UMYU Scientifica, Vol. 3 NO. 2, June 2024, Pp 224 – 235
https://doi.org/10.56919/usci.2432.024
ISSN: 2955 – 1145 (print); 2955 – 1153 (online)
A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina

ORIGINAL RESEARCH ARTICLE

Quantifying Carbon Sequestration in Woody Trees of Makurdi Zoological Garden, Benue State, Nigeria: A Non-Destructive Approach

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ABSTRACT
Carbon emissions and reflection are some of the most significant and urgent environmental problems in the world today due to climate change, and because of their ability to sequester Carbon, trees significantly reduce the amount of carbon dioxide in the atmosphere. This study used a non-destructive method to evaluate the capacity of twenty-seven species of woody trees from 16 distinct families to sequester Carbon in Makurdi Zoological Garden in Benue State. A girt measuring tape was used to measure DBH (diameter at breast heights) at 1.3 meters above ground, a haga altimeter was utilized in measuring the Height of trees and the estimation of AGB (above-ground biomass) was performed using the pantropical allometric equation. The results indicated that the twenty-seven tree species under study yielded 1512.7 tons/ha and 302.5 tons/ha of AGB and BGB, respectively. Additionally, 756.6 and 151.29 tons/ha for AGC and BGC were recorded, respectively. Poisson regression analysis shows significant deviance among the parameters studied ($p \leq 0.005$), Pearson correlation analysis shows strong positive correlations (1.000) between total Carbon sequestered and total ground Carbon, total ground Carbon, total below-ground Biomass and total above-ground Biomass, among others, and cluster analysis revealed 8 distinct clusters. This investigation showed how much carbon woody trees sequester and highlighted the importance of measuring the amount of Carbon stored by woody trees regularly, as this allows one to calculate the amount of CO_2 released into the atmosphere.

ARTICLE HISTORY
Received February 22, 2024.
Accepted May 05, 2024.
Published June 28, 2024.

KEYWORDS
Above-Ground, Below-Ground, Biomass, Carbon, Sequestration, Trees

INTRODUCTION

Carbon emissions and reflection are some of the most significant and urgent environmental problems in the world today due to climate change (Ajayi, 2021). Since various communities are experiencing the harmful effects of climate change, it has recently become more apparent and obvious (Wambede *et al.*, 2022). Extreme weather patterns and related agricultural diseases are examples of this, and they negatively affect crop output (Kumar *et al.*, 2018).

One of the main greenhouse gases, Carbon, increased in concentration from about 277 parts per million (ppm) in 1750 to 405.0 ± 0.1 ppm in 2017 (Le Quéré *et al.*, 2018), and recent estimates suggest that by 2025, levels could rise to 500 ppm. This buildup is fueled by the creation and acceptance of interventions to deal with the changes and create new models that adapt to the community's changing requirements (Thornton *et al.*, 2018). Since forests have been recognized for their potential as carbon sinks, such interventions have aided in the protection and regeneration of forests. (Wambede *et al.*, 2022).

A terrestrial ecosystem that involves biomass has five main carbon pools: above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter (Ojekunle *et al.*, 2023). Consequently, urban green spaces can inhibit atmospheric Carbon through autotrophs, which take up carbon dioxide from the atmosphere, release part of it back, and store the remnants in the plant tissues below and above ground, with a resultant effect on plant growth in the form of biomass (Ojekunle *et al.*, 2023). Trees are, therefore, regarded as the primary carbon sinks or sponges (Kruize *et al.*, 2019).

Because of their ability to sequester Carbon, trees significantly reduce the amount of carbon dioxide in the atmosphere (Patil and Kumar, 2017). According to

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How to cite: Paul, A. M., & Alfred, J. U. (2024). Quantifying Carbon Sequestration in Woody Trees of Makurdi Zoological Garden, Benue State, Nigeria: A Non-Destructive Approach. *UMYU Scientifica*, 3(2), 224 – 235. https://doi.org/10.56919/usci.2432.024

studies, photosynthesis allows urban trees to absorb carbon dioxide from the atmosphere, causing the trees to grow both horizontally and vertically (Ajayi, 2021). Photosynthesis involves the active absorption of CO_2 from the environment, stored in various plant parts such as the roots biomass found in tree trunks, foliage, branches, and soil (Wambede *et al*., 2022). Additionally, trees store and sequester significant amounts of atmospheric Carbon, making them crucial for reducing climate change (Iveren and Johnson, 2018).

In Africa, a 3.9 million-hectare annual rate of forest loss was recorded between 2010 and 2020, according to the Global Forest Resources Assessment. This loss could be attributed to fires, growing population pressure, and an overreliance on biomass (FAO, 2020). Growing trees is becoming more popular as a practical way to mitigate climate change due to the ongoing loss of forest areas and the resulting expansion of agricultural land (Wambede *et al*., 2022). However, despite their widespread occurrence on farmlands, in the vicinity of residences, and more recently on sizable farms and zoological parks, there is general doubt over the sequestration potential of many tree species (Dijkxhoorn *et al*., 2019).

When evaluating the ecological benefits of trees as commodities that provide environmental services, the calculation of carbon storage in tree components can serve as a fundamental point of reference (Carugati *et al*., 2018). Therefore, measuring and monitoring the amount of Carbon stored in forests is necessary for sustainable management if the mitigation potential of forests is to be fully realized (Iveren and Johnson, 2018). Therefore, one way to calculate the quantity of CO_2 released into the atmosphere is to periodically evaluate the amount of Carbon stored in the forest ecosystem, highlighting the need for this study, which sought to determine how much Carbon was stored in various tree species within the Makurdi Zoological Garden's Forest ecosystem to provide a foundation for the sustainable management of the forest ecosystem.

MATERIALS AND METHODS

Study Area

The Makurdi zoological garden in Benue State University served as the study area. Makurdi is Benue state's capital and has a coordinate of $7^0$43'50'N $8^0$32'10E.

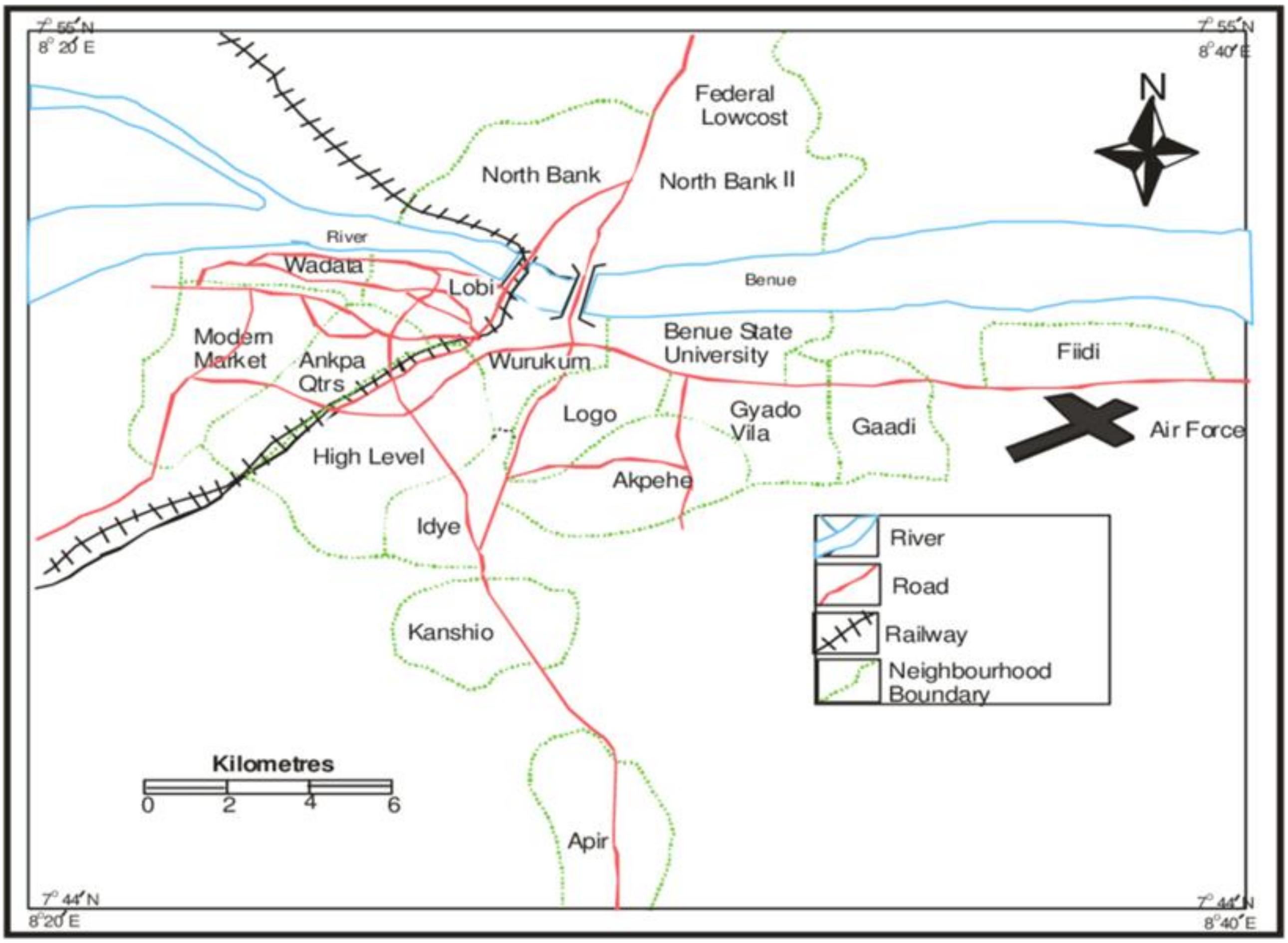

Figure 1: Map of Makurdi showing the study area
Source: Ministry of Land and Survey, Benue state

Sampling Design

In the field, 29 m × 29 m random sample plots were located using a Garmin positioning system (GPS), and plots were placed precisely and efficiently using GPS receivers. A 100-meter girt measuring tape was utilized in measuring the Height of all the trees in each plot whose DBH at 1.3m exceeded 5cm. A Haga altimeter was also used to measure the trees' heights.

Application of Pan Tropical Allometric Equation

The trees' above-ground biomass was estimated using the pan-tropical biomass allometric equation for tropical moist forests, which was proposed by Chanve *et al.* (2005).

Above-ground biomass (AGB)

Above-ground biomass was estimated using the equation below:

TAGB = exp − (2.977 + ln ($\varrho D2H$)) = 0.0509×ρD^2 .... (1)

Where ϱ, or wood density, is estimated to be 0.88, H is the overall Height, D is the DBH, and TAGB is the tree's biomass above the ground.

Below ground biomass

AGB is used to calculate Below Ground Biomass (BGB) by utilizing a non-destructive method that estimates vegetation's BGB values to be 20% of AGB, as shown in the equation below:

BGB = 20% × AGB

Meaning:

BGB = 20% × AGB……………......................... (2)

Above-ground carbon stock:

Above-ground Carbon (AGC) is determined by multiplying AGB by fifty per cent, as shown below:

AGC = total AGB × 0.50

Below ground carbon stock (BGC):

BGC is determined by multiplying BGB by fifty per cent, as shown below:

BGC = total AGB × 0.5

Total Carbon Sequestered

The total Carbon sequestered (TCS) by plant species was determined by an addition of above-ground carbon stock and below-ground carbon stock.

TCS = Above-Ground Carbon Stock + Below-Ground Carbon stock

Data Analysis

Relationship between Parameters

To model the relationship between the parameters studied [mean DBH, mean Height, total AGB (tons/ha), total BGB (tons/ha), total AGC (tons/ha), total BGC (tons/ha), and total Carbon Sequestered], Poisson regression analysis was performed, and Pearson correlation analysis was also carried out to determine the relation between the parameters.

Principal components analysis was performed to explore the dataset's underlying patterns, reduce the data's dimensionality and identify the key variables contributing most to the variation in above and belowground biomass estimates.

Grouping of Tree Species based on Carbon Sequestration Potentials

Cluster analysis was also performed based on all the parameters studied and was used in grouping tree species in the study area based on the potential to sequester Carbon and their biomass accumulation patterns.

All data analysis was performed using Minitab software version 21.

RESULT

Diameter at Breast Height

The total DBH class 51–70cm dominated, with 31–50cm, 71–90cm, and 10–30cm following suit (Figure 2).

For mean DBH, 88cm, which is the highest mean DBH, was recorded for *Parkia biglobosa*, 74cm and 62.3cm were recorded for *Pterocarpus erinaceus* and *Daniella oliveri* respectively, while *Lophira lanceolata* had the lowest mean DBH (15cm). See Figure 3.

Height Distribution of Trees

Distribution of Height was based on class range and mean Height; the approximate height distribution for the class ranges of 0–10, 11–15, and 16–20 was 170, 170, and 470, respectively, and the most distinct tree species are 16–20 meters tall, followed by trees that are 11–15 meters and 5–10 meters tall (Figure 4 and 5). The highest class (16 to 20 meters) had the majority of the trees (63.6%) and the highest diversity. Of all the trees, 23.5% were between 11 and 15 meters tall, while 12.9% were in the range of 5 and 10 meters tall (Figures 4 and 5).

Application of Pan Tropical Allometric Equation

Estimation of Biomass

Tree species' maximum and minimum amount of above-ground biomass (AGB) sequestered was 1037.3 tons/ha and 0.181 tons/ha, respectively, and 1512.7 tons was the total amount of AGB (Figure 6). The overall amount of below-ground biomass (BGB) for the examined region was 302.579 tons/ha, with the largest amount of BGB being 207.5 tons/ha and the least amount being 0.036 tons/ha (Figure 6). This result implies that above-ground biomass (AGB), such as the leaves and stems of tree species in the study area, sequestered more Carbon than the below-ground biomass (BGB), such as roots.

Estimation of Carbon Stocks

A total of 756.4 tons was recorded as above-ground Carbon (TAGC), 518.65 was the minimum, and 0.0905 tons/ha was the maximum AGC stock potentials recorded for the plant species (Figure 7). The area's subsurface Carbon or BGC stock sequestered at the highest rate was 103.73 tons/ha, and the lowest rate was 0.0181 tons/ha (Figure 7). By implication, in the study area, more Carbon is stored in the leaves and stems of plant species than in the roots.

Total Carbon Sequestered

The result of the total percentage of Carbon sequestered by the different tree species in the study area is shown in Figure 8. The highest amount of Carbon sequestered was by *Daniella oliveri* (69%), followed by *Azadirachta indica* (11%), *Pterocarpus erinaceus* (5%), *Lannea acida* (2%), *Elaeis guineensis* (2%), among others. This implies that the higher the number of tree species, the higher the amount of Carbon it will sequester.

Relationship between Parameters

Poisson regression analysis

The result of Poisson regression analysis is shown in Table 1. The result shows significant deviance in species number ($p = 0.000$), total above-ground Carbon ($p = 0.000$), total below-ground Carbon ($p = 0.000$), and mean Height ($p = 0.036$). This implies that species number, total above-ground Carbon, total below-ground Carbon, and mean Height of plant species significantly affect the species' potential to sequester Carbon.

Pearson correlation analysis

The result of the Pearson correlation analysis is shown in Table 2. Strong positive correlations were recorded between total Carbon sequestered and total above ground Carbon (1.000), total Carbon sequestered and total below ground Carbon (1.000), total Carbon sequestered and total below ground Biomass (1.000), total Carbon sequestered and total above ground Biomass (1.000), total above ground Biomass and total below ground Biomass (1.000), total above ground Biomass and total above ground Carbon (1.000), total above ground Biomass and total below ground Carbon (1.000), species number and total above ground Biomass (0.988), species number and total below ground Biomass (0.988), species number and total above ground Carbon (0.988), species number and total below ground Carbon (0.988), species number and total Carbon sequestered (0.988), while weak positive correlations were recorded between species number and mean Height (0.480), mean Height and total above ground biomass (0.449), mean Height and total below ground biomass (0.449), mean Height and total above ground carbon (0.449), among others. By implication, the total amount of Carbon sequestered by tree species depends on the total below-ground biomass, total above-ground biomass, total above-ground Carbon, total below-ground Carbon, number of tree species, mean diameter at breast height, and mean Height.

Principal components analysis

Principal components analysis (Table 3) shows that AGB, BGB, AGC and BGC contributed significantly to the total variations in the dataset as they were positively associated with the four principal components, accounting for 100% variability among the tree species. Species number is positively associated with the first and second principal components, while mean DBH is positively associated with the first and third principal components.

Grouping of Tree Species based on Carbon Sequestration Potentials

Cluster analysis revealed 8 clusters, with some tree species occupying distinct clusters alone (Figure 9). The tree species *Daniella oliveri* stood out in its potential to sequester Carbon, with no similarity with other tree species, and occupied cluster 8 alone. Tree species in cluster 1 belong to the families Anacardiaceae, Mimosoidecea, Meliaceae, Combretaceae, and Fabaceae; tree species in cluster 2 belong to the families Moraceae, Verbanaceae, Moraceae, and Mimosoideae; tree species in cluster 3 belong to the families Sapotaceae, Euphorbiaceae, Simaroubaceae, Araliaceae, and Onchnaceae; tree species in cluster 4 belongs to the families Aracaceae and Anacardiaceae; tree species in cluster 5 belongs to the Mimosoideae family; tree species in cluster 6 belongs to the Fabaceae family; tree species in cluster 7 belongs to the Meliaceae family and tree species in cluster 8 belongs to the Ceasalpinioidae family.

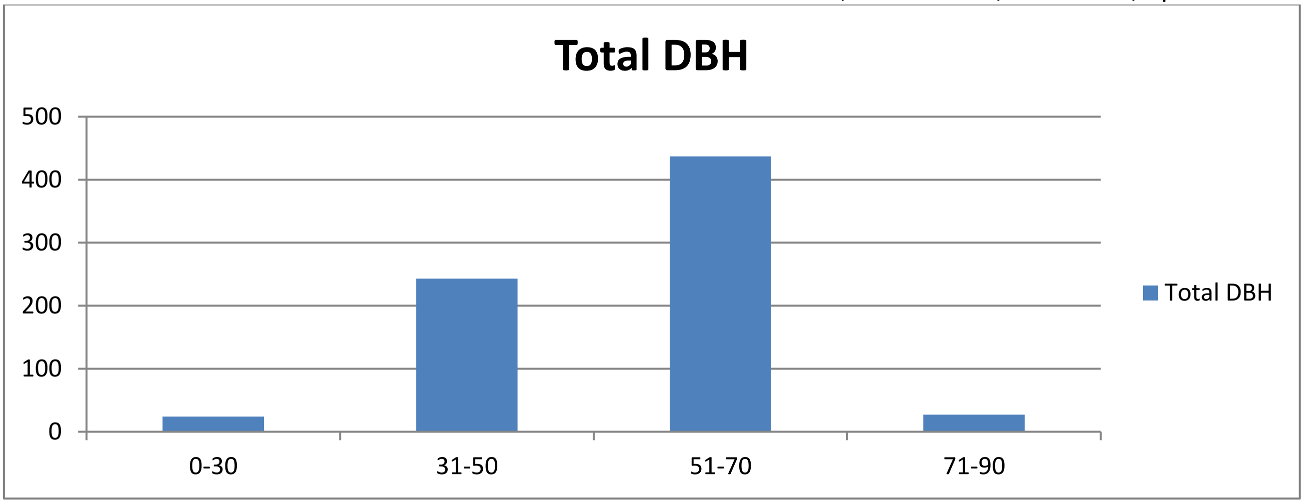

Figure 2: Diameter at Breast Height

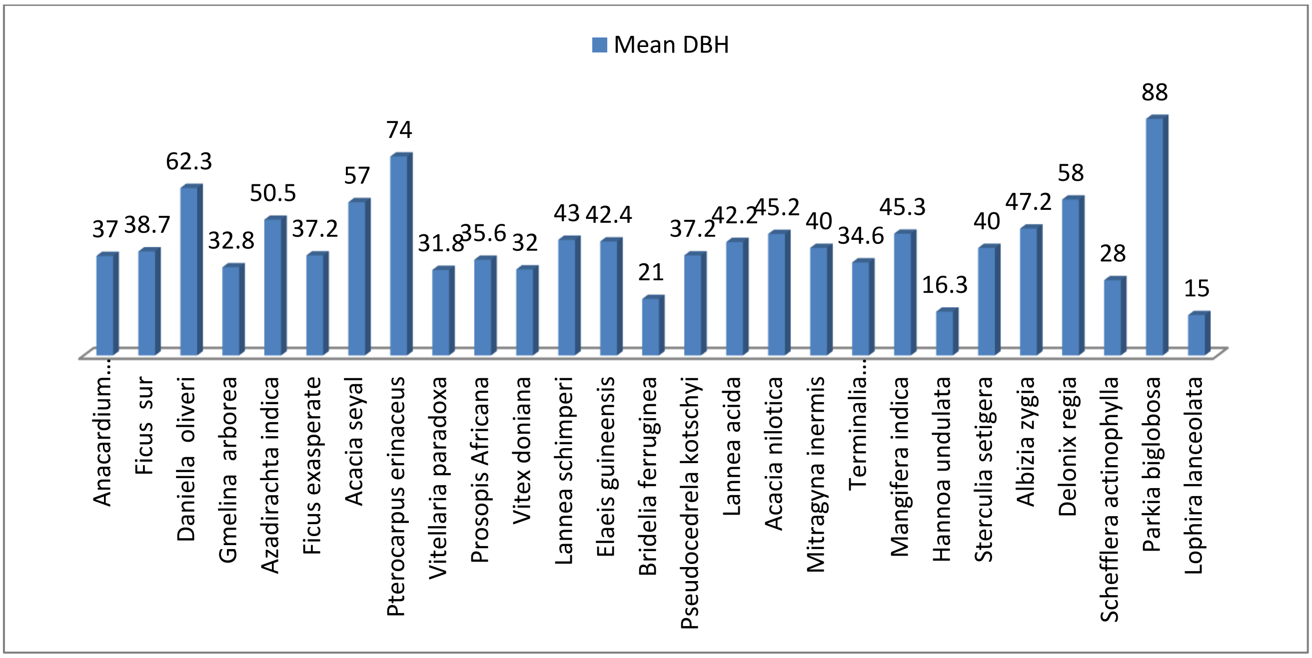

Figure 3: Mean DBH

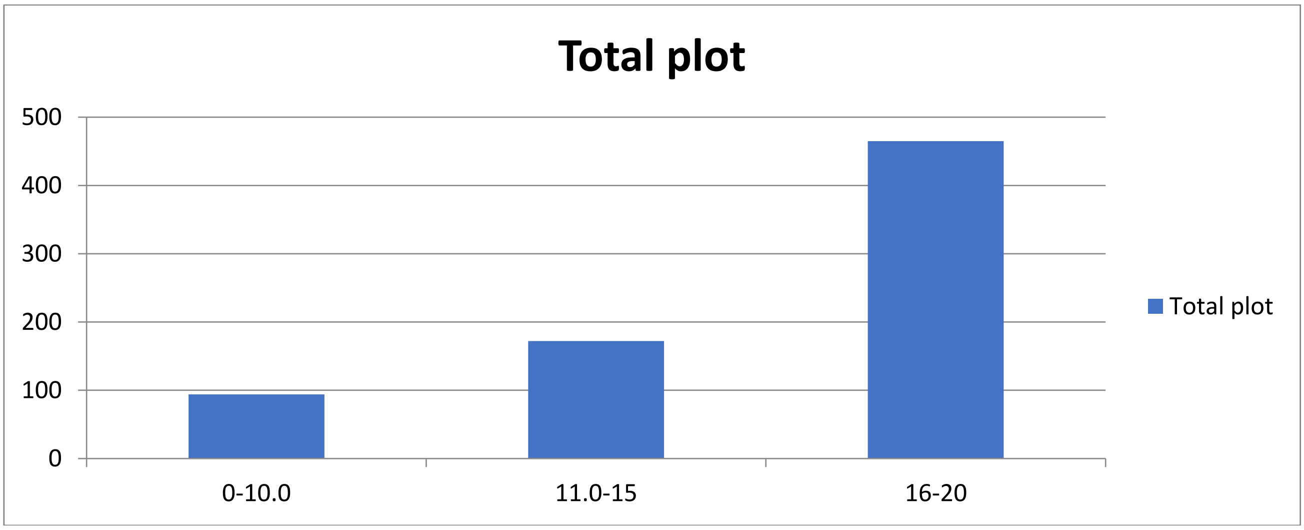

Figure 4: Height Class Distribution of Trees

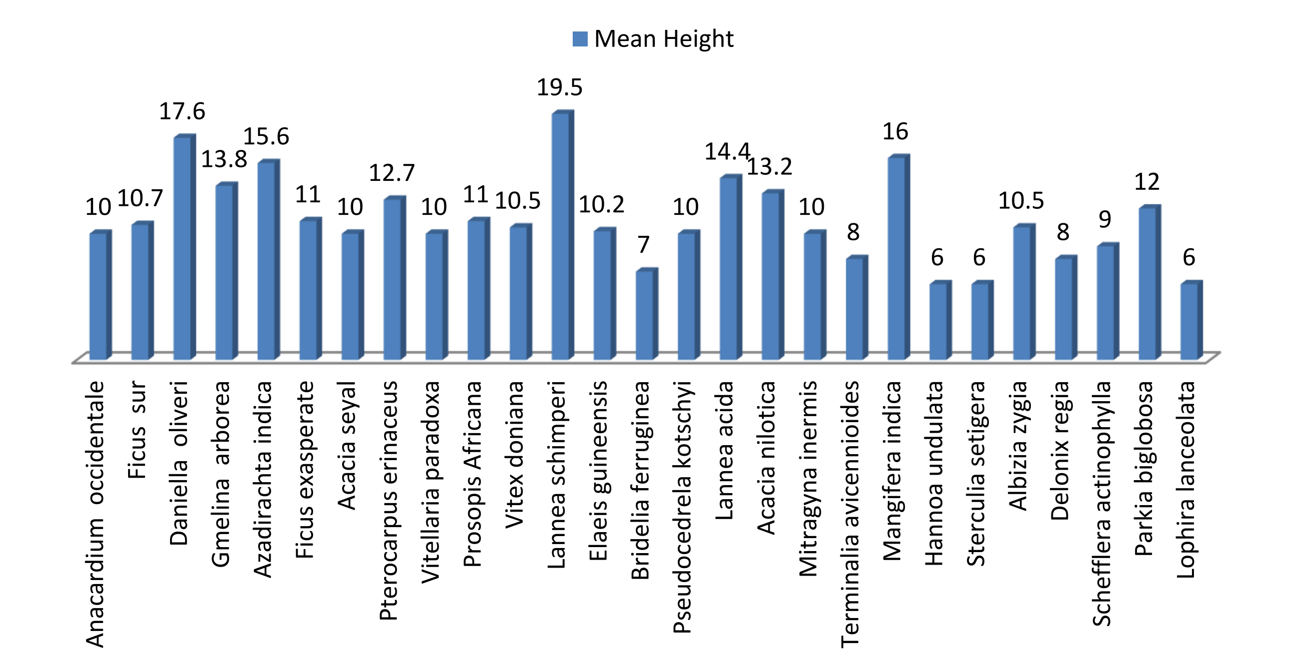

Figure 5: Mean Height of Tress

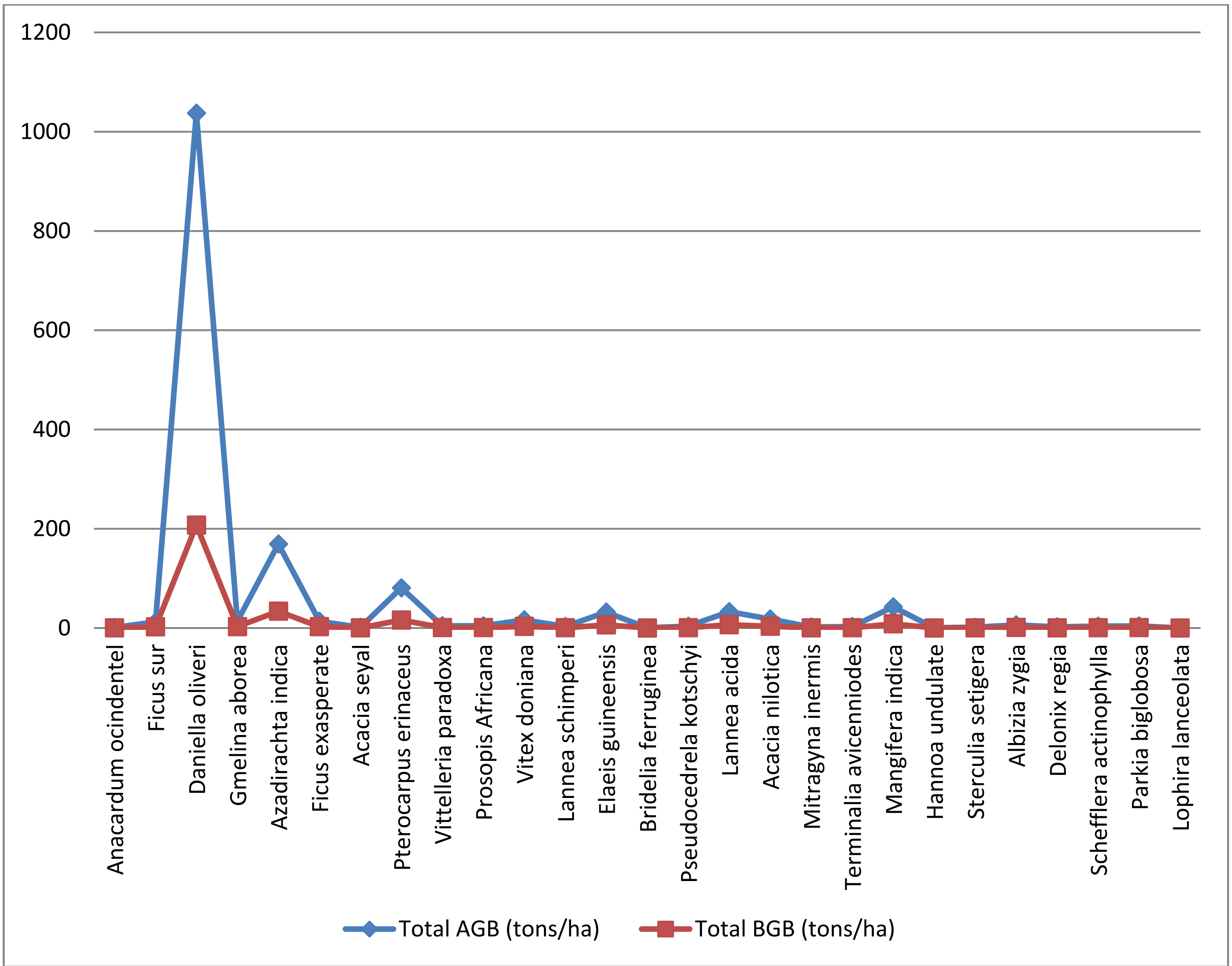

Figure 6: AGB and BGB

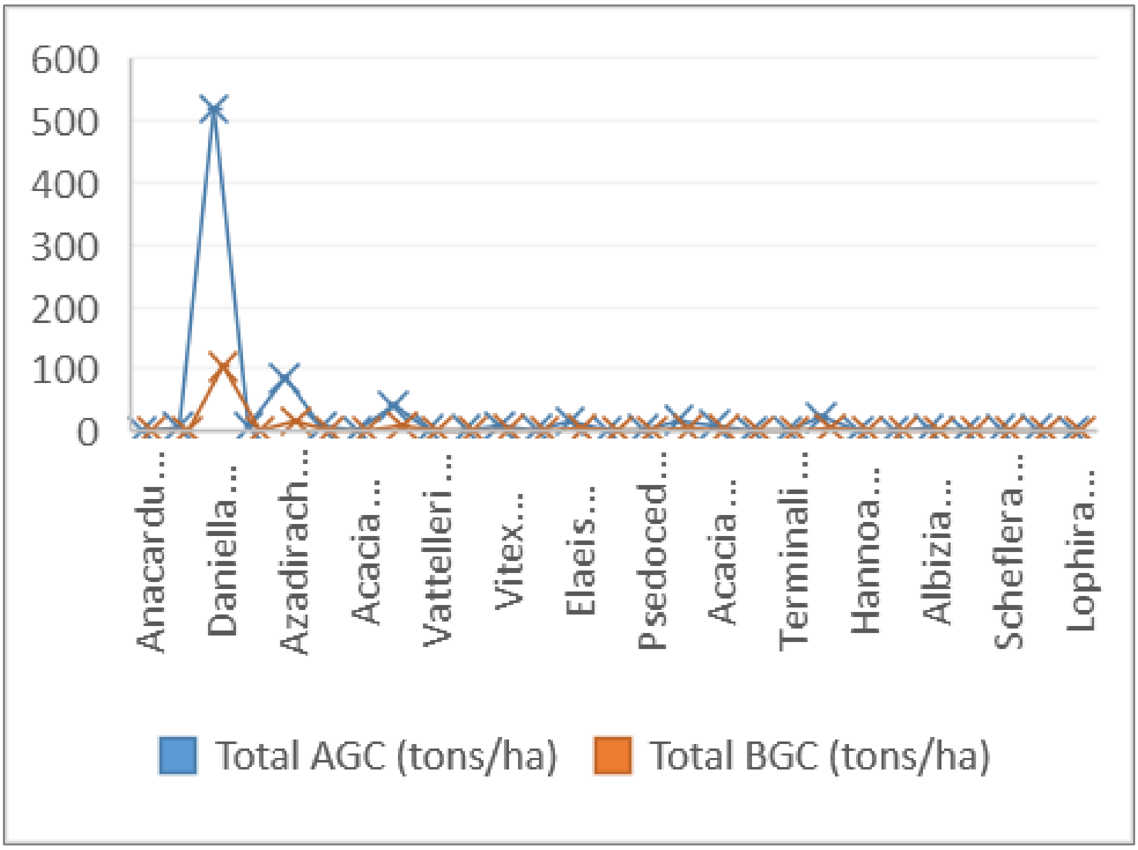

Figure 7: Estimated Carbon Stock

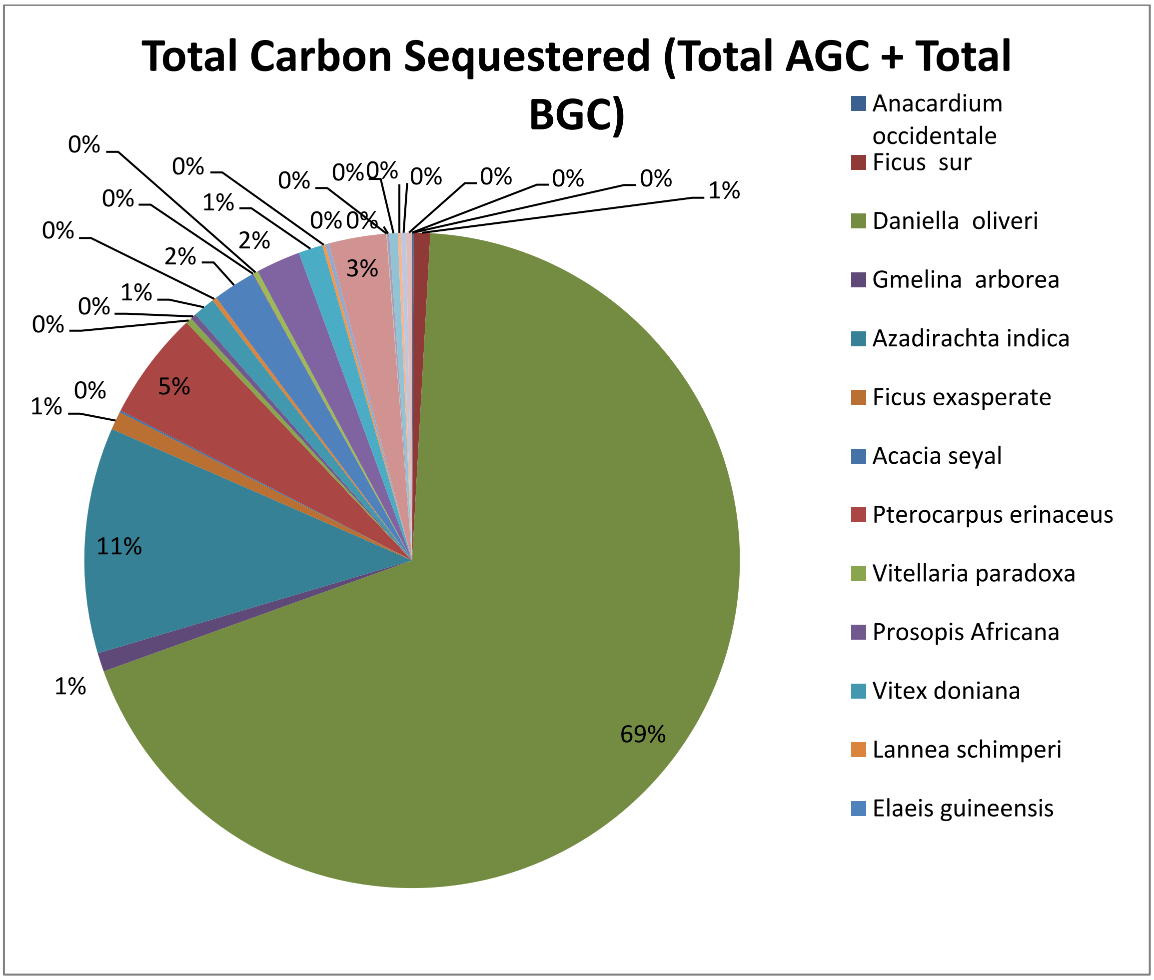

Figure 8: Total Carbon Sequestered

Table 1: Deviance Table of Poisson regression Analysis

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	7	3556.55	508.078	3556.55	0.000
Species Number	1	21.00	21.003	21.00	0.000
Mean DBH	1	0.17	0.173	0.17	0.677
Mean Height	1	4.40	4.401	4.40	0.036
Total AGB (tons/ha)	1	18.93	18.932	18.93	0.000
Total BGB (tons/ha)	1	71.37	71.373	71.37	0.000
Total AGC (tons/ha)	1	0.10	0.102	0.10	0.749
Total BGC (tons/ha)	1	56.48	56.478	56.48	0.000
Error	19	16.42	0.864		
Total	26	3572.97			

Regression Equation:

Total Carbon Sequestered (Total A = exp. (Y')

Y' = -0.658 + 0.0478 Species Number + 0.0044 Mean DBH + 0.0919 Mean Height
+ 160.7 Total AGB (tons/ha) - 849 Total BGB (tons/ha) + 16.7 Total AGC (tons/ha)
+ 8.77 Total BGC (tons/ha)

Table 2: Correlation Analysis

	Species Number	Mean DBH	Mean Height	Total AGB (tons/ha)	Total Carbon Seq.
Mean DBH	0.275				
Mean Height	0.480	0.453			
Total AGB (tons/ha)	0.988	0.303	0.449		
Total BGB (tons/ha)	0.988	0.303	0.449	1.000	1.000
Total AGC (tons/ha)	0.988	0.303	0.449	1.000	1.000
Total BGC (tons/ha)	0.988	0.302	0.448	1.000	1.000
Total Carbon Seq.	0.988	0.303	0.448	1.000	

Table 3: Principal Components Analysis

Variable	PC1	PC2	PC3	PC4
Species Number	0.392	0.100	-0.041	-0.913
Mean DBH	0.150	-0.763	0.626	-0.048
Mean Height	0.214	-0.595	-0.772	0.061
Total AGB (tons/ha)	0.395	0.102	0.044	0.173
Total BGB (tons/ha)	0.395	0.102	0.044	0.173
Total AGC (tons/ha)	0.395	0.102	0.044	0.173
Total BGC (tons/ha)	0.394	0.103	0.045	0.197
Total Carbon Sequestered	0.395	0.103	0.044	0.177
Eigenvalue	6.3394	1.1139	0.5297	0.0169
Proportion	0.792	0.139	0.066	0.002
Cumulative (%)	79.2	93.2	99.8	100

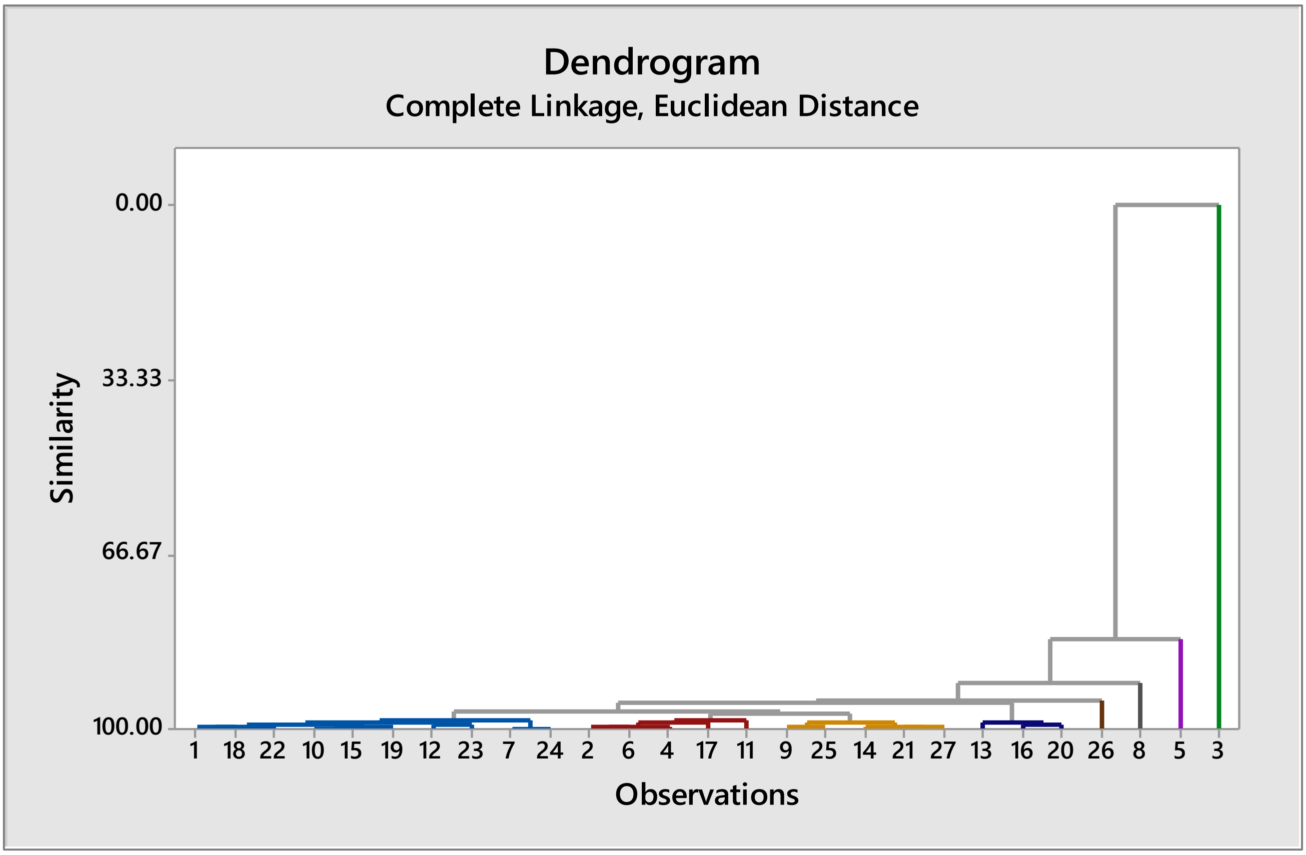

Figure 9: Cluster Analysis

Key: 1 = *Anacardium occidentale*, 2 = *Ficus sur*, 3 = *Daniella oliveri*, 4 = *Gmelina arborea*, 5 = *Azadirachta indica*, 6 = *Ficus exasperate*, 7 = *Acacia seyal*, 8 = *Pterocarpus erinaceus*, 9 = *Vitellaria paradoxa*, 10 = *Prosopis Africana*, 11 = *Vitex doniana*, 12 = *Lannea schimperi*, 13 = *Elaeis guineensis*, 14 = *Bridelia ferruginea*, 15 = *Pseudocedrela kotschyi*, 16 = *Lannea acida*, 17 = *Acacia nilotica*, 18 = *Mitragyna inermis*, 19 = *Terminalia avicennioides*, 20 = *Mangifera indica*, 21 = *Hannoa undulate*, 22 = *Sterculia setigera*, 23 = *Albizia zygia*, 24 = *Delonix regia*, 25 = *Schefflera actinophylla*, 26 = *Parkia biglobosa*, 27 = *Lophira lanceolata*.

DISCUSSION

Forest ecosystems are a major source of Carbon and are essential to the global carbon cycle (Popkin, 2015). The stem and branches of trees are the primary above-ground carbon sink, readily detectable, and quantifiable; they make up between 50 and 60 per cent of the total biomass of the tree (Andrianantenaina *et al.*, 2019). In this study, 731 woody trees in sixteen families were sampled to determine AGB and BGB, as well as to estimate the overall carbon stock and assess the overall amount of CO_2 sequestered. All tree species measured had average DBHs between 15 and 88cm (Figures 2 and 3). With a DBH of 62.3cm, *Daniella oliveri* had the greatest number (331), while *Parkia biglobosa* had the lowest number (1) with an average DBH of 88cm (Figure 3). The high values of DBH recorded in this study can be used to infer that the tree species have well-spread leaves and canopy patterns, as these have been reported by Syahid *et al.* (2020) to significantly contribute to the total DBH of tree species.

Estimating above-ground woody biomass produced by trees requires considering both wood density and stem radial growth (Andrianantenaina *et al.*, 2019). Radial increment and wood density differ throughout species based on heritable traits (Nabais *et al.* 2018; Lundqvist *et al.* 2018), age (Bouriaud *et al.*, 2015; Björklund *et al.*, 2017), climatic conditions (Rathgeber 2017; Björklund *et al.* 2017) and years spent from early-wood to late-wood (Cuny *et al.* 2014). Accurately estimated AGB and BGB, AGC, and BGC were utilized in this study to determine the total Carbon sequestered. The result of this study shows that the total BGB was 302.579 tons/ha, and 1037.3 tons/ha and 0.181 tons/ha to be the maximum and minimum AGB, respectively, and 1,512.7 tons as the total amount of AGB (Figure 6). The total AGB in this study is small compared to a total AGB of 162,826.343 tons ha-[1] reported by Makinde *et al.* (2017). Arguably, this variation could be due to this study being conducted in a zoological garden, which is a small catchment of forest ecosystem, while the study of Makinde *et al.* (2017) was carried out in Ondo state's Oluwa forest. However, AGB and BGC values in this study are similar to those reported by Syahid *et al.* (2020) and Andrianantenaina *et al.* (2019) and further demonstrate the importance of leaf types and canopy patterns in biomass accumulation.

In every ecosystem, estimation of total carbon stock [total above-ground Carbon (TAGC) and total below-ground Carbon (TBGC)] is important for the determination of total Carbon sequestered. This study recorded 756.4 tons as TAGC and 150.7 as TBGC (Figure 7). These values indicate that the tree species in the study area are slow-growing species, as Bouriaud *et al.* (2015), Björklund *et al.*

(2017), and Halim *et al.* (2023) posited that quick-growing species store more Carbon in their early life cycle but not in their whole life cycle, whereas slower-growing species store more Carbon over time due to their high specific gravity. In addition, it has been demonstrated that factors like species mix, age of forests, solar radiation, disturbances, climate, and soil characteristics influence the overall Carbon stored in any ecosystem (Andrianantenaina *et al.*, 2019). An increase in biomass accumulation through photosynthesis translates to an increase in carbon storage, and the present study makes it abundantly evident that the primary variables affecting the carbon supply, particularly the AGB, are the species mix and disturbance.

The allometric equations used in this study to compute carbon stocks showed varying amounts among the Tree species. This might be caused by elements related to site productivity and morphology. Despite the differences recorded in community ecology, the negative implications of functional characteristic differences amongst tree species on stand-level carbon stocks are rarely highlighted. Tree height and diameter range higher in Daniella oliveri than in other tree species can account for the increased carbon stocks reported in them (Tom-Dery *et al.*, 2015). This study estimated AGB using the pantropical biomass allometric equation, which has been evaluated and demonstrated to correctly estimate total AGB in multiple sites (Vasagadekar *et al.*, 2023).

In this study, *Daniella oliveri* sequestered the highest amount of Carbon (622.38 tons/ha), and the total Carbon sequestered was 907.0947 tons/ha (Figure 8). Contrary, Vasagadekar *et al.* (2023) reported a storage potential of 688.77 tons of carbon dioxide, Halim *et al.* (2023) reported an estimated carbon of 146.22 t C ha^{-1} in mangrove stand and an estimated carbon stock of 360.61 t C ha^{-1} in the sediment and Ajayi (2021) reported that *Gmelina arborea* sequestered the highest amount of Carbon and the total Carbon and carbon dioxide sequestered was 47.94 kg and 176.03 kg respectively. While this study was carried out in a zoological garden in North-central Nigeria and involved a total of 27 trees, the study of Halim *et al.* (2023) was carried out in the Mangrove ecosystem, while that of Ajayi (2021) was in South-west Nigeria and involved a total of 124 trees. This implies that the type of ecosystem, number of tree species, and ecological zone can affect the total amount of Carbon sequestered.

Also, *Daniella oliveri* sequestered the highest amount of Carbon (622.38 tons/ha) could be attributed to the age or maturity of the Tree. This assertion is supported by the results from the study of Wambede *et al.* (2022), which indicated a typical age-related increase in Height and diameter and of Janiola and Marin (2016), who reported trees that age have better photosynthetic activity and, as a result, accumulate more biomass. A species' biomass and potential to store carbon increase with age and its diameter, improving carbon sequestration. Patil and Kumar (2017) further noted that an older tree stores more Carbon because the activity in the flowers, bark, twigs, fruits, stalks, etc., increases as the tree grows, while Ojekunle *et al.* (2023) asserted that the size, growth rate, and lifespan of the tree at maturity all affect the annual rates of carbon sequestration.

Several studies have tried to model and establish the relationship between AGB, BGB, AGC, BGC and the total amount of Carbon sequestered in an ecosystem (Eneji *et al.*, 2014; Halim *et al.*, 2023; Ojekunle *et al.*, 2023; Vasagadekar *et al.*, 2023). In this study, Poisson regression analysis shows significant deviance in species number, total above-ground Carbon, total below-ground Carbon, and mean Height (Table 1), while Pearson correlation analysis shows strong positive correlations between total Carbon sequestered and total ground Carbon, total Carbon sequestered and total below ground Carbon, total Carbon sequestered and total below ground Biomass, total Carbon sequestered and total above ground Biomass, among others (Table 2). These findings indicate that the total amount of Carbon sequestered by tree species depends on the total below-ground biomass, total above-ground biomass, total above-ground Carbon, total below-ground Carbon, number of tree species, mean diameter at breast height, and mean Height. These findings are supported by Eneji *et al.* (2014), who reported that regression analysis of the link between tree height and CO2 sequestration yielded the equation y = 67898x + 9509 with R2 = 0.266, indicating negligible differences between the two variables at $P > 0.05$.

In the study area, cluster analysis revealed 8 distinct clusters, with some tree species occupying distinct clusters alone (Figure 9). The tree species *Daniella oliveri* stood out in its potential to sequester Carbon, with no similarity with other tree species, and occupied cluster 8 alone. Cluster analysis did not show any distinct clustering based on families but showed tree species with similar ability to sequester Carbon. This clustering can be utilized in reforestation efforts to mitigate climate change as tree species with similar sequestration potentials can be avoided in favour of species with unique sequestration potentials. Syahid et al. (2020) and Santos et al. (2014) reported some tree species clustered together in this study to show related patterns in areas like Height and DBH, which anthropogenic activities and ecosystem disturbances have shaped.

CONCLUSION

Forest ecosystems are a major source of Carbon and are essential to the global carbon cycle. A terrestrial ecosystem that involves biomass has five main carbon pools: above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter, and this study has demonstrated the importance of above-ground biomass and below-ground biomass in the determination of total Carbon sequestered in a forest ecosystem. This study modelled and established a clear relationship between the parameters studied [mean DBH, mean Height, total AGB (tons/ha), total BGB (tons/ha), total AGC (tons/ha), total BGC (tons/ha), and total Carbon Sequestered], clustered tree species based on their potential to sequester Carbon, posited that the primary variables affecting the carbon supply, particularly the AGB, are the species mix and disturbance and concluded that the total amount of Carbon sequestered by tree species is dependent on their above-ground and below-ground biomass. To mitigate climate change, the study recommends protecting forest ecosystems, establishing and maintaining green spaces in urban areas and further studies in other ecosystems in Benue State, Nigeria.

REFERENCES

Ajayi, E. (2021). Assessment of Carbon Sequestration Potential of some Selected Urban Tree Species. BioRxiv preprint. **[Crossref]**

Andrianantenaina, A.N., Rathgeber, C.B.K., Pérez-de-Lis, G., Cuny, H. and Ruelle, J. (2019). Quantifying intra-annual dynamics of carbon sequestration in the forming wood: a novel histologic approach. *Annals of Forest Science*, 76: 62. **[Crossref]**

Björklund, J., Seftigen, K., Schweingruber, F., Fonti, P., von Arx, G., Bryukhanova, M.V., Cuny, H.E., Carrer, M., Castagneri, D. and Frank, D.C. (2017). Cell size and wall dimensions drive distinct variability of early wood and latewood density in northern hemisphere conifers. *New Phytol*, 216:728–740. **[Crossref]**

Bouriaud, O., Teodosiu, M., Kirdyanov, A.V. and Wirth, C. (2015). Influence of wood density in tree-ring-based annual productivity assessments and its errors in Norway spruce. *Biogeosciences,* 12:6205–6217. **[Crossref]**

Carugati L., Gatto B., Rastelli E., Lo M.M., Coral C., Greco S. and Danovaro R. (2018). Impact of mangrove forests degradation on biodiversity and ecosystem functioning. *Scientific Reports*, 8(1), 1-11, **[Crossref]**

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B. W., Ogawa, H., Puig, H., Riéra, B. andYamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forest. *Oecologia*, 145: 87-99.

Cuny, H.E., Rathgeber, C.B.K., Frank, D., Fonti, P. and Fournier, M. (2014). Kinetics of tracheid development explain conifer tree-ring structure. *New Phytol*, 203:1231–1241. **[Crossref]**

Dijkxhoorn, Y., van Galen, M., Barungi, J., Okiira, J., Gema, J. and Janssen, V. (2019). The vegetables and fruit sector in Uganda: Competitiveness, investment and trade options. Wageningen Economic Research.

Eneji, I.S., Obinna, O and Azua, E.T. (2014). Sequestration and Carbon Storage Potential of Tropical Forest Reserve and Tree Species Located Within Benue State of Nigeria. *Journal of Geoscience and Environment Protection*, 2, 157-166. **[Crossref]**

FAO (2020). Global Forest Resources Assessment 2020 – Key findings. Rome. **[Crossref]**

Halim M.A.R., Soeprobowati T.R. and Hadiyanto H. (2023). Ecological Assessment of the Role of Mangrove Trees in Carbon Sequestration and Biodiversity in Karimunjawa National Park Indonesia. *Geography, Environment, Sustainability*, 3(16), 32-42. **[Crossref]**

Iveren, B.C. and Johnson, S.A.O. (2018). Mapping tree above-ground biomass and Carbon in Omo Forest Reserve Nigeria using Landsat 8 OLI data. *Southern Forests: A Journal of Forest Science.* **[Crossref]**

Janiola, M. D. C. and Marin, R. A. (2016). Carbon sequestration potential of fruit tree plantations in Southern Philippines. *J Biodivers Environ Sci*, 8 (5), 164-174.

Kruize, H., van der Vliet, N., Staatsen, B., Bell, R., Chiabai, A., Muiños, G., Higgins, S., Quiroga, S., Martinez-Juarez, P., Aberg Yngwe, M., Tsichlas, F., Karnaki, P., Lima, M.L., García de Jalón, S., Khan, M., Morris, G. and Stegeman, I. (2019). Urban Green Space: Creating a Triple Win for Environmental Sustainability, Health, and Health Equity through Behavior Change. *Int J Environ Res Public Health*, 16 (22):4403.

Kumar, P., Tokas, J., Kumar, N., Lal, M. and Singal, H. R. (2018). Climate change consequences and its impact on agriculture and food security. *International Journal of chemical studies*, 6 (6), 124-133.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J. and Arneth, A. (2018). Global carbon budget 2018. *Earth System Science Data*, 10 (4), 2141-2194.

Lundqvist, S.O., Seifert, S., Grahn, T., Olsson, L., García-Gil, M.R., Karlsson, B. and Seifert, T. (2018). Age and weather effects on between and within ring variations of number, width and coarseness of tracheids and radial growth of young Norway spruce. *Eur J For Res* 137:719–743. **[Crossref]**

Makinde, E. O., Womiloju,A. A. and Ogundeko,M. O.(2017). The geospatial modelling of carbon sequestration in Oluwa Forest, Ondo State. *Nigeria, European Journal of Remote Sensing*, 50:1, 397-413. **[Crossref]**

Nabais, C., Hansen, J.K., David-Schwartz, R., Klisz, M., López, R. and Rozenberg, P. (2018). The effect of climate on wood density: what provenance trials tell us? *For EcolManag* 408:148–156. **[Crossref]**

Ojekunle, O.O., Oyebamiji, N.A., Olaniyi, A.A., Majolagbe, M.O. and Akinrotimi, J.A. (2023). Assessing the Carbon Sequestration Potentials of Indigenous Trees among Academic Parks in Federal University of Agriculture, Abeokuta, Nigeria. *J. Appl. Sci. Environ. Manage.* 27 (9) 2021-2027. **[Crossref]**

Patil, P. and Kumar, A. K. (2017). Biological carbon sequestration through fruit crops (perennial crops-natural "sponges" for absorbing carbon dioxide from atmosphere). *Plant Archives*, 17 (2), 1041–1046.

Popkin, G. (2015). Weighing the world's trees. *Nature*, 523:20 – 22

Rathgeber, C.B.K. (2017). Conifer tree-ring density inter-annual variability-anatomical, physiological and environmental determinants. *New Phytol* 216:621–625. **[Crossref]**

Syahid L.N., Sakti A.D., Virtriana R., Wikantika K., Windupranata W., Tsuyuki S., Caraka R.E. and Pribadi R. (2020). Determining Optimal Location for Mangrove Planting Using Remote Sensing and Climate Model Projection in Southeast Asia. *Remote Sensing*, 12(22), 3734. **[Crossref]**

Thornton, P.K., Whitbread, A., Baedeker, T., Cairns, J., Claessens, L., Baethgen, W., Bunn, C., Friedmann, M., Giller, K.E., Herrero, M., Howden, M., Kilcline, K., Nangia, V., Ramirez-Villegas, J., Kumar, S., West, P.C. and Keating, B. (2018). A framework for priority-setting in climate smart agriculture research. *Agricultural Systems,* 167; 161–175. **[Crossref]**

Tom-Dery, D., Akomanyi, G., Korese, J. K. and Issifu, H. (2015). The contribution of mango agroecosystems to carbon sequestration in Northern Ghana.

Vasagadekar, P.R., Gargate, A.V., Patil, Y.Y. and Raut, P.D. (2023). Carbon sequestration potential of trees from urban green spaces of Kolhapur city, Maharashtra, India. *Environmental & Socio-economic Studies*, 11 (3): 22-32. **[Crossref]**

Wambede, M.N., Akello, G., Lugumira, J.S., Barasa, B., Amwonya, D. and Mulabbi, A. (2022). Carbon Sequestration of Fruit Trees under Contrasting Management Regimes. *Indonesian Journal of Geography*, 54 (3), 420-427. **[Crossref]**