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WOODY PLANT DIVERSITY AND CARBON STORAGE ASSESSMENT IN URBAN SECONDARY SCHOOLS, LAFIA, NASARAWA STATE, NIGERIA

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ABSTRACT
Despite the importance of urban greenery, research on trees in urban schools remains sparse. Hence, this study investigates woody plant diversity and carbon storage in three secondary schools in Lafia, Nasarawa State, Nigeria: Government Science School (GSS) Lafia, GSS Shabu, and GSS Tundun Kauri. Using systematic and random sampling, five plots per school were analyzed for tree diversity, with biomass measurement obtained through allometric equations. Tree diversity was quantified using Shannon and Simpson indices, while carbon storage and CO_2 equivalent were calculated from the biomass data. At GSS Lafia, Plot 2 (West) had the highest species diversity (Shannon index: 1.367, Fisher's alpha: 3.538), while Plot 5 (Central) had the lowest (Shannon index: 0.3488, Fisher's alpha: 0.7972). At GSS Shabu, Plot 2 (West) had the highest diversity (Shannon index: 1.082, Simpson's 1-D: 0.6563), whereas Plots 1 (East), 4 (North), and 5 (Central) had no diversity. GSS Tundun Kauri's Plot 2 (West) showed the highest diversity (Shannon index: 0.6931, evenness: 1), while Plots 2, 4, and 5 had none. Regarding carbon storage, GSS Shabu's Plot 2 (West) had the highest carbon storage of 15,3356.44 kg and CO_2 equivalent of 562.31 tons. In contrast, Plot 5 (Central) at GSS Tundun Kauri had the lowest carbon storage with 16,535.68 kg and CO_2 equivalent of 60.63 tons. GSS Lafia's Plot 2 (West) contributed significantly with CO_2 equivalent of 164.29 tons and carbon storage of 44,808 kg. These findings emphasize the need to maintain tree diversity for optimal carbon sequestration and urban green space management.

Keywords: Biodiversity, carbon storage, Lafia, urban forestry, woody plants

INTRODUCTION

Human activity is drastically accelerating species extinction, pushing the rate towards an unprecedented level far beyond historical norms (Ma *et al.*, 2023), primarily due to anthropogenic environmental changes (Shin *et al.*, 2022). Urban forests offer vital ecosystem services (ES) that enhance environmental quality and human well-being, mitigating air pollution, regulating climate, and promoting urban sustainability (Nawarth *et al*., 2021). These benefits include improved air quality, temperature regulation (Ma *et al.*, 2023; Nawarth *et al.*, 2021), enhanced student performance in schoolyards (Kweon *et al.*, 2017; Shepeley, 2019), contributions to urban food production, and alignment with global sustainability frameworks like the UN SDGs (particularly Goal 11) and the Paris Agreement (United Nations, 2021).

Since the 2005 Millennium Ecosystem Assessment, the ES framework has emphasized the link between biodiversity conservation and human well-being (Shumi *et al.*, 2019), highlighting how increased biodiversity improves essential ecosystem services (Diaz *et al.*, 2018). Biodiversity underpins supporting functions like nutrient cycling, provisioning services like food and timber, regulating mechanisms like climate control, and cultural benefits (Kreman and Miles, 2012), while also bolstering ecosystem resilience (FAO, 2014).

Despite the recognized importance of urban greenery, research specifically examining the role of trees within urban secondary schools remains limited. The lack of green spaces, particularly tree-filled environments, in these schools presents challenges to students' well-being and there engagement with nature (Moussa *et al.*, 2022). While green school environments offer improved air quality, aesthetic appeal, and outdoor learning opportunities, limited research on woody plant diversity in schoolyards hinders understanding of their full ecological and educational potential. This lack of green infrastructure restricts ecological connectivity and student exposure to biodiversity, thus, hindering environmental learning. A comprehensive assessment and management of woody plant diversity in urban secondary schools is crucial to ensure students benefit from improved cognitive performance, stress reduction, and an enriched learning environment.

Numerous studies highlight the global significance of plant species diversity and conservation. For example, Panista *et al*. (2021) demonstrated the need for education in sustainable development by showing how young citizens underestimate plant species richness and ecosystem services. Angessa*et al*. (2019) emphasized the impact of anthropogenic disturbances on woody plant diversity in Ethiopia, advocating for forest rehabilitation. Moussa *et al*. (2022) revealed significant biomass and carbon stock in Niger's urban schoolyard forests but noted students' limited biodiversity knowledge, recommending multipurpose woody species for urban greening and further research on academic performance. In Nigeria, Osabiyav *et al*. (2022) surveyed tree species diversity in protected areas, finding variations in species richness and density. Oyerinde *et al*. (2018) assessed avenue tree species on university campuses, recommending specific tree species for planting to enhance aesthetics and the learning environment. These studies, contribute to a broader understanding of the crucial role of plant diversity in various ecosystems and the importance of conservation efforts.

The present study aims at addressing the shortage of green spaces by assessing woody plant diversity and carbon storage in selected urban secondary schools in Lafia. The objectives are to evaluate woody plant diversity, quantify carbon storage, and determine the carbon dioxide equivalent rate within these school environments. This research will raise environmental awareness, support biodiversity conservation, and contribute to sustainability goals related to sustainable cities, responsible consumption, and climate action (Yale Sustainability, 2024). The findings will provide insights into the role of urban forests in promoting ecological sustainability, a greener future, and enriched educational experiences.

MATERIALS AND METHODS

Study area

The study was carried out in three secondary schools in Lafia namely Government Science School, Lafia, Nasarawa State (Lafia Central), Government Science School, Tudun Kauri Lafia, Nasarawa State (Lafia East) and Government Science School, Shabu Lafia, Nasarawa State, (Lafia North). Lafia, the capital of Nasarawa State in central Nigeria, is strategically located at approximately 8.49° N latitude and 8.52° E longitude within Nigeria's Middle Belt (Figure 1). This region is notable for its cultural diversity and agricultural potential. Lafia experiences a tropical savanna climate, characterized by distinct wet and dry seasons. The annual rainfall ranges from 1,000 – 1,500 mm, primarily occurring between April and October. The dry season, from November to March, sees significantly less rainfall and lower humidity (Wikipedia, 2024). The vegetation in Lafia is predominantly savanna, with grasses and scattered trees, supporting a variety of agricultural activities. Commonly grown vegetables and crops include tomatoes, okra, peppers, spinach, garden eggs (eggplants), and leafy greens such as fluted pumpkin leaves (ugwu) and amaranth. These crops are integral to the local diet and economy. Lafia's position within the tropical savanna zone, with well-distributed rainfall during the wet season, makes it an important agricultural hub in Nigeria (Agidi *et al.*, 2022).

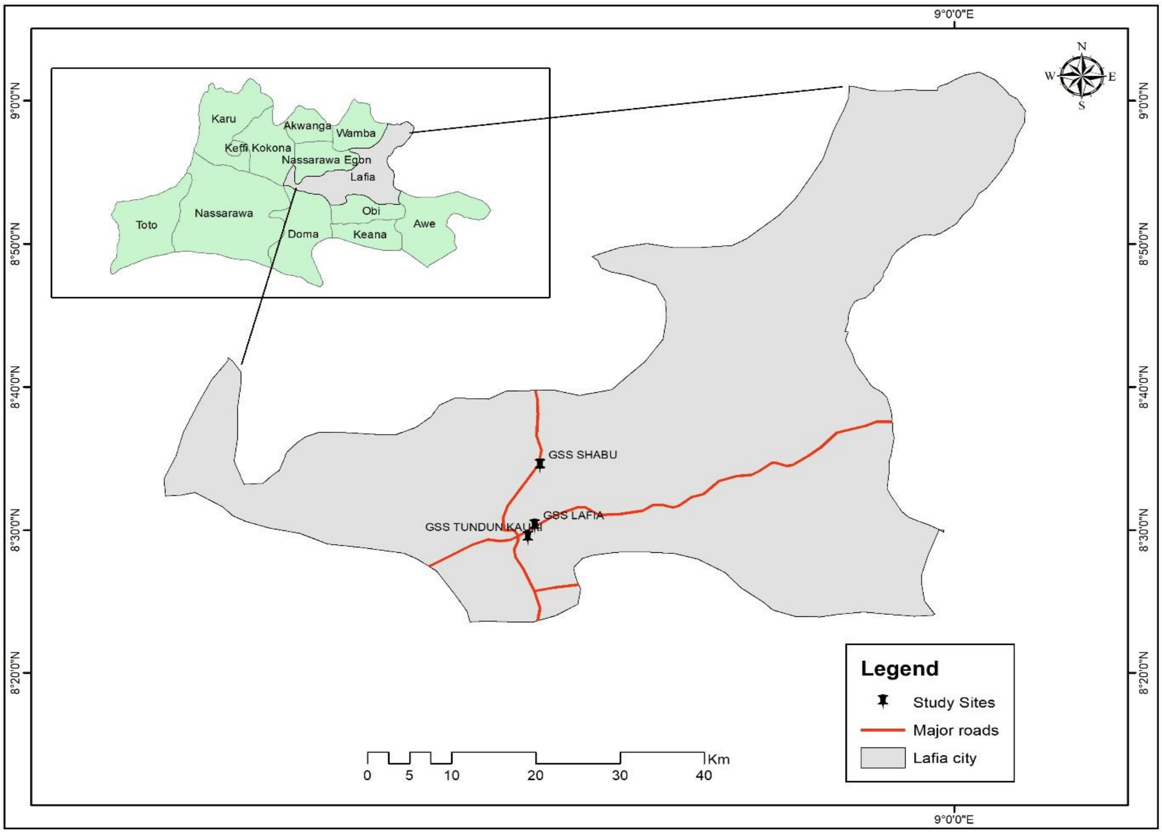

Figure 1: Map of Lafia and the study locations

Sampling design

Systematic and random sampling methods were employed to ensure representation of different areas within each school campus. The total land area of the school was divided into five areas (North, South, East, West and Central). One sample plot (30 x 30 m^2) was established in each of the five areas. The distance between the plots from each other was not less than 50 m. Within each sample plot, five subplots of size 2 x 2 m^2 were established for easier assessment of the woody plant diversity. All tree species within the subplots were identified, counted and recorded. For each tree plant, attributes such as species name and diameter at breast height (DBH) were measured and recorded. GPS coordinates of each sample plot were recorded to ensure accurate mapping.

Species diversity

Species richness (total number of species) and species evenness (distribution of individuals among species) was calculated for each sample plot. Shannon Diversity Index and Simpson's Diversity Index were also calculated to assess overall tree species diversity within each campus.

Estimation of above-ground biomass and below-ground biomass (AGB and BGB)

Above-ground and below-ground biomasses were estimated based on field measurements of diameter at breast height (DBH) of the tree using allometric equations. The equation given below is applicable to dry climates with annual rainfall < 1500 mm (MacDicken, 1997).

$$Above\ Ground\ Biomass = 34.4703 - 8.0671D + 0.6589D^2 \text{ ---------------------- (1)}$$

$$Below\ Ground\ Biomass = Above\ Ground\ Biomass \times (15/100) \text{------------ (2)}$$

Where; D is the Diameter at Breast Height (cm).

Estimation of total biomass (TB)

Total biomass of individual trees is the sum of their above- and below-ground biomasses, respectively, given by the following equation:

$$Total\ Biomass = Above\ Ground\ Biomass + Below\ Ground\ Biomass \text{ ------ (3)}$$

Estimation of carbon content

Generally, for any plant species, 50% of its biomass is its carbon content (IPCC, 2006).

$$Carbon\ Content = 0.5 \times Total\ Biomass \text{ -----------(4)}$$

CO_2 equivalent was calculated using the equation below:

$$CO2\ (eq.) = (Carbon\ content \times 44)/12 \text{ ----------(5)}$$

Data analysis

The diversity indices including the species richness, Shannon index and Simpson index of the woody plants at each secondary school were quantified using the PAST software 3.0. Morte-Carlos permutation test was used to determine the significant differences in the diversity indices between the plots. Principal component analysis (PCA) was used to determine the degree of contribution of the woody species to the woody plant community variation in each school.

RESULTS AND DISCUSSION

Woody plant diversity

Tree plants community characteristics of GSS Lafia

Ten plant species were observed in all the secondary schools sampled (Table 1). Table 2 showed that Plot 2 (West) exhibited the highest diversity with five taxa and eleven individuals, reflecting high biodiversity with a Shannon diversity index of 1.367 and Fisher's alpha of 3.538. It also showed considerable evenness (0.7845), suggesting a relatively balanced distribution of individuals among species. Plot 5 (Central), on the other hand, shows the lowest diversity and evenness, with only two taxa and a dominance index (D) of 0.8025, indicating one species' dominance. The Simpson's index and Shannon index values for Plot 5 are the lowest among the plots, underscoring its reduced biodiversity. The PCA scatter plot illustrates the contributions of different tree species to the overall variation in the community characteristics (Figure 2).

Table 1: List of Woody Plant Species Sampled in all the Three Locations

Scientific Name	Family Name	Common Name
Mangifera indica	Anacardiaceae	Mango
Anacardium occidentale	Anacardiaceae	Cashew Tree
Azadirachta indica	Meliaceae	Neem Tree
Khaya senegalensis	Meliaceae	African Mahogany
Ficus benjamina	Moraceae	Weeping Fig Tree
Ficus citrifolia	Moraceae	Wimba Tree
Gmelina aborea	Lamiaceae	White Teak Tree
Tectona grandis	Lamiaceae	Teak Tree
Delonix regia	Fabaceae	Flame of Forest Tree
Plumeria rubra	Apocynaceae	Frangipani

Table 2: Tree plants community characteristics of GSS Lafia

Parameter	Plot 1 East	Plot 2 West	Plot 3 South	Plot 4 North	Plot 5 Central
Taxa_S	4	5	4	3	2
Individuals	9	11	7	8	9
Dominance_D	0.284	0.3058	0.3878	0.3438	0.8025
Simpson_1-D	0.716	0.6942	0.6122	0.6563	0.1975
Shannon_H	1.311	1.367	1.154	1.082	0.3488
Evenness_e^H/S	0.9273	0.7845	0.7925	0.9837	0.7087
Brillouin	0.9472	0.993	0.7639	0.791	0.2441
Menhinick	1.333	1.508	1.512	1.061	0.6667
Margalef	1.365	1.668	1.542	0.9618	0.4551
Equitability_J	0.9455	0.8492	0.8322	0.9851	0.5033
Fisher_alpha	2.759	3.538	3.878	1.743	0.7972
Berger-Parker	0.3333	0.4545	0.5714	0.375	0.8889
Chao-1	4	8	7	3	2

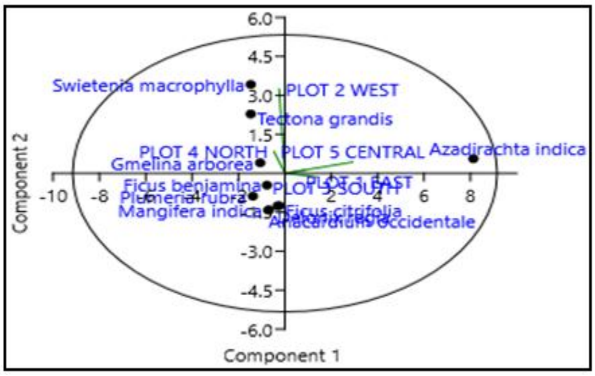

Figure 2: PCA scatter plot showing the contributions of the individual tree species to the pool of variation in GSS Lafia

Tree plants community characteristics of GSS Shabu

Table 3 showed that Plot 2 (West) stood out with the highest diversity, containing three taxa and eight individuals. This plot also had the lowest dominance index (D) of 0.3438 and the highest values for Simpson's diversity index (1-D) and Shannon diversity index (H), at 0.6563 and 1.082, respectively. This suggests a more even distribution of species and greater diversity compared to other plots. In contrast, Plots 1 (East), 4 (North), and 5 (Central) show very low diversity, each with only one taxon. The dominance index for these plots is 1, indicating complete dominance by a single species, which is also reflected in their Simpson's index and Shannon index values, both being zero. Plot 3 (South) has two taxa and two individuals, with moderate diversity indices, including a Shannon index of 0.6931 and a Simpson's index of 0.5. The Evenness (e^H/S) values are at maximum (1) for Plots 1, 3, 4, and 5, indicating that in these plots, where more than one species is present, individuals are evenly distributed. The Brillouin index and other richness indices such as Menhinick and Margalef also reflect similar trends, with Plot 2 showing the highest richness and diversity values.

Table 3: Tree plants community characteristics of GSS Shabu

Parameter	Plot 1 East	Plot 2 West	Plot 3 South	Plot 4 North	Plot 5 Central
Taxa_S	1	3	2	1	1
Individuals	2	8	2	3	2
Dominance_D	1	0.3438	0.5	1	1
Simpson_1-D	0	0.6563	0.5	0	0
Shannon_H	0	1.082	0.6931	0	0
Evenness_e^H/S	1	0.9837	1	1	1
Brillouin	0	0.791	0.3466	0	0
Menhinick	0.7071	1.061	1.414	0.5774	0.7071
Margalef	0	0.9618	1.443	0	0
Equitability_J		0.9851	1		
Fisher_alpha	0.7959	1.743	0	0.5252	0.7959
Berger-Parker	1	0.375	0.5	1	1
Chao-1	1	3	3	1	1

Table 4: Tree plants community characteristics of GSS Tundun Kauri

Parameter	Plot 1 East	Plot 2 West	Plot 3 South	Plot 4 North	Plot 5 Central
Taxa_S	2	1	2	1	1
Individuals	6	1	4	1	1
Dominance_D	0.5	1	0.625	1	1
Simpson_1-D	0.5	0	0.375	0	0
Shannon_H	0.6931	0	0.5623	0	0
Evenness_e^H/S	1	1	0.8774	1	1
Brillouin	0.4993	0	0.3466	0	0
Menhinick	0.8165	1	1	1	1
Margalef	0.5581	0	0.7213	0	0
Equitability_J	1		0.8113		
Fisher_alpha	1.051	0	1.592	0	0
Berger-Parker	0.5	1	0.75	1	1
Chao-1	2	1	2	1	1

Tree plants community characteristics of GSS Tundun Kauri

Table 4 revealed that Plot 1 (East) and Plot 3 (South) display moderate diversity compared to the other plots. Plot 1 has two taxa and six individuals, with a dominance index (D) of 0.5. The Simpson's diversity index (1-D) and Shannon diversity index (H) for Plot 1 are 0.5 and 0.6931, respectively. The evenness (e^H/S) is at maximum (1). Plot 3 also has two taxa but only four individuals, with a slightly higher dominance index (0.625) and lower diversity indices (Simpson's 1-D of 0.375 and Shannon's H of 0.5623). The evenness value is 0.8774, indicating a relatively balanced distribution, though not as evenly distributed as Plot 1. In contrast, Plots 2 (West), 4 (North), and 5 (Central) exhibit very low diversity, each with only one taxon and one individual. The dominance index for these plots is 1, indicating complete dominance by a single species. Consequently, the Simpson's index and Shannon index values are zero, reflecting the absence of diversity. These plots also show maximum evenness values (1), but this is trivial as there is only one species present. The Brillouin index and other richness indices such as Menhinick and Margalef are higher for Plot 1 and Plot 3, reflecting their greater richness and diversity compared to the other plots. Fisher's alpha follows a similar trend, being highest for Plot 3 (1.592), indicating higher species richness.

Carbon storage and CO_2 equivalent at GSS Lafia, Shabu and Tundun Kauri

GSSLafia

The carbon storage and CO_2 emissions at GSS Lafia vary significantly across different plots, as seen in Table 5. The central plot has species such as *Azadirachta indica* (Neem tree) and *Ficus citrifolia* (Wimba Tree), contributing the highest carbon storage with CO_2 emissions of 19.98 tons and 164.29 tons, respectively. The Neem tree, particularly in the west and south plots, also shows substantial carbon storage and CO_2 emissions, indicating its effectiveness in sequestering carbon. *Gmelina arborea* (White teak tree) in the north plot and *Mangifera indica* (Mango) in the south plot also show significant contributions to carbon storage and emissions.

GSS Shabu

At GSS Shabu, Table 6 shows that the north plot contains a *Khaya senegalensis* (Mahogany) tree with a mean DBH of 642.33 cm, which stores the highest amount of carbon (15,3356.44 kg) and has the highest CO_2 emissions (562.31 tons). This indicates that large trees, particularly mahogany, are vital for carbon sequestration. Other significant contributors include the central plot with a *Mangifera indica* (Mango tree) storing 52,400.54 kg of carbon and emitting 192.14 tons of CO_2, and the south plot with another mahogany tree contributing 69,693.24 kg of carbon and 255.54 tons of CO_2 emissions.

GSS Tundun Kauri

In GSS Tundun Kauri, as depicted in Table 7, the east plot with *Mangifera indica* (Mango tree) has the highest carbon storage (27,805.06 kg) and CO_2 emissions (101.95 tons). *Anacardium occidentale* (Cashew tree) is prevalent in multiple plots, showing moderate carbon storage and emissions. The central plot with another Mango tree also contributes significantly with 16,535.68 kg of carbon storage and 60.63 tons of CO_2 emissions.

Table 5: Comparative analysis of tree species and their carbon sequestration capabilities in GSS Lafia

S/N	Scientific name	Family name	Common name	Mean DBH (cm)	AGB (kg)	BGB (kg)	TB (kg)	Carbon (kg)	CO_2 Equivalent (kg)	CO_2 Equivalent (tons)
				EAST						
1	*D. regia*	Fabaceae	Flame of forest Tree	23.00	197.49	29.62	227.11	113.55	416.36	0.42
2	*A. indica*	Meliaceae	Neem tree	154.33	14482.99	2172.45	16655.44	8327.72	30534.97	30.53
3	*T. grandis*	Lamiaceae	Teak tree	71.00	2783.22	417.48	3200.70	1600.35	5867.96	5.87
4	*G. aborea*	Lamiaceae	White teak tree	293.50	54425.90	8163.89	62589.79	31294.90	114747.95	114.75
				WEST						
1	*T. grandis*	Lamiaceae	Teak tree	211.33	27756.37	4163.46	31919.82	15959.91	58519.67	58.52
2	*K. senegalensis*	Meliaceae	African Mahogany	122.00	8857.35	1328.60	10185.95	5092.98	18674.25	18.67
3	*G. arborea*	Lamiaceae	White teak tree	42.00	857.95	128.69	986.64	493.32	1808.85	1.81
4	*F. benjamina*	Moraceae	Weeping fig tree	34.00	521.88	78.28	600.16	300.08	1100.29	1.10
5	*A. indica*	Meliaceae	Neem tree	318.00	64099.74	9614.96	73714.70	36857.35	135143.61	135.14
				SOUTH						
1	*A. indica*	Meliaceae	Neem tree	219.25	29939.45	4490.92	34430.37	17215.19	63122.35	63.12
2	*F. benjamina*	Moraceae	Weeping fig tree	250.00	39198.95	5879.84	45078.79	22539.39	82644.44	82.64
3	*A. occidentale*	Anacardiaceae	Cashew tree	234.00	34225.50	5133.82	39359.32	19679.66	72158.76	72.16
4	*M. indica*	Anacardiaceae	Mango	296.00	55376.79	8306.52	63683.31	31841.65	116752.73	116.75
				NORTH						
1	*G. arborea*	Lamiaceae	White teak tree	252.00	39844.35	5976.65	45821.00	22910.50	84005.16	84.01
2	*T. grandis*	Lamiaceae	Teak tree	210.33	27486.60	4122.99	31609.59	15804.80	57950.92	57.95
3	*P. rubra*	Apocynaceae	Frangipani	280.00	49433.44	7415.02	56848.46	28424.23	104222.17	104.22
				CENTRAL						
1	*A. indica*	Meliaceae	Neem tree	126.00	9478.71	1421.81	10900.52	5450.26	19984.28	19.98
2	*F. citrifolia*	Moraceae	Wimba Tree	350.00	77926.24	11688.94	89615.17	44807.59	164294.48	164.29

Table 6: Comparative analysis of tree species and their carbon sequestration capabilities in GSS Shabu

S/N	Scientific name	Family name	Common name	Mean DBH(cm)	AGB (kg)	BGB (kg)	Total Biomass (kg)	Carbon (kg)	CO_2 Equivalent (kg)	CO_2 Equivalent (tons)
				EAST						
1	*A. indica*	Meliaceae	Neem tree	266.00	44509.75	6676.46	51186.21	25593.11	93841.39	93.84
				WEST						
1	*A. indica*	Meliaceae	Neem tree	179.50	19816.35	2972.45	22788.80	11394.40	41779.47	41.78
2	*T. grandis*	Lamiaceae	Teak tree	157.66	15140.67	2271.10	17411.78	8705.89	31921.59	31.92
3	*G. arborea*	Lamiaceae	White teak tree	133.66	10727.47	1609.12	12336.59	6168.29	22617.08	22.62
				SOUTH						
1	*M. indica*	Anacardiaceae	Mango tree	220.00	30150.47	4522.57	34673.04	17336.52	63567.24	63.57
2	*K. senegalensis*	Meliaceae	African Mahogany	435.00	121205.63	18180.85	139386.48	69693.24	255541.88	255.54
				NORTH						
1	*K. senegalensis*	Meliaceae	African Mahogany	642.33	266706.85	40006.03	306712.88	153356.44	562306.94	562.31
				CENTRAL						
1	*M. indica*	Anacardiaceae	Mango tree	378.00	91131.37	13669.71	104801.08	52400.54	192135.31	192.14

Table 7: Comparative analysis of tree species and their carbon sequestration capabilities in GSS Tundun Kauri

S/N	Scientific name	Family name	Common name	Mean DBH (cm)	AGB (kg)	BGB (kg)	Total Biomass (kg)	Carbon (kg)	CO_2 Equivalent (kg)	CO_2 Equivalent (tons)
				EAST						
1	*M. indica*	Anacardiaceae	Mango tree	277.00	48356.62	7253.49	55610.11	27805.06	101951.88	101.95
2	*A. occidentale*	Anacardiaceae	Cashew tree	84.00	4006.03	600.90	4606.94	2303.47	8446.05	8.45
				WEST						
1	*A. occidentale*	Anacardiaceae	Cashew tree	208.00	26863.16	4029.47	30892.64	15446.32	56636.50	56.64
				SOUTH						
1	*A. occidentale*	Anacardiaceae	Cashew tree	144.00	12535.76	1880.36	14416.12	7208.06	26429.56	26.43
2	*M. indica*	Anacardiaceae	Mango tree	259.00	42144.76	6321.71	48466.48	24233.24	88855.21	88.86
				NORTH						
1	*A. occidentale*	Anacardiaceae	Cashew tree	208.00	26863.16	4029.47	30892.64	15446.32	56636.50	56.64
				CENTRAL						
1	*M. indica*	Anacardiaceae	Mango tree	215.00	28757.70	4313.65	33071.35	16535.68	60630.81	60.63

Woody plant diversity in the urban secondary schools

The study of woody plant diversity encompasses species richness, composition, and structure, and is influenced by various environmental factors and land-use types. In GSS Lafia and GSS Shabu, differences in species richness and diversity indices reflect the influence of these factors. For instance, Plot 2 (West) in GSS Lafia showed high diversity with a Shannon index of 1.367 and a Fisher's alpha of 3.538, indicating a balanced species distribution. Similar patterns were observed in studies conducted in different regions. In Beijing's urban area, spatial patterns of woody plant diversity demonstrate significant differences influenced by geographic coordinates and urbanization (Li *et al.*, 2020).

In GSS Lafia, Plot 2 (West) exhibited the highest diversity with a Shannon diversity index of 1.367 and Fisher's alpha of 3.538, indicating a well-balanced and diverse tree community. This aligns with findings from studies such as Mensah *et al.* (2021), which also reported high biodiversity in urban areas with significant green space management. In contrast, Plot 5 (Central) shows the lowest diversity with a dominance index of 0.8025 and a Shannon index of 0.3488, reflecting a scenario where one species dominates. This mirrors results from studies like Adesina *et al.* (2019), where urban central plots often suffer from reduced biodiversity due to human activities and infrastructure development.

GSS Shabu's Plot 2 (West) stood out with the highest diversity indices, including a Shannon index of 1.082 and a Simpson's index of 0.6563, suggesting a more even species distribution. Similar results were observed in urban forest studies by Oluwole and Adeola (2020), where areas with proactive tree planting and maintenance showed higher diversity. Conversely, Plots 1 (East), 4 (North), and 5 (Central) exhibit very low diversity, each with only one taxon and dominance indices of 1, indicating complete dominance by a single species. This pattern is comparable to the findings of Ojo *et al.* (2018), which highlighted the impact of limited green space and neglect in certain urban zones.

In GSS Tundun Kauri, Plot 1 (East) and Plot 3 (South) displayed moderate diversity, with Shannon indices of 0.6931 and 0.5623, respectively. The evenness values for these plots also suggest a relatively balanced distribution of individuals among species. Studies by Bello *et al.* (2021) on suburban school environments noted similar moderate diversity levels, often influenced by the local microclimate and school gardening initiatives. However, Plots 2 (West), 4 (North), and 5 (Central) show very low diversity with dominance indices of 1, indicative of complete species dominance, consistent with findings from urban studies by Chukwuma *et al.* (2017), where certain plots are neglected or less prioritized in urban planning.

The PCA result for GSS Lafia revealed significant variance captured by the first principal component. This indicates that the majority of variation in tree community characteristics is explained by a single factor, which could be related to species richness or evenness. Similar patterns were observed in studies by Ajayi and Adegboye (2020), where PCA was used to identify key factors influencing urban tree diversity, often linked to environmental and anthropogenic factors.

Carbon storage and CO_2 equivalent among tree species in the urban secondary schools

Our study revealed notable differences in the carbon sequestration capabilities and CO_2 equivalent rates among different species. *Mangifera indica* demonstrates substantial carbon storage across all three locations, with the highest recorded at GSS Shabu (38,610 kg). This aligns with findings from Jagadamma *et al.* (2017), who reported that *Mangifera indica* has a high carbon sequestration potential due to its extensive canopy and biomass. Similarly, the high CO_2 equivalent observed for *Mangifera indica* at GSS Shabu (141,570 kg) suggest a dynamic carbon cycle, consistent with studies by Abraham *et al.* (2018), which emphasize the species' significant respiratory activity and biomass turnover.

Ficus citrifolia showed the highest carbon storage value at GSS Lafia (44,808 kg), indicating its potential as an effective carbon sink in urban environments. This observation is supported by research from Nowak *et al.* (2023), which found that *Ficus species* are efficient in capturing atmospheric CO_2 due to their rapid growth and dense foliage. The high CO_2 equivalent for *Ficus citrifolia* at GSS Lafia (164,294 kg) further corroborates its active metabolic processes, as highlighted by Nowak and Crane (2020).

Anacardium occidentale exhibited notable carbon storage at GSS Lafia (19,680 kg) and moderate levels at GSS Tundun Kauri (6,331 kg), suggesting its adaptability to different environmental conditions. This is consistent with findings by Kalaba *et al.* (2019), who reported that *Anacardium occidentale* can thrive in various climatic conditions and contribute significantly to carbon sequestration.

Khaya senegalensis showed an exceptionally high carbon storage value at GSS Shabu (129,388 kg) and a corresponding high CO_2equivalent (474,423 kg). This is in line with studies by de Carvalho *et al.* (2018), which highlight *Khaya senegalensis's* rapid growth and substantial biomass accumulation, leading to high carbon sequestration and CO_2 rates. The species' ability to store large amounts of carbon makes it a valuable asset for urban forestry projects aimed at enhancing carbon sinks (Carvalho *et al.*, 2018).

The significant carbon storage observed for *Plumeria rubra* at GSS Lafia (28,424 kg) and its high CO_2 equivalent (104,222 kg) reflected its robust carbon cycle. This finding is supported by research from Saha *et al.* (2019), which indicates that *Plumeria* species are effective in sequestering carbon due to their dense biomass and high photosynthetic activity.

CONCLUSION

The study revealed substantial variations in woody plant diversity and carbon storage across the selected secondary schools. The analysis of tree community characteristics indicated significant variations in species diversity among the schools. The overall lower diversity in some other parts of the schools suggests a need for increased species variety to enhance ecological balance. Carbon storage and Carbon dioxide equivalent also varied across the study sites. GSS Shabu, in particular, showed high carbon storage with *Mangifera indica* and *Khaya senegalensis* contributing significantly. This highlights the importance of large tree species in carbon sequestration. GSS Lafia also showed significant carbon storage, with species such as *Ficus citrifolia* and *Anacardium occidentale* contributing notably to absorption of CO_2. GSS Tundun Kauri's data indicated that *Mangifera indica* had the highest carbon storage while other parts with single-species dominance showed minimal carbon benefits. These findings underscore the role of diverse and larger trees in enhancing carbon sequestration and reducing CO_2 emissions. It is recommended that schools adopt strategies to increase tree species diversity, manage existing green spaces effectively, and integrate environmental education into the curriculum. Regular monitoring of tree health and carbon dynamics will ensure that urban school environments continue to provide valuable ecosystem services and contribute to climate change mitigation efforts.

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