Nigerian Journal of Environmental Sciences and Technology (NIJEST)
www.nijest.com
ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603
Vol 6, No. 1 March 2022, pp 214 - 224

Estimation of Carbon Storage and Sequestration by Tropical Urban Trees in Benin City, Edo State, Nigeria

Orobator P. O.[1,]* and Adahwara P. O.[1]
[1]Department of Geography and Regional Planning, Faculty of Social Sciences, University of Benin, Benin City, Edo State, Nigeria
Corresponding Author: *orobosa.orobator@uniben.edu

https://doi.org/10.36263/nijest.2022.01.0347

ABSTRACT

The present investigation was conducted to estimate carbon storage and sequestration by tropical urban trees in Benin City, Edo State, Nigeria. The non-destructive approach was adopted for the study with 65 trees out of 13 species randomly selected from Black Afara (Terminalia invorensis), Aridan (Tetrapleura tetraptera), Orange (Citrius sinensis), Ashoka (Polyathia longifolia), Teak (Tectona grandis), Oocarpa pine (Pinus oocarpa), Umbrella tree (Terminalia mantaly), Flame of the forest (Delonix regia), Opepe (Naucloa diderrichii), Dogoyaro (Azadirachta indica), Weeping fig (Ficus benjamina), Omo (Cordia melleni) and African Oil Bean (Pentacleethra macrophylla). Diameter at breast height, tree height and wood density were used as predicator variables to estimate total biomass, carbon storage and sequestration. The results revealed that estimations for total biomass were 797.23 kg while total carbon storage and total carbon dioxide sequestration were 398.67 kg and 1462.76 kg respectively. Out of the recorded 797.23 kg total biomass, above ground biomass was 632.76 kg while below ground biomass was 164.47 kg. The findings showed that Terminalia mantaly, Delonix regia and Cordia melleni had better carbon storage and sequestration capabilities. Our study recommended the cultivation of Terminalia mantaly, Delonix regia and Cordia melleni species in Benin City as a strategy for mitigating climate change effects and supporting environmental services. The findings of this investigation can offer significant data for urban forestry plans targeted at selecting suitable blend of tropical trees with superior carbon storage and sequestration performances.

Keywords: Carbon storage, Climate change, Diameter at breast height, Greenhouse gases, Tree height, Urban forestry

1.0. Introduction

One of the burning issues in contemporary time is the problem of change in climatic conditions and the damaging role greenhouse gases play in the fluctuating temperatures (Vishnu and Patil, 2016). The constantly increasing temperatures at global level will result to different impacts comprising of upsurge in atmospheric gaseous form of water, dissimilar losses from forests, modification in vegetation and its composition, amplified ocean acidification, life-threatening flooding, increase in weather events and altering of ecosystems that will possibly modify biological diversity (King, 2005). Metropolises are accountable for more than 80 % of global greenhouse gas emissions (Hoornweg *et al*., 2011) and this climaxes the role of urban areas for carbon dioxide (CO_2) emissions. United Nations (UN) (2015) stated that more than half of the world's populace currently resides in urban areas, in addition, this number will continue to surge at a proportion of 4% a decade by 2050. As municipal milieus become more central as dwelling spaces for humans, they are an amassing source of carbon emissions. Therefore, besides climate change, soaring urbanization have expanded our need to make cities more sustainable. Urban trees are often advocated as a means to that end (Erker and Townsend, 2019).

The capturing of carbon from the atmosphere and cumulatively storing it within diverse components of the ecosystem is referred to as carbon sequestration and urban trees in vegetative spaces can in detail sequester and store large amounts of carbon (Nowak and Crane, 2002). The estimation of carbon sequestration is hinged on the type of tree species and its growth physiognomies (Lawrence *et al.*, 2012). Carbon sequestration mitigation ability of urban trees can be considered a regulating ecosystem service by reducing the unwanted greenhouse gases in the atmosphere through capturing these gases and storing them (Nunes *et al*., 2019). Carbon capture and storage could help lessen global greenhouse gas emissions by 14 % by 2050, which totals 120 billion tons of captured and stored CO_2 between 2015 and 2050 (International Energy Agency, 2019). Tropical trees are specifically adapted to live in hot, wet climates or environments where it can be very dry and they are the unvalued heroes of our urban area whose roles cannot be over highlighted.

Urban trees are strategic components of the green substructure envisioned to make our growing cities more ecological in this period of climate change (Erker and Townsend, 2019). Estimation of carbon storage by tropical trees in municipal environments would be beneficial for evaluating environmental and economic benefits of the ecosystems. Urban trees influence local climate, carbon cycles, energy use and climate change but are repeatedly overlooked since their ecosystem services are not well understood or quantified (Nowak *et al*., 2013). Aboveground biomass (AGB) plays a significant role in the study of the climate change in the global terrestrial biota. Ekoungoulou *et al*. (2018) reported that as atmospheric CO_2 concentrate and its consequence on global climate change continues to increase; quantification of aboveground biomass (AGB) of tree ecosystems is needed to provide information on the carbon budgets. The estimation of carbon stored in trees may offer noteworthy evidence on carbon flux owing to water circulation, which may eventually permit assessment of the carbon cycle (Pinzón *et al*., 2020). The attention of scientific community, practitioners and policymakers has shifted to low carbon development (LCD). Low carbon development involves expending less energy, endorsing low or zero carbon technologies, initiating policies which deject carbon intensive practices and encouraging carbon sinks (DFID, 2009). The Kyoto Protocol established during the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, highlighted the necessity for a quantitative understanding of carbon storage and sequestration (Pinzón *et al*., 2020).

Trees are critical constituents of almost all ecosystems on earth both due to biomass and diversity (Meineke *et al*., 2016). In tropical municipalities, estimating carbon storage and sequestration by urban trees is yet to take its focal place in ecological researches (Velasco *et al*., 2016). Few investigators have carried out studies on urban trees particularly in Benin City, Edo State, Nigeria. Ogwu *et al*. (2016) investigated diversity and abundance of tree species in the University of Benin, Benin City, Nigeria; Ogwu *et al*. (2016) examined tree flora and their environmental services to man: a case study of University of Benin; Arabomen *et al*. (2020) studied understanding public willingness to participate in local conservation initiatives of urban trees in Benin City, Nigeria; Onwuanyi (2021) assessed deficiency of street trees in Benin City: a survey of residents' perceptions; Arabomen *et al*. (2021) investigated willingness-to-pay for environmental services provided by trees in core and fringe areas of Benin City, Nigeria; Arabomen *et al*. (2021) studied residents' attitudes towards tree care programs in cityscapes. The evidences from these prior investigations suggest that none undertook the estimation of carbon storage and sequestration by urban trees in Benin City. The dearth of empirical studies on quantification of carbon storage and sequestration by tropical trees in Benin City undervalues the focal place and understanding of their biogeographical and climatological utility. Velasco *et al*. (2016) reported that many city governments have embraced policies supporting tree-planting, the conservation of urban green spaces, and more lately green architecture (i.e. green roofs and facades). The findings of this research will aid to formulate environmental conservation policies targeted at mitigating and offsetting carbon dioxide emissions which will help tropical cities become carbon neutral.

In filling this gap in knowledge, this study builds on data from direct field measurement of tree parameters (diameter at breast height and tree height) to estimate carbon storage and sequestration by tropical urban trees in Benin City, Edo State, Nigeria. The main objectives of the research are to (1) quantify total biomass (above ground biomass and below ground biomass) of investigated tree species, (2) evaluate carbon storage by the examined urban trees, (3) estimate carbon dioxide sequestration by the sampled municipal trees and (4) identify tree species that have better carbon storage and sequestration capacities in the study area.

2.0. Methodology

2.1. Study area

This research was undertaken in the University of Benin Ugbowo main campus. The study area has a land area of 361 hectares (Ogwu *et al*., 2016) and lies within Latitudes 6° 24' 20" to 6° 23' 40" N and Longitudes 5° 36' 40" to 5° 37' 40" E (Figure 1). It is located in Benin City which has a humid tropical climate. The soils comprise of over 90% sandstone with shale intercalations, coarsely grained, gravelly, and locally fine grained (Idehai and Egai, 2014). The natural vegetation is related to that of tropical rainforest but had changed from forest to secondary forest and other agricultural land uses due to anthropogenic modifications over an extended period of time (Dania-Ogbe *et al*., 1992). Presently, there abound different tree species spatially located in the study area, indicating the rich vegetative biodiversity of University of Benin. Most of the water bodies on the campus drain into Ikpoba River. These drifts across the campus at the North axis into the Ikpoba river located about 3 Km away from the University.

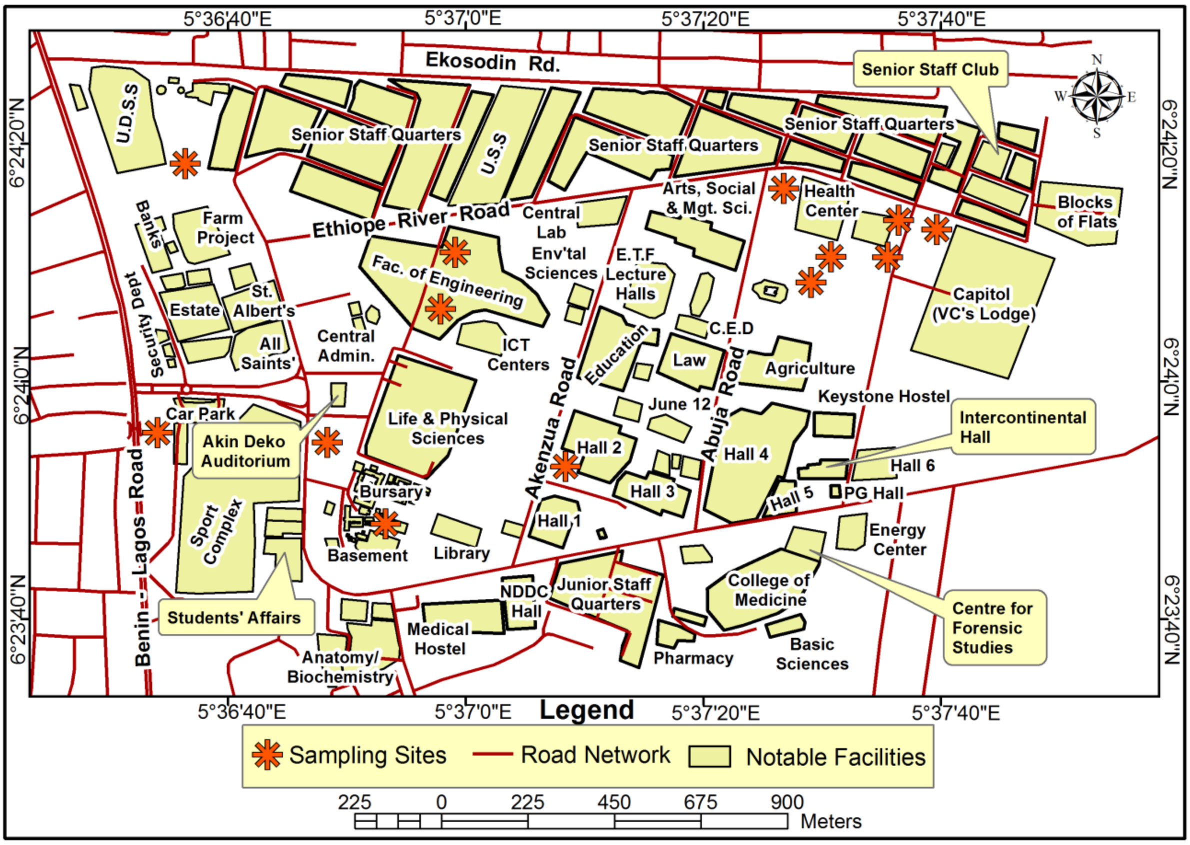

Figure 1: University of Benin showing tree species sampling sites

2.2. Reconnaissance survey and sampling technique

A reconnaissance survey was carried out in different locations within Benin City to ascertain the most suitable study area for this investigation. University of Benin, Ugbowo Campus located in an urbanized part of Benin City, Edo State, Nigeria was selected for the research because of the presence of varied tropical tree species. Over the study area, following a simple random sampling technique, Black Afara (*Terminalia invorensis*), Aridan (*Tetrapleura tetraptera*), Orange (*Citrius sinensis*), Ashoka (*Polyathia longifolia*), Teak (*Tectona grandis*), Oocarpa pine (*Pinus oocarpa*), Umbrella tree (*Terminalia mantaly*), Flame of the forest (*Delonix regia*), Opepe (*Naucloa diderrichii*), Dogoyaro (*Azadirachta indica*), Weeping fig (*Ficus benjamina*), Omo (*Cordia melleni*) and African Oil Bean (*Pentacleethra macrophylla*) (13 species) were chosen from 13 sampling sites. From each of the sampling site, 5 tree species were randomly selected for measurement of diameter at breast height and height of tree. In total, 65 trees were sampled for examination for the research. Belete *et al*. (2019) reported that the number of the studied trees is usual for biomass studies due to the extensive, time-consuming and costly work required, particularly for mixt scenery. Also, the choice of the sampled tree species was because they were the dominant ones in the study area and each of the sampling sites had only one type of tree species. All the trees were effectively identified in situ and to find out the type of tree species, each tree sample was scrutinized meticulously.

2.3. Types of data

The primary and secondary data were used in order to gather vital information to achieve the objectives of this research. Primary data were obtained through direct field measurements of the varied tree species parameters in the different sampling sites within the study area while the secondary data were collected from various materials like published and unpublished resources, reports and electronic websites.

2.4. Data collection and analysis

2.4.1. Measurement of tree height and diameter at breast height (DBH)

The study adopted the non-destructive method to estimate the biomass of the different tree species. Non-destructive sampling is used where diameter at breast height (DBH), local wood density (ρ), and tree height (H) are the estimator variables for aboveground biomass (Belete *et al*., 2019). Total height is the vertical distance from the level of the adjacent soil up to the highest point where the canopy of the tree is projected (Pinzón *et al*., 2020). Due to the unavailability of Haga Hypsometer, the height of the trees was estimated with the aid of a 10 m pole (Oliveira-Filho *et al*., 1994). In measuring the height of the tree, the 10 m pole was positioned on the base of the particular tree very close to its stem. To aid proper assessment in the measurement of the tree height, the 10m pole was marked at intervals of 1m each (Orobator, 2019). Diameter at breast height (DBH) was evaluated by measuring the tree Girth at Breast Height (GBH). DBH was taken at the main trunk at a height of 1.30 m from the level of the adjacent soil or base of the tree.

2.4.2. Above ground biomass (AGB) of trees

Gupta and Sharma (2014) stated that the above ground biomass (AGB) of tree includes the whole shoot, branches, leaves, flowers and fruits. For a small vegetation stand, the AGB calculation is more precise when based on actual field measurements (Li *et al*., 2020). Above ground biomass (AGB) was calculated using the following formula.

$$AGB = volume\ of\ tree \times wood\ density \quad (1)$$
$$V = \pi r^2 H \quad (2)$$

where;
V volume of the cylindrical shaped tree in m^3
r radius of the tree in meter
H Height of the tree in meter

Radius of the tree is calculated from GBH of tree. The values for each species' wood specific density (gravity) were accessed from Chave *et al*. (2003). The standard average density of 0.6 gm/cm was applied where the density value was not accessible for tree species.

2.4.3. Estimating below ground biomass (BGB)

The equation to estimate belowground biomass (BGB) by Cairns *et al*. (1997) and adopted for this research is shown as follows:

$$BGB = AGB \times 0.26 \quad (3)$$

Where;

BGB belowground biomass
AGB aboveground biomass and 0.26 is conversion factor (or 26% of AGB).

2.4.4. Estimation of total biomass

Total Biomass is the sum of above and below ground biomass (Vishnu and Patil, 2016).

$$Total\ Biomass\ (TB) = Above\ ground\ mass + Below\ ground\ mass \tag{4}$$

Zhou and Hemstrom (2009) reported that methods in biomass estimation hinge on the scale of investigation, need for detail, researcher's interests and/or goal of research. There is no study rationale to defend one method of estimation as being superior to another (Poudel and Temesgen, 2015).

2.4.5. Estimation of carbon storage

Estimations of carbon followed the methodology proposed by Pearson *et al*. (2005). For any plant species, 50% of its biomass is considered as carbon storage.

$$Carbon\ storage = Biomass \times 50\% \tag{5}$$

2.4.6. Carbon dioxide (CO_2) sequestration Estimation

The total carbon stock is converted to CO_2 equivalent by multiplying 44/12 or 3.67 (Pearson *et al*., 2007).

$$CO_2\ sequestration = Carbon\ value \times 3.67 \tag{6}$$

2.4.7. Distribution and classification of diameter at breast height (DBH), tree height and wood density

In this study, Aabeyir *et al*. (2020) approach was modified to show distribution and classification of diameter at breast height (DBH), total tree height and wood density (ρ) of the sampled tree species.

3.0. Results and Discussion

3.1. Distribution and classification of diameter at breast height (DBH), tree height (m) and wood densities

The data showing the distribution and classification of diameter at breast height (DBH), tree height (m) and wood densities of the investigated tree species is indicated in Table 1. The DBH of most of the tree species (*Delonix regia, Pentacleethra macrophylla, Pinus oocarpa, Ficus benjamina, Tectona grandis, Azadirachta indica, Polyathia longifolia, Terminalia invorensis* and *Tetrapleura tetraptera*) were within 0.91-1.90m DBH class, the number of tree species being 9 (Table 1).

Table 1: Distribution of trees within diameter at breast height (DBH), tree height (H) and wood density (ρ) classes

DBH class (m)	No of tree species	Height class (m)	No of tree species	Density class (gcm−3)	No of tree species
0.1-0.90	2	1.0 - 5.0	-	0.10 - 0.35	1
0.91 -1.90	9	5.1 - 10.0	2	0.36 - 0.61	8
1.91-2.90	2	10.1 - 15.0	8	0.62 - 0.87	4
		15.1 - 20.0	3		
Total	13		13		13

However, *Naucloa diderrichii* and *Citrius sinensis* were the only two tree species within the lowest DBH class of 0.1 - 0.90m. Only two tree species (*Cordia mellenii* and *Terminalia mantaly*) were in the uppermost DBH class of 1.91 - 2.90m. The large diameter at breast height of *Terminalia mantaly* and *Cordia mellenii* implies that they have capacity to store more carbon. Stoffberg *et al*. (2010) noted that trees with high diameter at breast height (DBH) may store about 1000 times more carbon than trees of low DBHs.

Majority of the examined tree species (*Delonix regia, Pinus oocarpa, Ficus benjamina, Tectona grandis, Azadirachta indica, Polyathia longifolia,Naucloa diderrichii* and *Terminalia invorensis*) were within the average height class of 10.1 - 15.0m (Table 1). Only 2 tree species species

(*Tetrapleura tetraptera* and *Citrius sinensis*) were within the lower height class of 5.1 - 10.0m. However, 3 (*Terminalia mantaly, Pentacleethra macrophylla* and *Cordia mellenii*) out of the 13 examined tree species were in the highest height class of 15.1 - 20.0m. The fast growth of *Terminalia mantaly, Pentacleethra macrophylla* and *Cordia mellenii* depicts their potential to store carbon more capably which makes them a possible preference for mitigating climate change (Kaushi *et al*., 2015). The findings of the current study are consistent with those of Aabeyir et al. (2020), who found that the height of most of the trees sampled were within 5.1 to 10.0m height class. Out of the 13 investigated diverse tree species, 4 tree species (*Naucloa diderrichii, Azadirachta indica, Ficus benjamina* and *Pentacleethra macrophylla*) were within the highest wood density class of 0.62 - 0.87gcm^{-3}, followed by 8 tree species (*Terminalia invorensis*, *Tetrapleura tetraptera*, *Citrius sinensis*, *Polyathia longifolia, Tectona grandis*, *Pinus oocarpa*, *Terminalia mantaly* and *Delonix regia*) which were in the wood density class of 0.36 - 0.61gcm^{-3} and 1 tree specie (*Cordia melleni*) was within the wood density class of 0.10 - 0.35gcm^{-3} (Table 1). The wood densities observed in this study are not consistent with that of Munishi *et al*. (2008). Wood specific density is one of the principal estimators of AGB, particularly when different types of vegetation type are investigated (Belete *et al*. 2019). The detected varied diameter at breast height (DBH), tree height (H) and wood density (ρ) of the investigated tree species may be due to differences in their morphological features.

3.2. Carbon storage and sequestration performances of trees

Data for tree wood density, average diameter at breast height, average height, volume (m^3), above ground biomass, below ground biomass, total biomass, tree count, carbon stored and carbon dioxide (CO_2) sequestered of the examined tree species is shown in Table 2. Total aboveground biomass estimated for the study was 632.76kg. This consists of 79.37% of the total biomass (797.23kg) estimated for this research. Vashum and Jayakumar (2012) stated that aboveground biomass constitutes the main components of carbon pool in vegetative ecosystems. Collectively, the top three biomass species found in this study were *Terminalia mantaly* (141.35kg), *Delonix regia* (80.71kg) and *Cordia melleni* (77.80kg). This infers that these specific tree species have better capacity to store carbon Aboveground biomass shows the tree potential to store carbon (Poudel and Temesgen, 2015). *Citrius sinensis* had the lowest aboveground biomass value of 10.17kg for this investigation. Our inquiry indicates that DBH class of 0.91 - 1.90m is the main class with the highest aboveground biomass input of 384.4kg. This is followed by large diameter class of 1.91 - 2.90m (219.15kg) and lowest diameter class of 0.1 - 0.90m (29.21kg). This contradicts the findings of Moussa *et al*. (2018), who found out that the trees with the large diameter classes dominated the aboveground biomass pool. Aboveground biomass was highest for tree height class of 10.1 - 15m (321.48kg), followed by 15.1 - 20.0m (285.71kg) and 5.1 - 10.0m (25.57kg) height classes. The wood density class of 0.36 - 0.61gcm^{-3} has the highest aboveground biomass of 390.03kg followed by 0.62 - 0.87gcm^{-3} (164.93kg) and 0.10 - 0.35gcm^{-3} (77.80kg) wood density classes.

Total belowground biomass estimated for this investigation was 164.47kg (Table 2). The estimated total belowground biomass make up 20.63% of the total biomass (797.23kg) estimated for the research. The results of this inquiry revealed that the value of aboveground biomass for each tree species was more than that of belowground biomass. Belowground biomass constitutes only a fraction of carbon pools in vegetation ecosystems. In examining above and belowground biomass and net primary production in a 73-year-old Scots pine forest, Xiao *et al*. (2003) observed a 0.14 ratio of belowground biomass to aboveground biomass. *Terminalia mantaly* (36.75kg), *Delonix regia* (20.98kg) and *Cordia melleni* (20.22kg) had the highest values of belowground biomass. The lowest ranked in belowground biomass were *Terminalia invorensis* (4.68kg), *Tetrapleura tetraptera* (4.00kg) and *Citrius sinensis* (2.64kg) trees. Our study shows that DBH class of 0.91 - 1.90m is dominant class regarding belowground biomass contribution. This is followed by DBH class of 1.91 - 2.90m (56.97kg) and 0.1 - 0.90m (7.59kg) DBH classes. Belowground biomass was highest for tree height class of 10.1 - 15.0m (83.56kg), followed by 15.1 - 20.0m (74.27kg) and 5.1 - 10.0m (6.64kg) height classes. The wood density class of 0.36 - 0.61gcm^{-3} has the highest aboveground biomass (101.38kg), followed by 0.62 - 0.87gcm^{-3} (42.87kg) and 0.10 - 0.35gcm^{-3} (20.22kg) wood density classes. The findings of the study are consistent with Czapowskyj *et al*. (1985), they found 80% biomass in the aboveground components and 20% biomass in the belowground components of black spruce (*Picea mariana* B.S.P. (Mill.) in Maine.

Table 2: Sampled urban tropical trees carbon storage and sequestration performances

S/N	Tree species (Scientific name)	Common Name	Location	Wood density (gcm^{-3})	Average DBH (m)	Average height (m)	Volume (m^3)	Above ground biomass	Below ground biomass	Total biomass	Tree count	Carbon stored (kg)	CO_2 sequestered (kg)
1	*Terminalia mantaly*	Umbrella tree	6°24..018' N 5°36.882' E	0.57	2.19	16.68	247.99	141.35	36.75	178.10	5.00	89.05	326.81
2	*Delonix regia*	Flame of the forest	6°24..899' N 5°37.363' E	0.60	1.85	12.68	134.53	80.71	20.98	101.69	5.00	50.84	186.60
3	*Cordia melleni*	Omo	6°24..848' N 5°37.092' E	0.34	1.97	19.02	228.82	77.80	20.22	98.02	5.00	49.10	179.87
4	*Pentacleethra macrophylla*	African oil bean	6°24...108' N 5°36.898' E	0.78	1.26	17.34	85.33	66.56	17.30	83.86	5.00	41.93	153.88
5	*Pinus oocarpa*	Oocarpa pine	6°24...891' N 5°36.929' E	0.55	1.59	13.08	102.50	56.38	14.65	71.03	5.00	35.51	130.32
6	*Ficus benjamina*	Weeping fig	6°24...338' N 5°36.350' E	0.65	1.40	12.70	77.16	50.15	13.04	63.19	5.00	31.59	115.93
7	*Tectona grandis*	Teak	6°24...270' N 5°37.677' E	0.50	1.41	13.80	85.05	42.52	11.05	53.57	5.00	26.78	98.28
8	*Azadirachta indica*	Dogoyaro	6°24...203' N 5°37.542' E	0.69	1.14	10.50	42.30	29.18	7.58	36.76	5.00	18.38	67.45
9	*Polyathia longifolia*	Ashoka	$6^0$24...733' N 5°36.934' E	0.60	1.15	10.37	42.51	25.50	6.63	32.13	5.00	16.06	58.94
10	*Naucloa diderrichii*	Opepe	6°24...246' N 5°37.541' E	0.63	0.84	13.82	30.22	19.04	4.95	23.99	5.00	11.99	44.00
11	*Terminalia invorensis*	Black afara	6°24...125' N 5°37.391' E	0.43	1.07	11.80	41.88	18.00	4.68	22.68	5.00	11.34	41.61
12	*Tetrapleura tetraptera*	Aridan	6°24.116' N 5°37.374' E	0.50	1.08	8.52	30.80	15.40	4.00	19.40	5.00	9.70	35.59
13	*Citrius sinensis*	Orange	6°24...255' N 5°37.341' E	0.59	0.86	7.52	17.24	10.17	2.64	12.81	5.00	6.40	23.48
	Total							632.76	164.47	797.23		398.67	1462.76

Total biomass (TB) estimated for the research was 797.23kg (Table 2). *Terminalia mantaly* (178.10kg), *Delonix regia* (101.69kg) and *Cordia melleni* (98.02kg) were top-ranked in total biomass while the lowest total biomass estimated for the study was observed in *Citrius sinensis* (12.81kg). The highest values of total biomass observed in *Terminalia mantaly, Delonix regia* and *Cordia melleni* species may be due to their maximum energy transformation potential and photosynthetic frequency (Srivastava and Ram, 2009) as well as the presence of numerous nodules produced in the roots (Kimothi *et al*., 1983). This implies that the observed high biomass keeping trees (*Terminalia mantaly*, *Delonix regia* and *Cordia melleni*) for this investigation can guarantee maximum removal of anthropogenic CO_2 (Yao *et al*., 2015). The findings of the research contradicts Dugaya *et al*. (2020), they observed that *Leucaena leucocephala*, *Schleichera oleosa* and *Dalbergia paniculata* species were the first three trees with maximum total biomass. The DBH class of 0.91 - 1.90m was the highest with total biomass values of 484.31kg, followed by 1.91-2.90m (276.12 kg) and 0.1 - 0.90m (36.8kg) DBH classes. Total biomass was highest for tree height class of 10.1 - 15.0m (405.04kg), followed by 15.1 - 20.0m (359.98kg) and 5.1 - 10.0m (32.21kg) height classes. The wood density class of 0.36 - 0.61gcm^{-3} has the highest aboveground biomass (491.41kg), followed by 0.62 - 0.87gcm-3 (207.8kg) and 0.10 - 0.35gcm^{-3} (98.02kg) wood density classes.

Total carbon storage estimated for this inquiry was 398.67kg (Table 2). The species that contributed the greatest carbon storage in the study were *Terminalia mantaly* (89.05kg), *Delonix regia* (50.84kg) and *Cordia melleni* (49.10kg). However, the findings of the current study do not support the previous research of Dugaya *et al*. (2020), who observed that *Leucaena leucocephala, Schleichera oleosa* and *Dalbergia paniculata* are the top tree species responsible for maximum carbon storage. Pinzón *et al*. (2020) observed an exceptional *Pera arborea* Pear species (*Euphorbiaceous)* with higher carbon storage than the other trees. They stated that the presence of this apparently distinctive species may be due to particular soil characteristics. The DBH class of 0.91 - 1.90m was the highest with carbon storage values of 242.13kg, followed by 1.91 - 2.90m (138.15kg) and 0.1 - 0.90m (18.39kg) DBH classes. Nowak and Crane (2002) reported that diameter distribution affects carbon storage. Carbon storage was highest for tree height class of 10.1 - 15.0m (202.49kg), followed by 15.1 - 20.0m (180.08kg) and 5.1 - 10.0m (16.1kg) height classes. The wood density class of 0.36 - 0.61gcm^{-3} has the highest carbon storage of 245.68kg, followed by 0.62 - 0.87gcm^{-3} (103.89kg) and 0.10 - 0.35gcm^{-3} (49.10kg) wood density classes.

Total carbon dioxide (CO_2) sequestration quantified for this inquiry was 1462.76kg (Table 2). *Terminalia mantaly* (326.81kg/tree), *Delonix regia* (186.60kg) and *Cordia melleni* (179.87kg/tree) has the highest estimated values of CO_2. This may be due their more foliage duration for photosynthesis, CO_2 fixation and extra litter biomass production (Majumdar and Selvan, 2018). Plants have the capability to sequester CO_2 through photosynthesis and can then store carbon in plant biomass (Fares *et al*., 2017). During photosynthesis, trees convert carbon dioxide and water into sugar molecules and oxygen, part of this sugar is stored, while majority is utilized by the tree for other purposes such as energy and structure (Ugle *et al.,* 2010). The findings of the study do not agree with Vishnu and Patil (2016), who reported that *Ficus benghalensis* sequestered 1333.44kg of CO_2 which was the highest compared to other tree species. The DBH class of 0.91 - 1.90m has the highest CO_2 sequestration values of 888.60 kg, followed by 1.91 - 2.90m (506.68kg) and 0.1 - 0.90m (67.48kg) DBH classes. CO_2 sequestration was highest for tree height class of 10.1 - 15.0m (743.13kg), followed by 15.1 - 20.0m (660.56kg) and 5.1 - 10.0m (59.07kg) height classes. The wood density class of 0.36 - 0.61gcm^{-3} has the maximum value of CO_2 sequestration (901.63kg), followed by 0.62 - 0.87gcm^{-3} (381.26kg) and 0.10 - 0.35gcm^{-3} (179.87kg) wood density classes.

4.0. Conclusions

The present investigation estimated carbon storage and sequestration by tropical urban trees in Benin City, Edo State, Nigeria. Based on non-destructive approach, Umbrella tree (*Terminalia mantaly*), Flame of the forest (*Delonix regia*) and Omo (*Cordia melleni*) trees had the highest estimated values of biomass, carbon storage and sequestration. These three specific tree species are better biomass accumulators and have greater carbon storage and sequestration capabilities compared to Black Afara (*Terminalia invorensis*), Aridan (*Tetrapleura tetraptera*), Orange (*Citrius sinensis*), Ashoka (*Polyathia longifolia*), Teak (*Tectona grandis*), Oocarpa pine (*Pinus oocarpa*), Opepe (*Naucloa diderrichii*), Dogoyaro (*Azadirachta indica*), Weeping fig (*Ficus benjamina*) and African Oil Bean (*Pentacleethra macrophylla*). This research endorsed the cultivation and sustainable management of *Terminalia mantaly, Delonix regia* and *Cordia melleni* tree species for mitigating climate change impacts, supporting biodiversity, maximizing ecological services as well as planning and promoting urban forestry in Benin City. The study will contribute as a baseline research for further studies and suggest that researches on carbon storage and sequestration potentials of urban trees planted along roadsides in Benin City, Edo State, Nigeria should be embarked on.

References

Aabeyir, R., Adu-Bredu, S., Agyare, W.A. and Weir, M.J.C. (2020). Allometric models for estimating aboveground biomass in the tropical woodlands of Ghana, West Africa. *Forest Ecosystems*, 7(41), pp. 1-23.

Arabomen, O. J., Babalola, F. D., Idumah, F. O. and Ofordu, C. S. (2021). Residents' attitudes towards tree care programs in cityscapes. *Revista Produção E Desenvolvimento*, 7. https://doi.org/10.32358/rpd.v7.462.

Arabomen, O., Chirwa, P. and Babalola, F. (2020). Understanding Public Willingness to Participate in Local Conservation Initiatives of Urban Trees in Benin City, Nigeria. *Arboriculture & Urban Forestry*, 46(4), pp. 247-261.

Belete, Y., Fentahun, A., Kebede, B. and Soromessa, T (2019). Nondestructive allometric model to estimate aboveground biomass: an alternative approach to generic pan-tropical models. *Journal of Environmental Studies and Sciences*, hal-02265451.1-26.

Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A. (1997). Root biomass allocation in the world's upland forests. *Oecologia*, 111, pp. 1-11.

Chave, J., Condit, R., Lao, S., Caspersen, J., Foster, R. and Hubbell, S. (2003). Spatial and temporal variation of biomass in a tropical forest: results from a large census plot in Panama. *Journal of Ecology*, 91, pp. 240–52.

Czapowskyj, M.M., Robison, D.J., Briggs, R.D. and White, E.H. (1985). Component biomass equations for Black Spruce in Maine. USDA Forest Service, Northeastern Research Station, Broomall, Pennsylvania, Research Paper NE-564.

Dania-Ogbe, F.M., Egharevba, R.K.A. and Bamidele, J. F. (1992). Field survey of indigenous and useful plants. Their preparation for food and home garden in Edo and Delta States, Nigeria. The United Nations University, Tokyo, Japan. 3:95.

Department for International Development (DFID) (2009). Greening disaster risk management: Issues at the interface of disaster risk management and low carbon development Frauke Urban, Tom Mitchell and Paula Silva Villanueva Strengthening Climate Resilience Discussion Paper. pp58.

Dugaya, D., Srirag, S., Pandey,A.K., Paul,A., Shukla ,D.D., Deo ,K., Sharma,N., Verma,S., Nagaria,S., Guhaprasad, S and Chaudhry, P (2020). Carbon Sequestration Potential of Trees Planted Along Roadsides: A Case From Bhopal City, India. *International Journal of Environment*, 9(2), pp. 104-119.

Ekoungoulou, R., Nzala, D., Liu, X.D. and Niu, S.K. (2018). Tree biomass estimation in central African forests using allometric models. *Open Journal of Ecology,* 8, pp. 209-237.

Erker, T. and Townsend, P.A. (2019). Trees in cool climate cities may increase atmospheric carbon by altering building energy use. *Environmental Research Communications,* 1: pp. 1-11.

Fares, S., Paoletti, E., Calfapietra, C., Mikkelsen, T.N., Samson, R and Le Thiec, D (2017). *Carbon Sequestration by Urban Trees.* In D. Pearlmutter et al. (eds.), The Urban Forest, Future City 7, DOI 10.1007/978-3-319-50280-9_4.

Gupta, B. and Sharma, S. (2014). Estimation of Biomass and Carbon Sequestration of Trees in Informally Protected Areas of Rajouri, J&K, India, *International Research Journal of Environment Science,* 3(6), pp. 56-61.

Hoornweg, D., Sugar, L. and Trejos-Gomez, C.L. (2011) Cities and greenhouse gas emissions: moving forward. *Environment and Urbanization*.23:207-227.

Idehai, I.M. and Egai. A.O. (2014). Aspects of Geophysical Exploration for Groundwater Using Vertical Electrical Sounding (VES) in Parts of University of Benin, Benin City, Edo State. *Journal of Applied Sciences and Environmental Management,* 18(1), pp. 19-25.

International Energy Agency (IEA) (2019). The Role of CO_2 Storage, IEA, Paris https://www.iea.org/reports/the-role-of-CO_2-storage.

Kaushi, S., Singh, Y.P., Kumar, D., Thapliyal, M. and Barthwal, S. (2015). Bamboos in India. ENVIS centre on Forestry. National Forest Library and Information Centre. FRI, Dehradun, India.

Kimothi, M.M., Raturi, D.P., Rawat, J.S. and Gurumurti. (1983). Proceedings of Symposium Advance in Electrochemistry on Plant Growth, CECRI, Karaikudi. pp. 135-53.

King, D. (2005). Climate Change: The Science and Policy. *Journal of Applied Ecology,* 42(5), pp. 779-783.

Lawrence, A.B., Escobedo, F.J., Staudhammer, C.L. and Zipperer, W. (2012). Analyzing growth and mortality in a subtropical urban forest ecosystem. *Landscape and Urban Planning,* 104, pp. 85-94.

Li, Y., Li, M., Li, C. and Liu, Z. (2020). Forest aboveground biomass estimation using Landsat and Sentinel-A data with machine learning algorithms. *Scientific Reports*, 10, 9952p.

Majumdar, T, and Selvan, T. (2018). Carbon Storage in Trees of Urban and Peri-urban Forests of Agartala, Tripura. *Journal for Advanced Research in Applied Sciences*, 5(2), pp. 715-731.

Meineke, E., Youngsteadt, E., Dunn, R.R and Frank, S.D. (2016). Urban warming reduces aboveground carbon storage. *Proceedings of the Royal Society B: Biological Sciences.* 283, 20161574.

Moussa, S., Kyereh, B., Tougiani, A.A. and Saadou, M. (2018). Carbon stocks of Neem tree (*Azadirachta indica* A. Juss.) in different urban land use and land cover types in Niamey city, Niger, West Africa. *South Asian Journal of Biological Research,* 1(2), pp. 153-165.

Munishi, P.K.T., Mhagama, M., Muheto, R. and Andrew, S.M. (2008). The role of urban forestry in mitigating climate change and performing environmental services in Tanzania. *Tanzania Journal of Forestry and Nature Conservation*, 77, pp. 25-34.

Nowak, D.J. and Crane, D.E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, 116, pp. 381-389.

Nowak, D.J., Greenfield, E.J., Hoehn, R.E. and Lapoint, E. (2013). Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution*, 178, pp. 229-236.

Nunes, L.J.R., Meireles, C.I.R. and Gomes, C.J.P. and Ribeiro, N.M.C. (2019). Forest Management and Climate Change Mitigation: A Review on Carbon Cycle Flow Models for the Sustainability of Resources. *Sustainability,* 11, 5276p.

Ogwu, M.C., Osawaru, M.E. and Iyamu, M. (2016). Tree flora and their environmental services to man: a case study of University of Benin. *Ilorin Journal of Science,* 3(1), pp. 40-68.

Ogwu, M.C., Osawaru, M.E. and Obayuwana, O.K. (2016). Diversity and abundance of tree species in the University of Benin, Benin City, Nigeria. *Applied Tropical Agriculture,* 21(3), pp. 6-54.

Oliveira-Filho, A. T., Vilela, E. A., Calvalho, D. A. and Gavilanes, M. L. (1994).Effects of soils and topography on the distribution of tree species in a tropical riverine forest in south-eastern Brazil. *Journal of Tropical Ecology*, 10(4), pp. 483-508.

Onwuanyi, N. (2021).Deficiency of Street Trees in Benin City: A Survey of Residents' Perceptions. In book: Land Use Management and Environmental Sustainability in Nigeria. Publisher: Parvenu/University of Uyo, Nigeria, pp. 1-12.

Orobator, P.O. (2019). Impact of Bushfire on Soil and Vegetation Properties of *Hevea brasiliensis* (Rubber) Plantations in Iyanomo, Edo State, Nigeria. Unpublished Dissertation Submitted to the Department of Geography and Regional Planning, Faculty of Social Sciences, University of Benin, Benin City, Edo State, Nigeria in partial fulfilment for the requirement of Doctor of Philosophy in Biogeography.

Pearson, T.R.H., Brown, S. and Ravindranath, N.H. (2005) Integrating carbon benefits estimates into GEF Projects UNDP, GEF Capacity Development and Adaptation Group Guidelines, pp. 1-56.

Pearson, T. R., Brown, S. L. and Birdsey, R. A. (2007). Measurement guidelines for the sequestration of forest carbon. Northern research Station, Department of Agriculture, Washington, D.C, pp. 6-15.

Poudel, K.P. and Temesgen, H. (2016), Methods for estimating aboveground biomass and its components for Douglas-fir and lodgepole pine trees. *Canadian Journal of Forest Research,* 46, pp. 77-87. dx.doi.org/10.1139/cjfr-2015-0256.

Pinzón,R., Fábrega, J., Vega,D., Vallester,E.N., Aizprúa,R., López-Serrano, F.R., Ogden, F.L and Espino, K. (2020). Estimates of Biomass and Fixed Carbon at a Rainforest in Panama. *Air, Soil and Water Research*, 5(1), pp. 79-89.

Srivastava, N.K. and Ram, L.C. (2009). Bio-restoration of coal mine spoil with fly ash and biological amendments. In (eds.) O.P. Chaubey, Vijay Bahadur and P.K. Shukla. Sustainable Rehabilitation of Degraded Ecosystems Aavishkar publishers, distributors Jaipur, Raj. 302 003 India, pp.77-99.

Stoffberg, G.H., Van Rooyen, M.W., Van der Linde, M.J. and Groeneveld, H.T. (2010). Carbon sequestration estimates of indigenous street trees in the City of Tshwane, South Africa. *Urban Forestry and Urban Greening*, 9(1), pp. 9-14.

Ugle, P., Rao, S. and Ramachandra, T.V. (2010). Carbon sequestration potential of urban trees. Conference on Wetlands. *Biodiversity and Climate Change*, pp. 1-12.

United Nations (UN) (2015). World Urbanization Prospects: The 2014 Revision. New York, NY: United Nations Department of Economic and Social Affairs, Population Division.

Vashum, K.T. and Jayakumar, S. (2012). Methods to estimate above-ground biomass and carbon stock in natural forests - a review. *Journal of Ecosystem & Ecography,* 2(4), pp. 1-7.

Velasco, E., Roth, M., Norford, L. and Molina, L.T. (2016). Does urban vegetation enhance carbon sequestration? *Landscape and Urban Plannin*, 148, pp. 99-107.

Vishnu, R.P. and Patil, S.S. (2016). Carbon Storage and Sequestration by Trees in and Around University Campus of Aurangabad City, Maharashtra. *International Journal of Innovative Research in Science, Engineering and Technology,* 5(4), pp. 5459-5468.

Xiao, C.W., Yuste, J.C., Janssens, I.A., Roskams, P., Nachtergale, L., Carrara, A., Sanchez, B.Y. and Ceulemans, R. (2003). Above- and belowground biomass and net primary production in a 73-year-old Scots pine forest. *Tree Physiology,* 23(8), pp. 505-516.

Yao, Z., Liu, J., Zhao, X., Long, D. and Wang, L. (2015). Spatial dynamics of aboveground carbon stock in urban green space: A case study of Xi'an, China. *Journal of Arid Land*, 7(3), pp. 350-360.

Zhou, X. and Hemstrom, M.A. (2009). Estimating aboveground tree biomass on forest land in the Pacific Northwest: a comparison of approaches. USDA Forest Service, Portland, Oregon, Research PaperPNW-RP-584.

Cite this article as:
Orobator P. O. and Adahwara P. O., 2022. Estimation of Carbon Storage and Sequestration by Tropical Urban Trees in Benin City, Edo State, Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, 6(1), pp. 214-224. https://doi.org/10.36263/nijest.2022.01.0347