PLANNING MALAYSIA:
Journal of the Malaysian Institute of Planners
VOLUME 17 ISSUE 2 (2019), Page 179 – 190

QUANTIFYING THE ABOVEGROUND BIOMASS AND CARBON STORAGE OF URBAN TREE SPECIES IN SOKOTO METROPOLIS, NORTH-WESTERN NIGERIA

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Abstract

Increases in human activities, land use/cover changes and urbanisation have led to continuous accumulation of carbon dioxide and other greenhouse gases in the atmosphere, thus threatening the efficiency of natural carbon sinks such as urban trees. This paper assessed the aboveground biomass and carbon stock of trees in Sokoto metropolis, North-Western Nigeria, using an allometric equation. The metropolis was stratified into five broad land use/cover types from which 200 sample plots of 30m × 30m were generated. Data on tree species and diameter at breast height were collected from all trees ≥ 5cm in diameter within the plots. A total of 722 trees belonging to 30 species in 17 genera and 14 families were identified. The trees stored 854.73 tonnes of biomass equivalent to 427.37 tonnes of carbon with the highest proportion being stored by *Azadirachta indica*, *Mangifera indica*, *Adansonia digitata*, and *Ficus polita*. There was a significant difference in tree biomass and carbon stock across the land use/cover types ($F = 4.730$, $p < 0.001$). The Green Area recorded the highest carbon density of 96.5t ha^{-1} while Farmland recorded the least carbon density (7.4t ha^{-1}). Urban areas have diverse tree species that could contribute significantly to reducing global atmospheric carbon. This potential, which varies with the species, number, and size of trees, as well as land cover, can be successfully estimated using allometric equations.

Keywords: aboveground biomass; carbon stock; diversity; native species; exotic species

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INTRODUCTION

Carbon dioxide (CO_2) contributes approximately 84% of global radiative forcing (World Meteorological Organization, 2014) and 60% of observed global warming (Grace, 2004) making it the most important anthropogenic greenhouse gas in the atmosphere. The atmospheric concentration of CO_2 rose from about 300 ppm in the pre-industrial 1880s to about 405.58 ppm in 2017 (World Meteorological Organization, 2014). This threatens the efficiency of global natural carbon sinks and accelerates the process of global warming (Canadell et al., 2010). Most of these increases are attributable to human activities such as burning fossil fuels, land use/cover changes (Wang et al., 2014), and urbanisation (Churkina, 2016).

Urban areas are centres of economic and commercial activities, as they accommodate more than half of the global population. These areas require higher amount of fossil fuel for transportation, cooking, heating, cooling, and electricity generation; thus, emitting higher atmospheric carbon (Pataki et al., 2006). According to the United Nations (2018), the rates of urbanisation are higher in Asia and Africa where levels of carbon dioxide emissions are also higher (Clerici, Rubiano, Abd-Elrahman, Posada, & Escobedo, 2016). It was envisaged that Africa would contribute about 21% of the global urban population, with Nigeria expected to contribute an estimated 186 million people by 2050 (United Nations, 2018).

Urban trees and forests are increasingly being recognised as important components of biodiversity, hence gaining more relevance for academic, planning, and urban sustainability purposes (Dahlhausen, Biber, Rötzer, Uhl, & Pretzsch, 2016). Trees enhance the resilience of ecosystems in the face of changes and losses due to pests or diseases (Conway & Vander Vecht, 2015). In urban areas, trees provide free ecosystem services such as the provision of food, shade and fuel, removal of air pollutants, provision of recreational activities and other physical and mental health (Justin et al., 2016), as well as psychological and spiritual benefits (Peter & Shackleton, 2017). Urban trees also sequester and store large amounts of carbon as they grow over time (Liu & Li, 2012). The potential for carbon sequestration and storage of trees depend on their density, composition, growing condition and environmental gradients (Chave et al., 2009; Nowak, Greenfield, Hoehn, & Lapoint, 2013). Despite its global importance however, carbon sequestration and storage potential of urban trees in Africa and many developing regions have not been adequately assessed and documented (McPherson, Xiao, & Aguaron, 2013). Most urban carbon studies were conducted in developed countries such as the United States (Liu & Li, 2012). The results obtained from such studies might therefore not extrapolate successfully to areas with different urbanisation patterns (Davies, Edmondson, Heinemeyer, Leake, & Gaston, 2011). This justifies the need for region-specific estimates so that relevant information for climate change mitigation and urban sustainability purposes could be generated. The aim of this paper is, therefore, to estimate the biomass and carbon stock of trees in Sokoto metropolis, North-Western Nigeria and highlight the contribution of individual tree species in the region to urban carbon balance (Tang, Chen, & Zhao, 2016), reduction of CO_2 emissions in the global carbon cycle, and climate change mitigation.

MATERIALS AND METHOD

The Study Area

Sokoto is located on latitudes 13°3'5"N and longitudes 5°13’53"E, and covers an area of about 94 km^2 (Figure 1). The city has an estimated population of 554,775 people (National Bureau of Statistics, 2016), and lies in a semi-arid region with typical Koppen’s tropical wet and dry (Aw) climate (Belda, Holtanová, Halenka, & Kalvová, 2014). The mean annual temperature in this zone ranges between 21℃ and 33℃ while mean annual rainfall ranges between 508mm in the driest part to 1,016mm in the wettest part (Sanni, Odekunle, & Adesina, 2012). Vegetation comprises the Sudano-Sahelian type of short, feathery grasses, and some spiny woody species (Nsangu, 2009). The soils are generally leached and ferruginous consisting of silt and sand with hydromorphic soils found in riverine areas (Swindell, 1986).

Sampling and Data Collection

This study adopted a stratified sampling approach (Zhang et al., 2016), which ensures better representation by taking into account variation in the size of clusters (Levy & Lemeshow, 2011), thereby increasing sampling precision (Yang, McBride, Zhou, & Sun, 2005). A Landsat 8 OLI TIRS image of the metropolis for 2015 was pre-processed and classified (see Liu & Yang, 2015) with TerrSet geospatial monitoring and modelling system into five broad land use/cover classes. These include the Built-up Area, Farmland, Green Area, Open Space, and Wetland/Water. A stratified sample of 200 points was then generated across the land cover classes using the TerrSet sampling facility (Figure 1). This is considered reasonable (Nowak, Crane, Stevens, & Hoehn, 2003; Nowak, Walton, Stevens, Crane, & Hoehn, 2008).

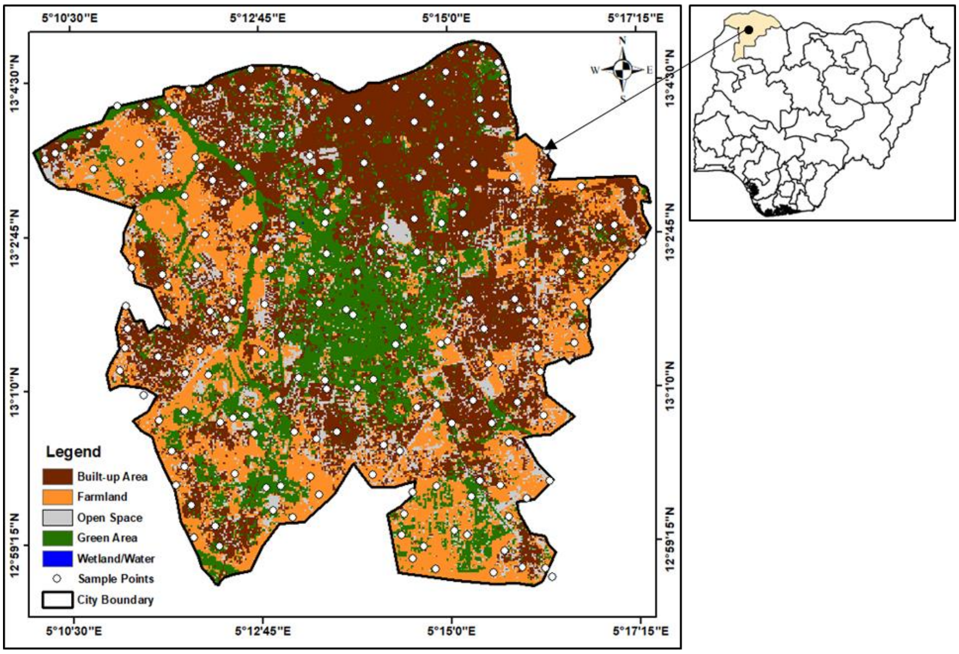

Figure 1 Classified land cover map of Sokoto metropolis and sample points distribution

Tree data were collected from 189 plots, as the remaining 11 plots were not accessible due to privacy issues. We demarcated 30m × 30m (0.09ha) quadrats at each sample point to coincide with the resolution of the Landsat image used in the classification (Ren et al., 2017). All trees with a diameter ≥ 5cm within the quadrats were identified to species level with the aid of a trained botanist. Species provenance (native or exotic) was established with reference to Lely (1925) and Keay, Onochie and Stanfield (1964), while nomenclature followed Hutchinson and Dalziel (1972). Tree diameter at breast height (DBH) was measured 1.3 m from the ground with a diameter tape, while basal area was derived from Equation (1):

$$\mathrm{BA} = (d\,\tfrac{1}{2})^2\pi \qquad \text{Equation (1)}$$

where,
BA = Basal Area
d = Diameter
π = 3.142

Data Analysis
Tree species composition, structural characteristics and density were calculated, while aboveground biomass (AGB) and carbon stock (C) were estimated using an allometric equation. Using allometric equations to estimate AGB is a more popular option (Vashum & Jayakumar, 2012) than the expensive and time-consuming, destructive approach (Chave et al., 2014). Many such equations exist in the literature (e.g. Chave et al., 2014; Feldpausch et al., 2011). However, this study adopted the equation provided by Brown, Gillespie and Lugo (1989), which was developed specifically to estimate AGB of trees in dry climates with less than 900mm annual rainfall and successfully used in other studies (e.g. O'Donoghue & Shackleton, 2013; Woldegerima, Yeshitela, & Lindley, 2017). This is given in Equation (2):

$$Y = \exp\{-1.996+2.32*\ln(D)\} \qquad \text{Equation (2)}$$

where,
Y = biomass per tree (kg)
exp = e – (the base of natural logarithms), raised to the power of (…)
D = DBH (cm)

The equation uses tree DBH as the predictor variable as this produces the most stable regional AGB estimates (Montagu, Düttmer, Barton, & Cowie, 2005), while also reducing uncertainties (Liu & Li, 2012). The results were multiplied by a conversion factor of 0.8 (Nowak et al., 2013) to account for the variability in biomass and carbon content between open-grown and high-biomass forest trees, which were used to develop most of the AGB estimation equations. This was then multiplied by 0.5 to obtain carbon stock (Liu & Li, 2012).

RESULTS AND DISCUSSION

Tree Species Composition, Biomass and Carbon Stock
The total number of species recorded, their status, nomenclature and corresponding biomass and carbon stock is given in Table 1. A total of 722 stems belonging to 30 species in 17 genera and 14 families were recorded. The native species accounted for 26.8% of the stems while exotic species accounted for 73.2%. Species with a higher number of stems include *Azadirachta indica* (424), *Mangifera indica* (68), *Adansonia digitata* (37), *Ficus polita* (37) and *Terminalia catappa* (24).

The total tree biomass was estimated at 854.73 tonnes, which is equivalent to 427.37 tonnes of carbon. Species with the highest biomass and carbon stock include *Azadirachta indica, Mangifera indica, Adansonia digitata* and *Ficus polita*. These species accounted for 86% of the total biomass and carbon stock recorded (Table 1).

Table 1 Trees Species composition, provenance, biomass and carbon stock in Sokoto metropolis

S/N	Species	Family	Stems	Status	Y(t)	C(t)	Mean C (t)
1	*Acacia machrostachya* (Reichenb. ex Benth.)	Fabaceae	9	Nt	11.70	5.85	1.30
2	*Acacia nilotica* (Linn., Willd. ex Del.)	Fabaceae	7	Nt	2.13	1.06	0.30
3	*Adansonia digitata* (Linn.)	Malvaceae	37	Nt	63.98	31.99	1.88
4	*Albizia lebbeck* (Linn.) Benth.	Fabaceae	5	Ex	5.07	2.54	0.85
5	*Anacardium occidentale* (Linn*)*	Anacardiaceae	1	Nt	0.03	0.02	0.03
6	*Anogeissus leiocarpus* (DC., Guill. & Perr)	Combretaceae	3	Nt	1.58	0.79	0.39
7	*Azadirachta indica* (A. Juss)	Meliaceae	424	Ex	521.4	260.7	1.24
8	*Balanites aegyptiaca (*Linn., DeI.)	Balanitaceae	16	Nt	16.19	8.10	1.01
9	*Borassus aethiopium (*Mart.)	Palmae	3	Nt	1.64	0.82	0.55
10	*Citrus aurantifolia (*Christm., Swingle)	Fruitaceae	1	Ex	0.30	0.15	0.30
11	*Cocos nucifera* (Linn)	Palmae	2	Ex	1.45	0.72	0.72
12	*Crescentia cujete* (Linn.)	Bignoniaceae	1	Ex	0.05	0.02	0.05
13	*Delonix regia* (Roxb.)	Fabaceae	11	Nt	10.41	5.20	1.16
14	*Eucalyptus smithi* (F. Muell. ex R.T. Baker)	Myrtaceae	14	Ex	5.17	2.58	0.37
15	*Ficus polita* (Vahl)	Moraceae	37	Nt	39.05	19.53	1.03
16	*Ficus thonongii* (Blume)	Moraceae	17	Nt	14.95	7.47	0.88
17	*Gmelina arborea* (Roxb.)	Lamiaceae	6	Ex	6.26	3.13	1.04
18	*Khaya senegalensis* (Desr.) A. Juss.	Meliaceae	1	Nt	1.49	0.74	0.50
19	*Lannea microcarpa* (Engl. & K. Krause*)*	Anacardiaceae	2	Nt	0.51	0.26	0.17
20	*Mangifera Indica* (Linn.)	Anacardiaceae	68	Ex	109.92	54.96	1.59
21	*Moringa oleifera* (Lam.)	Moringaceae	1	Nt	0.10	0.05	0.10
22	*Parkia biglobosa* (Jacq., Benth)	Fabaceae	7	Nt	10.85	5.43	1.55
23	*Phoenix dactylifera* (Linn.)	Palmae	1	Nt	1.90	0.95	1.90
24	*Piliostigma reticulatum (*DC., Hochst.)	Fabaceae	6	Nt	0.95	0.48	0.19
25	*Psidium guajava* (Linn.)	Myrtaceae	3	Ex	0.04	0.02	0.01
26	*Sclerocarya birrea* (A. Rich., Hochst.)	Pedaliaceae	3	Nt	3.63	1.82	1.21
27	*Tamarindus indica* (Linn).	Fabaceae	2	Nt	4.58	2.29	2.29
28	*Terminalia catappa* (Linn.)	Combretaceae	24	Ex	12.37	6.18	0.49
29	*Terminalia ivorensis* (A. Chev.)	Combretaceae	9	Nt	4.44	2.22	0.44
30	*Vitex doniana* (Sweet)	Verbenaceae	1	Nt	2.2	1.11	1.11
			722		**854.4**	**426.1**	

Nt = Native species; Ex = Exotic species; Y = Biomass; C = Carbon Stock; t = tonne

Tree Species, Biomass and Carbon Stock Distribution

Tree species and their individual stems were not evenly distributed across the metropolis. The highest number of stems (447) was recorded in the Built-up Area, followed by the Green Area (134), and Wetland/Water area (52), while the least number of stems (43) was recorded in the Open Space. Similarly, the highest stem density was obtained in the Green Area (184ha^{-1}) while the lowest stem density (12.9ha^{-1}) was recorded in the Open Space. The density and distribution of biomass and carbon stock also vary significantly between the different land use/cover types. The total biomass and carbon stock were higher in the Built-up and Green areas, while the lowest values were recorded in the Farmland. However, carbon density per hectare was higher in the Green Area (96.5 tonnes ha^{-1}) and Wetland/Water area (55.8 tonnes ha^{-1}) even though the Built-up Area had higher total biomass and carbon stock (Table 2).

Table 2 Trees species, biomass and carbon stock distribution

		Total Stems					
S/N	Land cover	Native	Exotic	Total	Y (t)	C (t)	C (t/ha)
1	Built-up Area	128	319	447	533.1	266.54	28.8
2	Farmland	33	13	46	42.5	21.23	7.4
3	Green Area	5	129	134	139.0	69.51	96.5
4	Open Space	16	27	43	49.8	24.92	7.5
5	Wetland/Water	11	41	52	90.3	45.16	55.8
	Total	**193**	**529**	**722**	**854.73**	**427.37**	

Y = Biomass; C = Carbon stock

DISCUSSION

The composition and distribution of trees species in this study (Table 1) shows that Sokoto metropolis is composed of few native and exotic tree species distributed disproportionately across the different land use/cover types. The exotic species however, have higher stem population, thus dominating the landscape. This has been reported in many studies (e.g. Kuruneri-Chitepo & Shackleton, 2011; Seburanga, Kaplin, Zhang, & Gatesire, 2014), thereby raising the fear that the exotic species may in the long run, outcompete the native species in many cities due to biotic homogenisation (McKinney, 2006). Hence, much need to be done to improve tree abundance and diversity in the metropolis through afforestation programmes and tree planting campaigns. Such programmes should take account of the many stresses urban tress are exposed to as a result of increasing urban temperatures, restricted rooting space, water deficiencies (Davies et al., 2011) and the ecosystem service potentials of the different tree species.

The total biomass and carbon stock recorded in this study are considerably high when compared to findings from other studies such as Liu and Li (2012), where mean carbon stock of 33.22t ha^{-1}, 30.25t ha^{-1} and 43.70t ha^{-1} were observed in Shenyang, Hangzhou, and Beijing cities, respectively. However, this is comparatively less than the 552,415 tonnes total carbon reported by Woldegerima et al. (2017) in Addis Ababa. The relatively high tree biomass and carbon stock recorded in this study may be attributable to the number of trees with medium to high trunk diameters, which are a characteristic of the Savannah ecosystem where the city is located (Glèlè Kakaï & Sinsin, 2009). Most of the stems (73.1%) have a trunk diameter between 30cm and 75cm. About 2.5% had a diameter of more than 75cm and only 24.4% of the stems have a trunk diameter of less than 30cm (Figure 2).

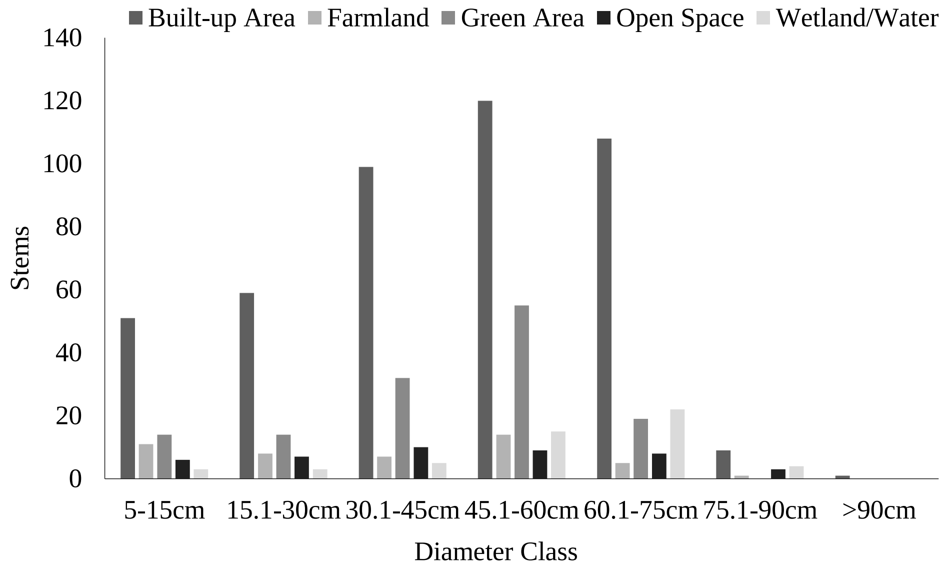

Figure 2 Stem diameter distribution

Although the carbon storage and sequestration potential of urban trees in this part of the world have somehow been neglected, this study shows that urban trees in the region are good carbon sinks. This however, varied with the type of species, diameter and land use/cover type. Species with the highest mean biomass and carbon stock include *Tamarindus indica, Phoenix dactylifera, Adansonia digitata, Mangifera Indica* and *Parkia biglobosa* (Table 1). Between the land cover types, the Built-up and Green areas accounted for 80% of the stems recorded and also accommodate most of the large-diameter trees. Higher total biomass and carbon stock were therefore recorded in these areas (Table 2).

The structural characteristics of tree species recorded in this study varied across the land use/cover types. These to a large extent, determined the biomass and carbon stock of trees in the metropolis. A one-way Analysis of Variance (ANOVA) revealed significant difference in mean stem diameter ($f = 5.79$, $p < 0.001$), mean stem basal area ($f = 5.21$, $p < 0.001$) and consequently, mean stem biomass and carbon stock ($f = 4.73$, $p < 0.001$) across the different land use/cover types. The highest mean stem biomass (1.73t/stem) was recorded in the

Wetland/Water where mean stem diameter was highest and the lowest mean stem biomass (0.92t/stem) was recorded in the Farmland where mean stem diameter was correspondingly lower (Table 3).

Table 3 Comparison of structural parameters and tree biomass

S/N	Parameter	BUA	Farmland	GA	OS	WW	*f*	*p*
1	Total Stems	477	46	134	43	52		
2	Stem Density (ha^{-1})	48.22	15.97	186.1	12.91	64.2		
3	Mean DBH (cm) ±SD	44.6± 20.8	36.8± 23.4	43.4± 16.95	43.3± 22.0	55.8± 18.8	5.79	.001
4	Mean BA (cm^2) ±SD	1903.7 ± 1645.43	1487.1± 1448.29	1701.7± 1016.16	1846.7± 1558.16	2714.4± 1395.61	5.21	.001
5	Mean Biomass (t) ±SD	1.19± 1.18	0.92± 0.96	1.03± 0.66	1.15± 1.05	1.73± 0.95	4.73	.001

BUA = Built-up Area; GA = Green Area; OS = Open Space; WW = Wetland/ Water

CONCLUSION

Sokoto metropolis is composed of a few tree species which are distributed disproportionately across the land cover classes. Depending on the tree species, tree density and diameter as well as land cover type, these trees store a considerable amount of aboveground biomass and carbon stock and thus, contribute significantly to the regional and global carbon budget. In view of climate change mitigation, *Tamarindus indica*, *Phoenix dactylifera*, *Adansonia digitata*, *Mangifera Indica* and *Parkia biglobosa* which have higher mean biomass and carbon stock storage should be adopted as species of choice in the metropolis and widely propagated.

ACKNOWLEDGEMENT

We acknowledge the support from Universiti Putra Malaysia under Grant GCS15-4002.

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Received: 12th January 2019. Accepted: 2nd August 2019

