

Carbon Stock in Gullele Botanical Garden: Implications for Carbon Emission Reduction, North Western Addis Ababa, Ethiopia

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Abstract

This study was aimed to examine the carbon Stock in the Gullele Botanical Garden. To meet the objective of the research, the study was entirely based on quantitative study design by considering 60 sample plot i.e., 10*20 m² which was systematically located at every 600m vertical height and 300m horizontal width in the Garden. The results shown the maximum carbon per tree is 37.84 tones for 2.9% of Eucalyptus globules and Juniperus procera. This indicates planting one tree could be sinking 0.56 ± 1.71 SD tones mean carbon in the above ground biomasses. In addition, the litter carbon concentration analyzed in the laboratory was 54.67 % maximum and 47.71% minimum per sample with mean carbon stock of 59.78%. Whereas, the analysis of soil organic carbon, The laboratory result had shown .3% minimum and 12.6% maximum soil organic carbon, while 121.49 t ha⁻¹ maximum and 2.67 t ha⁻¹ minimum value carbon stocks were recorded. Accordingly, 37.2608 ± 19.6554 t ha⁻¹ mean carbon stock Captured in soils, this indicates mean carbon captured in the soil pool was relatively greater than the other pools. Moreover CO₂ equivalent values showed the same trend as soil organic carbon which was 445.45t ha⁻¹ maximum and 9.79t ha⁻¹ minimum value sequestered in the soils. Comparatively, the lowest carbon stock is found in dead litter pool while the highest carbon stock found in soil pool i.e., soil pool 61.19%, above ground biomass pool 28.09 %, below ground biomass pool 5.62 % and dead litter pool 5.10 % which is in conformity with the already established knowledge. Thus, Undertaking different studies considering such issues have paramount importance for carbon trade, climate change mitigation and fund attraction. Consequently, intensifying indigenous knowledge for biodiversity conservation, climate change mitigation and urban greening option is very important in enhancing carbon sequestration potentials.

Key words: Biomass, Carbon stock, Carbon Stock equivalent, DBH, Gullele Botanical Garden

1. INTRODUCTION

The main carbon pools in tropical forest ecosystems are the living biomass of trees and understory vegetation and the dead mass of litter, woody debris and soil organic matter. The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation. More dominantly the impact of deforestation is the largest contributor of tropical land use emissions (Houghton, 2003), with Africa contributing 25-30% of tropical land clearing from deforestation, and as much as 0.37 Pg C yr⁻¹, in the last decades (DeFries *et al.*, 2002). Reducing Emissions from Deforestation and forest Degradation (REDD) is recognized as a potential option to mitigate the greenhouse effect (Santilli *et al.*, 2005) and REDD is now integrated into the international negotiations process. Though developing countries are acutely lacking data on carbon stock potentials, the implementation of the REDD is highly require estimates on the impact of forest degradation and deforestation on carbon (C) stocks, identifying baselines and monitoring forests.

Accordingly, the average temperature of the earth's surface has risen by 0.74 degrees centigrade's since the late 1800s. It is expected to increase by another 1.8°/ C to 4°/ C by the year 2100 - a rapid and profound change - if the necessary actions will not be taken (IPCC , 2006). Even if the minimum predicted increase takes place, it was larger than any century-long trend in the last 10,000 years. The principal reason for the mounting thermometer is a century and a half of industrialization: the burning of ever-greater quantities of oil, gasoline, and coal, the cutting of forests, and the practice of certain farming methods. These activities have increased the amount of "greenhouse gases" in the atmosphere, especially carbon dioxide, methane, and nitrous oxide. Such gases occur naturally - they are critical for life on earth, they keep some of the sun's warmth from reflecting back into space, and without them the world would be a cold and barren place. But in augmented and increasing quantities, they are pushing the global temperature to artificially high levels and altering the climate.

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). For this reason, the UNFCCC and its Kyoto Protocol recognized the role of forests in carbon sequestration. Specifically, Article 3.3 and 3.4 of the Kyoto Protocol pointed out forest as potential carbon storage (Brown, 2002) though countries like Ethiopia which have diverse natural resources are

not yet identifying carbon stock data's for different potential localities.

Ethiopia has variety of agro-climatic zones, which has made the country botanical treasure house, containing about 7000 different flowering plants out of which about 12% are endemic (FAO, 2001). This variety of flora is found in the natural forests, which had been declined from about 16 % in 1950s to about 2.5% in 1990s though currently different measures are undergoing to increase the country's forest cover. In this regard the contribution of national parks, botanic gardens, reserved forests etc. have played paramount importance in preserving the different varieties of forest species found in the country. Thus, undertaking different scientific studies have crucial role for the country and the citizens in preserving and sustainably use this natural resources. Accordingly, this paper gives emphasis to examine the importance of Botanical Gardens (i.e., Gullele Botanical Garden) in reducing carbon emissions from the atmosphere by identifying Carbon sequestration potentials among different tree species found in the Garden so as to provide information's for future possibilities of carbon trading and finance. The objective of the study is to draw lessons that are important to make informed decisions and sound policy statements about the importance of the Botanical Gardens (i.e., Gullele Botanical Garden) in Carbon sequestration and future possibilities for carbon trading, by estimating the carbon stock in the garden.

2. MATERIALS AND METHODS

2.1. Location of the Study Area

The study area is located at north western part of Addis Ababa city administration at a distance of 5-10 km. It belongs to the central plateau of Ethiopia, which shares its vegetation zone and climatic characteristics with adjacent part of Oromia National Regional State. The geographical co-ordinate of the garden lies between latitude 8° 55' N and 9°05' N and longitudes 38°05' E and 39°05' E and it accounts a total area of 936 hectare, from which 736 is in Addis Ababa city Administration where as the remaining 200 hectare is found in Oromia region.

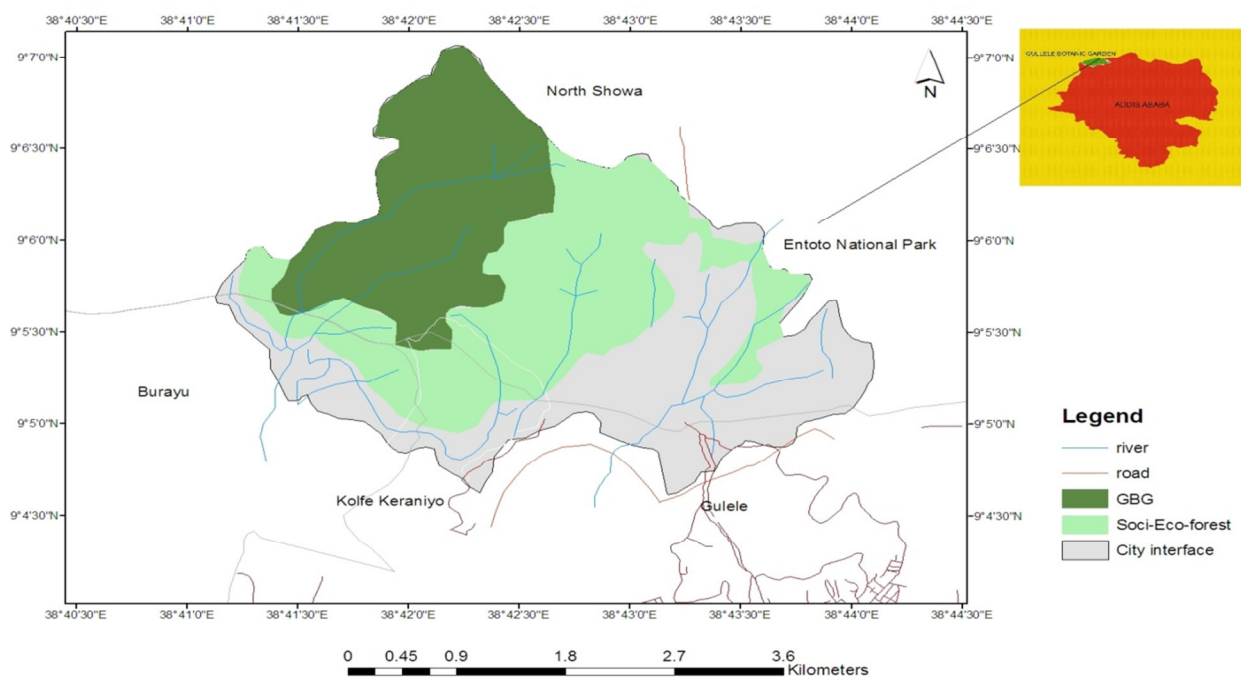


Fig.1: Map of the Study Area

2.2. Geology and Soil

According to Morton (1974) the rock type of Entoto (north of Addis Ababa) is Silicics. This formation of rock takes its name after a heal bordering the northern part of Addis Ababa, which dated 21.5 million years. The representative lithologies of this rock type are Trachyte and Rhyolite. The Rhyolite is composed of andesine-oligoclase and sanidine occurring as Phenocrysts, and a ground mass of devitrified glass, ironoxide, plagioclass laths and quartz. Trachyte is observed in the north eastern part of the area and it shows two varieties, i.e., pale grey and reddish grey.

2.3. Climate

The rainfall and the temperature condition of the area was described based on the data collected from 2006-2011 by the Ethiopian Meteorological Service Agency (EMSA) from Entoto station. According to the data from

EMSA the result of the analysis showed that the mean annual temperature of the study area is about 13.8°C. The range of mean minimum and maximum temperature of the study area is 7.5 and 20.7 in degree centigrade which belongs to December and February respectively.

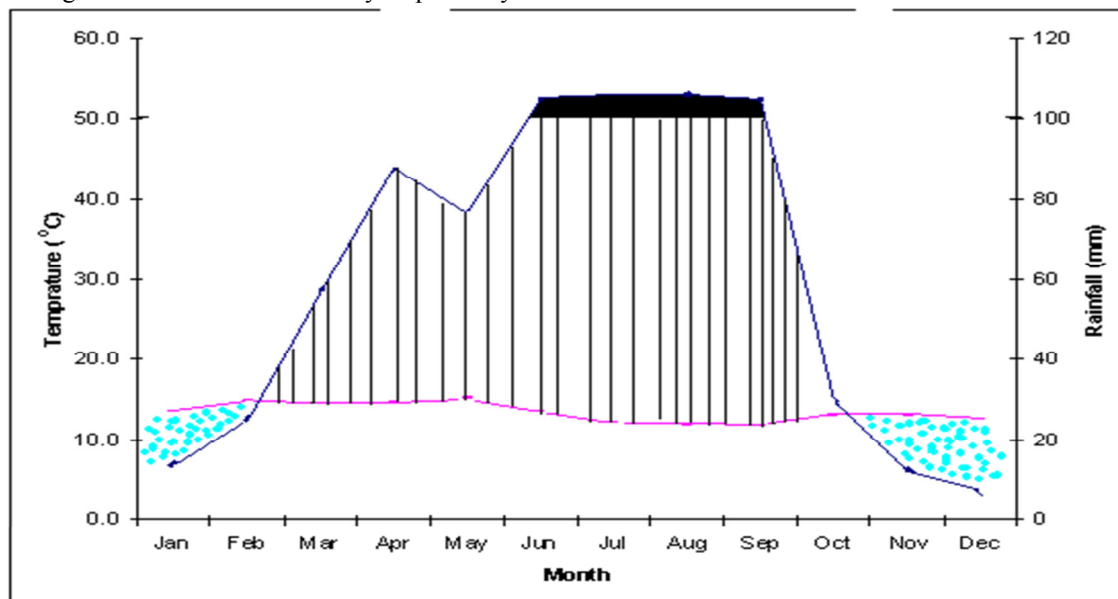


Fig. 2: Climatic Diagram of Gullele Botanic Garden Based on 6 years (2006-2011)

Source: Ethiopian Metrological Service Agency (EMSA), dry periods are dotted and wet periods are blackened

2.4. Study Design

A 'nested' sampling approach were used to assess large diameter trees (with a stem diameter above 30 cm) in rectangular plots of $20 \times 10 = 200 \text{ m}^2$, smaller trees (stem diameter 5 – 30 cm) in subplots of $5 \text{ m} \times 10\text{m} = 50 \text{ m}^2$, and under-storey vegetation and litter in smaller sub-subplots of $1 \text{ m} \times 1 \text{ m}$ within $10\text{m} \times 5\text{m}$ plot size as used by (Person T., 2005) by keeping the central point. Plot locations were systematically selected at every 300m horizontally and 600m vertically in the Garden by using GPS instrument, i.e., beginning from the lower parts of the garden to the upper parts.

Thus, to measure carbon stock of the study area both destructive and nondestructive sampling methods were employed for the litter, undergrowth layer, and for large trees (both for standing and fallen trees), respectively. Rectangular plots were used as they tend to include more of the within-plot heterogeneity, and thus be more representative than square or circular plots of the same area (Person, 2005).

2.4.1. Biomass and Necromass Estimation

The total standing above-ground *biomass* of woody vegetation elements is often one of the largest carbon pools. The above-ground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous undergrowth Kurniatun *et al.*, (2001). The dead organic matter pool (*necromass*) includes dead fallen trees and other coarse woody debris. An estimate of the vegetation biomass can provide us with information about the nutrients and carbon stored in the vegetation as a whole. To measure the biomass of vegetation which includes trees is not easy, especially in mixed, uneven-aged stands. Thus, it is hardly ever possible to measure all biomass on a sufficiently large sample area by *destructive sampling* and some form of allometry and hence, this study considers non destructive sampling methods for large trees greater than 5cm in DBH.

2.4.2. Plot size Design for nested plots

As the nondestructive sampling methods were rapid and covered a much larger area and number of trees in the sampling area, it has good potentials for reducing the sampling error encountered with the destructive method. Yet, half of the biomass of a natural forest can be in the few trees of the largest diameter class ($> 50 \text{ cm}$). Hence, the study considers trees with a DBH above 30 cm in a $20 * 10=200 \text{ m}^2$ sampling area to increase accuracy of the data.

2.4.3. Species identification

Plant identification was done in the field by using Flora of Ethiopia and Eritrea volume and Useful trees and shrubs for Ethiopia (Azene Bekele, 1993). For those species difficult to identify in the field, fresh specimens were collected and then pressed properly for identification at the National Herbarium of Addis Ababa University.

2.4.4. Diameter measurement

The DBH of all trees having diameter 30 cm in study site were measured as mentioned in the above figure 3 in a

rectangular quadrant of (20m x 10m) of 200 m². Besides DBH measurement for the trees between 5cm < diameter < 30cm were undertaken from the sample area of 5m x 10m by running 10 m line through the central line at 2.5 meter from side of the tape. For each tree the diameter will measure at 1.3 m above the soil surface, except where trunk irregularities at that height occur (plank woods, tapping or other wounds) and necessitate measurement at a greater height. For trees > 30 cm diameter larger sample 20 * 10 m² were needed to include all trees with a diameter > 30 cm Kurniatun *et al.*, (2001).

2.4.5. Under story and Litter sampling

Moreover, 10m x 5m sampled area sizes were used to sample litter less than 5 cm DBH. In a given sampled plot there was 6 studies quadrant, in total 360 quadrates' were laid. The litter sample were collected from sub-quadrant of 1m x 1m along with the central transect by placing it systematically in each quarter of the length of the central rope. Accordingly, two sampling quadrants at each side of the central rope were laid. All litter samples in the sub-quadrant were collected manually. Each sample was measured for wet weight while 100 gm sub-sample and mixed manually to select the 100 gm sample for laboratory analysis.

Laboratory analysis: The 100 gm sub-sample wet weights were taken for laboratory and oven dried at 65⁰C while oven dry weights were taken for each sub-sample. The six sub-sample oven dried collect from each quadrant were mixed homogenously while carbon fraction was measured in the laboratory using Walkley-Black Method (Walkley, A. and I. A. Black. (1934)). As mentioned above, the total samples for laboratory analysis were sixty. Finally carbons in dead litter t ha⁻¹ for each site were determined.

2.4.6. Soil sampling

The soil samples for soil carbon determination were collected at the same sampling sub-quadrants used for litter sampling. In each sub-quadrant one soil sample were taken using core sampler auger at depth of 30 cm. Accordingly, a total of 360 soil samples were collected from sampled area and mixed manually to select the 60 soil samples analyzed in the laboratory.

Laboratory analysis: The soil samples collected from each sub-quadrant were air dried while dry weights of each sample were taken. Four equal weight of each sample from each quadrant were taken and mixed homogenously while carbon fraction of each homogenous sample were measured in the laboratory using Walkley-Black Method (Walkley, A. and I. A. Black. (1934)). on the bases of this finally the bulk density, soil organic carbon and soil organic matter were calculated.

2.3. DBH Measurement Approach

Trees that have straight and not tagged were measured at normal 1.3m above the ground. Otherwise, when trees are tagged, the numbered tag and nail should be placed at 10cm below DBH to avoid errors arising from bumps or other imperfections that can develop at the site where the nail enters the tree.

2.4. Estimation of Parameters

2.4.7. Estimation of Carbon in Above Ground Biomass

Biomass is defined as the total amount of live and inert organic matter above and below ground expressed in tone of dry matter per unit area (Brown *et al.*, 1989). Accordingly, the above ground and below ground biomasses of all trees found in the study plots were measured. The equation is as follows:

$$Y = 34.4703 - 8.0671(DBH) + 0.6589(DBH^2) \dots\dots\dots (equ.1)$$

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

Then, Below Ground Biomass (BGB):

$$BGB = AGB \times 0.2 \dots\dots\dots (equ.2)$$

Where, AGB is above ground biomass, 0.2 is conversion factor from literature. Finally, carbon content in the biomass was estimated by multiplying of 0.47 while multiplication factor 3.67 was used to estimate CO₂ equivalent (Pearson *et al.*, 2005).

In addition to this mentioned allometric equations the following parameters were used to measure carbon statuses of a forest according to Person *et al.*, (2005);

$$\text{Carbon stock per tree} = \text{Biomass of the tree} / 2 \dots\dots\dots (equ.3)$$

$$\text{Carbon stock in a sub plot} = \text{summation of carbon stock of trees in sub plots} \dots\dots\dots (equ.4)$$

$$\text{Estimation of carbon stock for the sample plot (200m}^2\text{)} = (\text{Summation of carbon stock of plots} / \text{area of sub plots}) \times 1000\text{m}^2 \dots\dots\dots (equ.5)$$

$$\text{Carbon stock in ton per hectare} = \text{Carbon stock of the sample plot} / 10,000$$

$$\text{Estimation of the mean above ground carbon stock of the plot in carbon dioxide equivalent AG carbon stock in CO}_2\text{ equivalent (i.e., ton CO}_2\text{ equivalent) is calculated as; carbon stock in ton/ha} \times 44/12 \dots\dots\dots (equ.6).$$

2.4.8. Estimation of Carbon in Understory Vegetation and Litters

The forest floor, or litter layer, is defined as all dead organic surface material on top of the mineral soil. Some of this for example include, Understory vegetation (including trees < 5 cm in diameter), Coarse/standing litter, Fine

litter and Surface roots etc. thus to estimate liter biomass and carbon in litter the following questions were used based on the (Person *et al.*, 2005).

$$LB = \frac{W_{field}}{A} * \frac{W_{sub_sample(dry)}}{W_{sub_sample(fresh)}} * \frac{1}{10000} \dots\dots\dots (equ.7)$$

Where: LB = Litter (biomass of litter t ha⁻¹)

W_{field} = weight of wet field sample of litter sample within an area of size 4 m² (g);

A = size of the area in which litter were collected (sample area);

W sub-sample, dry = weight of the oven-dry sub-sample of litter take to the laboratory to determine moisture content (g), and

W sub-sample, fresh = weight of the fresh sub-sample of litter take to the laboratory to determine moisture content (g) (Person *et al.*, 2005).

Carbon stocks in litter biomass

$$C_L = LB * \% C \dots\dots\dots (equ.8)$$

2.4.9. Soil carbon estimation

To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables were measured: (1) soil depth, (2) bulk density (calculate from the oven-dire weight of soil from a know volume of sample 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 (Person *et al.*, 2005). In this study soil will simple at constant depth of 30 cm.

$$V = h * \pi r^2 \dots\dots\dots (equ.9)$$

Where, V is volume of the soil in the core sampler augur in cm³, h is the height of core sampler augur in cm, and r is the radius of core sampler augur in cm (Pearson *et al.*, 2005).

$$BD = \frac{W_{av, dry}}{V} \dots\dots\dots (equ.10)$$

Where, BD is bulk density of the soil sample per, W_{av, dry} is average air dry weight of soil sample per 5m × 10m quadrant, V is volume of the soil sample in the core sampler augur in cm³ (Person *et al.*, 2005).

$$SOC = BD * d * \% C \dots\dots\dots (equ.11)$$

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 will take (30 cm), and %C = Carbon concentration (%) (Person *et al.*, 2005). Carbon fraction in dead litter and soil pools were analyzed in the laboratory, using Walkley-Black method.

The carbon stock densities were calculated by summing up the carbon stock densities of the individual carbon pools of each study site using the following formula (Pearson *et al.*, 2005).

$$C_{density} = C_{AGB} + C_{BGB} + C_{Lit} + SOC \dots\dots\dots (equ.12)$$

Where:

C_{density} = Carbon stock density for all pools for each site [ton ha⁻¹]; C_{AGTB} = Carbon in above -ground tree biomass [t C ha⁻¹]; CBGB = Carbon in below-ground biomass [t C ha⁻¹]; C_{Lit} = Carbon in litter [t C ha⁻¹]; SOC = Soil Organic Carbon [t C ha⁻¹]

2.5. Data Analysis

The relationships between different parameter were tested by linear regression, one way ANOVA, and descriptive statistics. The DBH data were arranged in classes for applying appropriate model of biomass estimation equation.

3. Existing Forest Profile in the Gullele Botanical Garden

3.1.1. Density of Tree/ Shrubs Species

The sampled 60 plots have the tree density of 3534 individuals with the highest number in sample plot 50, 48, and 43 with 120, 106, and 101 individuals per sampled plots respectively. Whereas, plots 1, 15 and 16 have the smallest share of tree individuals in the sampled plots i.e., 22 tree individuals for each samples. This result reveals that the maximum tree density is found on the upper parts of the garden while lower part of the garden contains very small proportion of tree individuals. This may be associated with the reason mentioned by the officials of the garden and said; “the lower or the areas very near to the city have been easily affected by social contacts and, the nearby societies also utilize the resources without the consent of the garden”.

Concerning the tree species distribution of in the Gullele Botanical Garden, the analysis result shows the existence of clear dominance in some exotic tree species like *Eucalyptus globulus* which occupied large parts of the garden and shares about 1042 (29.49%) of the sampled tree/shrub individuals. In addition, indigenous species like *Juniperus procera* shares relatively large tree/shrub individuals i.e., 643 (18.19%). The dominance of exotic species may lead to think for the species consideration of the Botanic garden so that they give priority to have more native species.

Furthermore, tree species like *Ficus sur*, *Discopodium penninervum*, and *Hypericum revolutum* respectively were among the lowest tree density in the sampled plot (they have only 4,6, and 7 individuals), i.e.,

they are among the rarely distributed tree species in the Garden.

No.	Species name	Density	Rank	Percent	Cumulative Percent
1	<i>Acacia abyssinica</i>	86	7 th	2.4	2.4
2	<i>Acacia melanoxylon</i>	33	16 th	.9	3.4
3	<i>Bersama abyssinica</i>	33	16 th	.9	4.3
4	<i>Carissa spinarum</i>	97	6 th	2.7	7.0
5	<i>Croton macrostachyus</i>	32	17 th	.9	8.0
6	<i>Discopodium penninervum</i>	6	23 nd	.2	8.1
7	<i>Dombeya torrid</i>	63	10 th	1.8	9.9
8	<i>Dovyalis abyssinica</i>	69	9 th	2.0	11.9
9	<i>Ekebergia capensis</i>	27	19 th	.8	12.6
10	<i>Erica arborea</i>	12	21 st	.3	13.0
11	<i>Eucalyptus globules</i>	1042	1 st	29.5	42.4
12	<i>Ficus sur</i>	4	24 th	.1	42.6
13	<i>Hagenia abyssinica</i>	15	20 th	.4	43.0
14	<i>Hypericum revolutum</i>	7	22 nd	.2	43.2
15	<i>Juniperus procera</i>	643	2 nd	18.2	61.4
16	<i>Maesa lanceolata</i>	93	6 th	2.6	64.0
17	<i>Maytenus addat</i>	86	7 th	2.4	66.4
18	<i>Maytenus arbutifolia</i>	237	4 th	6.7	73.1
19	<i>Myrsine Africana</i>	31	18 th	.9	74.0
20	<i>Myrsine melanophloeas</i>	56	12 th	1.6	75.6
21	<i>Nuxia congesta</i>	78	8 th	2.2	77.8
22	<i>Olea europaea</i>	28	19 th	.8	78.6
23	<i>Olinia rochetiana</i>	239	3 rd	6.8	85.4
24	<i>Osyris quadripartite</i>	69	11 th	2.0	87.3
25	<i>Pavetta abyssinica</i>	12	21 st	.3	87.7
26	<i>Pittosporum viridiflorum</i>	43	14 th	1.2	88.9
27	<i>Prunus Africana</i>	51	13 th	1.4	90.3
28	<i>Rhamnus staddo</i>	12	21 st	.3	90.7
29	<i>Ricinus communis</i>	31	18 th	.9	91.5
30	<i>Rosa abyssinica</i>	190	5 th	5.4	96.9
31	<i>Rubus abyssinica</i>	31	18 th	.9	97.8
32	<i>Scolopia theifolia</i>	35	15 th	1.0	98.8
33	<i>Vernonia amygdalina</i>	43	14 th	1.2	100.0
	Total	3534		100.0	

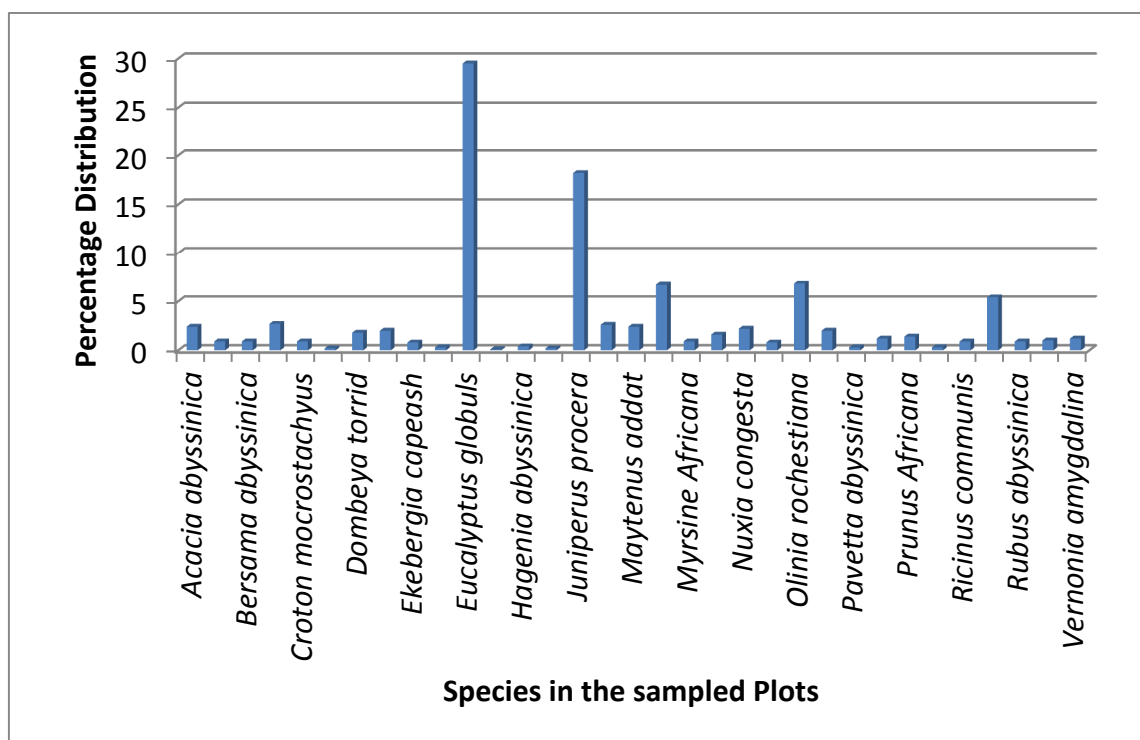


Fig. 9: Graphical Representation of Species in the sampled Plots

3.1.2. Tree/Shrub DBH

The tree/shrub DBH is classified into categorical forms for the requirement of easy analysis and understanding of the table. Accordingly, the classification includes ≤ 5 cm, 6-20cm, 21-40cm, 41-60cm, 61-100cm, 101-150cm, 151-200cm, 201-250, 251-300cm and ≥ 301 . Based on the classification made only 0.74% of the trees included in the sample have DBH ≤ 5 cm whereas, the majority i.e., about 99% of the sample trees have DBH greater than 5cm. Majority of the trees found in the sampled plot have DBH between 6-60cm, i.e., 86.36% (See table 7 and figure 10 for the detailed comparison of the tree DBH).

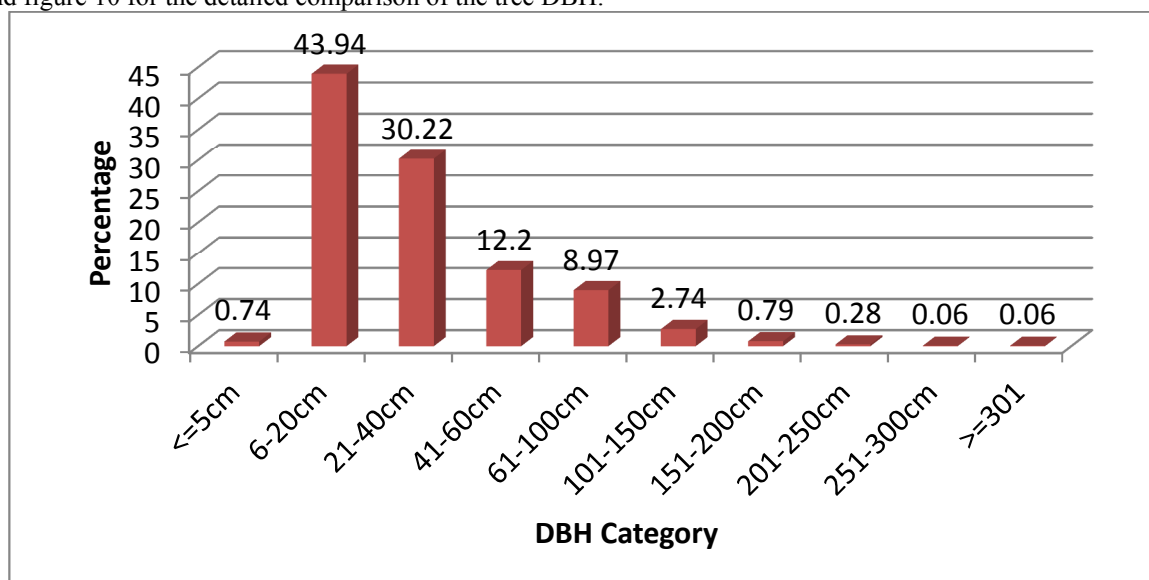


Fig. 10: Tree DBH Comparison

Concerning the comparison of tree DBH by tree/shrubs species (annex 3), species like *Eucalyptus globulus* and *Scolopia theifolia* are trees which have the highest DBH in the Garden i.e., scored greater or equal to 300cm and followed by *Juniperus procera* which lies in the DBH category of 250-300cm.

3.2. Above Ground and Below Ground Biomass

The minimum ABG biomass was 3.15t ha⁻¹ in study plot of 29 while the maximum above ground biomass was

119.85t ha⁻¹ in study site plot 11. This result was differed from previous study like Tulu Tolla (2011), in Addis Ababa by considering different churches. According to this study, 444.15t ha⁻¹ and 20.03t ha⁻¹ respectively recorded which show large difference in carbon sequestration between the two studies.

Moreover the mean above ground biomass in the Gullele Botanical Garden were 34.21t ha⁻¹. (Table 9). Generally the mean biomass values recorded in the Garden were less than the values recommended by IPCC for tropical dry forest 130.00 t ha⁻¹ (IPCC, 1997). The study result in different forest and different tree species in Ethiopia shown as age of tree increase basal area and biomass also increase (Negash Mamo *et al.*, 1995 and Negash Mamo, 2007).

According to different literature global above ground biomass in tropical dry and wet forests ranged between 30-273 t ha⁻¹ and 213- 1173 t ha⁻¹, respectively (Murphy and Lugo, 1986). Above ground biomass in Amazonian Brazil forests ranged between 290- 495 t ha⁻¹ (Alves *et al.*, 1997). In contrary, the above ground biomass reported in the present study (3.15 – 119.85t ha⁻¹) which is partially less than the range reported for various tropical dry and moist forests, mixed and old growth forests and evergreen moist tropical forests (Brown and Lugo, 1982; Brown, 1997). Moreover, the average above ground biomass in the Gullele Botanical Garden with value of 34.21 t ha⁻¹ were three fold less than the previous estimates with value of 101 t ha⁻¹ of plant biomass for forests of Ethiopia (Brown, 1997).

Table 9: Above and below ground Biomass Descriptive statistics

Statistical Description	AGB	BGB
Mean	34.21	6.84
Std. Deviation	26.16	5.23
Minimum	3.15	0.63
Maximum	119.85	23.97

Regarding biomass difference by tree species, Eucalyptus globulus, Juniperus procera, Maytenus arbutifolia, Rosa abyssinica and Olinia rochetiana respectively have the highest biomass per tree and Carissa spinarum, Discopodium penninervium, Dovyalis abyssinica, Ekebergia capensis, Erica arborea, Myrsine melanophloeas, Osyris quadripartita, Pavetta abyssinica, and Rhamnus staddo has least biomass. This indicates Eucalyptus globulus, Juniperus procera, Maytenus arbutifolia, Rosa abyssinica and Olinia rochetiana respectively sequestered highest carbon per trees while Carissa spinarum, Discopodium penninervium, Dovyalis abyssinica, Ekebergia capensis, Erica arborea, Myrsine melanophloeas, Osyris quadripartita, Pavetta abyssinica, and Rhamnus staddo did the least, due to direct relationship between biomass and carbon sequestration potential. Thus, planting trees which have more biomass plays significant role in reducing concentration of carbon dioxide in the atmosphere which is the major cause of global warming than those which sequestered.

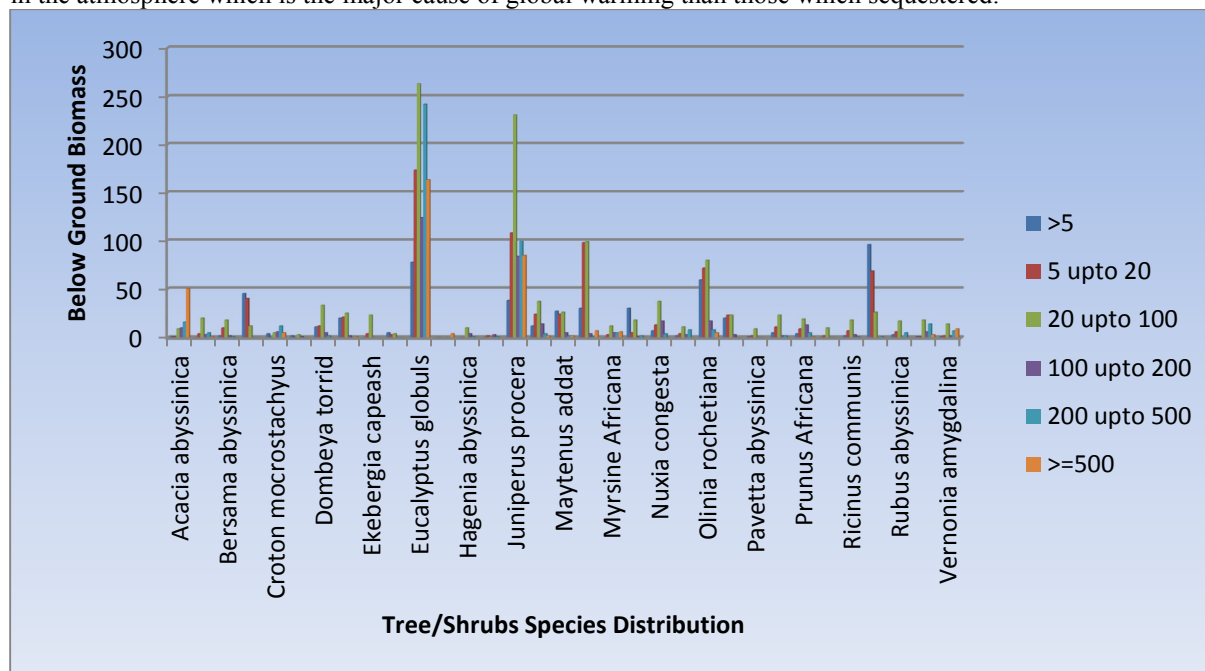


Fig. 11: Belowground biomass by tree species

3.3. Carbon stock in different pools

3.3.1. Carbon stock in the above ground biomass

The minimum carbon per tree is 0.005 tones for 10%, 8.3%, 5.8%, 4.6%, 17.9%, 8.3%, 4.3%, 3.2%, 3.1%, and 6.2% of *Rosa abyssinica*, *Pavetta abyssinica*, *Osyris quadripartita*, *Olinia rochetiana*, *Myrsine melanophloeas*, *Erica arborea*, *Dovyalis abyssinica*, *Dombeya torrida*, *Croton macrostachyus* and *Carissa spinarum* respectively, whereas, the maximum carbon per tree is 37.84 tones for 2.9% of *Scolopia theifolia*. According to the present study planting one tree could be sinking 0.56 ± 1.71 SD tones mean carbon which is significant contribution on climate change mitigation.

The maximum carbon density was 59.93 t ha^{-1} in study plot 11 while the minimum carbon was 1.57 t ha^{-1} in the sample plot of 29. The overall summations of carbon in above ground biomass in the study site were 1026.335 tones (see Annex 4). This shown as, the Botanical Garden in addition to preserving the natural resources and offering recreational services, provide environmental service by sinking mean 17.34 ± 13.14 SD t ha^{-1} carbon in the above ground biomass (see Annex 4).

In addition annex 4 shows a trend of carbon dioxide in the above ground biomass is also the same as carbon in the below ground biomass. A single study plot could be sinking at minimum carbon dioxide of 5.77 tones while at maximum plot 219.73 tones. Saving and protecting of an area of $10 * 20 \text{ m}$ (200 m^2) like the Gullele Botanical Garden from deforestation (cutting) sinks 63.59 ± 48.17 SD tones of mean carbon dioxide. Over all summations of carbon dioxide stock sequestered in the above ground biomass was 3763.23 tones. This shown significance of Botanical gardens for climate change mitigation role in addition to other environmental and social service. Generally, the Botanical Garden is characterized by higher carbon stock in the higher DBH class while very few carbon stock in the lower DBH class which is mostly associated with low planting activities from year to year.

3.3.2. Carbon Stock in Below Ground Biomass

In below ground biomass 0.00098 tones minimum and 7.57 tones maximum carbon stock were sequestered in each trees. Each tree in the study sites were captured mean 0.11 ± 0.34 SD tones of carbon stock in the below ground biomass. In the study site 0.31 t ha^{-1} minimum and 11.99 t ha^{-1} maximum carbon stock in the below ground biomass were recorded while 3.42 ± 2.62 SD t ha^{-1} mean carbon stock and 12.54 t ha^{-1} mean carbon dioxide stock in below ground biomass (See Annex 4 and Table 10). Accordingly standing trees in the study sites in addition to above ground biomass was captured significant amount of carbon stock in their roots. Over all trees in the study sites were played significant role by capturing 3763.23 and 752.64 t ha^{-1} carbon and carbon dioxide in their roots which is major causes of global warming.

Table 10: Below ground Carbon stock Description per tree

Statistics	BGC in tones per tree	BGC in t ha^{-1}
Mean	0.111572	3.4211
Std. Deviation	0.342494	2.61607
Minimum	0.00098	0.31
Maximum	7.56769	11.99

3.3.3. Carbon Stock in Dead Litter

The litter carbon concentration analyzed in the laboratory were 54.67 % maximum and 47.71% minimum per sample were recorded in study site 57 and study site 48 respectively while mean carbon concentration in each sample were 59.78 %. But this average result is above the value mentioned in different literatures like 45 % to 50 % of dry weight of litter biomass is carbon (Chan, 1982). The existing low range between the maximum and minimum carbon percentage and the very small difference among the different sample plots indicates the presence of low contamination with soil organic matter during sampling. While 1.22 t ha^{-1} minimum and 6.6 t ha^{-1} maximum carbon stocks in dead litter were recorded in sample plot 48 and 43 respectively while mean carbon stock in dead litter were 3.11 t ha^{-1} (see Table 11). The mean value were higher than the values cited in IPCC, (2006) while carbon in dead litter pool was 2.1 t ha^{-1} for tropical dry forests and 49 t ha^{-1} for moist boreal broad leaf forests.

Dead litter fall in tropical and sub-tropical forests in Puerto Rico ranged between $3.1-8.61 \text{ t ha}^{-1}$ (Weaver and Murphy, 1990). In a related study, dead litter fall ranged between $4.88- 6.71 \text{ t ha}^{-1}$ in a dry forest in India (Singh and Singh, 1991) and between $3-10 \text{ t ha}^{-1}$ for a variety of dry tropical forests (Murphy and Lugo, 1986b) while dead litter biomass in the present study ranged between 2.46 to 43.56 t ha^{-1} . This might be due to more litter drop and makes this value differ from other tropical forests. The carbon in dead litter biomass also the same trend as biomass.

3.3.4. Soil Organic Carbon

The laboratory result shown as 0.3% minimum and 12.6% maximum soil organic carbon concentration were recorded in study plot 48 and 22 respectively. Soil organic matter is the same trend as soil organic carbon (Table 12). Accordingly these values were coinciding with the literature result recommended for soil organic carbon

concentration.

In the study sites in 0.30 cm depth mineral soils 121.49 t ha⁻¹ maximum and 2.67 t ha⁻¹ minimum value carbon stocks were recorded in study plot 32 and 3 respectively (annex 5 and table 12). This shown as forests in the study sites in addition to AGB, BGB and DL were captured 37.26± 19.66t ha⁻¹ mean carbon stock in soils. This product is found between the results affirmed by Tulu (2011) i.e., 135.94 ± 21.26SD t ha⁻¹ mean carbon stock in soils. Both studies, indicates mean carbon captured in the soil pool was relatively greater than the other pools. Moreover CO₂ equivalent valves showed the same trend as soil organic carbon which was 445.45t ha⁻¹ maximum at sample plot 32 and 9.79t ha⁻¹ minimum at sample plot 3.

Table 12: Statistical summary of Soil Carbon

Statistical Description	SOC T Ha ⁻¹	Soil CO ₂ T Ha ⁻¹
Mean	37.2608	136.6187
Std. Deviation	19.65541	72.06922
Minimum	2.67	9.79
Maximum	121.49	445.45

4.3.5. Comparison of Carbon Stock in Different Pools

As the results of the current study show, the lowest carbon stock is found in dead litter pool while the highest carbon stock found in soil pool. Though the percentages of carbon in each pool are not uniform, the overall proportion of carbon in different pools were as follows: soil pool 61.19%, above ground biomass pool 28.09 %, below ground biomass pool 5.62 % and dead litter pool 5.10 %, see table 13, figure 12 and figure 13 below for the comparison of different carbon pools in the Gullele Botanic Garden. This result relatively goes with previous study done by Tulu Tolla (2011) in Addis Ababa churches with the overall proportion of carbon in different pool i.e., soil pool 43.91%, above ground biomass pool 41.94 %, below ground biomass pool 8.39 % and dead litter pool 5.76 %. Thus, the highest carbon stocks were captured in the mineral soil pool, which is in conformity with the already established knowledge. i.e., the maximum Carbon was captured by soil than any other pools of carbons.

Table 13: Comparison of Carbon Stock in Different Pools

Carbon pools		AGC THA -1	BGC THA -1	CDL THA -1	SOC THA -1	Total
	count	1026.34	205.27	186.35	2235.57	3653.52
	%	28.09	5.62	5.10	61.19	100.00

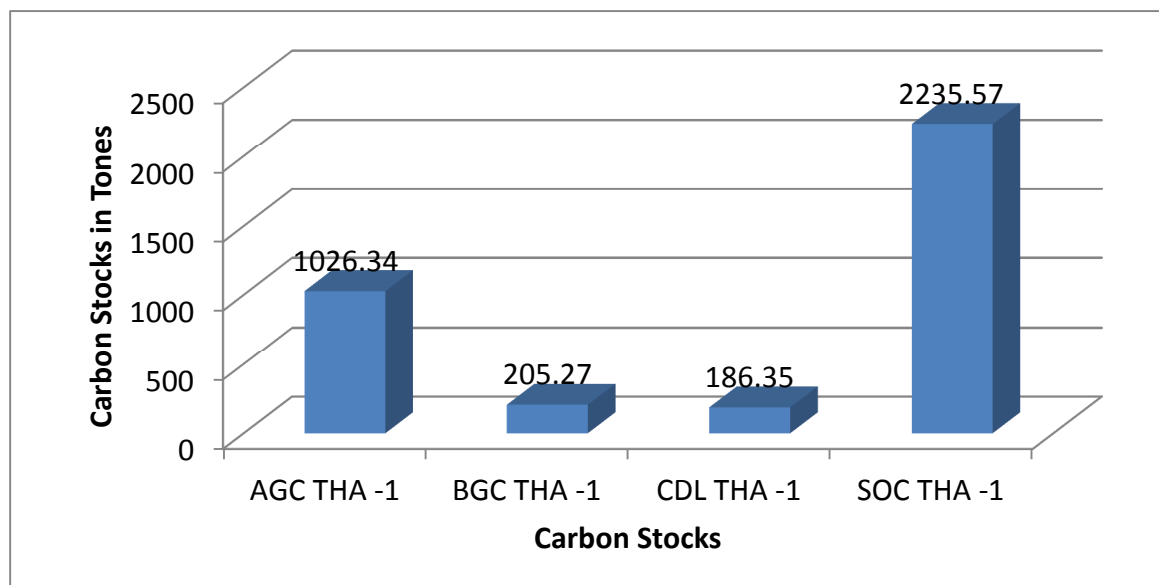


Fig.12: Graphical Comparison of Different Carbon pools

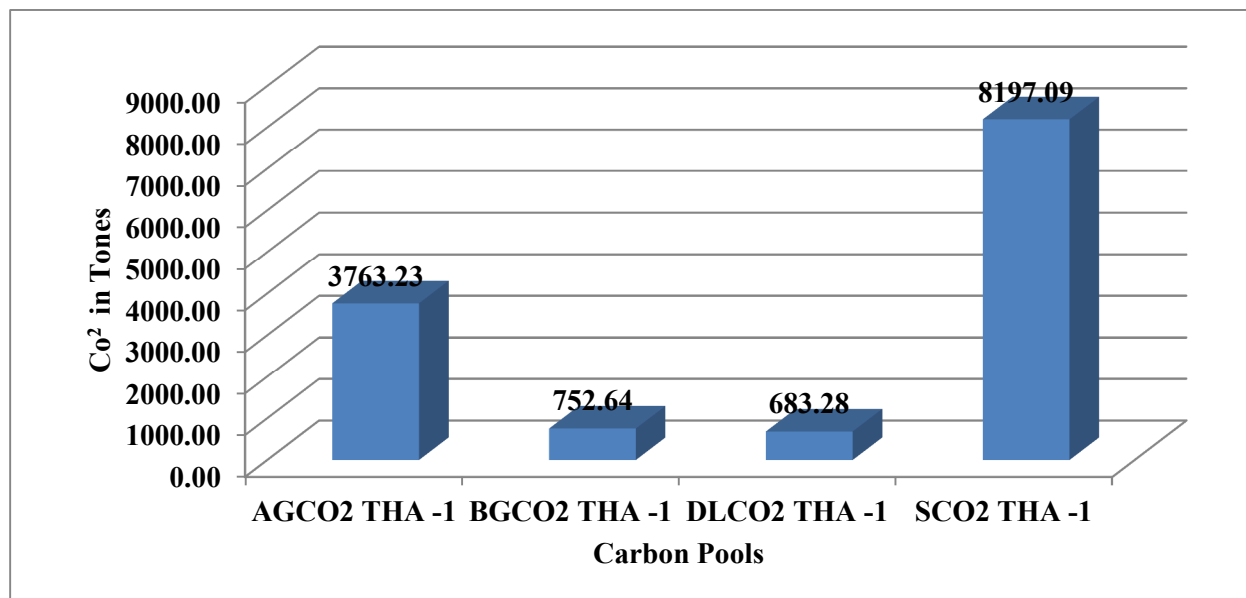


Fig.13: Graphical Comparison of Different CO₂ Sinks

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

On the basis of the findings of the study the following conclusions were made. As we all knows in Botanical Garden plants are grown and displayed primarily for scientific and educational purposes. A botanical garden consists chiefly of a collection of living plants, grown out-of-doors or under glass in greenhouses and conservatories. Accordingly, the Gullele Botanical Garden played a significant role in reducing carbon emission from the atmosphere in addition its above mentioned purposes. For example, the current study sequestered minimum carbon per tree is 0.005 tones for 10%, 8.3%, 5.8%, 4.6%, 17.9%, 8.3%, 4.3%, 3.2%, 3.1%, and 6.2% of *Rose Abyssinica*, *Pavetta Abyssinica*, *Osyris Quadripartia*, *Olinia Rochestiana*, *Myrsine Melanophloeas*, *Erica Arborea*, *Dovyalis Abyssinica*, *Dombeya Torrida*, *Croton Mocrostachyus* and *Carissa Spinarum* respectively, Whereas, the maximum carbon per tree is 37.84 tones for 2.9% of *Eucalyptus globules* and *Juniperus procera*. This indicates planting one tree could be sinking 0.56 ± 1.71 SD tones mean carbon which is significant contribution on climate change mitigation. In other wards the study area sequestered mean carbon 17.34 ± 13.14 SDt ha⁻¹ in the above ground biomass i.e., a single study plot could be sinking at minimum carbon dioxide of 5.77 tones while at maximum 219.73tones. From this the researcher concludes, Saving and protecting of an area of 10 *20m (200M²) like the Gullele Botanical Garden from deforestation (cutting) sinks 63.59 ± 48.17 SD tones of mean carbon dioxide from the atmosphere.

Carbon Stock in Below Ground Biomass in Gullele Botanical Garden sequestered 0.00098 tones minimum and 7.5677 tones maximum carbon stock per tree, i.e., each tree in the study sites were captured mean 0.11 ± 0.34 SD tones of carbon stock. In addition $0.31t$ ha⁻¹ minimum and $11.99t$ ha⁻¹ maximum carbon stock were sequestered in the below ground biomass i.e., 3.42 ± 2.62 SD t ha⁻¹ mean carbon stock and $12.54t$ ha⁻¹ mean carbon dioxide stock in below ground biomasses were sequestered.

In addition, the litter carbon concentration analyzed in the laboratory were 54.67 % maximum and 47.71% minimum per sample were recorded in study site 48 and study site 57 respectively while mean carbon concentration in each sample were 59.78 %. But this average result is above the value mentioned in different literatures like 45 % to 50 % of dry weight of litter biomass is carbon (Chan, 1982). The existing low range between the maximum and minimum carbon percentage and the very small difference among the different sample plots indicates the presence of low contamination with soil organic matter during sampling, with $3.11t$ ha⁻¹ mean carbon stock. The mean values were higher than the values cited in IPCC (2006) i.e., carbon in dead litter pool was $2.1t$ ha⁻¹ for tropical dry forests and $49 t$ ha⁻¹ for moist boreal broad leaf forests.

Concerning the Soil Organic Carbon, the laboratory result had shown 0.3% minimum and 12.6% maximum soil organic carbon, while $121.49 t$ ha⁻¹ maximum and $2.67 t$ ha⁻¹ minimum value carbon stocks were recorded. Accordingly, $37.2608 \pm 19.65541t$ ha⁻¹ mean carbon stock Captured in soils, this indicates mean carbon captured in the soil pool was relatively greater than the other pools. Moreover CO₂ equivalent values showed the same trend as soil organic carbon which was $445.45t$ ha⁻¹ maximum and $9.79t$ ha⁻¹ minimum value sequestered in the soils. Comparatively, the lowest carbon stock is found in dead litter pool while the highest carbon stock found in soil pool i.e., soil pool 61.19%, above ground biomass pool 28.09 %, below ground

biomass pool 5.62 % and dead litter pool 5.10 % which is in conformity with the already established knowledge.

Furthermore, the Gullele Botanic Garden dominated by Exotic tree species like *Eucalyptus globulus* though played a significant role in carbon sequestration as they grow faster and has more basal area than the others. In addition indigenous species like *Juniperus procera* have a paramount importance in sequestering carbons in the Garden.

Generally, the study concludes Undertaking different studies considering such issues have supreme importance for carbon trade, climate change mitigation and fund attraction. Thus, intensifying this indigenous knowledge for biodiversity conservation, climate change mitigation and urban greening option is very important.

5.2. Recommendation

On the basis of the study of the findings and conclusion made, the following recommendations are forwarded.

- ❖ The study result reveals aboveground biomass found in the Gullele Botanic Garden are sparsely distributed, therefore, more tasks should be given to plant trees of indigenous species to compromise the current dominance of exotic species.
- ❖ Considering such Botanic Garden and other reserved places for *in-situ* and *ex-situ* biodiversity conservation is very important and it may be a successes full activity.
- ❖ In urban like, Addis Ababa, which lack sufficient urban green area, treating such botanical garden forests as urban greening should be empowered.
- ❖ To extend the scientific knowledge on the issue different studies (researches) should be strengthened and motivated by concerned institutions.
- ❖ As discussed in the analysis part the lower part of the garden, i.e., areas close to the city were exposed to different deforestation and un wise use of the reserved resources, thus measures should be undertaken to reduce the current burden so to sustainably use the resources in the future.
- ❖ Undertaking different studies which help the preservation of natural resources and have an impact for carbon trade, climate change mitigation and fund attraction should be empowered.

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