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Application of Allometric Equation for Estimating Above-Ground Biomass and Carbon Stock of Urban Trees in Selected Areas of Southern Bénin (West Africa)

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Abstract— *Urban trees play a crucial role and natural role in sequestrating carbon from the atmosphere. This study estimates the above ground biomass, carbon stock and carbon dioxide equivalent of urban trees in southern part of Benin Republic. A complete enumeration of street trees was carried out from which 1119 trees were observed and measured for total height and diameter at breast height. Above ground biomass and carbon stock of trees were estimated using allometric equation, because tree carbon stocks are generally not measured directly whenever the biomass estimation involves rare tree species or trees that are meant for protective and aesthetic purposes. The results of the analysis indicated that the total above ground biomass, carbon stock and carbon dioxide equivalent were 1306.097mt, 613.883mt and 2250.647mt respectively. All trees encountered during data collection belonged to Casuarinaceae, Combretaceae Fabaceae, Myrtaceae, Sterculiaceae, Verbenaceae and Meliaceae families and they comprised eleven different tree species with Khaya senegalensis as the dominant tree species. It can be concluded from this study that the urban trees in southern part of Benin act as a reservoir of atmospheric carbon dioxide and further play important part in the global climate change mitigation.*

Keywords— ***Allometric Equation, Biomass Accumulation, Carbon Stock, Southern Bénin, Urban trees.***

I. INTRODUCTION

Urban forest tree is typically described as a woody perennial plant that is found in towns and cities and has a single stem or trunk with a distinct crown [1]. Planting of trees in urban areas, such as roadsides, streets, parks and gardens, provides various ecological, social, economic, aesthetic, and health benefits that are usually overlooked because their financial value is unknown [2]. In a study carried out by [3], it was reported that public Urban trees in Bangkok, Thailand, reduced approximately 65 tons of air pollutants per year, reduced 2.11 million cubic meters of storm water runoff per year, and absorbed 13,000 tons of carbon dioxide per year. Furthermore, the author discovered that 70,000 tons of carbon could be stored by Urban trees over their lifetime. Urban trees, such as street trees have been found to be beneficial to the survival of avifauna in Los Angeles County of the United States of America thereby contributing to biodiversity conservation [4].

The rise in greenhouse gas concentrations has had and will continue to have a significant impact on the global climate [5], [6]. The trees act as a major carbon dioxide sink, absorbing carbon from the atmosphere and storing it in the form of fixed biomass during the growth process. The total global potential for afforestation and reforestation activities is estimated to be 1.35Pg C per year from 1995 to 2050, with the tropics accounting for 70% of the total value [5]. In a study on the quantification of tree carbon stock in Sub Saharan Africa, specifically in Benin republic [7] , observed that the aboveground carbon stock in savannah, woodland, and gallery forest was 23 ± 5, 30 ± 8 and 42 ± 12 MgC per hectare respectively. The estimation of biomass and carbon stocked in forests and urban trees is crucial for appropriate assessment of the impact of forest trees on the reduction of carbon emission and global climate change. Biomass and carbon pools of the terrestrial ecosystem mostly exist in five carbon reservoirs, which according to the Intergovernmental Panel on Climate Change [5] are: the aboveground biomass, below-ground biomass, litter, woody debris and soil organic matter.

In the recent times, research works have been focused on the contribution of forests and urban trees in reducing atmospheric carbon dioxide. The estimation of above and below ground biomass pools is essential for determining the structure and function of ecosystems [8]. The quantitative information on tree biomass ensures full understanding of carbon accumulation within forest ecosystems and also serves as an ecological indicator for long-term sustainability [9].

There are two common methods for taking field measurements on tree biomass. The first is a destructive method of estimating tree biomass. Among all available biomass estimation methods, the destructive method, also known as the harvest method, is the most direct method for assessing above-ground biomass (AGB) and carbon stocks stored in the forest ecosystems [10].This method entails harvesting all of the trees in the known area and weighing the various components of the harvested tree, such as the tree trunk, leaves, and branches, after they have been oven dried [11]. The destructive method is the most accurate method for determining tree biomass. The method is labour-intensive and time-consuming, and it is usually limited to small trees on small scales ([12] - [13]). In general, tree harvesting necessitates special permission, which is not always easy to obtain. It also draws the attention of the local population, who frequently request compensation for trees harvested in their area. Furthermore, tree felling is not always permitted in areas where trees are planted for protection and aesthetic reasons. The non-destructive method of biomass estimation is suitable for ecosystems with rare or protected tree species were harvesting of such species is not practical, feasible or allowed, such as urban trees. In situations like these, the most widely used method for estimating tree biomass is through the application of allometric equations. Allometric relationships have traditionally been used in forest sciences to estimate stem volume or tree biomass. [14] revised the pan tropical multi-species allometric equations and proposed allometric equations for wet, moist, dry, and mangrove forest ecosystems. Tree diameter, wood specific gravity, and tree height were the most important predictors of tree AGB, in that order, and the inclusion of tree height in the model predictors excluded the differences between forest types [15]. [16]) provided a catalogue of available equations which can be applied for tree biomass and carbon stock estimation in sub-Saharan Africa. Though volume estimation is critical for forest management and timber commercialization, there has been a renewed interest in biomass estimation for about a decade [17]. Climate change mitigation strategies, specifically REDD+, require accurate and repeatable estimations of forest biomass and carbon stocks [18], and the selection of an appropriate allometric model has been demonstrated to be a critical step ([19]; [20]).

As reported by Chave et al. [21], the allometric equations for biomass estimation are obtained by developing a relationship between the various tree growth variables, such as the diameter at breast height, the length of the tree trunk, the total height of the tree and crown diameter. [22] estimated AGB of secondary forest and gallery forest of Congo in the Republic of Congo using allometric equation of Chave et al. [14]:

$$AGB= wd*\exp((-1.239+1.980\ln(Dbh)+0.207(\ln(Dbh))^2 -0.0281(\ln(Dbh))^3)$$

A lot of Allometric equations for estimating aboveground biomass of woody species in West Africa have been developed. In a study carried out in Ghana by Henry et al. [23], the authors developed an allometric equation for tropical forests by integrating total tree height, Dbh, and wood density (WD) from 42 trees with a maximum Dbh of 150 cm. [24] developed different allometric equations for AGB estimation for some tree species in Benin Republic. The authors recommended the use of allomeric equations of the forms; $\ln(AGB) = -2.3129+1.7953*\ln(Dbh)+0.6833*\ln(H)$ and $\ln(AGB)= -2.4996+1.5133\ln(Dbh)+1.1256\ln(H)$ for AGB estimation of *Afzelia africana* and *Anogeissus leiocarpus* respectively. In the same vein, Aabeyir et al. [25] developed and applied a local allometric model for estimating above ground biomass of tropical woodlands in Ghana, the authors observed that an equation of the form: $AGB = 0.0580 \rho((Dbh)^2H)^{0.999}$ is better than for use West Africa than the Pantropic model developed by Chave et al. [15]. The local allometric model was thereafter, recommended for use in Ghana and in other parts of West African sub regions for efficient quantification of above ground biomass. Furthermore, Aabeyir et al. [25] developed a mixed allometric model for estimating AGB for tropical woodlands in Ghana. The authors compared the local allometric model with the pantropic allometric model of Chave et al. [15] and recommended that the local model can be easily be used in place of pantropic model for estimating woodlands biomass in West Africa and other countries in the region with similar climatic conditions.

Even though the estimates of biomass and carbon stocks in urban trees are required for inclusion in the United Nations Framework Convention on Climate Change (UNFCCC) program, as stipulated by the Kyoto Protocol, there are few studies on the application of appropriate local allometric model for the quantification of the above ground biomass of urban trees in the southern part of Benin Republic. The aim of this paper, therefore, was to estimate the quantity of above ground biomass and carbon accumulation of urban trees in the study area.

II. MATERIALS AND METHODS

2.1. Study Area.

The study area is in the southern region of Benin, generally referred to as Department of Ouémé. It lies between latitudes 6° 21' and 6° 32' North and longitudes 2° 22' and 2° 39' East. Two major cities found in this area are Porto-Novo and Sèmè-Kpodji. The map of the study area shows Porto-Novo metropolis which covers a land area of 52 km^2 and bounded to the north by Akpro-Missérété and Avrankou, to the south by Sèmè-kpodji, to the east by the commune of Adjarra, and to the west by the commune of Aguégués (Fig.1). As reported by Akionla [26], the climatic conditions are typical of a humid sub-equatorial with two rainy seasons (April to July and and October to November) and two dry seasons (December to February and August to September). Between March and April, the average monthly temperature is 32 degrees Fahrenheit, whereas between August and December, the average monthly temperature is 23.1 degrees Fahrenheit. The area is characterized by an annual average rainfall between 1100 mm and 1200 mm. Sèmè-Podji covers an area of 250 km^2, is bordered in the north by Porto-Novo and the Aguégué, in the south by the Atlantic Ocean, in the east by the Federal Republic of Nigeria, and in the west by Cotonou. Sèmè-Podji is a coastal plain surrounded by numerous bodies of water (the Atlantic Ocean, the Porto-Novo lagoon, the Ouémé River, and Lake Nokoué). It has two dry seasons (December to February and August to September) and two wet seasons (April to July and October to November). High relative humidity and yearly precipitation of 1100 mm with a mean temperature of approximately 27 °C.

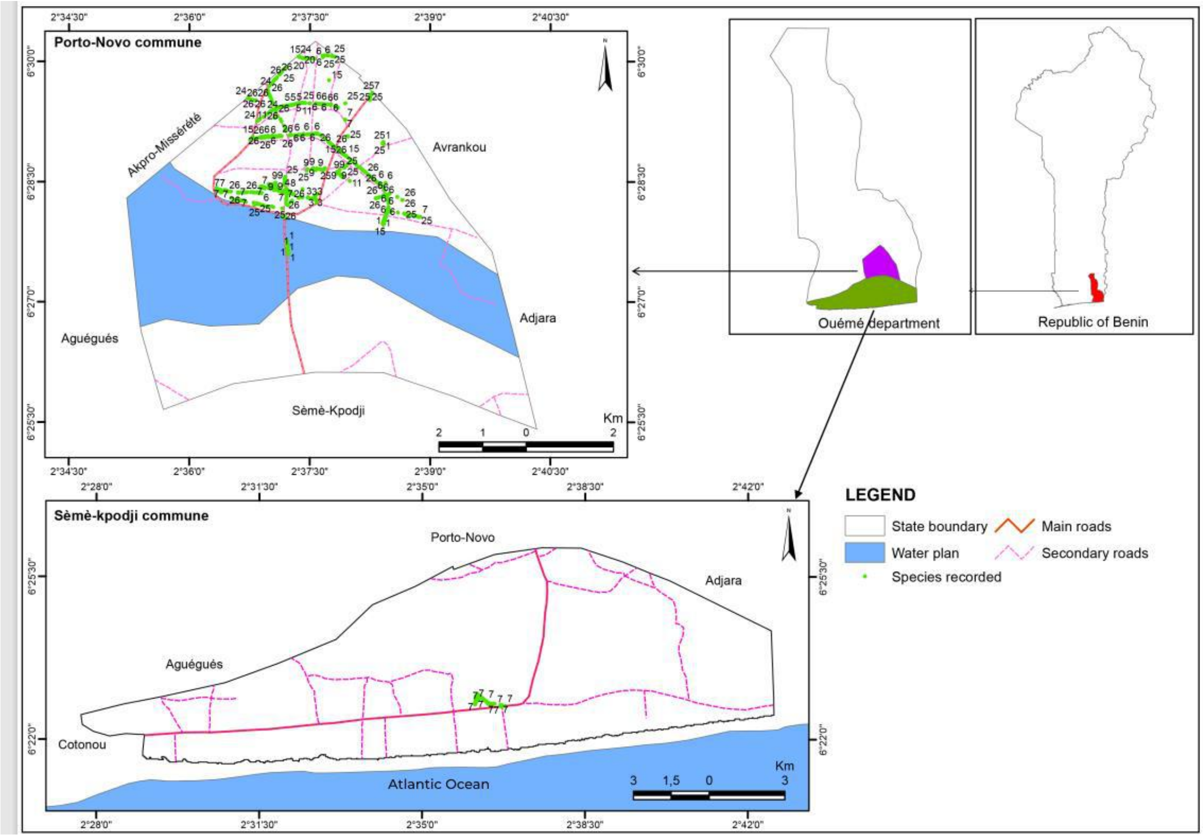

Fig. 1. Map of study Area.

2.2. Data Collection.

The field work for Above ground biomass inventory was conducted on street trees along all tar roads and streets with interlocking block pavement in Porto-Novo and Seme-Kpodji cities. A complete enumeration of all perennial tree species, with diameter at breast height of ≥ 10 cm, were identified, recorded by their botanical names. Both diameter at breast height (Dbh at 1.3 m above the ground) and height of individual live woody plant species cm were measured. Woody plants which have multiple stems at 1.3 m height were considered as a single individual and Dbh of the largest stem was taken using diameter tape and Suunto Hypsometer, respectively. Botanical name of each woody plant recorded and measured on the field was cross-checked using volumes of Flora of West Africa.

The wood density for each tree species was obtained from other studies and databases [27] and their values were incorporated into the selected allometric equation for the biomass estimation. For the unknown tree species, average value of wood density of 0.6 g/cm3 was used in accordance with the value reported for wood density of trees in Africa which ranges between 0.58 and 0.67 g/cm3 [16]. The total carbon stock was further converted to metric tons of Carbon dioxide (CO_2) equivalent by multiplying it by 44/12 or 3.67 of molecular weight ratio of CO_2 to O_2 [28] to establish the climate change mitigation potential of the trees in the study area.

2.3. Allometric Equation Adopted.

In this study, none of the enumerated tree was felled as all urban trees were deliberately planted for protective and aesthetic purposes. Therefore, model II of non-destructive method of estimating above ground biomass and carbon stock, as developed by Aabeyir et al. [25], was adopted for the estimation in the study area. The allometric model, (Equation 1), has been described as the best model for biomass and carbon stock assessment in West African sub region based on climatic condition, Dbh of trees and forest type of the study area to determine the above ground biomass of tree species having at least ≥5 cm Dbh [25]

2.4. Data Analysis.

Above Ground Biomass (AGB) and Carbon stock Estimation: Estimation of total above ground biomass, carbon stock and carbon dioxide equivalent were carried out using Equations 1-3 respectively.

The allometric model for above ground biomass estimation is given as:

$$AGBest = 0.0580*\rho*((Dbh)^2H)^{0.999} \quad (1)$$

Where, AGBest is eestimation of the Above Ground Biomass (kg), H is Total Tree height (m),

Dbh(cm) is Tree Diameter at breast height and ρ is Wood density (t/m^3), 0.0580 and 0.999 are constants.

Furthermore, the above ground carbon stock in each standing tree was estimated using the formular:

$$AGCest = AGBest *0.5 \quad (2)$$

Where: AGC is above ground carbon stock and 0.47 is a constant.

$$CO_2 \text{ Equivalent} = AGCest *3.67 \quad (3)$$

Where: AGCest is above ground carbon stock and 3.67 is a constant.

Total estimated above ground biomass (AGB), above ground carbon stock (AGC) and carbon dioxide equivalent (CO_2 e) were obtained by adding up of values for all trees measured for the study.

Furthermore, floristic composition assessment was undertaken in the study area for identification of tree species and their families.

All data obtained from field measurements were subjected to statistical analysis using Statgraphics Centurion 18 Version software.

III. RESULTS AND DISCUSSION

From the field measurement and analysis, a total of 1119 trees were encountered in all the observed locations in the study area. Table 1 shows the statistical summary of the trees' growth variables. The diameter at breast height (Dbh) ranged between 10.00cm and 108.60cm while that of the total tree height was between 0.63m and 34.80m. The actual means for Dbh and height observed were 41.21cm and 11.14m respectively.

Table 1. Summary Statistics of Trees' Growth Variables.

Variables	Mean	Standard Error	Lower limit	Upper limit	Minimum	Maximum
Dbh(cm/Tree)	41.21	0.69	39.85	42.57	10.00	108.60
Total Height(m/Tree)	11.14	0.13	10.88	11.39	0.63	34.80

Table 2 shows the diameter at breast height class distribution for all the urban trees enumerated. Diameter class of 20 – 35cm had the highest number of individuals (450) followed by class 35 – 50cm with 166 trees. The smallest number of trees (11) was found in the class of 95 - 110cm. Diameter classes of 05 – 20 and 50 – 65 also have 153 and 166 trees respectively.

Table 2. Frequency Distribution for the Dbh (cm)

Diameter Class Interval	Frequency
05 - 20	153
20 - 35	450
35 - 50	166
50 - 65	132
65 - 80	93
80 - 95	114
95 - 110	11
Total number of trees	1119

3.1 Biomass and Carbon Estimation.

The application of Aabeyir et al. [25] allometric equation, which incorporated the Dbh, tree height and wood density,for biomass estimation in sub Saharan Africa, had been carried out in this study. The results of the estimation of above ground biomass, carbon stock and carbon dioxide equivalents (CO_2e) are presented in Table 3. The means per tree for above ground biomass (AGB), above ground carbon stock (AGCS) and above ground carbon dioxide equivalent ($AGCO_2e$) were 1.1672 metric tons, 0.5486 metric tons and 2.0113 metric tons respectively. The mean value of AGB ranged between 1.073 and 1.2612, that of AGCS was between 0.5044 and 0.927 while $AGCO_2e$ was within 1.8493 and 2.1733. The total AGB for all trees enumerated was 1,306.097 Mt, AGCS had 613.883Mt and total carbon dioxide equivalent ($AGCO_2e$) was 2,250.647Mt.

Table 3. Summary Statistics of the Estimated AGB, Carbon Stock and Carbon Dioxide Equivalent.

Variables	Number of Trees	Mean	Minimum	Maximum	Lower limit	Upper limit	Quantity (Mt)
AGB (Mt)	1119	1.1672	0.0072	12.4186	1.0732	1.2612	1,306.097
AGCS (Mt)	1119	0.5486	0.0034	5.8367	0.5044	0.5927	613.883
$AGCO_2e$ (Mt)	1119	2.0113	0.0123	21.3993	1.8493	2.1733	2,250.647

N.B: AGB stands for Above Ground Biomass, AGCS is Above Ground Carbon Stock and $AGCO_2e$ is Above Ground Carbon Dioxide Equivalent.

The graphical representation of the relationship between the tree diameter at breast eight and the estimated above ground biomass is presented in Figure 2. The graph shows an exponential trend between the Dbh and AGB.

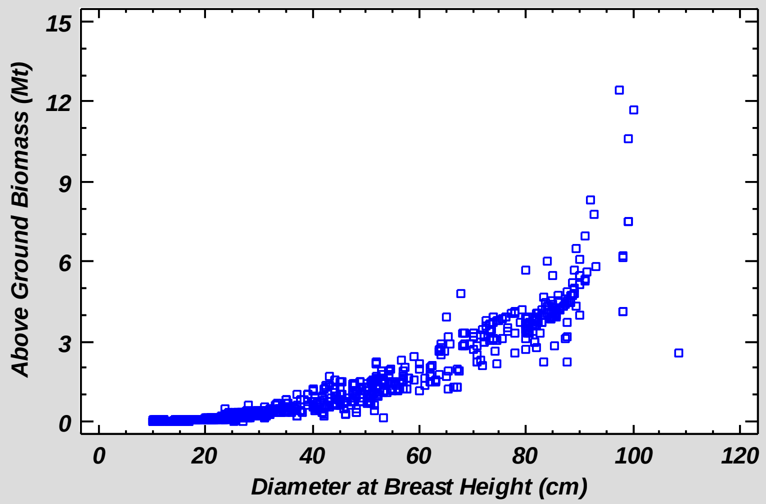

Fig.2 Relationship between AGB and Dbh

3.2 Floristic Composition of the Urban Trees.

Information on the floristic composition of trees in the study area is presented in Table 4. All tree species belong to seven families: Casuarinaceae, Combretaceae Fabaceae, Myrtaceae, Sterculiaceae, Verbenaceae and Meliaceae. From the total trees enumerated, *Khaya senegalensis* dominated the tree species found with 309 trees (27.62%), followed by three major tree species of *Teminalia mentally* with 286 trees (25.56%), *Terminalia catappa* 241 trees (21.54) and *Terminalia superba* with 168 trees (15.01%) respectively.The least common tree species observed is *Triplochiton scleroxylon* with one tree (0.09%).

Table 4. Floristic Composition of Urban Trees.

Scientific Names of Tree Species	Number of Trees	Percentage (%)
Acacia auriculiformis	25	2.23
Azadirachta indica	16	1.43
Casuarina equisetifolia	10	0.89
Eucalptus camaldulensis	41	3.66
Eucalptus torrlliana	6	0.54
Gmelina arborea	16	1.43
Khaya senegalensis	309	27.62
Terminalia catappa	241	21.54
Terminalia mentally	286	25.56
Teminalia superba	168	15.01
Triplochiton scleroxylon	1	0.09
Total	1119	100 %

IV. DISCUSSION

The study indicated that, with the observed values of diameter at breast height which ranged between 10cm and 108.60cm and mean of 41.21cm, the distribution of tree dbh was positively skewed. This confirmed that majority of the urban trees were within the lower diameter class limit. More so, the dbh class limit of 20-35 had the largest number of trees, and with this class limit, serious damage to urban infrastructure by tree sizes would minimize. The means of AGB, above ground carbon stock and above ground carbon dioxide equivalent were 1.1672mt /tree,0.5486mt/tree and 2.0113mt/tree respectively. These mean values, when compared to a similar study in Niger Republic, were higher than the mean values of urban tree biomass for cities in Niamey with 31.63mt/ha and Maradi with 58.30mt/ha respectively as obtained by [29]. The number of the observed tree species indicated that plant flora of Porto Novo and Seme Kpodji is very diverse. This finding is in agreement with the observation of [30] in a study on woody plant species in urban forestry in Lome, Togo Republic. The authors noticed that the capital city of Togo Republic, Lome, has about 48 different tree families. Furthermore, the most commonly found tree species in the study area were the *Khaya senegalensis* (27%) and *Terminalia mentally* (25.56%) while *Triplochiton scleroxylon* (0.09%) was less common. Other notable tree species were *Terminalia catappa* (21.54%) and *Terminalia superba* (15.01).

V. CONCLUSION

This work has adopted the application a suitable biomass allometric equation for estimating total above ground biomass, carbon stocks and carbon dioxide equivalent in urban trees of Porto Novo and Seme Kpodji cities of Republic of Benin. The observed results indicated that there were 1119 urban street trees with diameter at breast height range of 10cm and 108.60cm and mean value of 41.21cm. The floristic composition showed that eleven tree species were present and belonged to different seven families: Casuarinaceae, Combretaceae, Fabaceae, Myrtaceae, Sterculiaceae, Verbenaceae and Meliaceae. The Meliaceae family was found to be the most dominant in the area. Furthermore, a total of 1306.097mt of above ground biomass, 613.883mt of above ground carbon stock and 2250.647mt of carbon dioxide equivalent were estimated from the study site. Urban trees are diverse in nature and could contribute to reducing global atmospheric carbon and as such could be incorporated into climate change mitigation program in the country. Although, the only variables used for the whole estimation were the diameter at breast height, total tree height and wood density, there is still need for further development of more suitable methods for above ground biomass estimation in the study area.

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