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Original Research Article

Carbon Sequestration Potentials of Neem Plant (*Azadirachta Indica* A. Juss.) Along Lokoja-Okene Road for Climate Change Resilience in Kogi State, Nigeria

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Abstract

In recent years, climate change influenced by increased emission of carbon dioxide into the atmosphere has generated serious environmental concerns globally. It is against this backdrop, that this study was carried out to evaluate the carbon sequestration potentials of *Azadirachta indica* along Lokoja-Okene road, Kogi State, Nigeria. Bark, wood, and leaf samples were collected from three different locations namely; Irepeni, Irapana and Osara along Lokoja- Okene highway. The plant tissues were collected at distances of 0, 20, 40, and 100 m from the road. Carbon content was determined using the Walkley and Black wet oxidation method. Data were analyzed using appropriate statistical software and tools. The result revealed that the highest percentage carbon content across all locations were recorded in the bark (62.27 ± 2.88, 58.13±2.82 and 60.08 ± 2.68 for Irepeni, Irapana and Osara respectively). While, the lowest percentage carbon content were recorded in the leaves (28.24±2.89, 25.98±2.89 and 40.53±3.01 for Irepeni, Irapana and Osara respectively). Also, carbon content was influenced by distance from the road, with the highest and lowest percentage carbon content generally recorded at 0 and 100 m respectively, within plant tissues and across the study locations. Tree height showed a negative correlation with percentage carbon content in bark (-0.423) and wood (-0.379), while DBH showed a positive correlation with bark and wood with correlation coefficient (r) values of 0.809 and 0.747 respectively. The study concludes that *A. indica* has appreciable carbon storage potential when compared to other studied tree species and can contribute to roadside vegetation management and climate change mitigation. It was however recommended that *A. indica* should be massively cultivated close to the roadside so as to capture more carbon and to serve as a buffer between carbon pollution and other edible crops in an agroforestry system.

Introduction

Climate change has become one of the most critical environmental challenges globally due to the continuous increase in atmospheric greenhouse gases, especially carbon dioxide (Adebayo et al., 2021). The pollution of the atmosphere by carbon dioxide has risen significantly as a result of anthropogenic activities such as fossil fuel combustion, deforestation, industrialization, urbanization, and unsustainable land-use practices (IPCC, 2021; Upahi et al., 2024). These activities have disrupted the natural carbon cycle and contributed to global warming, altered rainfall patterns, biodiversity loss, desertification, and ecosystem degradation (Adebayo et al., 2021). In Nigeria and other developing countries, rapid infrastructural development and increasing vehicular emissions along highways have further intensified atmospheric carbon accumulation, thereby increasing environmental pollution and climate-related risks (Upahi et al., 2026).

Plant carbon sequestration refers to the absorption and storage of atmospheric carbon dioxide by plants through photosynthesis, where carbon is stored in plant biomass such as roots, bark, leaves, and wood tissues. Among these plants, roadside vegetation can serve as an effective biological tool for improving air quality and reducing environmental carbon loads, especially in areas with high vehicular activities (Amusa et al., 2023).

Among the numerous plant species with environmental importance, *Azadirachta indica* commonly known as neem, has attracted considerable attention because of its fast growth, wide adaptability, and ecological functions. *A. indica* is a multipurpose evergreen tree widely distributed in tropical regions including Nigeria. (Ibrahim et al., 2020) Apart from its medicinal and economic importance, the species contributes immensely to environmental sustainability through shade provision, erosion control and air purification. Its large woody biomass and extensive canopy make it highly suitable for carbon sequestration studies (Awe Djongmo et al., 2019).

Highway environments are characterized by continuous vehicular emissions which release substantial quantities of carbon dioxide and other pollutants into the atmosphere (Ige & Ajiboye, 2024). Vegetation growing along highways therefore plays a critical role in trapping particulate matter, absorbing gaseous pollutants, and sequestering atmospheric carbon. However, despite increasing environmental concerns associated with transportation corridors, roadside vegetation remains underutilized and under-assessed in carbon sequestration research in Nigeria. Most previous studies have focused primarily on urban trees while little attention has been given to roadside species such as *Azadirachta indica* (Adeboye et al., 2023).

Lokoja-Okene Highway in Kogi State experiences intense vehicular movement due to its strategic position linking northern and southern Nigeria. Consequently, the highway corridor is exposed to high atmospheric carbon emissions and environmental disturbances. The vegetation along this highway may therefore provide an important natural mechanism for atmospheric carbon reduction. Evaluating the carbon sequestration potentials of *Azadirachta indica* along highway will contribute to existing literature by addressing the research gap on highway vegetation and its role in climate change mitigation within Kogi State and Nigeria at large. Therefore, this study was aimed at evaluating the carbon sequestration Potentials of *Azadirachta indica* along Lokoja-Okene Road, Kogi State, Nigeria.

Materials and Methods

Description of the Study Area

This research was carried out at three different locations namely; Irapana, Irepeni and Osara along Lokoja-Okene road, Kogi state, Nigeria (Figure 1). The state is located between latitude 07º 30′ N and longitude 06º 42′ E in the North Central region of Nigeria (Figure 1). The state is centrally placed. It has a population of about 3.3 million people as at 2006 census with a total land area of 29, 833 km^2 (Etudaye & Upahi, 2024; Adeboye et al., 2025).

Sample Collection and Preparation

Sampling of *Azadirachta indica* was carried out using the method described by Ige & Ajiboye (2024). Mature *A. indica* found along the three locations were identified and sampled at intervals of approximately 50 meters on both sides of the road. Bark, wood, and leaf samples were collected in triplicates from selected *A. indica* at a distance of 0, 20, 40 and 100 m from the road side.

The collected samples were transported to the laboratory at the department of Biology, Confluence University of Science and Technology Osara, Kogi State in labeled polythene bags. Samples were air-dried at room temperature and further freeze-dried to constant weight. Dried samples were grinded into fine powder using a laboratory grinding machine and stored in labelled envelops prior to analysis (Yahaya et al., 2025).

Determination of Percentage Carbon Content in the plant tissues

The percentage carbon content of the plant tissues was determined using the Walkley & Black (1937) wet oxidation method as adopted by Ibrahim et al., (2018).

Approximately 0.03 g of each powdered sample were weighed into a 250 ml Erlenmeyer flask using a sensitive weighing balance. 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) solution was added into each flask and mixed properly for uniform dispersion. Thereafter, 20 ml of concentrated sulfuric acid (H_2SO_4) was rapidly introduced into the flask while swirling gently to facilitate oxidation. The mixture was allowed for about 30 minutes for complete digestion of organic matter. Following digestion, distilled water was added to dilute the solution, after which 2-3 drops of ferroin indicator was introduced. The resulting mixture was titrated against 0.5N ferrous sulfate solution until the color changes sharply from blue-green to reddish brown, indicating the endpoint. A blank titration without plant sample was also prepared to standardize the dichromate solution. Organic carbon percentage was subsequently calculated using the formula:

$$\text{Organic \% carbon} = \frac{(\text{me K2Cr2O4} - \text{me FeSO4}) \times 0.003 \times 100 \times \text{F}}{\text{g of samples}}$$

Where: me = Normality × Volume of solution used, F is the Correction Factor = 1.33

Data Analyses

Data obtained were subjected to Analysis of Variance (ANOVA) to test for significant difference in means, Duncan Multiple Range Test DMRT at p≤0.05 was used to separate the means. Pearson correlation was used to determine the effect of Tree height and Diameter at Breast Height on the percentage carbon content of the plant tissues. Analyzed data were presented using tables and charts.

Results

Intra-specific Variation in the Mean Percentage Carbon Content of *A. indica*

Figure 2 presents result for the intra-specific variation in the mean percentage carbon content of the bark, wood and leaves of *Azadirachta indica* at Irapana, Irepeni and Osara. Generally, there was significant difference in percentage carbon content between the plant tissues in all the locations across the study area with the highest and lowest percentage carbon content recorded in the bark and leaves respectively in most cases.

At Irapana, the highest percentage carbon content recorded in the bark (58.13±2.82) was significantly higher than the carbon content recorded in the wood and leaves. This was followed by the value recorded in the wood (47.19±2.81) which was significantly higher than the lowest observed in the leaves (25.98±2.89) of *A. indica* (Figure 2). The difference among the tree parts was statistically significant ($P = 0.005$).

At Irepeni, similar trend was observed with Irapana in the sense that, the bark also recorded the highest percentage mean carbon content (62.27±2.88). This was followed by wood (52.70±5.59) the lowest percentage carbon content recorded in the leaves (28.24±2.89) was significantly lower than the carbon content recorded in the bark and wood ($P < 0.001$) of *A. indica* (Figure 2).

At Osara, Unlike Irapana and Irepeni, there was no significant difference in the recorded percentage carbon content of bark and wood of *A. indica*. However, the lowest percentage carbon content recorded in the leaves (40.53±3.01) was significantly lower than that recorded in the other tissues of the plant species at (P = 0.008).

Effect of Distance on the Mean Percentage Carbon Contents in the Tissues of *A. indica*

Table 1 presents the effect of distance from the road on the mean percentage carbon content of bark, wood and leaves of *A. indica* at the three different locations across the study area. Generally, the result revealed a significant difference among distances in all the tissues at each location across the study area.

At Irapana, the highest percentage carbon content recorded at 0 m was significantly higher than all the other distances in all the tissues with the exception of the wood where the highest carbon content recorded at 0 m was similar to that at 20 m but significantly higher than those recorded at 20 and 100 m from the roadside. Also, the lowest percentage carbon content recorded at 100 m from the roadside was significantly lower than all other distances in all the tissues with the exception of that recorded in wood, where the lowest recorded at 100 m was similar to that at 40 m from the roadside (Table 1).

At Irepeni and Osara, similar trend was observed in all the tissues with the exception of wood at Irepeni. The unique trend was such that, the highest carbon content observed at 0 m was significantly higher than all the other distances in all the tissues. This was followed by that recorded at 20 m which was similar to that at 40 m from the roadside. The lowest carbon content observed at 100 m from the roadside was significantly lower than all the other distances (Table 1). However, the highest percentage carbon content recorded at 0 m in the wood of *A. indica* at Irepeni was only significantly higher than the lowest observed at 100 m from the roadside (Table 1)

Relationship between Tree Height, Diameter and Carbon Content of *Azadirachta indica*

Table 2 presents the correlation matrix between tree metrics (tree height and diameter) and percentage carbon content in bark and wood of *A. indica.*

Tree height showed a significant negative correlation with bark carbon content (r = -0.423) and wood carbon content (r = -0.379), statistically significant at $p < 0.05$. However, A strong significant positive correlation was observed between tree diameter and percentage carbon content in Bark and wood with correlation coefficient (r) values of 0.809 and 0.747 respectively (Table 2).

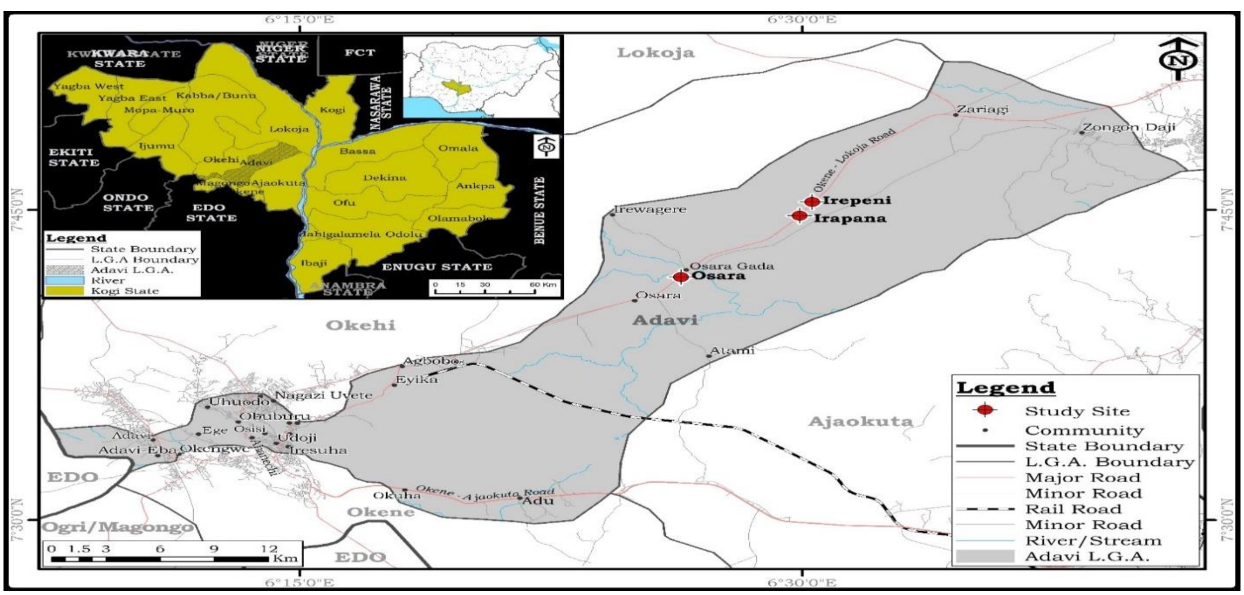

Figure1: Map Showing Sampled sites

Source: OpenStreetMap data.

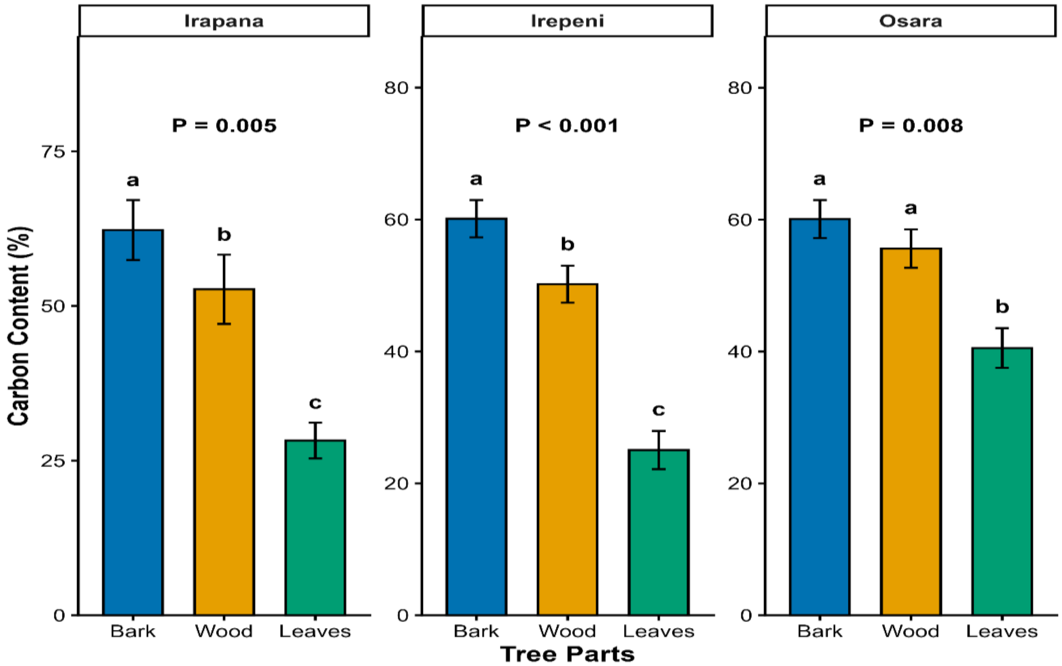

Figure 2: Intra-specific variation of the mean percentage carbon content of *A. indica* across the study area

Table 1; Effect of Distance on the mean % carbon content in the different tissues of *A. indica* across the study area

		% Carbon Content		
Location	Distance	Bark	Wood	Leaves
Irepeni	0	58.71±2.86a	47.38±1.12a	25.93±2.28a
	20	43.03±1.71b	45.53±2.10a	18.96±0.58b
	40	40.03±2.29b	19.45±0.29b	10.91±0.06c
	100	27.90±1.53c	15.40±0.70b	4.08±0.01d
	P value	0.001**	0.000***	0.000***
Irapana	0	52.58±1.66a	53.95±1.00a	26.53±1.00a
	20	35.33±1.22b	50.65±2.17a	13.33±1.07b
	40	32.74±2.05b	48.84±1.53a	11.85±0.70b
	100	10.43±0.26c	15.18±1.22b	6.98±0.58c
	P value	0.003**	0.030*	0.001**
Osara	0	42.58±1.66a	63.95±1.00a	20.53±1.00a
	20	25.33±1.22b	50.65±2.17b	13.33±1.07b
	40	30.74±2.05b	49.84±1.53b	11.85±0.70b
	100	15.43±0.26c	15.18±1.22c	5.18±0.58c
	P value	0.003**	0.000***	0.001**

NB: Means with the same letter(s) within each column are not significantly different ($p \leq 0.05$), using DMRT. ns= non-significant *=significant at $p < 0.05$, **= highly significant at $p < 0.01$, ***= Highest significant at $p < 0.001$.

Table 2: Correlation matrix between Tree height and diameter and % carbon content in bark & wood of *A. indica*

Variable	Height	Diameter	Bark	Wood
Height	1			
Diameter	0.900**	1		
Bark	-0.423*	0.809**	1	
Wood	-0.379*	0.747*	0.804**	1

NB: *=significant at p <0.05 **= highly significant at p <0.01,

Discussion

Intra-specific Variation in Percentage Carbon Content of *A. indica* across the study area

The findings of this study revealed that the carbon content of *Azadirachta indica* varied considerably among different parts of the tree and across the study locations. The significant differences recorded at the three locations indicate that the different parts of the tree did not contain the same amount of carbon. In general, bark and wood recorded higher carbon values than leaves, with bark consistently showing the highest values across all locations. Bark and wood contains similar range of chemical constituents such as cellulose, hemicelluloses, and lignin plus extractives including fats, sterols, terpenes and various polyphenols (Ibrahim et al., 2018) Therefore, the observed high bark carbon content in the plant species could be attributed to tree richness in lignin, suberin, cell wall composition and defense compounds which are carbon-dense compounds that provide structural strength and protection against environmental stress (Zanne, 2009). These findings are consistent with previous studies that have reported higher carbon concentrations in bark and wood tissues compared to leaves. As noted by Nowak et al. (2013), woody tissues accumulate carbon over extended periods through the deposition of lignin, cellulose, and other structural carbohydrates, whereas leaves, being more directly involved in physiological activities such as photosynthesis, respiration, and nutrient exchange, have relatively lower and more variable carbon concentrations.

The observed low carbon content in the wood compared to the bark in the present study may be attributed to woods lower lignin content compared to bark which is characteristic of some tree species (Viera & Soalleiro 2019). This trend of higher bark carbon content compared to the wood could be as a result of the development of specialized bark tissues which produces polymeric materials peculiar to bark eventually acting as additional carbon compounds to lignin thereby increasing the overall carbon compounds in the bark of tree species (Madiwalar et al., 2023).

The variation observed among the three locations also indicates that trees of the same species growing under different environmental conditions may not have identical carbon content. This finding aligns with the observations of Awe Djongmo et al. (2019), who reported that carbon sequestration potential of tree species varies with site conditions, including soil properties, microclimate, and management practices. The observed variation may be related to differences in soil characteristics, water availability, and microclimatic conditions at the different locations along the highway corridor. Amusa et al. (2023) similarly documented location-based variations in carbon stocks of plantation trees in southwestern Nigeria, emphasizing the influence of site-specific factors on carbon accumulation.

Effect of Distance on Percentage Carbon Content of *A. indica* across the Study area

The findings in this study revealed that distance from the road was significantly associated with differences in the carbon content of bark, wood and leaves at the various locations. This finding is consistent with the observations of Adebayo et al. (2021), who reported that roadside vegetation exhibits varying carbon content depending on proximity to emission sources due to differential exposure to vehicular pollutants and carbon dioxide enrichment.

A general pattern observed from the results was that carbon content decrease as distance from the road increased, with the highest and lowest carbon content recorded at 0 and 100 m respectively at the three locations across the study area. This pattern aligns with the findings of Adeboye et al. (2023), who reported that highway vegetation closer to roads exhibited higher carbon content, which they attributed to elevated atmospheric CO_2 concentrations near highways resulting from vehicular emissions. According to Ige & Ajiboye (2024), plants growing in proximity to high-traffic roads are exposed to elevated CO_2 concentrations, which can stimulate photosynthesis and increase carbon accumulation in plant tissues, a phenomenon known as the CO_2 fertilization effect.

The reduction in carbon content with increasing distance from the road is important because it demonstrates that the carbon characteristics of the sampled trees varied along the road-distance gradient. This finding has practical implications for roadside vegetation management. As noted by Bununu et al. (2023), roadside vegetation plays a critical role in mitigating vehicular emissions and should be strategically managed to maximize carbon sequestration benefits. The results suggest that trees growing closest to the road (0 m) may have the greatest carbon storage potential, possibly due to their exposure to higher CO_2 concentrations from vehicular emissions.

Relationship between Tree Metrics and Percentage Carbon Content of *A. indica*

Tree height showed negative correlations with percentage carbon content in bark and wood. This finding suggests an inverse relationship within the sampled trees such that increases in height were associated with decreases in the measured carbon content of bark and wood. However, tree diameter showed positive correlations with bark and wood carbon content, with the relationship between diameter and bark percentage carbon content being particularly strong. The correlation between tree height and carbon content in both bark and wood suggests that taller trees may allocate carbon resources towards vertical growth rather than radial expansion. Meanwhile, the positive correlation between tree diameter and percentage carbon content is an indication that larger trees possess greater biomass thereby acting as more substantial carbon sinks. These findings are consistent with the observations of Ibrahim et al. (2018), who reported that tree diameter was a better predictor of carbon storage than height in urban tree species due to the fact that diameter provides a more direct indication of the amount of stem development and woody material present in a tree. Also, Nowak et al. (2013), emphasized that diameter at breast height (DBH) is a more reliable predictor of tree biomass and carbon content than height because it directly reflects the volume of woody tissue accumulated over the tree's lifetime.

Conclusion

Azadirachta indica showed variation in carbon content, with wood and bark generally having higher carbon content than leaves. The highest percentage carbon content (62.27 ± 2.88) was recorded in the bark. While, the lowest percentage carbon content (25.98±2.89) was recorded in the leaves. Also, carbon content was influenced by distance from the road, with the highest and lowest percentage carbon content generally recorded at 0 m and 100 m respectively, within plant tissues and across the study locations. Tree height showed a negative correlation with percentage carbon content in bark (-0.423) and wood (-0.379), while DBH showed a positive correlation with bark and wood with correlation coefficient (r) values of 0.809 and 0.747 respectively, indicating that trees with larger diameter generally have greater potential for carbon storage.

Recommendations

In view of these findings, it is recommended that *A. indica* should be massively cultivated since their barks are used for medicinal purposes and has also contributed significantly to the storage of CO_2 from the atmosphere. Also, further studies on other tree species and shrubs should be carried out to compare their carbon sequestration potentials particularly with respect to the different parts. Also, it is recommended that the plantation of tree species should be done close to the roadside so as to capture more carbon and to serve as a buffer between carbon pollution and other edible crops in an agroforestry system

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Conflict of Interest

The authors unanimously declare that there is no conflict of interest regarding the publication of this article.

Author Contribution

Upahi, L. drafted the research, analysed and interpreted the data, Aina, O. A. discussed the findings, Owoleke, V. A. and Yahaya, R. A. revised the work. All authors reviewed the findings and approved the final version of the manuscript.

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