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Carbon Sequestration Potential among Forest Trees In Adamawa State, Nigeria

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Abstract: **The growing impacts of climate change emphasize the urgency for nature-based solutions like forest carbon sequestration, especially in biodiversity-rich areas such as Adamawa State, Nigeria. Forests serve as crucial carbon sinks, helping to offset rising greenhouse gas emissions. The objective of the study is to take inventory of tree species families across the Central Zone of Adamawa State and assess their total carbon sequestration potential (CSP). A non-destructive sampling method was employed to estimate both above- and below-ground biomass. Individual trees were measured for diameter at breast height (DBH), and allometric equations were used to estimate carbon storage. A total of 100 individual trees across 25 tree families were sampled. The result shows that trees within forest areas stored up to 108,048.10 kg of carbon, equivalent to 396,176.37 kg of CO_2. Significant variation in sequestration potential was observed among species. Baobab tree *Adansonia digitata* had the highest carbon content at 58,382.20 kg, equivalent to 214,068.07 kg CO_2, equivalent to 214.07 CO_2 (tons), and *Piliostigma reticulatum* had the lowest with 22.22 kg of carbon content, which is equivalent to 81.47 kg CO_2, equivalent and 0.08 CO_2 equivalent in (tons). From the study, the Malvaceae family has the highest number with 36% and the lowest was recorded in the Fabaceae family with 4%. The findings highlight the vital role forests play in climate mitigation and reveal that indigenous hardwoods possess higher carbon storage capacities. The study provides critical baseline data for integrating forest conservation into national and regional policies, supporting efforts to combat deforestation and safeguard biodiversity and also help reduce the impact of climate change in the region.**

Keywords: **Carbon Sequestration Potentials, Forest, Tree Species, Biomass estimation, Environment.**

1. INTRODUCTION

Ecologically undisturbed forests stores and purify drinking water, can mitigate natural disasters such as drought, and floods, help store carbon, and regulate the climate, they provide food and produce rainfall, and provide a vast array of goods for medicinal, cultural and spiritual purposes (World Wildlife Fund, 2023). In addition, the majority of Nigerians have traditionally relied on the forest for environmental improvement, economic growth, and survival. This is contributing substantially to the National Gross Domestic Product (GDP). In spite of its importance, the natural forest has continued to diminish rapidly in the world especially in Africa as a continent and particularly in Nigeria as a country (WWF, 2023). Apart from providing essential environmental services like uncontaminated air and water, forests also aid in biodiversity preservation and the fight against climate change (FAO, 2015).

Forest provides a wide variety of ecosystem services, including provisioning, regulating, cultural, and supportive services. These ecosystem services not only deliver the basic material needed for survival, but also underlie other aspects of well being, including health, security, good social relations and freedom of choice. In the past, timber production was regarded as the dominant function of forests. However, in recent years this perception has shifted to a more multifunctional and balanced view. Today, it is understood that forest biodiversity underpins a wide ranges of goods and services for human well- being (Tajudeen, 2024).

Forests, which make up almost 30% of the planet's total area, are home to great majority of trees (FAO, 2020). Because they absorb more carbon dioxide from the atmosphere than they emit, forests are crucial to the global carbon cycle (Pan, Birdsey, Fang, Houghton, Kauppi, & Kurz, 2013).

According to FAO (2022), between 1991 and 2003, roughly 25% of the forest cover was destroyed, leaving about 75% of the original forest. Additionally, according to FAO (2022), between 2000 and 2005, the nation lost 55.7% of its whole primary forest, and the annual rate of forest change climbed by 31.2%.

Carbon sequestration is the active removal of carbon from the atmosphere and depositing it in a reservoir (Sadeli, 2013). Although there are various methods of carbon sequestration that are currently being researched such as; satellite imagery methods, models using species coefficients, online modeling programs and laboratory analysis methods, currently the laboratory analysis methods is the most common method used in carbon sequestration and storage in biomass(Jerry, 2016). Arul and Karthick (2013), in their study reported that the total carbon stock sequestration of tree species was determined by non-destructive methods which include, field survey, laboratory analysis and allometric equations. By implementing proper management and forestation policies, the amount of carbon dioxide (CO_2) being sequestered annually by biomass has the potential to increase substantially (Jerry, 2016). Trees act as major CO_2 sink which captures carbon from the atmosphere and acts as sink, stores the same in the form of fixed biomass during the growth process (Skole, Mbow, Mugabowindekwe, Brandt, & Samek, 2021). Active absorption of carbon dioxide (CO_2) from the atmosphere in photosynthetic process and its subsequent storage in the biomass of growing trees or plants is the carbon storage (Sadeli, 2013). Amount of carbon that tree assimilate from atmosphere during photosynthesis process is also define as carbon sequestration (Siraj & Teshome, 2017). Sequestration process will depend on tree growth and mortality. Trees with large diameter sequester more carbon compared to small diameter. Beside, forest with particular management also influence rate of carbon sequestration (Nurum, 2013; Frontiers, 2020).

When a forest is considered as a carbon sink that absorbs atmospheric CO_2, it is assessed in the Kyoto Protocol for one of the carbon sequestration options to reduce the amount of greenhouse gases (FAO, 2020). Apart from its scientific merit in understanding the global carbon cycle, accurate and precise quantification of emissions from land use change has also become a key issue for policy makers considering the recent developments associated with the reduction of the emissions caused by deforestation and degradation (REDD) in developing countries as a climate mitigation strategy.

Terakunpisut, Gajaseni, and Ruankawe (2017) conducted research on carbon sequestration potential in aboveground biomass of Thong Pha Phum National Forest, Thailand. They used a total inventory for woody stem at 4.5 cm diameter at breast height (DBH). Aboveground biomass was estimated using allometric equation and aboveground carbon stock was calculated by multiplying the 0.5 conversion factor to the biomass. The result indicated that carbon sequestration varied in different types of forests tropical rain forest and mixed deciduous forest 137.73 ± 48.07, 70.29 ± 7.38 and 48.14 ± 16.72 tone C/ha, respectively. It further indicated that habitat variability caused differences of biomass accumulation, species composition and the allometric relationships of forests. All forest had a similar pattern of tree size class, with a dominant size class at 4.5-20 cm; with the 4.5- 20 cm trees potentially provided a greater carbon sequestration in tropical rain forest and dry evergreen forest while the size of > 20- 40 cm gave potentially high carbon sequestration in mixed deciduous forest. They conclude that the greatest carbon sequestration potential is in mixed deciduous forest and followed by tropical rain forest and dry evergreen forest, and that appropriate forest ecosystem management can be an alternative solution for carbon dioxide reduction in terms of carbon sink role.

Siraj and Teshome (2017) evaluate the potential difference of trees species in carbon sequestration performance through biomass estimation and quantification in Gambo district. Identification to species level and their diameter at breast height (DBH) and height are recorded using ground measurements. The study finding shows that *G. robusta, P. radiata, C. lusitanica, P. patulla and E. grandis* were ranked 1st, 2nd, 3rd, 4th and 5th in carbon sequestration performance in the same condition respectively. Standard –sized trees have better CO_2 sequestration potential than the sapling and pole –sized. In addition, regression analysis indicated that the rate of CO_2 sequestered and stored on trees are related to the growth characteristics as trunk diameter (DBH) and total height, but not with wood density.

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2. MATERIALS AND METHOD

Study Area: With a total land area of about 6,419.69km2, Adamawa Central is located between latitudes 8^0 38' 47'' and 9^0 50' 17'' North and longitudes 11° 58'54'' and 13° 18' 31'' East. The study area borders the Cameroon Republic to the east, the Local Governments of Mayo-Belwa and Jada to the southwest, Song to the north, and Demsa to the west in Adamawa State. Like all of Guinea Savannah, this region has distinct rainy and dry seasons, and the humidity and temperature change with the season. With 750 to 1000 mm of yearly rainfall on average, the rainy season lasts from April to October (Adebayo,1999).

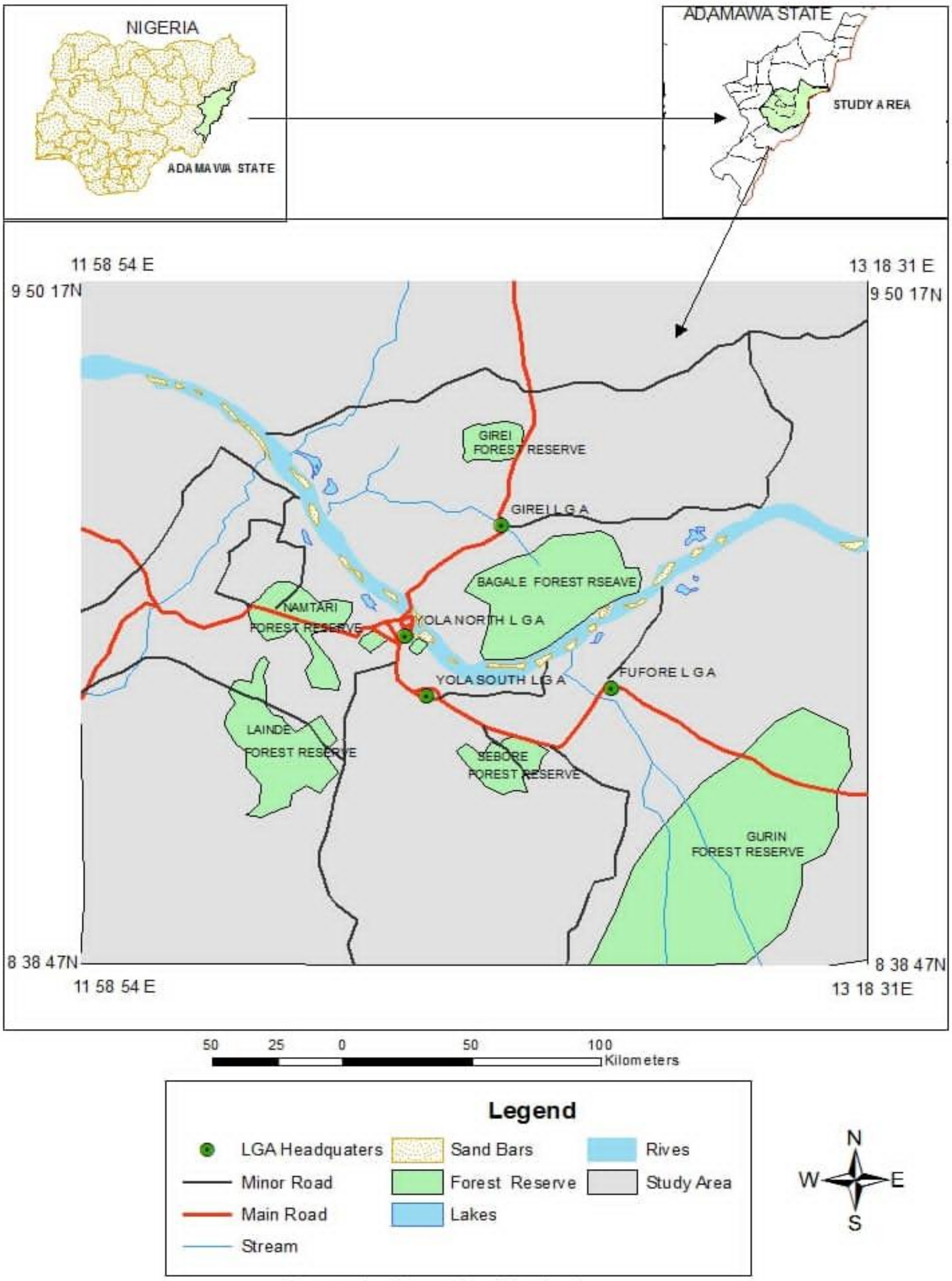

Figure 1: Map of the Study Area

Source: Adamawa State Ministry of Land and Survey

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Methods:

Measuring Tape and handheld GPS were used for data collection. Measuring tape was used to measure the diameter at breast height of individual tree at 1.3m above shoulder height, while GPS was used in taking coordinates of the tree species. The Global Positioning System (GPS) has developed into an efficient GIS data technology, which allows users to compile their own data sets directly from the field as part of the 'ground truthing'. Point data (coordinates) were collected for every tree species in the forests.

However, in the case of Trees inside forest biomass estimation, plot/quadrants sampling techniques was adopted (Sutherland, 1997). In the study of forests, plot with appropriate size is important, although a square plot is often used, the shape of the plot is unimportant as long as you know the area of the plot (Sutherland, 1997). Thus, a plot of 10,000m^2 (1km^2) was delineated in each of the selected forest reserve, namely; Bagale, Gurin and Mayo-Ine (one for each). Diameter at breast hieght of trees in the Forest Reserves were measured; 33 (Bagale), 33 (Gurin) and 34 (Mayo-Ine) (100 trees) for biomass estimation. The Trees were inventoried using systematic random sampling technique (Scott and Deirdre, 2009). A total of 100 trees were sampled and the mean total sample was used for biomass estimation analysis.

The allometric equation following Arul and Karthick, (2013) was used to estimate aboveground and belowground biomass. The allometric equations are given below:

Estimation of aboveground biomass (AGB):

$Y=34.4703- 8.0671D + 0.6589D^2$ ------------------ *Equation* 1

Where Y is above ground biomass, D is diameter at breast height in cm

Estimation of below ground biomass (BGB):

BGB= AGB x (15/100) -------------------------------*Equation* 2

Total biomass (TB):

TB= AGB + BGB ------------------------------------- Equation 3

Estimation of carbon content:

Generally, for any plant species, 50% of its biomass is its carbon content.

Carbon Content = 0.5 X Total Biomass --------Equation 4

Estimation of Carbon dioxide equivalent:

CO_2 equivalent is then calculated using below given equation –

CO_2 (eq.) = (Carbon content X 44)/12 -----------Equation 5

3. RESULTS AND DISCUSSIONS

The biomass of the sampled tree species are presented in table 1. The biomass was based on the diameter of each tree species using allometric equation adopted from Arul and Karthick (2013). Cumulatively, the trees inside forest constituted 25 specie families. In one hundred individual trees sampled each and every individual tree carry its X and Y coordinate in meters, name, frequency and diameter (Dbh). The individual tree diameter is then used on the allometric equation to get its above ground biomass (AGB), below ground biomass (BGB) and total biomass (TB) in kilogram per cubic centimetre. The individual tree total biomass is then added up to get the total biomass stated in the table. The result revealed that the total biomass of trees inside forest were 216096.25kg/cm^3.

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Table 1: Trees Inside Forest Biomass Estimation

S.No	Specie Name	Total No. of Stem	DBH	AGB	BGB	TB(kg/cm3)
1	Chlorofora elcelxer	8	419.1	12518.16	1877.71	14395.87
2	Detarium senegalense	7	278.66	5857.29	878.59	6735.87
3	Anogeissus leiocarpus	7	285.68	6014.26	902.13	6916.39
4	Diasphyrous mispliformis	4	115.91	1428.13	214.22	1642.35
5	Burkea Africana	3	109.87	1951.96	292.79	2244.76
6	Terminalia laxiflora	8	278.03	4884.18	732.63	5616.79
7	Buturuspermum paradoxum	6	239.8	5067.70	760.15	5827.86
8	Adansonia digitata	9	1220.38	101534.27	15230.14	116764.40
9	Tamarindus indica	7	384.39	11770.10	1765.51	13535.60
10	Ptericarpus irinaceous	3	124.2	3184.61	477.68	3662.29
11	Sterculia setigera	4	178.99	4238.91	635.83	4874.73
12	Ficus iteophylla	3	141.08	3964.47	594.67	4559.14
13	Lannea microcarpa	8	327.7	7129.71	1069.47	8199.16
14	Arnebia hispidissima	3	125.8	2598.92	389.84	2988.74
15	Sclerocarya birrea	3	114.33	2061.68	309.25	2370.94
16	Daniellia oliveri	4	184.07	4751.42	712.71	5464.13
17	Piliostigma reticulatum	1	12.74	38.64	5.80	44.44
18	Khaya selegalensis	2	71.98	1243.42	186.52	1429.94
19	Vitex doniana	1	38.22	688.65	103.30	791.94
20	Commiphora Africana	2	46.18	406.51	60.97	467.49
21	Cassia avera	1	22.29	182.03	27.30	209.33
22	Parkia biglibosa	1	57.32	1736.93	260.54	1997.47
23	Stereospermum kunthianum	3	98.09	1466.32	219.95	1686.25
24	Acasia seberiana	1	42.36	875.06	131.26	1006.32
25	Commiphora kerstingii	1	65.29	2316.52	347.48	2664.00
	TOTAL	100				216096.25

AGB= above ground biomass, BGB= below ground biomass, TB= total biomass

Source: Field work, 2024

Carbon sequestration potential of trees inside forest is calculated using their total biomass. The carbon stock in kilogram, carbon dioxide equivalent in Kg and CO_2 equivalent in tonnes of the 25 different families of tree species in the study area which constituted 100 individual trees were determined. The species with highest total carbon stock (kg) is *Adansonia digitata* (no=9) with total carbon content of 58,382.20 kg; 214,068.07 CO_2 Eq (kg), and 214.07 CO_2 Eq (tonnes). Followed by *Chlorofora elcelxer* (no=8) with total carbon stock of 7,197.94kg; 26,392.43 Co_2 Eq (kg) and 26.39 Co_2 Eq (tonnes). Then, *Tamarindus indica* (no=7) has total carbon stock of 6,767.80kg; 24,815.27 Co_2 Eq(kg) and 24.82 Co_2Eq (tonnes). *Lannea microcarpa* (no=8) with total carbon stock of 4,099.58kg; 15,031.79Co_2 Eq(kg), and 15.03 Co_2Eq (tonnes). Followed by *Anogeissus leiocarpus* (no=7) which has total carbon stock of 3,458.20kg; 12,680.05Co_2 Eq(kg), 12.68 Co_2Eq (tones). *Detarium senegalense* (no=7) has total carbon content of 3367.94kg; 12,349.10Co_2 Eq(kg), 12.35Co_2Eq(tones). *Buturuspermum paradoxum (*no=6) has a total carbon stock of 2913.93kg; 10684.41Co_2 Eq(kg), 10.68Co_2Eq(tonnes). *Terminalia laxiflora* (no=8) has a total carbon stock of 2,808.40kg; 10,297.45 Co_2 Eq(kg) and 10.30 Co_2 Eq(tonnes). Carbon stock and CO_2 equivalent of the remaining trees are presented in Table 2. The overall total carbon content of all trees inside forest was 108048.10 kg, 396176.37kg stands for total carbon dioxide equivalent in kilogram and then 396.18 stands for the overall total of carbon dioxide equivalent (in tonnes).

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Table 2: Carbon Sequestration Potential by Trees Inside Forest

S.No	Specie Name	Total No.of Stem	TB(kg)	C.S (Kg)	CO_2 EQ (Kg)	CO_2 EQ (Tons)
1	Chlorofora elcelxer	8	14395.87	7197.94	26392.43	26.39
2	Detarium senegalense	7	6735.87	3367.94	12349.10	12.35
3	Anogeissus leiocarpus	7	6916.39	3458.20	12680.05	12.68
4	Diasphyrous mispliformis	4	1642.35	821.18	3010.98	3.01
5	Burkea Africana	3	2244.76	1122.38	4115.39	4.12
6	Terminalia laxiflora	8	5616.79	2808.40	10297.45	10.30
7	Buturuspermum paradoxum	6	5827.86	2913.93	10684.41	10.68
8	Adansonia digitata	9	116764.40	58382.20	214068.07	214.07
9	Tamarindus indica	7	13535.60	6767.80	24815.27	24.82
10	Ptericarpus irinaceous	3	3662.29	1831.15	6714.20	6.71
11	Sterculia setigera	4	4874.73	2437.37	8937.01	8.94
12	Ficus iteophylla	3	4559.14	2279.57	8358.42	8.36
13	Lannea microcarpa	8	8199.16	4099.58	15031.79	15.03
14	Arnebia hispidissima	3	2988.74	1494.37	5479.36	5.48
15	Sclerocarya birrea	3	2370.94	1185.47	4346.72	4.35
16	Daniellia oliveri	4	5464.13	2732.07	10017.57	10.02
17	Piliostigma reticulatum	1	44.44	22.22	81.47	0.08
18	Khaya selegalensis	2	1429.94	714.97	2621.56	2.62
19	Vitex doniana	1	791.94	395.97	1451.89	1.45
20	Commiphora africana	2	467.49	233.75	857.07	0.86
21	Cassia avera	1	209.33	104.67	383.77	0.38
22	Parkia biglibosa	1	1997.47	998.74	3662.03	3.66
23	Stereospermum kunthianum	3	1686.25	843.13	3091.46	3.09
24	Acasia seberiana	1	1006.32	503.16	1844.92	1.84
25	Commiphora kerstingii	1	2664.00	1332.00	4884.00	4.88
	TOTAL	**100**	**216096.25**	108048.10	396176.37	396.18

TB= Total biomass, C.S=Carbon Stock, CO_2 Eq.kg=Carbon dioxide equivalent in kilogram or tones.

Source: Field work, 2024

This study indicates that trees with larger diameter tends have larger biomass content and hence sequester more carbon. Carbon sequestration potential of trees inside forest in this study showed that trees with larger trunk diameter sequester more carbon than trees with smaller diameter as in table 2. Ishan *et al*. (2013), in their study reported that the higher the diameter of the tree the higher its biomass and tends to have higher carbon storage capacity and sequester more carbon dioxide from the atmosphere. Nurum (2013) and Frontiers (2020) also reported that tree with larger diameter sequester more carbon compared to that of small diameter. This finding also conformed to Stephenson *et al*. (2014) who reported that standard- sized trees have better CO_2 sequestration potential than the sapling and pole – sized. These trees have the biggest merchantable height, trunk diameter and wood density.

4. CONCLUSION

The study reveals that forest trees play a significant role in capturing and storing atmospheric carbon dioxide, thereby contributing to climate change mitigation. The research found that the total biomass of the sampled trees was 216,096.25 kg/cm³, with a corresponding total carbon content of 108,048.10 kg and a carbon dioxide equivalent of 396.18 tonnes. Among the species studied, *Adansonia digitata* exhibited the highest carbon stock, followed by *Chlorofora excelsa*, *Tamarindus indica*, and others. The analysis confirms that trees with larger trunk diameters have greater biomass and, consequently, higher carbon sequestration potential. This pattern aligns with previous studies, emphasizing that mature, standard-sized trees are more effective carbon sinks than smaller or younger trees.

5. RECOMMENDATIONS

1. Given the high carbon sequestration potential of mature trees, efforts should be intensified to conserve existing forests and protect large-diameter trees from logging and other forms of degradation.
2. Initiatives to plant new trees and restore degraded forest areas should prioritize species with proven high carbon sequestration capacities, such as *Adansonia digitata* and *Chlorofora excelsa*.
3. Implementing sustainable management practices that encourage the growth and maintenance of large-diameter trees will enhance carbon storage and support biodiversity.
4. Policymakers should integrate carbon sequestration objectives into forest management and land-use policies, supporting programs that recognize the role of forests as carbon sinks and promote climate change mitigation strategies.
5. Engage local communities in forest conservation activities by raising awareness of the economic and ecological benefits of carbon sequestration, thereby fostering stewardship and sustainable use of forest resources.
6. Continued research is recommended to monitor carbon sequestration trends across different forest types and tree species, which can inform adaptive management and policy decisions.

These recommendations, if implemented, will not only help in mitigating climate change but also enhance the ecological, economic, and social benefits provided by forests in Adamawa State and similar regions.

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