several reports affirm that Ethiopia has limited information about carbon stocks of forest in regional and local context (Adugna Feyissa et al. 2013; Abel Girma et al. 2014). In Konso wereda there are Kalla and Pamale forests, those are belong to Kalla and Pamale family respectively. These forests are rich in woody species diversity and managed culturally by family kings since ancient time. Similarly, in Konso specifically in Kalla forests there is limited studies that describe the effect of elevation gradient on woody species and carbon stock. The objective of this study, therefore, is to investigate the effect of elevation gradients on carbon stocks of Kalla Forest, southern Ethiopia.

2 Methods and materials

2.1 Description of Study Area

Kalla natural forest is located in Konso zone in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia. Konso district is found 356 km far away from Hawassa City to South, and 562 km far from Addis Ababa, Capital city of Ethiopia (Figure 1). Geographically, the study area is located at 5°19' 60” N and 37°19'60” E in the Great Rift Valley. Soil texture is sandy loamy and pH almost neutral (6.97).

2.2 Vegetation

According to zone agricultural office and personal observation, in Konso zone there are vegetation covers managed by government and clan king. Kings’ managed forest includes Pamale and Kalla forests. This forests are dry afromontane forests and located at elevation ranges between 1605 m and 1860 m.a.s.l and cover about 205 ha. Konso people are internationally known by traditional tracing, which is registered by UNESCO as world heritage. In crop production areas of the farms, *Moringa stenopetala* (Haleko) is the dominant woody species while *J. procera, Euphorbia tirucalli, Acacia senegal, Acokaathera schimpori* and *Euclea racemosa* are the most abundant woody species in natural forests.

2.3 Sampling techniques and sample layout

A systematic sampling technique was employed. The forest was divided into three elevation gradients, namely, low (here after referred as LE) (1605 m – 1690 m), middle (ME) (1691 m -1775 m) and high elevation (HE) (1776 m- 1860 m).

Narrow elevation ranges was fixed owing to steep slope nature of the studied forest. In each of elevation category, transect lines were laid along the contour at center of each elevation ranges 30 m away from the forest edge to avoid border effect. Sample plots of 20 m x 20 m were laid down along the transect lines at 200 m distance between them and at 50 m interval distance between sample plots. A total of 60 sample plots were surveyed (20 in each elevation category). The first sample plot was randomly assigned at the beginning of the transect line. Inside each main plot, five subplots (1m x 1 m), four at the corners, and one at the center were established to collect soil samples and litter.

2.4 Data collection methods

Inventory

The inventory of woody plants in sample plots included the measurement of stem diameter at breast height (DBH) $\geq$ 5 cm, diameter at stump height (DSH) and total height (H). The field survey was conducted during the dry season of December and January, 2017. DBH and DSH were measured at 1.3 m and 30 cm from the ground, respectively (Alamgir and Al-Amin 2008). Individual tree height in each plot was systematically measured using a clinometer and a graduated pole for low trees. In case of multi- stemmed woody species, each stem was measured separately and the equivalent diameter of plant was calculated as the square root of the sum of diameters of all stems per plant (Snowdon et al. 2002). Woody vegetation identification was done in the field using key informants and each vernacular name was translated to their botanical names using flora of Ethiopia and Eritrea (Hedberg et al. 1995; Edwards et al. 1997; Edwards et al. 2000); useful trees and shrubs for Ethiopia (Azene Bekele 2007) and Woldemichael et al. (2010).

Litter sampling

Litter samplings were collected from five 1 m x 1 m subplots from each main plot and mixed to make a composite sample. Fresh weight of litter samples were recorded in the field using string balance. Then a 100 g sub-sample was taken and transported to Hawassa University WGCFNR soil laboratory to determine dry to fresh weight ratios.

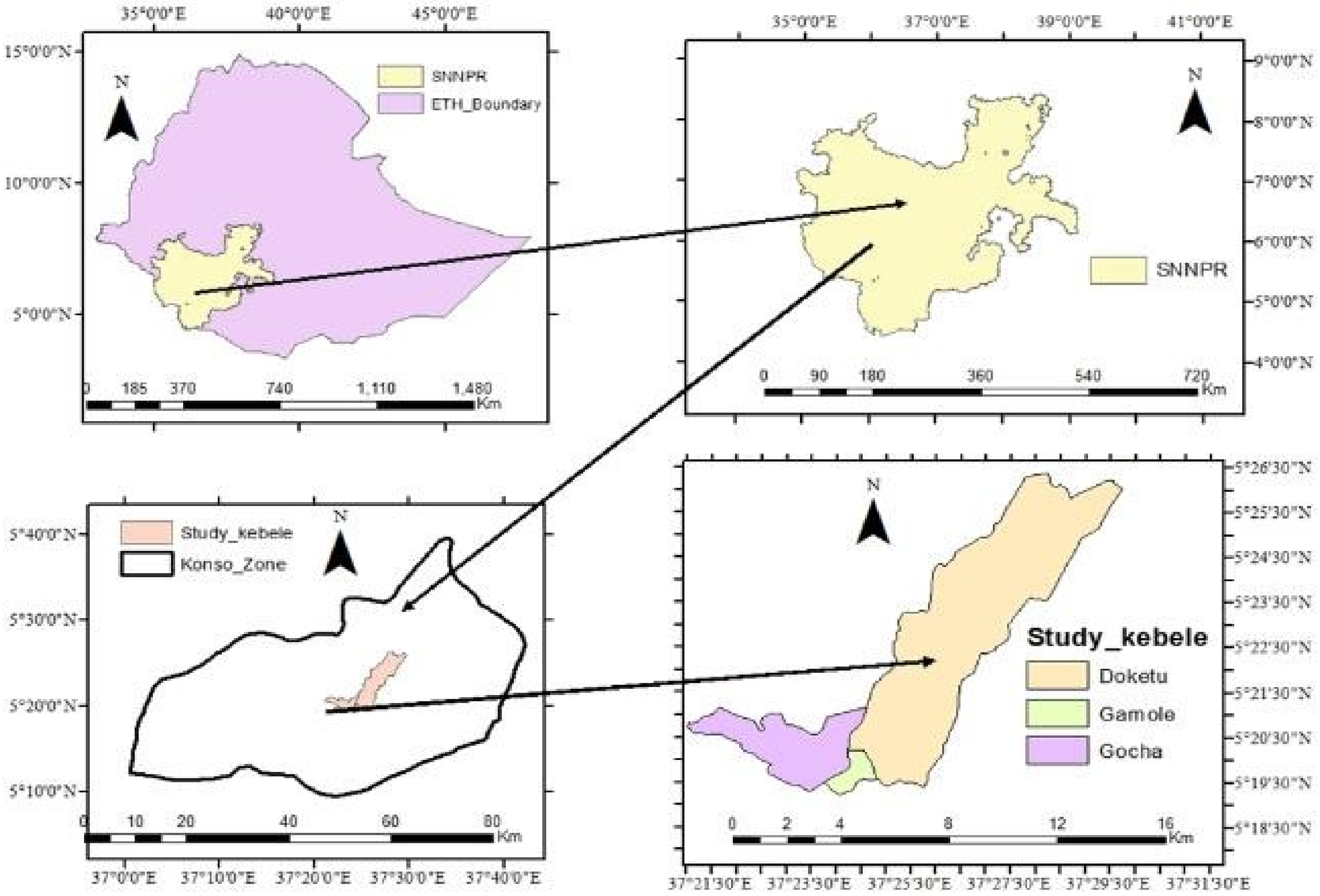

Figure 1: Study area map

Soil sampling

Soil samples were collected from five pits arranged within four corners and from central point. The pits were dug to 60 cm depth and soil samples taken uniformly along 0 - 30 and 30 - 60 cm soil depths by hand trowel. A total 120 soil samples (40 from each) from the two depths were taken along the three studied elevation gradients. Similar size of soil sample plots were collected separately for bulk density determination. A sharp edged steel cylinder corer (height 15 cm and diameter 7.2 cm) had been forced manually into the soil for drawing the samples for bulk density.

2.5 Laboratory work for litter and soil samples

Determination of litter dry biomass and carbon content analysis

The collected litter samples were air-dried first and oven-dried for 24 hours at 65 ºC until it attains constant weight. Then, the samples were weighed, ground using mortar and pesto then sieve with 2 mm mash. The loss on ignition (LOI) method was used to estimate percentage of carbon in the litter. From the oven dried grinded sample 3.00 g of each litter sub sample was taken in pre-weighted crucibles, and then put in the furnace at 550 ºC for two hours to ignite (Negash and Starr 2013). The crucibles were cooled slowly for two hours inside the furnace. After cooling, the crucibles with ash were weighed and loss of organic matter fraction was calculated according to Allen et al. (1986).

Soil analysis

The collected soil samples were air-dried, ground, homogenized and then sieved with a 2 mm mesh size sieve. Bulk density was estimated using oven dried samples at 105 ºC for 48 hours. Soil organic carbon was determined using Walkley & Black Method (Walkley and Black 1934), soil particle sizes for < 2 mm fractions by Boycouos hydrometric method (Bouyoucos 1962), bulk density using core method (Blake and Hartge 1986) and soil pH using digital pH (Carter 1993).

2.6 Data Analysis

The above-ground biomass (AGB) of each elevation range with DBH ≥ 5 cm was estimated using the model developed by

(Chave,2014). This model was selected because it was developed for a wide range of climatic conditions and vegetation types. It uses the most important biomass predictor variables, such as diameter at breast height (DBH), wood density, and total height. This model is currently being proposed for inclusion in the IPCC Emission Factor Database and is used by REDD+ protocols.

The AGB (in kg) is calculated as:

$$\text{AGB (kg)} = 0.0673 \times (\rho \times \text{DBH}^2 \times h)^{0.976}$$

The AGB carbon stock is then derived as:

$$\text{AGB Carbon Stock} = \text{AGB} \times 0.5$$

where:

- AGB: Above-ground biomass (kg/tree)
- ρ: Wood density (g/cm^3)
- DBH: Diameter at breast height (cm), ranging from 5–158 cm
- h: Height (m)

Since direct measurement of below-ground biomass (BGB) is expensive and time-consuming, it is derived from AGB using the root-to-shoot ratio. The BGB is estimated to be 20% of AGB (Gibbs, 2007; Ponce-Hernandez, 2004):

$$\text{BGB} = 0.2 \times \text{AGB}$$

where:

- BGB: Below-ground biomass (kg/plant)
- AGB: Above-ground biomass (kg/plant)

Extrapolating carbon stocks from a per-plot basis to a per-hectare basis requires the use of expansion factors. This standardization is necessary to ensure that results can be easily interpreted and compared to other studies. According to (Pearson,2005), the expansion factor is calculated as:

$$\text{Biomass Expansion Factor} = \frac{10,000\,\text{m}^2}{\text{Area of plot, frame, or soil core (m}^2\text{)}}$$

Litter Dry Biomass and Carbon Estimation

The dry biomass of herbaceous litter was calculated using the following equation (Pearson,2005):

$$\text{LDM} = \frac{\text{Sub-sample dry mass} \times \text{Fresh mass of the whole sample}}{\text{Sub-sample fresh mass}}$$

where LDM is the litter dry biomass.

The expansion factor to hectare was converted using:

$$\text{Expansion Factor} = \frac{10,000\,\text{m}^2}{\text{Area of plot (m}^2\text{)}}$$

The percentage of organic carbon was calculated as:

$$\text{Ash} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

$$\text{C\%} = (100 - \%\text{Ash}) \times 0.5$$

The percentage carbon content was estimated as 50% of organic matter ()Berhe,2013), where:

- C: Biomass carbon stock
- W_1: Weight of crucible
- W_2: Weight of the oven-dried ground sample and crucible
- W_3: Weight of ash and crucible

The carbon density of herbaceous plants was then calculated by multiplying the biomass of herbs per unit area by the percentage of carbon determined for each sample:

$$\text{CSL} = \text{LDM} \times \%C$$

where CSL is the total carbon stock in dead litter (t/ha), and %C is the carbon fraction determined in the laboratory (Pearson, 2005).

Soil Analysis

To determine the soil organic carbon (SOC), the bulk density was first calculated using the formula:

$$\text{Bulk Density} = \frac{\text{ODW}}{\text{CV} - (\text{RF}/\text{PD})}$$

where:

- CV: Core volume (cm^3)
- ODW: Oven-dry mass of fine fraction (< 2 mm) in g
- RF: Mass of coarse fragments (> 2 mm) in g
- PD: Density of rock fragments (g/cm^3), typically given as 2.65 g/cm^3

The SOC was calculated using Pearson (2007):

$$\text{SOC (t ha}^{-1}\text{)} = \left[\text{Soil Bulk Density (g/cm}^3\text{)} \times \text{Soil Depth (cm)} \times \%C\right] \times 1$$

In this equation, %C is expressed as a decimal fraction.

Statistical Analysis

A normality test (Kolmogorov-Smirnov test) and equality of variance test (Levene's test) were conducted to check the data. After confirming a normal distribution, further statistical analysis was performed. Elevation ranges (low, middle, and high) were treated as independent variables, while species richness, species diversity, density, basal area, DBH, height, soil organic carbon, biomass carbon stock, and ecosystem carbon stock were treated as dependent variables. The size and variation in species richness, diversity, and carbon stocks for each elevation were described using the mean and standard deviation. Descriptive statistics were used to test for differences in woody species richness, diversity, soil carbon stock (0–60 cm), and ecosystem carbon stock between elevation ranges. A two-way Analysis of Variance (ANOVA) was used to evaluate the effect of elevation ranges (low, middle, and high) and soil depths on soil organic carbon stock. A Kruskal-Wallis ANOVA was conducted to evaluate differences between elevation ranges in terms of woody species stand structure and biomass carbon stock. All statistical analyses were performed using IBM SPSS Statistics software (version 21) (IBM,2012).

3 Results

3.1 Biomass carbon stocks

Above and belowground biomass carbon stocks of woody species significantly differed among LE, ME and HE ($p<0.05$) (Table 1). The above ground biomass carbon stocks accounted for 80 % of the total biomass carbon stock of across the three studied elevations. The total biomass carbon stock recorded in LE was nearly 50% higher than ME and HE.

Similar letters show no significant differences among groups and different letters indicate significant differences

Also as depicted in figure 2 below, *J. procera* and *E. tirucalli* in LE contributed altogether 79% of the total biomass carbon stocks. While *E. tirucalli* and *J. procera* in the ME and *E. racemosa* and *J. procera* in HE contributed altogether 69 and 48 % of the total biomass carbon stocks, respectively.

3.2 Litter carbon stocks

There was no significant variation ($p > 0.05$) in the litter carbon stock among the three elevation categories. The average litter carbon stock estimated to be 4.74 ± 0.42 t ha^{-1} for HE, 4.86 ± 0.48 for ME and 5.04 ± 0.18 for LE.

3.3 Soil organic carbon stocks

The SOC stocks (t ha^{-1}) within 0 - 30 cm depth showed significant difference between the LE, ME and HE ($p < 0.05$). The surface layer (0 - 30 cm) contributed 58.5%, 61.3 % and 62.9% of the total SOC stock for the LE, ME and HE, respectively.

Similar letters show no significant differences among groups and different letters indicate significant differences

4 Discussion

4.1 Above and belowground biomass carbon stock

The higher biomass carbon stock in LE indicates that there is good comfort zone for woody species mainly due to better rainfall amount and temperature influence, stem density, diameter and height growth. Several studies in other parts of Ethiopia also reported similar findings (Hamere et al. 2015) and contradict with the findings of Thokchom and Yadava (2017). Moreover, the difference between HE and LE in above ground biomass carbon stock was comparable with those found by Alefu Chinasho et al. (2015). In contrast the total biomass carbon stock of this study also somewhat lower as compared with study conducted in highlands of Oromia, Ethiopia (Adugna Feyissa and Teshome Soromessa, 2017) and in mid highlands found elsewhere in Ethiopia (Hailu et al., 2014). This could be due to variation in tree dendrological parameters measured, allometric equations applied, carbon fraction and root: shoot ratio used. Outside from Ethiopia, this study is also in line with similar studies conducted in other countries (Shazmeen 2015).

4.2 Litter biomass carbon stock

Higher litter biomass carbon stock in low elevation might be due to high abundance of species. The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density), climate and relatively fast decomposition rate in the tropics. In overall, the smaller litter carbon sock in the study areas may be associated with less amount of litter fall and fast litter decomposition rate. In this study result indicates there was no significant difference between HE and ME in litter biomass carbon stock. This result is consistent with the findings of Hamere et al. (2015) and contradicts with the findings of Alefu Chinasho *et al.* (2015).

4.3 Soil organic carbon stock

Soil organic carbon plays a vital role in the global carbon cycle and C pools (Sundarapandian et al. 2015). The rate of soil organic carbon stock was significantly affected by changing in elevation (Girmay et al. 2008; Zhang et al. 2009; Sundarapandian et al. 2015).

Table 1: Mean AGBC and BGBC t ha-1) along three studied elevation gradients of Kalla Forest, southern Ethiopia. The value in the parenthesis indicates standard deviation

Elevation category	AGBC	BGBC	TBC	p-value
HE ($n = 20$)	96 (48)^a	19.2 (9.6)^a	115.5 (57.6)^a	0.034
ME ($n = 20$)	108 (72)^b	21.6 (14.4)^b	129.6 (86.4)^b	0.033
LE ($n = 20$)	162 (108)^b	32.4 (21.6)^b	194.4 (129.6)^b	0.035

Values are mean (standard deviation). Superscripts indicate significant differences between groups (Tukey's HSD, p ¡ 0.05).

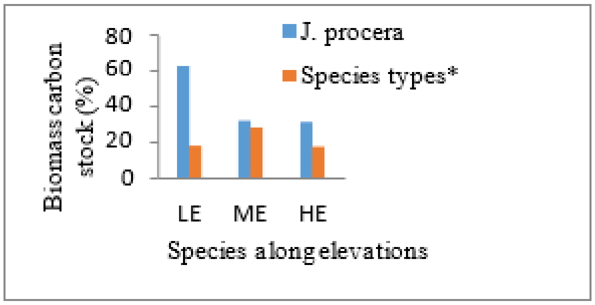

Figure 2: Proportion of biomass carbon stock contribution of the dominant tree species along the elevation gradients of Kalla Forest, southern Ethiopia Species types* represents for LE, ME and HE is E. tirucalli, E. tirucalli and E. racemosa respectively

The soil organic carbon in LE was higher than the adjacent ME and HE. This may be due to the accumulation of soil organic carbon on the quantity of litter and root activity such as rhizo - deposition and decomposition. This result was consistent with other studies in Ethiopia (Hamere et al. 2015) and in China (Biao et al. 2016). In contrast, (Alefu Chinasho et al. 2015) reported that elevation did not influence soil organic carbon. This study showed that SOC stock increased by 48 % through the low elevation over high elevation. This might be due to increased vegetation composition, reduced erosion loss and the subsequent production and decomposition of litter fall from vegetation.

In LE, there was higher litter biomass accumulation than middle elevation and high elevation. Litter fall contributes a major role for the return of organic matter to the soil (Liang et al. 2011). The higher soil organic matter accumulation in LE might also be related to the presence of *J. procera* for which the litter might be decompose and mineralized at slower rate. In contrast the mean SOC stock in the high elevation was lower owing to the low woody species abundance and the subsequent small litter fall that impacted the return of organic matter to the soil.

The present study showed soil organic carbon content decreases with soil depth. This might be due to the presence of lower accumulation of organic matter resulting from lower belowground root biomass in the sub- surface layer; which is similar with the justification of Yimer et al. (2015).

The total SOC stock (0-60 cm) in LE was higher than those reported from tropical dry forest that ranged between 33.36 and 48.82 t ha^{-1} (Sundarapandian et al. 2013). Our SOC stock in ME is substantially higher than those found in African savannahs and woodlands at middle elevation, SOC stock ranged between 30 and 140 t ha^{-1} (Williams et al. 2008). Also, higher than SOC stock reported by Woollen et al. (2012) in the central Mozambique middle elevation woodlands (40.1 ± 2.5 Mg C ha^{-1}). Maintaining of higher SOC levels ensures the productivity of degraded land as well as regulating the climate system.

4.4 Ecosystem carbon stock

The contribution of SOC stock in the present was higher than the total biomass carbon stock. Similar results were reported in other studies (Mekuria et al. 2009; Mekuria 2013). The total ecosystem carbon stock (in biomass plus soil, 0- 60cm) in the LE was higher than the report of Alefu Chinasho *et al.* (2015) and lower than other studies in Sothern Ethiopia (Mekuria et al., 2009; Mekuria 2013). The ecosystem carbon stock estimate with other sites may due to difference in the model used to estimate the biomass, variation in soil type, management of forest and topography.

5 Conclusion

The present study affirms elevation differences contribute to the variation in carbon stocks in the studied forest. The elevation effects mainly reflect the variation in climatic and edaphic factors. Total biomass carbon stock and soil organic carbon decrease as elevation increases. The low elevation in Kalla forest favors high accumulation of the carbon stocks in both the biomass and soils. In overall, our study show that Kalla indigenous forest can serve as a good candidate for REDD+ finical schemes.

Table 2: Mean soil carbon stock mean (t C ha^{-1}) of the three studied elevation categories of Kalla Forest, southern Ethiopia. The value in the parenthesis indicates standard deviation.

Depth, cm	N	HE	ME	LE	p-value
0-30	20	177.6 (58.8)^a	242.4 (87)^b	282 (171.6)^b	0.013
30-60	20	126.6 (60.6)^a	148.2 (71.4)^b	166.2 (85.2)^b	0.030
0-60	40	153 (64.8)^a	195 (91.8)^b	224.4 (145.8)^b	0.009

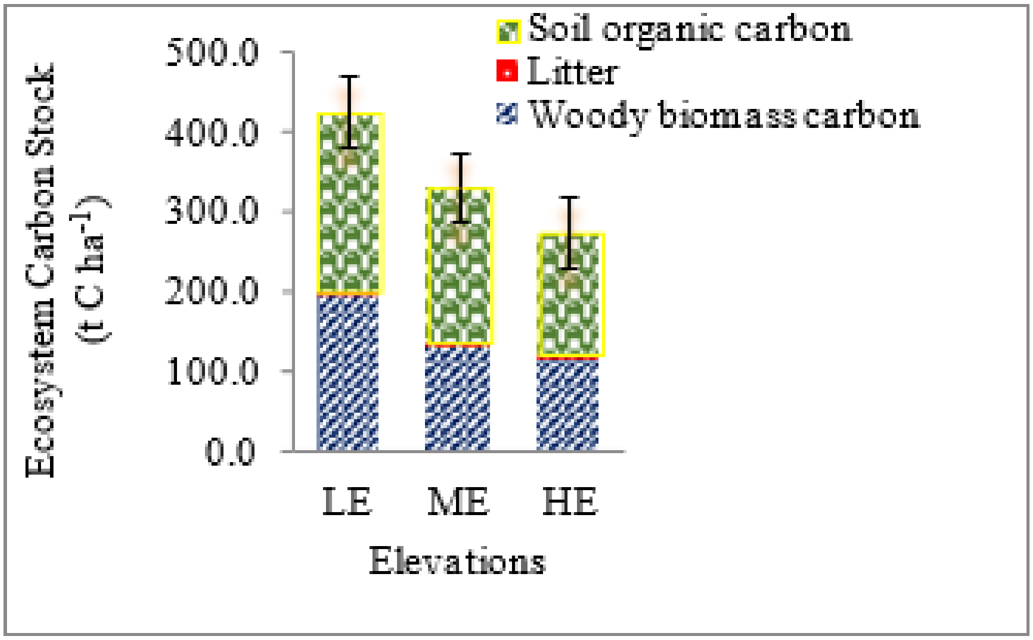

Figure 3: Ecosystem carbon stocks (in biomass plus soil) along elevation gradients of Kalla Forest, southern Ethiopia

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Conflict of interest

No conflict of interest

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