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Carbon Stock Variation along altitudinal gradient of Wacho Forest in Hawa Galan District, Kellem Wollega Zone, Oromia Region, Ethiopia

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Abstract

Background: Forest ecosystem plays a crucial role in the global carbon cycle; as such, mitigating high atmospheric concentrations of carbon dioxide and other greenhouse gases by naturally taking carbon from the atmosphere through photosynthesis. Verification and accounting of carbon stock in forest ecosystem have been renowned as a potential strategy to reduce and stabilize atmospheric concentrations of greenhouse gas. Forest sequesters and store more carbon than any other terrestrial ecosystem and it is an important natural break on climate change. It acts as a carbon reservoir by storing large amount of carbon in trees, undergrowth vegetation, forest floor and soil.

Result: The mean carbon stock of each carbon pool was changed along altitudinal class of the study area. The largest mean above and below ground carbon stock was found in the second altitudinal class(1560.01-1643m) followed by first altitudinal class(1435-1560m) and the third altitudinal class (1643.01-1704m) of the study area. The largest mean dead tree and dead wood carbon stock was also stored in the first altitudinal class followed by the third and the second altitudinal class of the study area. The largest mean litter carbon stock was found in the first altitudinal class followed by the second and the third altitudinal class of the study area. The largest mean soil organic carbon was found in the third altitudinal class followed by the second and the first altitudinal class of the study area.

***Conclusions:** The carbon stock variation along altitudinal gradients indicated that, altitude had no a statistically significant effect on any of the carbon pools except litter carbon of the study area at 95% of confidence interval.*

Key words: Wacho forest, Carbon stock, Altitudinal gradient

Background

The carbon stock of forest is impaired by deforestation and forest degradation, which results the release of carbon dioxide to the atmosphere [13]. This increases the concentration of Greenhouse gases (HGs) in the atmosphere, which is documented as the leading cause of human induced global climate change [15]. Carbon dioxide is the major greenhouse gases, which accounted about 60 % of the global warming that projected to increase the world temperature [10]. In Africa, deforestation accounts nearly 70 % of the total greenhouse gas emission [5]. The clearing of tropical forest destroys globally important carbon sinks that are currently sequestering carbon dioxide from the atmosphere, and which are critical for future climate stabilization [22].

Climate change and anthropogenic stress factors are accelerating the rate of tropical forest degradation and increasing carbon dioxide emissions [8]. The trees and forests of Ethiopia are under tremendous pressure because of the radical decline in mature forest cover and the continual pressures of population increase, inappropriate farming techniques, land use competition, land tenure, forest modification and forest conversion [25]. The ecosystem services that can be generated from the dry Afro Montane forests of Ethiopia are threatened mainly by anthropogenic pressures, including extensive forest resource utilization and land use changes [24]. The government of Ethiopia has developed Climatic Resilient Green Economy since 2012 aimed at keeping the greenhouse gas constant and makes the country carbon neutral by 2025 by applying abatement measures in different sectors of the country like forestry, agriculture and industries [16].

Even though, Ethiopia does not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests, some scholars like Feyissa et al.[6], Melese et al.[18],Gedefaw et al. [7], Nega et al.[19], Chinasho et al.[4], and Abere et al. [1] have studied the carbon stock variation along altitudinal gradient of Edgu forest, Woody plants of Arba Minch ground water forest, Tara Gedam forest, Danaba community forest, Humbo forest, and Banja forest respectively. But no study has been conducted in Wacho forest and any of the above researchers didn't investigate the carbon stock variation of dead tree and dead wood carbon along altitudinal gradient of their study areas. On the other hand, this research investigated the carbon stock variation of Wacho forest by including the carbon pool of dead tree and dead wood carbon along altitudinal gradient of the study area. Therefore, this paper filled the

deficient scientific quantitative data of carbon stock variation along altitudinal range of the forest as well as it filled the gap stated in the above researchers.

Methods

Description of the Study Area

The study area is located in Hawa Galan district, Kelleme Wollega Zone, Oromia Region, Ethiopia. The forest covered 720 hectares (ha) of land and it is located at about 630km to the South west of the capital city of Ethiopia, Addis Ababa and about 22 km to the town of Dambi Dollo. Geographically, it is found between 8°42'32"N -8°42'34"N and 40°52'49"E - 40°53'55"E which is shown in figure (a).

Figure a: Location of the study area

The altitudinal range of the study area also ranges from 1435 to 1704m above mean sea level. The mean maximum and minimum temperature of the study area was 30.84°C and 16.38°C respectively, and the mean annual rainfall was also 1,645mm, which is shown in figure (b).

Figure b: Maximum & minimum temperature and mean rainfall of the study area

Procedures of Data Collection

Delineation of the study area

The boundaries of the study area were delineated by taking geographic coordinates through Geographical positioning system (GPS) at each turning point of the study area.

Stratification of the study area

Wacho forest was divided into stratum based on the relative homogenous unit of topography, which helps to form more or less homogeneous units of the forest to increase the efficiency and accuracy of the forest carbon accounting.

Determine size and shape of sample plot

About 400m² areas of square sample plot were employed for sampling of the study forest. Because square plot has a better probability to incorporate more of within plot heterogeneity and thus be more representative than the other shape of sample plots of the same area as indicated by Hairiah et al. [11].

Determine sampling techniques and sample size

Sample plots of 20m×20m were laid through systematic random sampling techniques to collect the required and relevant data of the study forest at every 200m difference between each sample plot and 300m difference between each transect line. Finally, a total of 73 sample plots were laid by using GPS instruments starting from the lower to the higher elevation of the forest figure (c).

Figure c: Location of sample plots along altitudinal gradient of the study area

Field Measurements

Sampling and identification of trees and shrubs

According to Pearson et al. [20] all tree and shrub species having ≥ 5 cm diameter at breast height (DBH) were measured from 400m² areas of sample plots using diameter tape, and the height of those trees was also measured by using hypsometer. Woody plants having multiple stems at 1.3 meter were considered as a single tree and the largest stem was taken, while woody plants forked below 1.3 meter was treated as a single individual as indicated by Pearson et al.[20,21]. Plant identification was done at the National Herbarium of the Addis Ababa University using published volumes of Flora of Ethiopia and Eritrea.

Sampling of dead trees and dead woods

The samples of dead tree and dead wood were collected by using the principles of Goslee et al. [9] as follows.

Standing dead trees in class one which characterized by the existence of branches and twigs only having ≥ 5 cm DBH were measured from 400m² area of sample plots by using DBH tape and the height of those trees were measured by hypsometer. But the other types of standing dead trees with small and large branches only, trees with large branches only, and trees with bole only were measured its diameter at the base of the dead tree by using DBH tape and the height of those dead standing trees were measured by hypsometer. The lying dead woods, having ≥ 10 cm diameter were divided into sections of roughly one meter and the exact length and diameter at the middle of each section was recorded.

Sampling of litters

According to the principles of Pearson *et al.*[20] litter samples were collected manually from each of the five 1m×1m areas of subplots, which located at the four corners and one at the center of the main plot. About 100 grams of a composite sample was taken by mixing litter samples from each of the five sub plots of the main plot. Then it was placed in a plastic bag and labeled to which sample plot it belongs. Then after about 100 grams of 73 labeled composite samples were taken to the laboratory of Debrezeit horticoop Agricultural research center and the litter samples were oven dried to a constant weight at 105°C for 12 hours and the carbon fraction of litter samples were determined in the laboratory using Walkley-Black Method, 1934.

Sampling of soil organic carbon and bulk density

The samples of soil organic carbon (SOC) were collected by using the auger at a depth of 30cm from each of the five 1m×1m areas of subplots, which located at the four corners and one at the center of the main plot. About 100 grams of a composite sample were taken by mixing soil samples from each of the five sub plots of the main plot. Then it was placed in a plastic bag and labeled to which sample plot it belongs. Then after about 100 grams of 73 labeled composite samples were taken to the laboratory of

Addis Ababa Agricultural research center. Then the field moist soil samples were dried to a constant weight in an oven at 105°C for 12 hours and the percentage of organic carbon was determined in the laboratory using Walkley-Black Method, 1934.

The bulk densities (BD) of the soil samples were also collected by using a core sampler at a depth of 30cm from each of the five 1m×1m areas of subplot pits, in which the samples of SOC were taken. The sub samples of BD were oven dried to a constant weight in an oven at 105°C for 24 hours to determine the oven dry weight of soil samples. The design of the main plot and subplot of the study samples is shown in figure (d).

Figure d: Design of the main plot and the subplots for field measurements

Estimation of Carbon Stocks

Estimation of above ground tree biomass and carbon stock

The above ground biomass of trees and shrubs existed in the study area were calculated using the general allometric model of Chava et al.[3] as follows.

$$AGB=0.0673 \times (\rho DBH^2 H)^{0.976} \dots\dots\dots (eq.1)$$

Where,

AGB– aboveground biomass (kg)

DBH– Diameter of trees at breast height (cm)

H– Height of tree (m)

ρ – Wood density= (0.6 ton/m³), which is the average value of wood density of trees in Africa Henry et al.[12]

The above ground carbon and carbon dioxide equivalent sequestrated in above ground biomass of trees and shrubs found in the study area was calculated by the principles of Pearson et al. [20 &21] respectively as follows.

$$\text{Above ground carbon (AGC)} = \text{Above ground biomass} \times 0.5 \dots\dots\dots (eq.2)$$

$$\text{The CO}_2 \text{ equivalent sequestered in the aboveground biomass} = \text{AGC} \times 3.67 \dots\dots\dots (eq.3)$$

Estimation of below ground tree biomass and carbon stocks

Below ground biomass of trees and shrubs found in the study area was estimated by using root-shoot ratio factor of Mac Dicken [17]. According to Mac Dicken [17] and Pearson et al.[20], standard methods of estimating below ground biomass(BGB) and below ground carbon(BGC) can be obtained as 20% and 10% of above ground tree biomass respectively.

$$BGB = AGB \times 0.2 \dots\dots\dots (eq. 4)$$

$$BGC = BGB \times 0.5 \dots\dots\dots (eq. 5)$$

Where,

BGB= below ground biomass

BGC = carbon content of below ground biomass and 0.2 is the conversion factor (or root -shoot ratio), which is 20% of the above ground biomass.

The amount of CO₂ equivalent sequestered in below ground biomass of the study area was calculated by multiplying BGC by the molecular mass ratio of carbon dioxide to Carbon (44/12) which is 3.67 as indicated by Pearson et al.[21].

Estimation of dead tree and dead wood biomass & carbon stock

The biomass of standing dead trees which characterized by the presence of branches and twigs and the absence of leaves was calculated using the appropriate equations of Chave et al.[3] as biomass estimation techniques of live trees, but about 6% of the biomass of leaf was subtracted as it recommended by Pearson *et al.*[20].

$$SDWB = 0.0673 \times (\rho DBH^2 H)^{0.976} (-6\%) \text{ ----- (eq.6)}$$

SDWB= Biomass of standing dead tree without leaves (kg)

DBH– Diameter of standing dead tree at breast height (cm)

H– Height of standing dead trees (m)

ρ –Wood density (0.5g/cm³) as it suggested by Hairiah et al.[11]

The carbon stock of those standing dead trees was calculated by multiplying the standing dead tree biomass by 0.47, which is the default carbon fraction of Intergovernmental panel on climate change(IPCC) [14]).

The biomass of standing dead tree, which characterized by the presence of small and large branches only, the presence of large branches only, and trees having trunk or bole only was calculated using the volume of the cone as it recommended by Goslee *et al.*[9]

$$VOL_{cone} \text{ (cm}^3\text{)} = \frac{1}{3} \times \pi \times h \text{ (d1)}^2 \text{ ----- (eq.7)}$$

$$DB = V \times \rho \times 0.001 \text{ ----- (eq.8)}$$

VOL_{cone} =volume of cone (cm³)

h=height (cm),

d1=diameter at the base of the tree (cm)

DB=dry biomass (kg)

ρ =density of wood (0.5g/cm³) as it suggested by Hairiah et al.[11].

The carbon stock of those dead trees was calculated by multiplying the dry biomass of dead tree with 0.47, which is the default carbon fraction of IPCC [14].

The biomass of lying dead wood was also calculated by using the volume and density of wood as recommended by Pearson et al. [20].

$$BLDW = V \times \rho \text{ ----- (eq.9)}$$

$$V = (\pi)^2 \left[\frac{d1+d2+dn}{8L} \right] \text{ ----- (eq.10)}$$

Where,

BLDW= biomass of lying dead wood

V=volume of lying dead woods (m³/ha)

ρ = density of the wood (0.5g/cm³) as suggested by Hairiah et al.[11].

d1, d2.....dn = diameter of intersecting pieces of dead lying wood (cm)

L= length of the dead lying wood (m)

The carbon stock of those dead lying wood was calculated by multiplying the dry biomass of dead wood with 0.47, which is the default carbon fraction of IPCC [14].

The total carbon stock of dead tree and dead wood was calculated by summing up all carbon stock of dead trees and dead woods as follows.

$$TDWC=SDTC1+SDTC2+DLWC\text{-----} \text{ (eq.11)}$$

TDWC=Total carbon stock in dead tree and dead wood

SDTC1= Carbon stock of standing dead tree without leaves

SDTC2=Carbon stock of standing dead tree with small and large branches and without twigs, trees with large branches only, and trees with only bole

DLWC=Carbon stock of dead lying wood

Estimation of litter biomass and carbon stock

The litter biomass found in the study area was calculated by the formula of Pearson et al. [20] as follow.

$$LB=\frac{W_{field}}{A} * \frac{W_{subsample(dry)}}{W_{subsample(fresh)}} * \frac{1}{10,000} \text{.....} \text{ (eq.12)}$$

Where,

LB=Biomass of litter (t/ha)

W field=weight of a wet field sample of litter in gram from an area of 1m²

A = size of the area in which litter samples was collected

W sub-sample (dry) =weight of the oven dry sub sample of litter taken to the laboratory to determine moisture content

W sub-sample (fresh)=weight of the fresh sub sample of litter taken to the laboratory to determine the moisture content (g)

$$CL = LBM \times \% C \text{.....} \text{ (eq. 13)}$$

Where,

CL= is total carbon stocks in the litter biomass (t/ha)

LBM= is oven-dry biomass of litter and %C = carbon fraction of litter samples determined in the laboratory.

Estimation of soil organic carbon (SOC)

The carbon stock density of soil organic carbon found in the study area was calculated using the volume and bulk density of soil as it recommended by Pearson *et al.* [21].

$$V = h \times \pi r^2 \dots\dots\dots (eq.14)$$

Where,

V= volume of the soil in the core sampler (cm³), h = the height of core sampler (cm), r = the radius of core sampler (cm). Moreover the bulk density of soil sample was calculated as follows.

$$BD = \frac{W_{av,dry}}{V} \dots\dots\dots (eq.15)$$

Where,

BD= soil bulk density (g/cm³), W_{av, dry}= average oven dry weight of soil sample per sample plot, and V= volume of soil sample in core sampler (cm³).

$$SOC = BD * d * \% C \dots\dots\dots (eq.16)$$

Where,

SOC= soil organic carbon stock per unit area (t/ha), BD = soil bulk density (g/cm³), d = the total depth at which the samples were taken (30 cm) and %C= carbon fraction of soil samples, determined in the laboratory.

Estimation of total carbon stock density

The total carbon stock density of the study area was calculated by using the equation of Subuied et al.[23] by summing the carbon stock densities of the individual carbon pools of the study area.

$$CT = AGC+BGC+DTWC+LC+SOC \dots\dots\dots (eq.17)$$

Where,

- CT=Carbon stock density for all carbon pools (t/ha)
- AGC=Carbon stock in above ground tree and shrub biomass (t/ha)
- BGC=Carbon stock in below ground tree and shrub biomass (t/ha)
- DTWC= Carbon stock in dead tree and dead wood biomass (t/ha)
- LC= Carbon stock in litter biomass (t/ha)
- SOC= Soil organic carbon (t/ha)

Data Analysis

The collected data like DBH of live trees & dead trees, height of live trees & dead trees, dry weight & carbon fraction of litter samples and soil samples were recorded on the Microsoft excel data sheet of 2007 and it was analyzed by using Statistical Package for social science (SPSS) software version 21. The relationships between different dependent variables (AGC, BGC, DTWC, LC and SOC) and independent variable (altitude) were processed and tasted by descriptive statistics and one way analysis of variance (ANOVA) at 95% of confidence interval. Descriptive statistics were used to summarize the mean carbon

stock of each carbon pool of the study area, while one way ANOVA was used to determine the statistical significance difference of carbon stock along altitudinal gradient of the study area.

Results

There was a variation of mean carbon stock of each carbon pool along altitudinal gradient of Wacho forest, but it is not statistically significant at 95% of confidence interval except litter carbon stocks (table 1).

Table 1: Mean carbon stock of each carbon pool along altitudinal range of the study area

Altitudinal class	AGC	BGC	DTWC	LC	SOC
1435-1560m	278.95±7.25	55.77±1.48	3.3±3.33	2.13±0.62	107.79±16.57
1560.01-1643m	280.1±31.69	56.02±6.34	3.02±0.27	1.80±0.31	109.60±14.56
1643.01-1704m	274.52±50.13	54.84±9.97	3.07±0.34	1.70±0.4	109.92±14.5
P-Value	0.864	0.864	0.066	0.019	0.92
F-Value	0.146	0.146	2.835	4.222	0.083

Discussion

Carbon stock variation along altitudinal gradient of Wacho forest

The mean carbon stock of each carbon pools was changed along altitudinal class of the study area. The largest mean above and below ground carbon stock was found in the second altitudinal class (1560.01-1643m) followed by the first altitudinal class (1435-1560m), and the third altitudinal class(1643.01-1704m) of the study area(table 1). This was due to the predominance of larger DBH and height of tree species at the second altitudinal class than the first and the third altitudinal class of the study area. Even though both the mean AGC and BGC were not evenly distributed along altitudinal class of the study area, their variations were not statistically significant at $\alpha=0.05$ ($F=0.146$, $P=0.864$)(table 1). The result was similar to the mean AGC and BGC stock distribution of Banja forest, that the largest mean AGC and BGC stock of Banja forest was reserved in the middle altitudinal class of the study area without a statistically significant mean differences of carbon stock at $\alpha=0.05$ ($F=0.3765$, $P=0.7935$), that studied by Abere et al.[1].

The mean carbon stock of dead tree and dead wood was slightly varied in each altitudinal class of the study area. The largest mean dead tree and dead wood carbon stock was stored in the first altitudinal class followed by the third and the second altitudinal class of the study area(table 1). This might be due to

the presence of higher human and livestock disturbances in the first altitudinal class than the other altitudinal class. But the variation of the mean dead tree and dead wood carbon stock distribution was not statistically significant along altitudinal class of the study area at $\alpha=0.05$ ($F=2.835$, $P=0.65$)(table1).

The largest mean LC stock was found in the first altitudinal class followed by the second and the third altitudinal class of the study area (table 1). This was due to the existence of open canopy of trees in the first altitudinal class of the study area, which favor the growth of understory vegetation, annual herbs and grasses. The variation of the mean LC stock distribution was statistically significant at $\alpha=0.05$ ($F=4.222$, $P=0.019$)(table 1). The mean LC stock distribution of wacho forest was in line with the mean LC stock distribution of Tara Gedam forest, which studied by Gedefaw *et al.*[7]. The largest mean LC stock of Tara Gedam forest was existed in the first altitudinal class of the study area with statistically significant mean differences of carbon stock at $\alpha=0.05$ ($F=3.222$, $P=0.046$).

The largest mean SOC was found in the third altitudinal class followed by the second and the first altitudinal class of the study area (table1). Because some part of the third altitudinal class of class of the study area was the place in which deposition of sediments due to soil erosion takes placed. Also, it might be due to soil type, soil depth, soil texture, tree cover and tree species, and degree of disturbance regime. But the variation of the mean SOC stock distribution was not statistically significant along altitudinal class of the study area at $\alpha =0.05$ ($F=0.84$, $P=0.920$) as shown in (table 1). The mean SOC stock distribution of wacho forest was similar to the mean SOC stock distribution of Edgu forest, in which the largest mean SOC stock of Edgu forest was found in the upper altitudinal class followed by the middle and lower altitudinal class of the study area without statistically significant at $\alpha=0.05$ ($F=1288$, $P=0.311$)[6].

Conclusion

The carbon stock of different carbon pools such as above ground carbon, below ground carbon, dead tree and dead wood carbon, litter carbon and soil organic carbon were varied within the study area due to the variation of environmental gradient. The upper altitudinal class of the study area was high in soil organic carbon, while the middle altitudinal class of the study area was high both in above and below ground carbon stock. The lower altitudinal class of the study area was also high both in dead tree and dead wood carbon stock and litter carbon stock. Even though altitudinal gradient was the factor that affects the carbon stock distributions of the study area, the carbon stock variations were not statistically significant at 95 % of confidence interval except litter carbon stock. So it was possible to conclude that; altitudinal gradient had not a statistically significant influence except litter carbon stock of Wacho forest.

Abbreviations

AGB: aboveground; AGB: Above ground biomass; AGC: Above ground carbon; ANOVA: analysis of variance; BD: Bulk Density; BGB: Below Ground Biomass; BGC: Below Ground Carbon; BLDW: Biomass of lying dead wood; CL: Total carbon stocks in the litter biomass; DBH: Diameter at Breast Height; DLWC: Carbon stock of dead lying wood; GPS: Geographical Positioning System; H: Height of tree; Ha: hectare; HGs: Greenhouse Gases; LB: Biomass of litter; LBM: Oven-dry biomass of litter ; SDWB: Biomass of standing dead tree without leaves; SOC: Soil Organic Carbon; SPSS: Statistical Package for social science; TC: Total carbon; TDWC: Total carbon stock in dead tree and dead wood.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing Interest

The authors declare that they have no conflict of interest.

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Authors' Contribution

Gezahegn Gashu, GG, SD, ZF, and HA have collected the data. Gezahegn Gashu perform the experiment and analyzed the data and wrote the paper. All authors read and approved the final manuscript.

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Figures

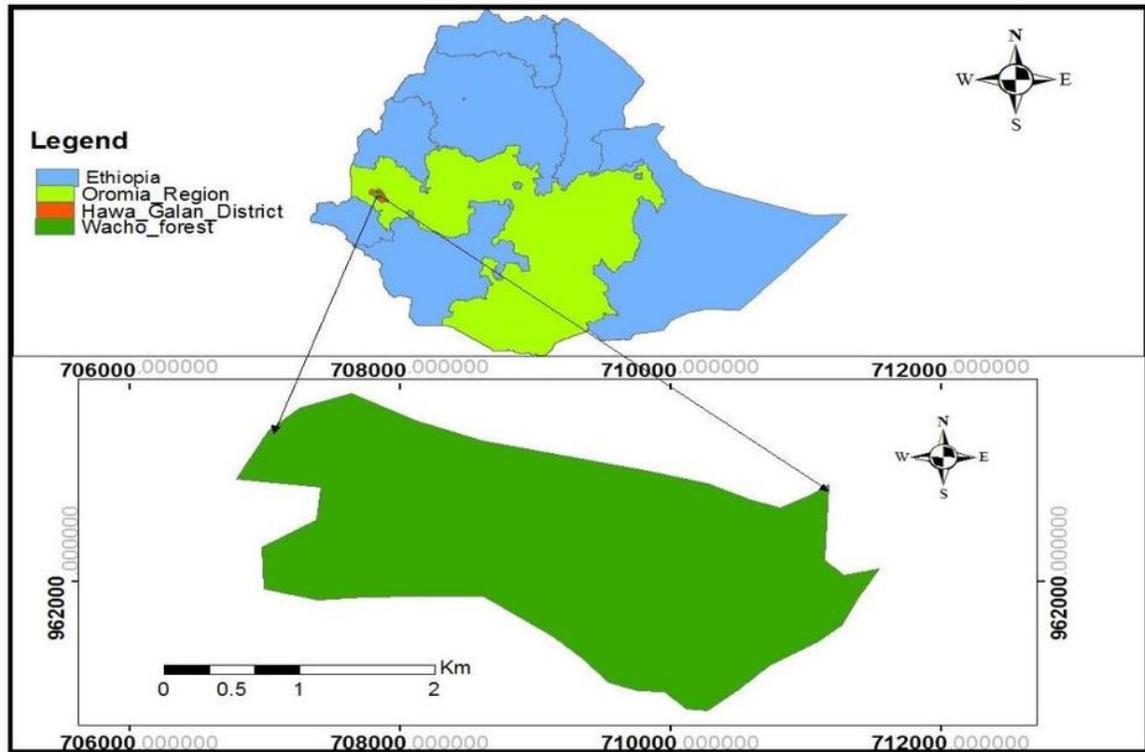


Figure a

Figure 1

Location of the study area

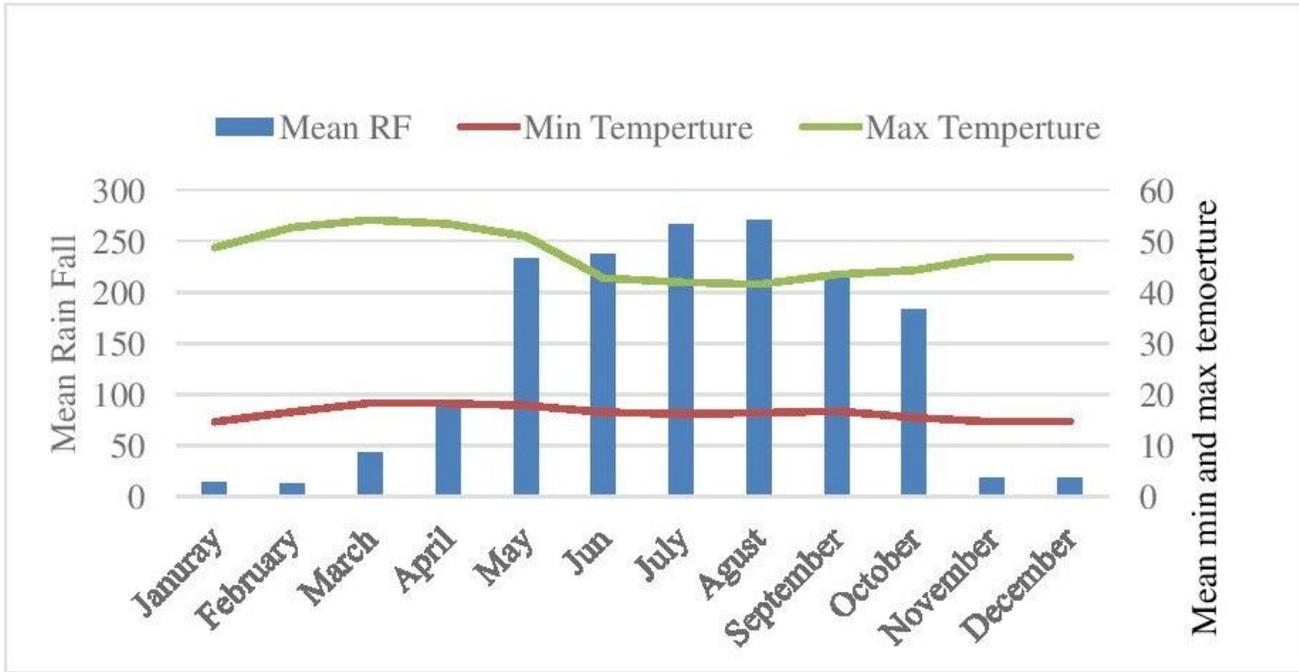


Figure b

Figure 2

Maximum & minimum temperature and mean rainfall of the study area

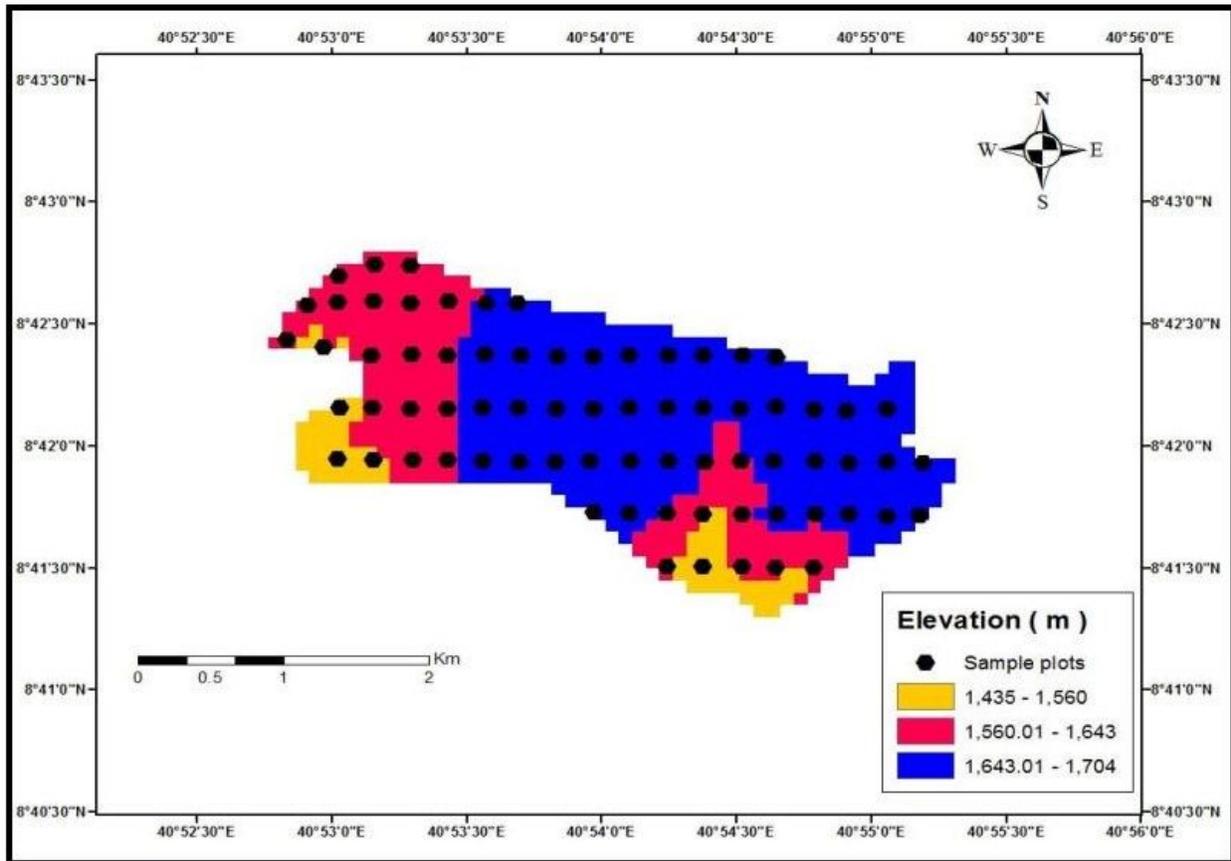
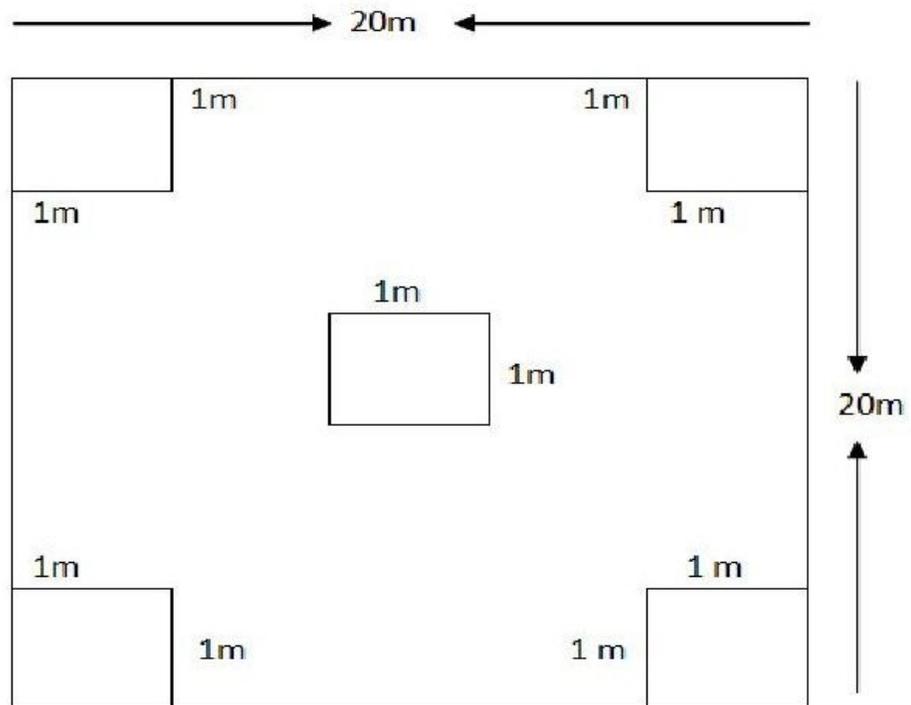


Figure c

Figure 3

Location of sample plots along altitudinal gradient of the study area



Key: $20\text{m} \times 20\text{m} = \text{main plot}$ and $1\text{m} \times 1\text{m} = \text{sub plot}$

Figure d

Figure 4

Design of the main plot and the subplots for field measurements