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Quantification of Above-Ground Biomass and Carbon Sequestration Potential of Roadside Trees in the Plateau Department of Benin Republic

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Abstract

Roadside trees are effective natural solutions for mitigating climate change. Despite the usefulness of trees to carbon sequestration, there is a dearth of information on the estimation of biomass and carbon stock for roadside trees in the study area. This study aimed to estimate the carbon stock and carbon dioxide equivalent of roadside trees. A complete enumeration of trees was carried out in Kétou, Pobè and Sakété within the communes of the Plateau Department, Bénin Republic. Total height and diameter at breast height were measured from trees along the roads while individual wood density value was obtained from wood density database. The allometric method of biomass estimation was adopted for the research. The results showed that the total estimations for above-ground biomass, carbon stock and carbon equivalent from all the enumerated roadside trees were 154.53 mt, 72.63 mt and 266.55 mt, respectively. The results imply that the roadside trees contain a substantial amount of carbon stock that can contribute to climate change mitigation through carbon sequestration.

Keywords

Above-Ground Biomass, Allometric Model, Carbon Sequestration, Roadside Trees, Bénin Republic

1. Introduction

Urban trees play a crucial role in mitigating the effects of climate change. Due to the accumulation of greenhouse gases in the atmosphere, particularly carbon dioxide, global temperatures have significantly risen (CO_2), and the environment and people's well-being are being negatively impacted by this predicament (Murray & Ebi, 2012). To mitigate the consequences of climate change, a number of measures have been proposed, such as the use of natural carbon sinks like forests, wetlands, and agricultural regions (Murray & Ebi, 2012). Roadside trees have been cited as one of the most effective natural solutions for minimizing climate change, since they also capture carbon dioxide from the environment via photosynthesis and store it in their biomass (Adotey et al., 2022).

The process of determining the quantity of biomass and carbon stored in a certain ecosystem or land use system, such as trees planted along streets, is referred to as a biomass and carbon stock estimate. The ability to quantify the amount of carbon that is stored in urban trees is what gives carbon stock estimation its significance when it comes to understanding the contribution of street trees to carbon sequestration in a given area (IPCC, 2009). The ability to quantify the amount of carbon stored in urban trees can help determine the potential of those trees to mitigate climate change. Street trees are an essential component of urban forests because they offer a broad variety of ecological services, one of which is the storage of carbon dioxide. Allometric equations are statistical models that relate tree biomass to a variety of variables, such as tree diameter and/or height, wood-specific gravity, or forest type (Fayolle et al., 2018).

Several studies, using allometric equations, have shown how important it is to estimate the carbon stock to understand how street trees help sequester carbon in Sub-Saharan Africa. For example, in a study conducted by Aabeyir et al. (2020), the authors developed and applied a local mixed-species allometric model for estimating above-ground biomass (AGB) in the savannah woodlands of Ghana and concluded that the use of only diameter at breast height (Dbh) as a predictor of AGB is widely acknowledged compared to the inclusion of wood density (ρ) and height (H). In the Republic of Congo, Ekoungoulou et al. (2014) used allometric equations to estimate the carbon stocks of above-ground biomass (AGB) in the Lesio-louna tropical rainforest and the study found that the forest ecosystem contained substantial amount of carbon stock. In the same vein, Chabi et al. (2016) contrasted Model III, which uses Dbh, height, and wood density, with Model II, which uses simply Dbh and height and Model I which relies solely on Dbh. The authors suggested that the allometric model Type I could be used effectively to estimate biomass and carbon stock instead of using Models II and III which are more complex to apply.

Despite the usefulness of trees to carbon sequestration, there is a dearth of information on the estimation of biomass and carbon stock for roadside trees in many parts of Sub-Saharan Africa, including the Plateau Department of the Republic of Bénin. Accurate estimation of carbon stock and carbon dioxide equivalent (CO_2e) of above-ground biomass of roadside trees is critical to assessing their potential for carbon sequestration and climate change mitigation in urban areas. Therefore, this study aimed to estimate the carbon stock and carbon dioxide equivalent of above-ground biomass of roadside trees in the Plateau Department of the Republic of Bénin.

2. Materials and Methods

2.1. Study Area

The study was conducted within three communes of the Plateau Department (**Figure 1**), namely Kétou, Pobè and Sakété. The Department of Plateau is located in the north of the Collines Department, east of the Federal Republic of Nigeria, west of the Zou Department and south of the Ouémé Department. It is composed of five communes, namely Kétou, Pobè, Adja-Ouèrè, Sakété and Ifangni, with a

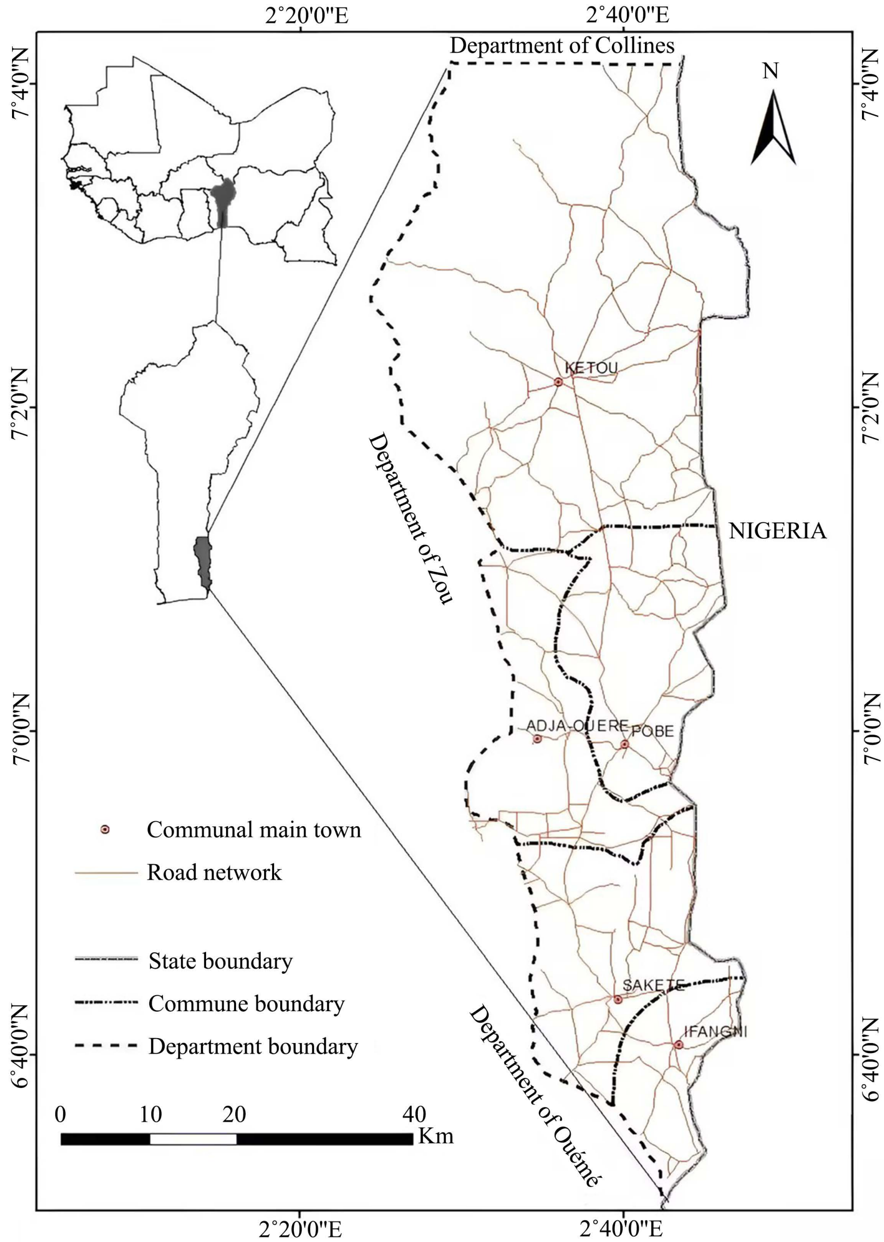

Figure 1. Map of the study area.

total land area of 3264 km^2 according to Akoègninou and Lisowski (2004), representing about 3% of the country total land area. The area is situated in the Guinean-Congolese region between latitudes 6˚25'N and 7˚50'N and longitudes 2.5˚E and 3˚E (Adomou et al., 2007). The climate is sub-equatorial with two rainy seasons and two dry seasons with an average annual rainfall of 1300 mm. The soils of the region are mainly ferralitic, vertisols, hydromorphic soils and tropical ferruginous soils (Azontondé, 1991). The vegetation consists mainly of wooded and shrubby savannahs, selected palm groves, shrubby fallows, patches of semi-deciduous forest, gallery forests and mangroves.

2.2. Data Collection

The assessment of above-ground biomass was conducted on trees along important streets and highways in Kétou, Pobè and Sakété as part of a field survey. All perennial tree species having a diameter at breast height of less than 10 centimeters were identified and documented using their scientific names. The height and diameter at breast height (Dbh at 1.3 m above the ground) of each living woody plant species were measured in meters and centimeters, respectively. Multiple-stemmed woody plants at 1.3 m in height were counted as a single individual, and the diameter tape and Suunto Hypsometer were used to measure the Dbh of the biggest stem. During the Dbh measurement, there were a few measurement instances, such as leaning trees on flat land. The breast height was measured on the leaning side of the tree. In addition, for trees that are on a slope, such as up and down, the breast height was measured at the slope's highest point. For the unknown tree species, an average wood density value of 0.6 g/cm^3 was utilized in agreement with the stated range of 0.58 to 0.67 g/cm^3 for the wood density of trees in Africa. The total carbon stock was then converted to metric tons of carbon dioxide (CO_2) equivalent by multiplying it by 44/12, or 3.67, of the CO_2 to O_2 molecular weight ratio in order to determine the climate change mitigation, the trees in the research area in addition, an evaluation of the floristic makeup of the research region was conducted in order to identify tree species and their families.

3. Data Analysis

Estimation of total above-ground biomass, carbon stock and carbon dioxide equivalent were carried out with the help of an already developed and validated allometric equation of Fayolle et al. (2018) which is given as:

$$AGB_{est} = 0.125 * WSG^{1.079} * Dbh^{2.210} * H^{0.506},$$

where AGB is the above-ground biomass, WSG is wood density, Dbh is diameter at breast height while H stands for total tree height. This model Type III was chosen for application because the essential three growth parameters; Dbh, H and wood density were easily obtained for the study area. All field measurement data was subjected to statistical analysis using Statgraphics Centurion 18 Version software.

4. Results and Discussion

The results of descriptive statistics are presented in **Table 1**. The dataset analysed consists of 1002 trees, with parameters such as diameter at breast height (Dbh), total height, volume, above-ground biomass (AGB), carbon content, and carbon dioxide equivalent (CO_2e). The average values are: 16.5 cm for Dbh, 7.4 meters for total height, 0.13 cubic meters for volume, 154.2 kg for AGB, 72.5 kg for carbon content, and 266.0 kg for CO_2e. The minimum values observed include 5.1 cm for Dbh, 3.0 meters for total height, 0.004 cubic meters for volume, 4.37 kg for AGB, 2.05 kg for carbon content, and 7.52 kg for CO_2e. Conversely, the maximum values are: 98.2 cm for Dbh, 77.0 meters for total height, 2.58 cubic meters for volume, 5063.31 kg for AGB, 2379.76 kg for carbon content, and 8733.72 kg for CO_2e. The dataset offers a comprehensive understanding of tree parameters, which can inform researchers and policymakers in making decisions related to forest management and conservation efforts.

Table 2 shows a frequency distribution of data organized into 11 class intervals, with each interval containing a specific number of occurrences. The data range from 5.1 to 100.1 and are unevenly distributed across the class intervals. The highest frequency, 272 occurrences, is found in the 10.1 - 15.1 interval, while the lowest frequency, just one occurrence, appears in the 50.1 - 55.1, 90.1 - 95.1, and 95.1 - 100.1 intervals. Other intervals show varying frequencies: 252 occurrences in the 5.1 - 10.1 interval, 173 occurrences in the 15.1 - 20.1 interval, 131 occurrences in the 20.1 - 25.1 interval. This distribution allows for the identification of trends and patterns within the dataset. It is evident that most data points fall within lower intervals, while higher intervals have fewer occurrences. By analysing the frequency distribution, researchers can gain insights into the underlying data and make more informed decisions based on the observed patterns. The table thus serves as a useful tool for summarizing and visualizing large datasets.

Table 3 provides an overview of the above-ground carbon stock for various tree species. It presents data on the tree species, botanical family, biomass, carbon content, and potential CO_2 equivalent. The table lists 17 different tree species, each belonging to a specific botanical family. *Khaya senegalensis* (Meliaceae family) has the highest values for biomass, carbon, and CO_2 among all listed species while *Casuarina equisetifolia* (Casuarinaceae family) and *Tectona grandis* (Verbenaceae family) have the lowest values for biomass, carbon, and CO_2

Table 1. Descriptive statistics of tree growth parameters.

	Dbh (cm)	Th (m)	Vol (m^3)	AGB (kg)	Carbon (kg)	CO_2e
Mean	16.5	7.4	0.13	154.2	72.5	266.0
Minimum	5.1	3.0	0.004	4.37	2.05	7.52
Maximum	98.2	77.0	2.58	5063.31	2379.7	8733.72
No. of Trees	1002	1002	1002	1002	1002	1002

Table 2. Distribution of trees by diameter class in the study area.

Diameter Class	Frequency
5.1 - 10.1	252
10.1 - 15.1	272
15.1 - 20.1	173
20.1 - 25.1	131
25.1 - 30.1	77
30.1 - 35.1	62
35.1 - 40.1	30
40.1 - 45.1	2
50.1 - 55.1	1
90.1 - 95.1	1
95.1 - 100.1	1

Table 3. Above-ground biomass, carbon stock and carbon dioxide equivalent of tree species.

Tree Species	Families	ABG (kg)	Carbon Stock (kg)	CO_2e (kg)
khaya senegalensis	Meliaceae	120504.39	56637.06	207858.14
Ficus spp.	Moraceae	549.05	258.05	947.05
Mangifera indica	Anacardiaceae	521.47	245.09	899.49
Gmelina arborea	Verbenaceae	144.14	67.76	248.69
Salix babylonica	Salicaceae	160.48	75.43	276.83
Casuarina spp.	Casuarinaceae	46.21	21.72	79.71
Azadirachta indica	Meliaceae	4922.87	2313.75	8491.46
Terminalia mentali	Combretaceae	9054.49	4255.65	15618.24
Cocos nucifera	Arecaceae	561.81	264.05	969.06
Terminalia catappa	Combretaceae	10408.55	4892.08	17953.9
Roystonea regia	Arecaceae	688.42	323.56	1187.47
Terminalia superba	Combretaceae	5816.12	2733.58	10032.26
Tectona grandis	Verbenaceae	65.82	30.94	113.55
Eucalyptus spp.	Myrtaceae	108.51	51.0	187.17
Anacardium spp.	Anacardiaceae	267.37	125.66	461.17
Blighia sapida	Sapindaceae	647.45	304.3	1116.78
Acacia auriculoformis	Fabaceae	60.26	28.32	103.94
Total		**154527.41**	**72628**	**266544.91**

Note: AGB (kg) = above-ground biomass; CO_2e (kg) = carbon dioxide equivalent.

among the listed species). The total above-ground biomass for all listed species is 154527.41 kg (or 154.53 metric tons), the total carbon is 72,628 kg (or 72.63 metric tons), and the total CO_2 equivalent is 266544.91 kg (or 266.54 metric tons). This information is essential for understanding the potential of each tree species to contribute to climate change mitigation efforts. The above-ground carbon stock of various tree species and their families emphasises the role of trees in storing carbon and their potential contribution to climate change mitigation efforts in the study area. A similar trend was observed by Agbelade and Onyekwelu (2020) in their research work on the benefits of urban trees.

5. Conclusion

The study analysed a dataset of 1002 trees and reported on various parameters, including diameter at breast height (Dbh), total height, volume, above-ground biomass (AGB), carbon content, and carbon dioxide equivalent. Descriptive statistics presented in **Table 1** showed that, on average, trees had a Dbh of 16.5 cm, a total height of 7.4 meters, a volume of 0.13 cubic meters, an AGB of 154.2 kg, a carbon content of 72.5 kg, and a CO_2e of 266.0 kg. In addition, the diameter distribution shows that the majority of data points fall within lower intervals, while higher intervals have fewer occurrences. It was observed from the study that the above-ground biomass, carbon content, and potential CO_2e equivalent are being protected by street trees. *Khaya senegalensis* has the highest values for biomass, carbon, and CO_2e among all listed species and it is the most preferred tree species for urban use while *Casuarina equisetifolia* and *Tectona grandis* have the lowest values. The total above-ground biomass for all listed species is 154.53 metric tons, with a total carbon of 72.63 metric tons and a total CO_2e equivalent of 266.54 metric tons. This study highlights the significant role of trees in storing carbon and their potential contribution to climate change mitigation efforts in the study area and will enable town planning agents and environmentalists to focus more on urban tree planting and conservation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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