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CARBON SEQUESTRATION AND CARBON CREDIT POTENTIAL IN A MIXED VEGETATION SITE IN SOUTHERN NIGERIA

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Abstract: Carbon sequestration is a critical natural process for mitigating climate change by capturing and storing atmospheric carbon dioxide (CO_2). This study evaluated the carbon sequestration potential of a mixed forest stand within the University of Benin, Nigeria. The total AGB was calculated to be 148,292.428 kg/ha, resulting in a carbon sequestration value of 342,555.51 kg/ha. This indicates the forest's capacity to offset the annual CO_2 emissions of approximately 571 individuals in Nigeria. Economically, the plantation could generate an estimated $6,800 (≈₦92 million) in carbon credits based on the Africa Carbon Markets Initiative's projections. The findings of this study underscore the potential of university-managed mixed forests for climate change mitigation. The study recommends the development of species-specific allometric models, the integration of remote sensing, and the adoption of sustainable forest management to enhance carbon capture strategies in similar ecosystems.

Keywords: Carbon credit, CO_2-Emission, Climate Change, Carbon Sequestration.

Introduction

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide (CO_2) which is a crucial climate mitigation strategy, especially despite rising emissions and deforestation. Although CO_2 constitutes only 0.04% of the atmosphere, it plays a major role in global warming. Human activities, particularly the burning of fossil fuels and land-use changes, have increased CO_2 concentrations by 46% since pre-industrial times, reaching 412 ppm by 2020 (Marvel *et al.*, 2023). CO_2 absorbs and emits infrared radiation, making it a significant heat-trapping gas and driver of climate change (Jacobs, 2022).

Forests, which act as vital carbon sinks through photosynthesis, store significant quantities of carbon in their biomass. However, widespread deforestation and forest degradation, as observed in Benin City due to urbanization and unregulated logging, have resulted in the substantial loss of aboveground biomass and increased atmospheric CO_2. Nigeria faces annual economic losses estimated at US$750 million due to declining forest cover, and if deforestation continues, all future employment and revenue from forest resources may vanish by 2030 (Temidayo, 2021). Deforestation also undermines ecosystem services, such as flood control, erosion prevention, biodiversity preservation, and water regulation, disproportionately affecting vulnerable communities.

Although they cover only 2% of the Earth's surface, urban areas are responsible for over 70% of greenhouse gas emissions and house more than half of the global population, positioning cities at the heart of the climate crisis and decarbonization efforts (Erker & Townsend, 2019). However, accurate data on carbon stocks in urban and peri-urban forest areas remain limited, hampering climate action. Allometric models used to estimate biomass often lack precision, especially in diverse, mixed forest stands, due to variation in species composition and forest structure.

This study addresses these gaps by focusing on a mixed forest stand at the University of Benin. Therefore, this study aims to estimate the carbon sequestration and carbon credit potential of the study site, thus contributing to climate change mitigation and sustainable forest management strategy. It will also guide CO initiatives and improve the accuracy of biomass estimation methods in similar forest ecosystems. By developing site-specific allometric models and selecting the most suitable one based on defined evaluation criteria, this research will enhance understanding of the carbon storage capacity of this forest and inform policies for long-term ecological and climate resilience.

Materials and Methods

Study Area

This study was conducted at a rain forest site in Ugbowo, Benin City, Nigeria. The total land area covers 361 hectares and is located at latitude 6° 23' 53.16" N and longitude 5° 36' 54.36" E and latitude 6° 23' 53.16" N and longitude 5° 37' 51.96" E. The study site is situated within two local government areas, i.e., Egor and Ovia North-East local government area, Benin City, Edo, Nigeria (Mitanna, 2021), covering 571.4m^2. Edo State has a total land area of approximately 2,301 km^2. Rock deposits formed during the Cretaceous and Tertiary periods characterize the geology of Edo State. The area experiences high levels of sunlight throughout the year, with some reports indicating over 1600 h of sunshine annually. Sunshine levels vary depending on the season. The natural vegetation in this area is typically similar to that of a tropical lowland rainforest. However, due to human activity over a long period, the original forest has been replaced by a secondary forest that has regrown after significant disturbance.

Data Collection

To assess the carbon sequestration potential, the aboveground biomass was estimated. Therefore, a size-based sampling approach was applied. A total of 173 trees with a diameter at breast height (DBH) greater than 10cm were identified and measured within the study area, representing a total enumeration of all qualifying trees based on the set DBH threshold.

Each tree was marked and identified taxonomically. Key measurements, including tree height (total and merchantable), were taken using a Spiegel relaskop, DBH stick, and measuring tape, determined from top and bottom readings along with horizontal distance using the Spiegel relaskop . Diameters at the base, middle, top, and breast height were also measured using the Relaskop based on the horizontal distance and scale.

Based on these measurements, the basal area and tree volume were calculated using Newton's formula. This dataset formed the basis for estimating the above-ground biomass and subsequently the carbon sequestration potential of the mixed forest stand. To assess the carbon storage capacity, we computed the tree volume, aboveground biomass, belowground biomass, and total ground biomass.

Volume of the Trees

The tree volume was calculated using Newton's formula:

$$V = \frac{\pi H}{24}\left(D_b^2 + 4D_m^2 + D_t^2\right) \qquad \ldots\ldots\ldots\ldots\ldots \qquad (1)$$

Where H is the tree height, Db is the diameter at the base, Dm is the diameter at the middle, and Dt is the diameter at the top. (Brack C., 1997)

Aboveground biomass

AGB includes the stem, branches, leaves, flowers, and fruits of the tree. It was estimated using field data and volume calculated using Newton's formula.

$$AGB = \text{volume} \times \text{density} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (2)$$

A standard wood density of 0.6 g/cm³ was applied when specific density values were unavailable (Orobator and Adahwara, 2022).

Estimating below-ground biomass (BGB)

Below-Ground Biomass was estimated to be 26% of AGB using the following formula:

$BGB = AGB \times 0.26$ (Surabhee *et al.*, 2018) ………………. (3)

Estimation of total biomass

Total biomass (TB) is the sum of AGB and BGB:

$TB = AGB + BGB$ (Dadhich *et al.*, 2023) ………………… (4)

Carbon Content

The carbon content was considered to be 50% of the total biomass:

$C = 0.5 \times TB$ (Vieilledent *et al.*, 2012) ………………. (5)

Carbondioxide (CO_2) Sequestration Estimation

The carbon stock was multiplied by a conversion factor of 3.67 to estimate CO_2 sequestration:

$$CO_2 \text{sequestration} = \text{Carbon value} \times 3.67 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

(Pascua *et al.*, 2021; Orobator and Adahwara, 2022)

Data Analysis

This study used both descriptive and inferential statistical methods to analyze the carbon sequestration data. Descriptive statistics, such as mean and standard deviation, were applied to summarize the measurements, while graphical tools, such as bar charts, helped visualize the carbon distribution trends across the study area. Although measurements were taken only once without replications, the analysis provided valuable insights into the mixed forest stand's carbon storage potential.

Results

This study identified 16 plant families within the uneven-aged plantation at the University of Benin (UNIBEN). These families include: Annonaceae, Bombacaceae, Boraginaceae, Buseraseae, Combretaceae, Fabaceae, Guttiferae, Irvingiaceae, Lamiaceae, Lauraceae, Malvaceae, Meliaceae, Moraceae, Myristicaceae, Rubiaceae, and Sapotaceae. This diversity highlights the forest stand's ecological richness, which plays a crucial role in supporting carbon sequestration through a variety of species contributing to biomass accumulation and carbon storage.

Data Analysis of Aboveground Biomass

Table 1: Comparison of aboveground biomass (kg) between families

Family	Mean	n	SD	AGB	Min	Max
Annonaceae	796.7648	2	781.28654	1593.53	244.31	1349.22
Bombacaceae	872.4920	4	874.87912	3489.97	20.31	2097.05
Boraginaceae	1298.7620	6	908.46590	7792.57	87.22	2221.71
Buseraseae	97.8405	3	74.68179	293.52	15.76	161.78
Combretaceae	469.2431	22	379.58934	10323.35	64.22	1836.08
Fabaceae	452.3846	8	538.18338	3619.08	26.78	1657.25
Guttiferae	103.2680	5	62.88342	516.34	32.23	175.30
Irvingiaceae	99.0574	5	91.45530	495.29	26.46	227.60
Lamiaceae	1461.1310	6	1434.14557	8766.79	16.59	3602.88
Lauraceae	89.4601	1	.	89.46	89.46	89.46
Malvaceae	2210.7378	13	5072.59642	28739.59	8.59	18660.84
Meliaceae	807.8317	51	1983.97663	41199.41	4.51	12110.77
Moraceae	698.3034	3	620.17138	2094.91	58.83	1297.18
Myristicaceae	1419.6650	1	.	1419.67	1419.67	1419.67
Rubiaceae	775.9963	20	962.47417	15519.93	51.70	4532.53
Sapotaceae	971.2623	23	729.57861	22339.03	9.71	2581.92
Total	**857.1817**	**173**	**1865.97822**	**148292.43**	**4.51**	**18660.84**

Note: *n, number* of observations; SD, standard deviation; Min, minimum; Max, maximum

Table 1 shows that the aboveground biomass (AGB) analysis reveals significant variability both across and within different plant families. The overall mean AGB was 857.18 kg, with a high standard deviation of 1865.98 kg, highlighting the diverse biomass accumulation patterns. The mean AGB ranges considerably among families, from a low of 97.84 kg in Buseraseae to a high of 2210.74 kg in Malvaceae. Factors such as species composition, growth rates, and ecological niches influence this variation. Malvaceae and Fabaceae show high standard deviations within families, indicating various AGB among their members. Conversely, Lauraceae exhibited lower variability, implying a more uniform AGB distribution. Outliers, particularly in Malvaceae and Meliaceae, point to species with exceptional biomass accumulation potential. These findings are crucial for understanding the carbon sequestration potential and ecological roles of different plant families. Families with higher mean AGB contribute more to carbon storage and ecosystem productivity. Comprehending AGB distribution is vital for ecosystem management, climate change mitigation, and conservation efforts.

Analysis of Data for Carbon Sequestration

Table 2: Comparison of carbon sequestration (kg) between families

Family	Mean	n	SD	CO_2SEQ	Min	Max
Annonaceae	1840.5268	2	1804.77191	3681.05	564.36	3116.69
Bombacaceae	2015.4564	4	2020.97077	8061.83	46.92	4844.17
Boraginaceae	3000.1401	6	2098.55624	18000.84	201.48	5132.14
Buseraseae	226.0116	3	172.51494	678.03	36.40	373.71
Combretaceae	1083.9515	22	876.85138	23846.93	148.35	4241.34
Fabaceae	1045.0084	8	1243.20360	8360.07	61.87	3828.25
Guttiferae	238.5490	5	145.26071	1192.74	74.46	404.94
Irvingiaceae	228.8225	5	211.26175	1144.11	61.12	525.75
Lamiaceae	3375.2127	6	3312.87627	20251.28	38.31	8322.66
Lauraceae	206.6529	1	.	206.65	206.65	206.65
Malvaceae	5106.8043	13	11717.69772	66388.46	19.83	43106.55
Meliaceae	1866.0911	51	4582.98601	95170.65	10.41	27975.87
Moraceae	1613.0809	3	1432.59588	4839.24	135.90	2996.49
Myristicaceae	3279.4262	1	.	3279.43	3279.43	3279.43
Rubiaceae	1792.5515	20	2223.31532	35851.03	119.43	10470.15
Sapotaceae	2243.6159	23	1685.32658	51603.17	22.43	5964.24
Total	**1980.0896**	**173**	**4310.40969**	**342555.51**	**10.41**	**43106.55**

Note: *n, number* of observations; SD, standard deviation; Min, minimum; Max, maximum

Figure 1 shows that the Malvaceae and Lamiaceae families show several carbon storage capacities across their species, while the Myristicaceae species exhibit remarkable uniformity, storing similar amounts of CO_2 across all members. Some species, particularly within the Malvaceae family, are outliers, storing exceptionally high amounts of carbon.

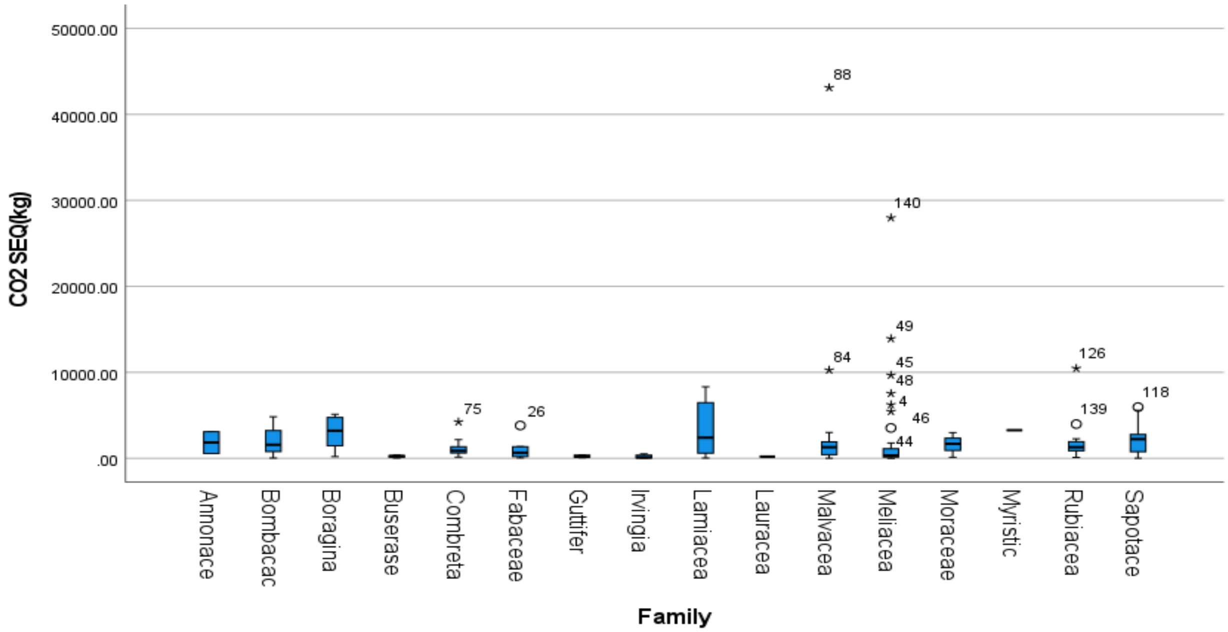

Figure 1: Bar chart of carbon sequestration compared with family size

These differences in carbon storage have significant ecological implications. By understanding the carbon storage abilities of various plant families, the health and climate change mitigation potential of ecosystems can be better evaluated. This knowledge is also valuable for practical applications such as afforestation. Plant families with high carbon storage potential, such as Malvaceae, can be prioritized to enhance the effectiveness of tree planting efforts to combat climate change. However, even families with lower carbon storage capacity contribute to ecosystem resilience and health.

Relationship between carbon sequestration and biomass aboveground

The relationship between AGB and carbon sequestration reveals a clear trend: trees with higher AGB tend to sequester more carbon dioxide (CO_2). This is because larger trees accumulate more biomass through photosynthesis, storing greater amounts of carbon. Although the correlation is positive, it is not perfectly linear, highlighting the influence of other factors, such as tree species, wood density, age, and site conditions.

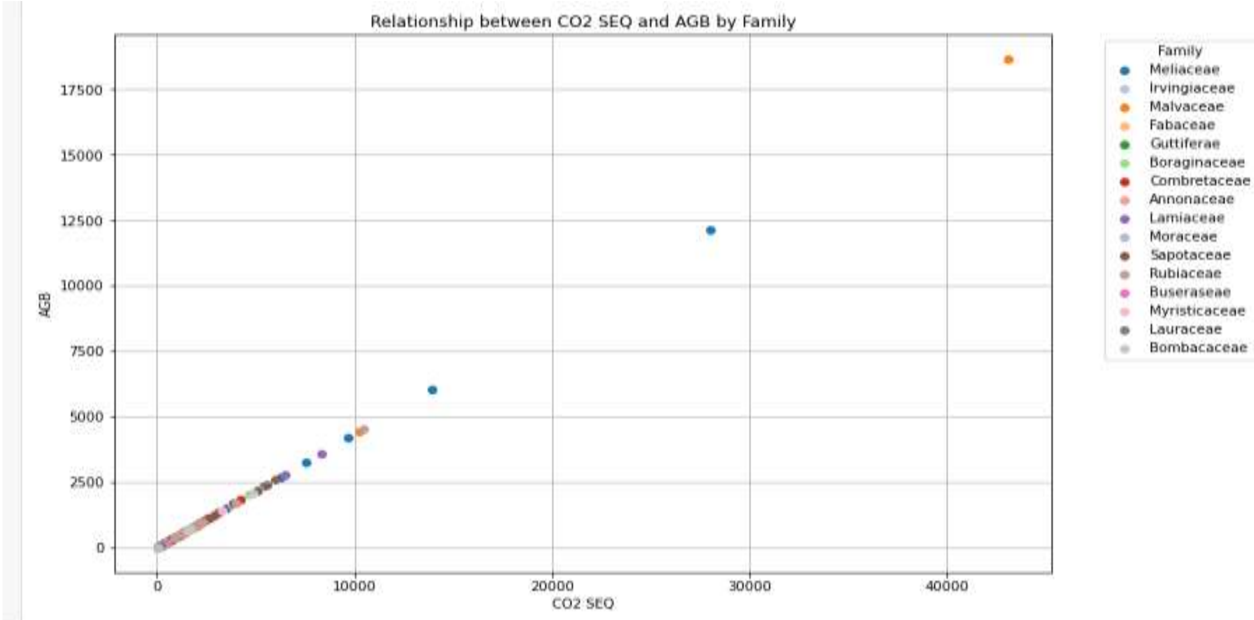

Figure 2: Scattered plot of the relationship between aboveground biomass and carbon sequestration

For instance, species with denser wood or those growing in nutrient-rich environments store more CO_2 for a given size. Younger, fast-growing trees may also sequester CO_2 more rapidly although older trees accumulate more CO_2 over their lifetime. These variations underscore the importance of considering multiple ecological and physiological factors when evaluating the carbon sequestration potential of a forest.

Discussion

The total aboveground biomass in the study area was estimated to be 148,292.428 kg/ha, corresponding to a carbon sequestration potential of 342,555.51 kg/ha. Traditionally, estimating forest biomass relied on measuring the harvested wood from trees. It only considers the harvested wood, neglecting other biomass components such as leaves, branches, roots, and even dead trees. These contribute significantly to the total forest biomass, and it does not account for remaining trees after harvest that still have carbon (Chaturvedi and Singh, 1987). Biomass had a direct relationship with carbon sequestration, with a positive correlation (Westlake, 1963). The estimation of the net release of carbon (C) at the global level is highly uncertain. This high degree of uncertainty is due to the fact that carbon moves through various Earth systems—atmosphere, land, and oceans—with complex interactions. Accurately tracking these transfers across vast areas is challenging, and it ranges from 0.4-1.6 Gigatons (Gt) (109t or 1015g) of C/year to 1.1-3.6 Gt C/year (Houghton, 1993). The Earth's atmosphere is experiencing a worrying trend: carbon dioxide (CO_2) levels are climbing at an alarming rate of 4% per decade (Jo & McPherson, 2001). This rise in CO_2, along with other greenhouse gases, is projected to cause a significant temperature increase of 1.4°C–5.8°C over the next century (Bhadwal & Singh, 2002). The concept of carbon sequestration of trees in this uneven forest is a primary role of carbon estimation and will lead to the estimation of carbon credit (Kumar *et al.,* 2018). The benefits of carbon credit will be a major part of the population's income by conserving forest stands with appropriate care (SEforALL, 2023). Estimation of carbon from these plantations will be a unique approach for biomass production and income from the carbon credit. A carbon credit represents one tonne (1000 kilograms) of carbon dioxide (CO_2) that has been either removed from the atmosphere or prevented from being released. A carbon credit represents the amount of CO_2 a tree can store (like a permit to pollute less), and those credits can be sold to companies that need to offset their emissions (Kumar *et al.*, 2018). Essentially, the trees act like a natural carbon bank, and the credits are a way to value their service of cleaning the air. Carbon credits have been a viable source of income as they have contributed to the development of infrastructures, such as schools, roads, and other amenities (Jindal *et al.*, 2008). The Africa Carbon Markets Initiative (ACMI) estimated that Nigeria could generate as many as 30 million carbon credits annually by 2030. At a price of $20 per credit, the country's Voluntary Carbon Market (VCM) will be worth over half a billion dollars per year. At this level of production, the industry could potentially support over 3 million Nigerian jobs. Moreover, Nigeria has only a portion of Africa's total potential, and the impact on the continent as a whole could be far greater (SEforALL, 2023). Using this rate for the year 2030 for the uneven-age forest, the voluntary carbon market of the forest in this study will be worth an estimated $6,800 dollars annually, which could support grants and scholarships for students and help create a better learning environment.

Conclusion

The UNIBEN uneven-aged forest effectively stores carbon and produces biomass, making it a valuable tool for combating climate change. The plantation's success stems from its ability to thrive under suitable conditions, yielding timber and providing habitat for wildlife. Efficient resource utilization minimizes waste and maximizes growth. The study estimated the total aboveground biomass of the plantation at 148,292.428 kg/ha, translating to a substantial carbon sequestration potential of 342,555.51 kg of CO_2 equivalent. Based on Nigeria's 2022 per capita CO_2 emissions (600 kg) and population (218.5 million), the UNIBEN plantation's carbon storage capacity is equivalent to the annual emissions of 570.93 Nigerians. While acknowledging potential uncertainties from data source limitations (e.g., remote sensing resolution), this finding underscores the plantation's significant contribution to offsetting CO_2 emissions in Nigeria. The conclusion emphasizes the need for the Nigerian government to establish and maintain over a thousand similar uneven-aged plantations. Such an initiative could collectively store CO_2 equivalent to the emissions of 570,930 people, representing roughly 10% of Edo State's population, a monumental step toward mitigating climate change.

Conflict of Interest

The authors declare that there is no competing interest exists.

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