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COMPARATIVE METHODS OF BIOMASS AND CARBON STOCK ASSESSMENT OF SOME SELECTED TREE SPECIES USED FOR CHARCOAL PRODUCTION IN THE GUINEA SAVANNA ECOLOGICAL ZONE OF NIGERIA

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ABSTRACT

Non-destructive method of above-ground biomass (AGB) and carbon stock assessment is the most frequently used method to quantify the amount of carbon sequestered by the trees/vegetation because it involves assessing the biomass and carbon without cutting down the tree species. However, to validate the claim of the biomass and carbon stock

Introduction

Carbons exist as carbon dioxide in the atmosphere and constitute a very small percentage of about 0.04%. However, it plays an important role in supporting life on earth, as plants are making use of it (Vashum and Jayakumar, 2012). In terrestrial ecosystems, the living biomass of trees, the understorey vegetation and the dead wood (standing and fallen), woody debris and soil organic matter constitute the main carbon pool. According to Eggleston *et al.*, (2006), there are five carbon pools in the terrestrial ecosystems involving biomass namely; the above-ground biomass; below-ground biomass; dead mass of litter; dead wood and soil organic matter.

of the non-destructive method, the destructive method must be employed to ascertain the real biomass and carbon stock by harvesting the tree species. This study incorporated both the destructive and non-destructive biomass and carbon stock assessment methods. The results of the independent t-test ($t = 3.351$, $p = 0.00475$) between the two methods revealed that the destructive method had higher biomass ($M=0.425$, $SD=0.14313$) than the non-destructive method ($M=0.2338$, $SD=0.07463$) at an alpha value of 0.05. The ANOVA among the tree species harvested for charcoal production further revealed a significant difference in the mean biomass, where *Vitellaria paradoxa* and *Parkia biglobosa* had the highest. At the same time, *Pterocarpus erinaceus* and *Daniellia oliveri* recorded the least biomass and carbon stock of the tree species used for charcoal production in the study area.

Keywords: Aboveground Biomass; Tree Species; Charcoal; Destructive and Non-Destructive Methods

The CO_2 fixed by plants during photosynthesis is transferred across the different carbon pools. When these plants or trees die or burnt, the carbon stored in them are released back into the atmosphere. This natural cycling of the carbon is maintained and controlled by a dynamic balance between biological and inorganic processes since the geological history of earth (Vashum and Jayakumar, 2012). The above-ground biomass of trees is mainly the largest carbon pool and it is the most important and visible carbon pool of terrestrial ecosystem (Ravindranath and Ostwald, 2008). Generally, the estimated biomass components are the above-ground live biomass which includes the trees and the shrubs excluding the roots, dead above-ground biomass like litters and fallen branches and the below-ground biomass which comprises the roots.

The change in the forest areas and the changes in forest biomass due to management and re-growth greatly influence the transfer of carbon between the terrestrial ecosystem and the atmosphere (Houghton, 2005). Hence, estimating the forest carbon stocks is mainly important to assess the magnitude of carbon exchange between the forest ecosystem and the atmosphere. Assessment of the amount of carbon sequestered by a forest will give us an estimate of the amount of carbon emitted into the atmosphere when this particular forest area is deforested or degraded. Furthermore, it will help us to quantify the carbon stocks which in turn will enable us to understand the current status of carbon stocks and also derive the near-future changes in the carbon stocks (Gibbs *et al*., 2007; Houghton, 2005). Though savanna tree species are often scattered crooked and bend they equally (like all other woody tree species) constituted a great biomass of terrestrial ecosystem and store a significant amount of carbon. Most of the studies on tree biomass and carbon stock assessment often neglect savanna region concentrating more on forest areas and plantation. As such, information on savanna vegetation such as volume, biomass composition, carbon sequestration capacity is very scanty. There is a growing demand for reliable information on forest and tree carbon stock at both country and global levels. This requires transparent and verifiable methods, quantification of uncertainties and appropriate monitoring systems for carbon stocks. The objectives of this study were to estimate the biomass and carbon stock of some savanna tree species used for charcoal production using both destructive and non-destructive method.

Study Area

This study was carried out in Guinea savanna of Moro Local government area of Kwara State, situated between latitudes 8°20′ N and 8°50′ N and Longitudes 4°25′ E and 4°65′E (figure 1) with a tropical wet and dry climate and average yearly rainfall of about 1200 mm. Its mean annual temperature is about 26.2 °C; which peaks at about 30 °C in the month of March and about 45% humidity. Wet season is generally experienced between April and October and dry season between November and March. April is the warmest month and December has the lowest average temperature of about 22.5°C with an average of 264 mm.

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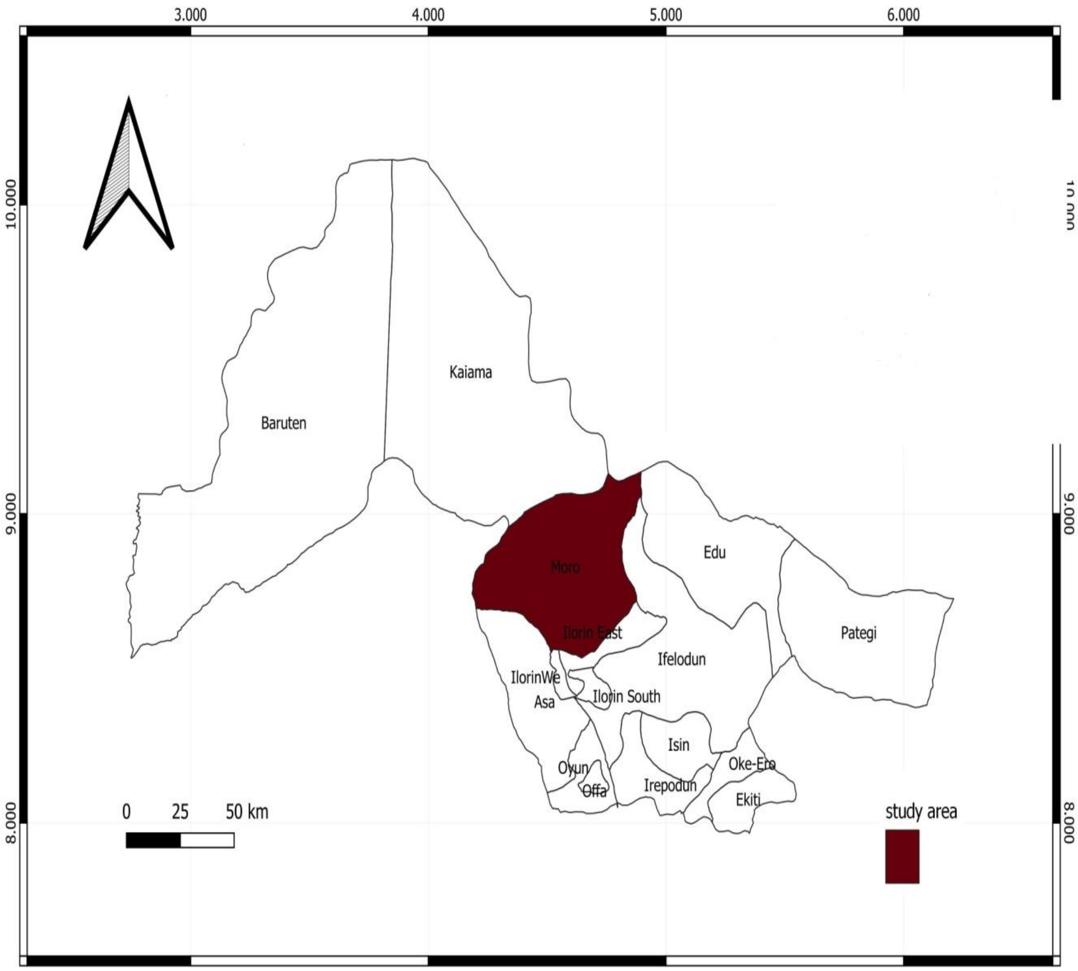

Figure1: Map of Kwara State showing the study area

Field sampling design

Destructive and non-destructive methods of sampling were employed. For the destructive method, since it involved complete cutting down of trees, Charcoal producers in the study areas were contacted to take advantage of the time of their charcoal production (they usually obtain permit from management). The non-destructive method, which involved measurements without cutting the tree, was employed, where all the tree variables were measured using spegiel relascope and diameter tape and core samples were also taken to determine wood density by the use of increment borer.

Non-destructive method

Diameter at base (db) and diameter at breast height (dbh) were measured with Diameter tape while diameter at middle (dm), diameter at top (dt) and total height of the potential charcoal trees marked for felling by the charcoal producers were measured using Spiegel relascope (Plate 2). For the destructive method of biomass estimation, other tree variables such as length of stem, diameter at base, middle and top were measured with diameter tape for more precision after tree felling. A core sample of the trees was extracted using an Increment borer at 1.3m (dbh) of the tree bole. The length of the core extracted was measured in centimeters; the diameter of the core was obtained using the diameter of the increment borer (0.4cm) used for the extraction. The samples were taken to the laboratory for oven-drying to obtain dry weight of the core samples.

Destructive method

The felled trees were de-branched to obtain a clean bole. Each bole was then cross-cut into sizeable length to enhance weighing on the weighing scale on the field (Plate 3). Fresh weight of the clear stem, all branches and all foliage were obtained right on the field (fresh weight) using a 150kg weighing balance (Plate 1). Sample of discs from the stem (g), sample of branch (g) and sample of foliage (g) were collected and weighed using portable 5kg weighing balance (Plate 4). The discs and the samples of the branches and leaves were taken to the laboratory for oven drying. Discs and branch samples were dried at 103±2 ^{o}C until constant weight was attained, while foliage samples were dried at 65 ^{o}C (Tella and Fuwape, 2005). Using the ratio of fresh weights to dry weights of the discs, ($\frac{dw.sd}{fw.sd}$ x fw.cs) the bole fresh weight would be then converted into dry weights (Fuwape and Akindele, 1997). Likewise the dry weight of branch and foliage were determined through the same method.

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Data Analysis

Non-destructive method of biomass and carbon stock assessment

An Independent samples students'- t test was conducted to compare the means values of non-destructive and destructive methods of biomass and carbon stock assessment.

Tree volume

The volume of the trees was estimated by the use of Newton's formula, as described by Adekunle *et al.* (2013).

$$V = h\left(\frac{Ab+4Am+At}{6}\right) \; or \; \frac{h\pi}{24}(D^2_b+4D^2_m+D^2_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

V= volume of tree (m^3)

h = height (m)

Ab = area at base (m^2)

Am = area at middle (m^2)

At = area at top (m^2)

Db= diameter at base (cm)

Dm = diameter at middle (cm)

Dt = diameter at top (cm)

Volume of core sample

Since the shape of the core sample is cylindrical in nature, equation (2) below was therefore used to estimate the volume of the core samples

$$V_s = \frac{\pi d_s^2}{4} l \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where;

d_s =diameter of the core sample, (cm)

l =length of the core sample, (cm)

V_s = volume of the core sample (cm^3)

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Density of the core sample

The density of the core sample was obtained by dividing the dry weight (mass) of the sample with the volume of the core sample obtained

$$D_{cs} = \frac{mass}{vol.} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where;

D_{cs} = density of the core sample, (g/cm^3)

mass = dry weight of the core sample, (g)

vol_{cs}= volume of the core sample, (cm^3)

Tree species density

This was obtained by dividing the values with a conversion factor of$\left(\frac{1}{1000}\right)$. That means that, the density of core sample in g/cm3 was converted to tree density in kg/m3 by multiplying it with 1000.

Biomass and carbon stock

The biomass of tree was obtained after all the water has been removed through oven drying (dry matter). The biomass of the tree species was then computed by the formula in equation 4

$$Biomass_{tree} = desity_{tree} \times vol_{tree} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Since the carbon constituted about 50% of dry matter (biomass), the carbon stock was computed by multiplying the biomass obtained with 0.5 or dividing the biomass with 2 as in the equation 5 (Akindele, 2022)

$$Carbon\ stock_{tree} = Biomass_{tree} \times 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The total carbon stock was then converted to tons of CO_2 equivalent by multiplying it with the molecular weight of carbon and oxygen (44/12) or 3.67 as shown in equation 6 (Pearson *et al.*, 2007).

$$CO_2 \text{ equiv.} = \text{Carbon stock}_{tree} \times \frac{44}{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Destructive method of biomass and carbon stock assessment

Analysis of variance (ANOVA) was performed to check the significance difference in total biomass and carbon stock among the four savanna regions using R statistical software. An Independent samples students'- t test was also conducted to compare the means values of destructive and non-destructive methods of biomass and carbon stock assessment. The following variables of destructive method were computed.

Stem biomass

To compute the dry weight of a stem, a ratio of dry to wet (fresh) weight of sample disc were used. This was calculated by dividing dry weight with wet weight of the sample disc gotten from the tree stem and then multiplies it by the weight of the clear stem obtained in the field.

$$\text{Dry weight of stem (biomass)} = \frac{dw.sd}{fw.sd} \times fw.cs \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where; dw.sd = dry weight of sample disc (g)
fw.sd = fresh weight of sample disc (g)
fw.cs = fresh weight of clear stem (kg)

Branch biomass

To compute the dry weight of a branch, a ratio of dry to wet (fresh) weight of sample branch was used. This was obtained by dividing dry weight with wet weight of the sample branch gotten and then multiplies it by the weight of all branches obtained in the field.

$$\text{Dry weight of branch (biomass)} = \frac{dw.sb}{fw.sb} \times fw.ab \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where; dw.sb = dry weight of sample branch (g)
fw.sb = fresh weight of sample branch (g)
fw.ab = fresh weight of all branches (kg)

Foliage biomass

The dry weight of foliage (biomass) was also computed by the ratio of dry to wet (fresh) weight of sample foliage. The ratio obtained was then multiplied by the weight of all foliage obtained in the field.

Dry weight of foliage (biomass) = $\frac{dw.sf}{fw.sf}$ x fw.af…………………………………….. (9)

Where; dw.sf = dry weight of sample foliage (g)

fw.sf = fresh weight of sample foliage (g)

fw.af = fresh weight of all foliage (kg)

Total tree biomass

Total dry weights of the tree components (stem, branch and foliage) were sum up together to formed the total biomass of a tree.

Tree biomass = $\frac{dw.sd}{fw.sd}$ x fw.cs + $\frac{dw.sb}{fw.sb}$ x fw.ab + $\frac{dw.sf}{fw.sf}$ x fw.af ……………….(10)

Where; dw.sd = dry weight of sample disc (g)

fw.sd = fresh weight of sample disc (g)

fw.cs = fresh weight of clear stem (kg)

dw.sb = dry weight of sample branch (g)

fw.sb = fresh weight of sample branch (g)

fw.ab = fresh weight of all branches (kg)

dw.sf = dry weight of sample foliage (g)

fw.sf = fresh weight of sample foliage (g)

fw.af = fresh weight of all foliage (kg)

Carbon stock

Since the carbon constituted about 50% of a dry matter (biomass), the carbon stock was computed by multiplying the biomass obtained with 0.5 or dividing the biomass with 2, thus

Carbon $stock_{tree}$ = $Biomass_{tree}$ x 0.5…………………………………………… (11)

The total carbon stock was then converted to tons of CO_2 equivalent by multiplying it with the molecular weight of carbon and oxygen (44/12) or 3.67 (Hauchhum, 2017).

$$CO_2 \text{ equiv.} = \text{Carbon stock}_{tree} \times \frac{44}{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

RESULTS

Biomass and carbon stock assessment of non-destructive method

The biomass and carbon stock of some selected tree species were assessed. The summary of tree measurements of twenty (20) tree species selected were presented in Table 1. The wood densities of the selected tree species for the charcoal production was also assessed and presented in Table 2. The results revealed that there are 1.88 tons of biomass and 0.94 tons of carbon stock from the 20 selected tree species (Table 6).

Table 1: Summary of tree measurement data from non-destructive sampling

Tree species	F	Mean Dbh (cm)	Mean H(m)	Mean Den. (kg/m³)	Mean Vol. (m³)
Anogeissus leiocarpus	2	24.53	8.75	860	0.11
Burkea Africana	3	24.77	10.21	830	0.11
Daniellia oliveri	3	26.24	9.75	640	0.14
Parkia biglobosa	2	27.71	9.88	760	0.16
Prosopis Africana	3	28.21	10.93	820	0.15
Pterocarpus erinaceus	2	27.42	8.40	710	0.14
Syzygium guineense	3	25.78	10.23	640	0.13
Vitellaria paradoxa	2	27.44	9.56	860	0.13
Sub total	**20**				

Table 2: Wood densities used for biomass estimation

Tree species	Wood den. (g/cm^3)	Wood den. (kg/m^3)	Source
Anogeissus leiocarpus	0.86	860	Field survey, 2021/2022
Burkea Africana	0.83	830	Field survey, 2021/2022
Daniellia oliveri	0.64	640	Field survey, 2021/2022
Parkia biglobosa	0.76	760	Field survey, 2021/2022
Prosopis Africana	0.82	820	Field survey, 2021/2022
Pterocarpus erinaceus	0.71	710	Field survey, 2021/2022
Syzygium guineense	0.64	640	Field survey, 2021/2022
Vitellaria paradoxa	0.86	860	Field survey, 2021/2022

Table 3: Mean biomass of tree species of non-destructive method

Tree species	Biomass
Prosopis Africana	120.63[a]
Parkia biglobosa	119.50[a]
Vitellaria paradoxa	108.90[ab]
Pterocarpus erinaceus	97.03[abc]
Anogeissus leiocarpus	91.83[bc]
Burkea Africana	89.58[bc]
Daniellia oliveri	87.76[bc]

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Syzygium guinenses	81.12[c]

Means followed by same letter(s) are not significantly different at 0.05 level of significance

Biomass and Carbon Stock Assessment of Destructive Method

Twenty (20) selected tree species were harvested, the biomass and carbon stock were assessed. The summary of tree measurements of the twenty (20) tree species selected was presented in Table 4. The results revealed 3.44 tons of biomass and 1.72 tons of carbon stock from the 20 harvested tree species (Table 6 and Figure 2).

Table 4: Summary of tree measurement data from destructive sampling

Species	F	Mean Dbh (cm)	Mean H(m)	Mean weight Stem (kg)	Mean weight branch (kg)	Mean weight foliage (kg)
Anogeissus leiocarpus	2	24.53	8.75	276.20	226.90	24.60
Burkea africana	3	24.77	10.21	456.20	413.30	33.50
Daniellia oliveri	3	26.24	9.75	390.30	299.20	57.90
Parkia biglobosa	2	27.71	9.88	351.90	404.70	65.00
Prosopis africana	3	28.21	10.93	566.20	437.30	78.60
Pterocarpus erinaceus	2	27.42	8.40	246.80	210.80	18.00
Syzygium guineense	3	25.78	10.23	484.90	359.50	106.80
Vitellaria paradoxa	2	27.44	9.56	360.00	328.80	117.00
Sub total	**20**					

Table 5: Mean biomass of tree species of destructive method

Tree species	Biomass
Vitellaria paradoxa	213.39[a]
Parkia biglobosa	207.97[a]

Prosopis africana	200.56[ab]
Burkea Africana	198.29[ab]
Syzygium guinenses	155.89[bc]
Anogeissus leiocarpus	154.78[bc]
Pterocarpus erinaceus	148.66[c]
Daniellia oliveri	141.54[c]

Means followed by same letter(s) are not significantly different at 0.05 level of significance

Table 6: Biomass and carbon stock estimates of destructive and non-destructive methods

Selected tree species	F				Destructive method		Non-destructive method	
		Mean dbh (cm)	Mean H(m)	Stem length (m)	Total biomass (t)	Total C.S. (t)	Total biomass (t)	Total C.S. (t)
Anogeissus leiocarpus	2	24.53	8.75	2.75	0.31	0.15	0.18	0.09
Burkea Africana	3	24.77	10.21	3.10	0.59	0.30	0.27	0.13
Daniellia oliveri	3	26.24	9.75	2.97	0.42	0.21	0.26	0.13
Parkia biglobosa	2	27.71	9.88	2.85	0.42	0.21	0.24	0.12
Prosopis africana	3	28.21	10.93	2.87	0.60	0.30	0.36	0.18
Pterocarpus erinaceus	2	27.42	8.40	3.10	0.30	0.15	0.19	0.10

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Syzygium guineense	3	25.78	10.23	2.93	0.47	0.23	0.24	0.12
Vitellaria paradoxa	2	27.44	9.56	2.60	0.43	0.22	0.22	0.11
Sub total	**20**				**3.41**	**1.71**	**1.88**	**0.94**

DISCUSSION

Biomass and carbon stock of the selected tree species of non-destructive method

The biomass of the twenty (20) selected tree species used for the charcoal production was assessed through destructive and non-destructive methods. The results revealed the above ground biomass of 3.45 tons and 1.88 tons of destructive and non-destructive methods respectively from the 20 selected tree species. The analysis of variance (ANOVA) of non-destructive method revealed that, there is significant difference among the biomass of the tree species. *Prosopis africana* and *Parkia biglobosa* were ranked first ($p > 0.05$), followed by *Vitellaria paradoxa*, while *Syzygium guinenses* recorded the least biomass and carbon stock (table 3). This is evident because the height, diameter at breast height (dbh) and basal area of the stated trees were relatively higher compared to those that that recorded the least the biomass. Agboola *et al.* (2021) reported a total biomass of 277,047 kg in the neighboring rainforest of Oyo State where they encountered 89 tree species from the 6 plots (25m x 25m). A number of tree species encountered by Agboola *et al.* (2021) were also part of the tree species selected for this research. The aboveground carbon stock range of 98.67–555.96 Mg C ha^{-1} were also reported by Agboola (2021). Though, the value of carbon stock obtained in this research was based on individuals' trees not per plot or hectare (plot less), corresponded to this, if the carbon stock were to be reported per tree basis.

Okoh *et al.* (2019) reported carbon stock of litter production of four tree species of guinea savanna, *M. lucida* had the highest sequestered carbon in litter fall and litter biomass (0.607; 1.107 tones m^{-2} y^{-1}), while *Prosopis africana* had the lowest (0.113; 0.116 tones $m^{-2}y^{-1}$. This results is similar to 0.02 tC (though not per m^2) of *Prosopis africana* obtained in this research.

The results from Ibrahim *et al.* (2018) on carbon contents of wood and bark of some tropical tree species indicated that *Khaya senegalensis* had 49.5% and 44.77% total carbon content of the bark and wood respectively. This is similar to what is obtained by this research where *Khaya senegalensis* recorded a total carbon of 0.07 tC.

Biomass and carbon stock of the selected tree species of destructive method

The biomass of the selected tree species used for charcoal production was assessed using destructive method of assessment. The analysis of variance (ANOVA) of destructive method revealed that, there is significant difference among the biomass of the tree species. *Vitellaria paradoxa* and *Parkia biglobosa* were ranked first (p> 0.05), followed by *Prosopis africana* and *Burkea africana* whereas *Pterocarpus erinaceus* and *Daniellia oliveri* recorded the least biomass (Table 5).

Odiwe *at al.* (2017) reported above ground biomass in a neighboring State (Osun), of 5 tree species with *Celtis zenkeri* (985.58±88.99 kg) having the highest aboveground biomass than other four species studied. Chave *et al.* (2014) reported values varying from 291.8 to 559.7 M ha-1 in pan tropical forest.

Difference between destructive and non-destructive methods of biomass assessment

The independent samples t-test was used to evaluate the differences between the two methods. The biomass of the destructive method (M=0.425, SD=0.14313) compared to the non-destructive method of the 8 tree species (M=0.2338, SD=0.07463) demonstrated a significant score t = 3.351, p =

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0.00475. Since the p value is less than the alpha value (0.05), it is therefore significant. The difference in means between group *destructive method* and group *non-destructive method* is not equal to 0. Therefore, there is significant difference of biomass of the two methods of assessments. The destructive method revealed higher biomass than the non-destructive method of biomass and carbon stock assessment.

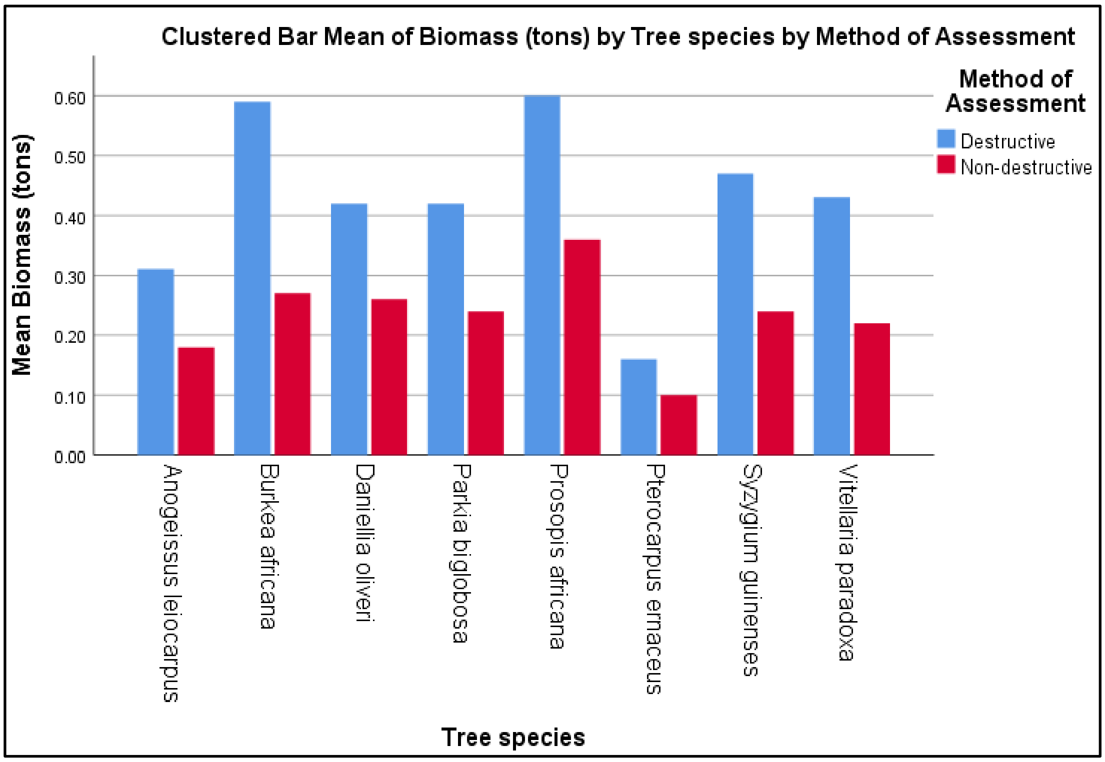

Figure 2: Biomass of Destructive and Non-destructive Methods among the tree species

Conclusion and Recommendation

Biomass and carbon stock assessment is one of the most widely used method to quantify the amount of carbon sequestered by trees/vegetation. The two most widely used methods (destructive and non-destructive methods) were compared. The results shows that the destructive method yield more biomass and carbon stock than the non-destructive method. This is evident because the destructive method take into account all the tree components (stem, branch and foliage) in assessing the biomass content whereas the non-destructive method only assess the biomass of the tree stem. Furthermore, the results of the ANOVA among the tree species harvested for charcoal production revealed a significance difference in the mean biomass, where *Vitellaria paradoxa* and *Parkia biglobosa* had highest while *Pterocarpus erinaceus* and *Daniellia oliveri* recorded the least biomass and carbon stock among the tree species used for charcoal production in the study area.

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Appendix 1: ANOVA tables for the destructive and non-destructive method

Non-destructive method

Source of variation	Df		Sum of Squares	Mean Square	F	Sig.
Tree species	7		4152.25	593.178	4.3	.013*
Error	12		1655.24	137.937		
Total	19		5807.49			

Destructive method

Source of Variation	df		Sum of Squares	Mean Square	F	Sig.
Tree species	7		15293.6	2184.8	4.439	.012*
Error	12		5906.77	492.23		
Total	19		21200.4			

Plate 1: Destructive method: weighing of tree branches

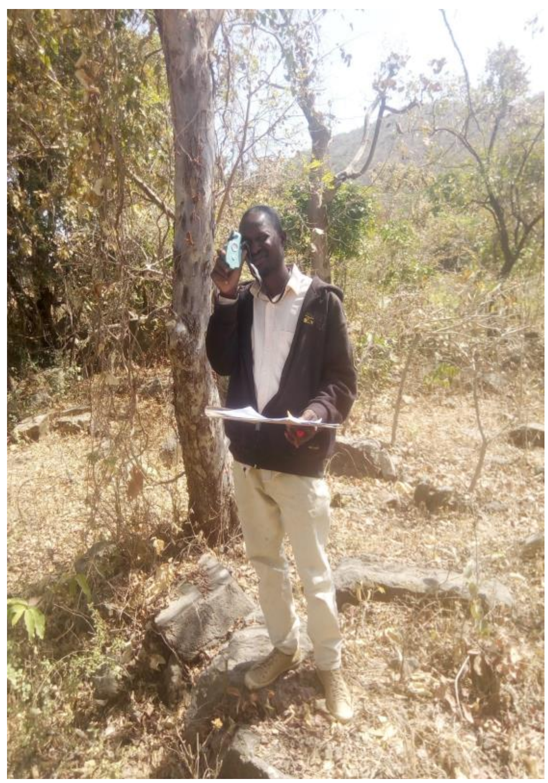

Plate 2: Non-destructive method: measurement of tree height

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Plate 3: Destructive method: weighing of tree stem

Plate 4: Oven drying and weighing of disc, branches and foliage sample