Journal of Research in Forestry, Wildlife & Environment Vol. 12(2) June, 2020
E-mail: jrfwe2019@gmail.com; jfewr@yahoo.com
http://www.ajol.info/index.php/jrfwe
jfewr ©2020 - jfewr Publications
ISBN: 2141 – 1778

ESTIMATION OF BOLE BIOMASS AND CARBON STOCKS THROUGH THREE VOLUME EQUATIONS FOR TREE SPECIES IN OGBA ZOO, NIGERIA

[*]Aghimien E.V.,[1] Adams O.T.,[2] Adedeji M.S.[2]

[1]Federal College of Forest Resources Management, Edo State, Nigeria
[2]Federal College of Forestry, Ibadan, Nigeria
***Corresponding Author**: *aghimien4@yahoo.com*; +2347031238830

ABSTRACT

Precise and accurate estimates of bole Carbon Stocks (CS) sequestration are crucial for sustainable forest management related to climate change. Therefore, the study is aimed at estimating CS through three volume equations techniques with a view to identify how CS sequestration varies across volume equation. A total of ten (10) Temporary Sample Plots (TSPs) of 20m x 20m (0.04ha) in size were randomly laid in the study site. Tree species in all of the TSPs with a diameter ≥ 10 were measured for diameters and heights. Data were analysed using descriptive statistics, volume equations, regression and analysis of variance at $\alpha_{0.05}$. A total of twenty five (25) tree species comprising of fourteen (14) families were found in the TSPs from hundred and one (101) individual trees. There were differences in CS with respect to the three volume equations. There were very strong linear relationship between CS and the three volume equations with R^2 value > 90%. There was statistical difference amongst Hossfeld's equation, Geometric equation for the truncated cone and Smalian's equation with t-Test value of 0.01, while Geometric equation for the truncated cone showed statistical difference with Hossfeld's equation with t-Test value of 0.00. There was no statistical difference between Smalian's equation and Geometric equation for the truncated cone with t-Test value of 0.57. Therefore, the scatter plots shows that the three bole volume equations are good predictors for estimating CS. However, Geometric equation for the truncated cone and Smalian's equation had a high standard error and uncertainty values of 5%, 143% and 6%, 145%.

Keywords: carbon stocks, carbon dioxide equivalent, volume equation, tree species, Ogba Zoo

INTRODUCTION

Ogba Zoo and Nature Park is an urban tropical rainforest reserve within metropolitan area in Benin City, Edo State, Nigeria. The vegetation structure is considered as the composition of plants community in terms of specific morphological characteristics (Martin, 1996). Bole Carbon Stocks (CS) estimation with the three volume equations techniques is essential in view of their carbon dioxide equivalent (CO_{2e}) estimates in understanding the extent of CS in the ecosystems. CO_2e is a measure for estimating how much amount of greenhouse gas may cause, using the functionally equivalent amount of CS as the reference (Aghimien and James, 2019, Aghimien *et al.*, 2020). The role of tree based techniques in the global carbon balance is widely recognized and the determination of CS sequestration through biomass estimation has been the most widely followed approach for mitigating atmospheric carbon dioxide (CO_2) concentrations (Brown *et al.*, 1989, Brown 1997, Chambers *et al.*, 2001). Land conversions to agriculture and poor land management practices have been the major contributors to this sharp increase in Greenhouse Gases (IPCC, 2000). Bole CS has been estimated in different ways by different researchers and there is a clear and wide difference in the estimates made by different scientist's (Kishwan *et al.*, 2009). However, precise and accurate estimates of CS sequestration are crucial for development of management plans related to climate change. Therefore, the study is aimed at estimating bole CS using three volume equations techniques with a view to identify how CS sequestration varies across volume equation.

MATERIALS AND METHODS

Ogba Zoo and Nature Park (OZNP) cover an area measuring 59,729 hectares and is situated along Oko-Ogba Road in Oredo Local Government Area. It is located at latitude 6^{o} 17′ 020″N and longitude; 005^{o} 35′ 016″ E / 6.28889^{o}N and 5.58778^{o}E with an average elevation of 46m above sea-level. Areas within the OZNP area currently enclosed within a perimeter wire mesh fence were considered as undisturbed, while the areas outside the confinement are assumed to be disturbed.

Sampling design and sample size

A total of ten (10) Temporary Sample Plots (TSPs) of 20m x 20m (0.04ha) in size were randomly laid in the study site. Tree species were measured for diameters and heights in the corresponding TSPs, according to tree sizes. Two (2) diameter measurements were taken using the Criterion RD 1000 laser dendrometer; diameter at base (D_{base}); diameter at top (D_{top}), while bole height (h_b) were measured using TruPulse 200B ranger finder. Tree species in all of the TSPs with a diameter ≥ 10 were measured.

Estimation of wood density

Condit, (2008) reported that wood density is defined as the ratio of the oven-dry mass of a wood sample divided by the mass of water displaced by its green volume. Wood densities of tree species were acquired from the Global Wood Density Database (GWDD) for this study Aghimien *et al.,* (2019). Aghimien *et al.,* (2019) reported that GWDD has been widely used by scientists in the estimation of bole carbon stocks.

Bole volume estimation

Three (3) volume equations were used to estimate bole Carbon Stocks (CS). However, foresters have long employed volume formulae derived from classical quadrature. It is a mathematical techniques used for evaluating an integral without an exact formula. Quadrature rules used in forestry include the familiar Huber's, Smalian's, and Newton's formulae (Husch *et al.,* 2003). Volume of bole sections are often calculated using Smalian's formulae, or alternatively by using the Geometric equation for the truncated cone, and Hossfeld's equation. They are mathematically expressed as follows:

$$V_b = \frac{\pi.H}{12}\left(D^2{}_{base} + (D_{base}.D_{top}) + D^2{}_{top}\right)$$ ..(*Geometric equation for the truncated cone eqn. 1*)

$$V_b = H\left(\frac{\left(3.D_{\left(\frac{1}{3}\right)base}\right) + D_{top}}{4}\right)$$ …… Hossfeld's(eqn.2)

$$V_b = \pi.H\left(\frac{D^2{}_{base} + D^2{}_{top}}{8}\right)$$ ……… Smalian's (eqn. 3)

Where:
V_b = Bole volume (m^3)
h_b = Bole height (m)
D_{base} = Diameter at base (cm)
D_{top} = Diameter at top (cm)
π (pi) = 3.143.
eqn. = equation

Estimation of bole carbon stocks

Bole CS was estimated by measuring and multiplying Bole Biomass (BB) with corresponding carbon fractions of 0.4748 (IPCC, 2006). Thereafter, 44/12 was multiplied by CS (Kg) to acquire CS ($KgCO_{2e}$), the result was then divided by 1000 to obtain CS ($MgCO_{2e}$) and later multiplied by 0.04 (20m x 20m plots in hectare**)** to obtain CS ($MgCO_{2e}ha^{-1}$) in hectare (Aghimien *et al.*, 2019).

Statistical analysis

Data collected were entered and arranged for analysis using Microsoft Excel 2010 version. Analysis of variance (ANOVA), were performed to test for significant differences among volume equations. It was also analyzed for descriptive statistics and regression analysis at $\alpha_{0.05}$.

RESULTS

Vegetation structure and composition of tree species and wood density

A total of twenty five (25) tree species comprising of fourteen (14) families were found in the temporary sample plots (TSPs) from hundred and one (101) individual trees in the study site. Figure 1 showed diameter distribution size classes with variation in diameter across the classes. The highest frequency distribution was in diameter size class 45-70cm and 20-45cm as a result of the abundant tree species structure and composition. The most abundant tree species were found in the bole height distribution size class of 20-30m, followed by 10-20m and 30-40m, respectively as presented in Figure 2. Wood density is an essential predictor when estimating bole Carbon Stocks (CS). The wood density distribution size classes were highest at 0.36-0.46Kgm^{-3}, followed by 0.66-0.76Kgm^{-3} and 0.46-0.56Kgm^{-3}, respectively. The least wood density distribution size class was found each at 0.76-0.86Kgm^{-3}and 0.86-096Kgm^{-3}, respectively as presented in Figure 3. The wood density value that is greater than one (1) will sink when immerse in water (Aghimien *et al.*, 2019). A similar observation is also made by Kotto-Same *et al.*, (1998) that the diameter distribution appeared in an inverted J shape and the frequency distribution on height size classes was highest between 30-40m which is in conformity with the findings of Murali *et al.*, (2005), Mani and Parthasarathy (2007), Kumar and Nair (2011).

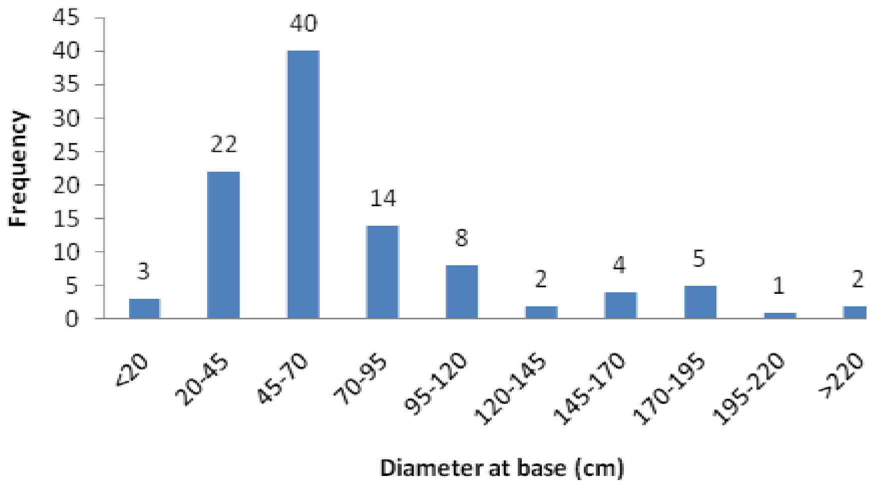

Figure 1: Distribution of diameter at the base size classes

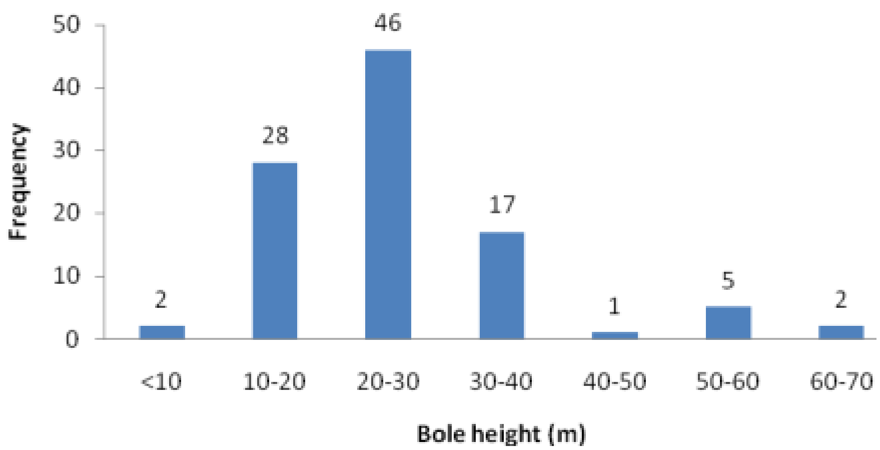

Figure 2: Distribution of bole height size classes

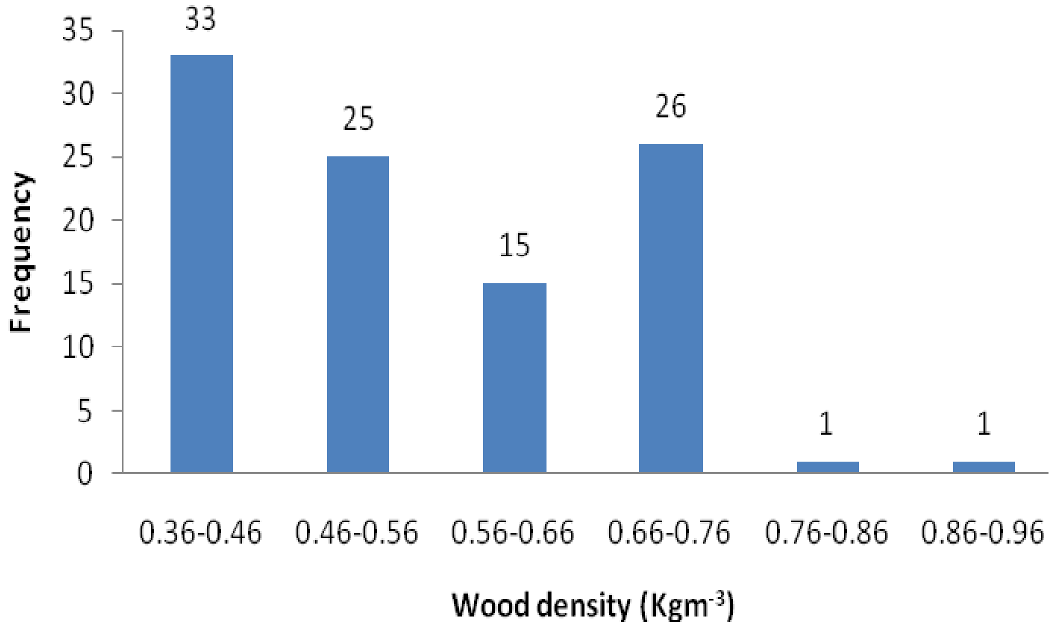

Figure 3: Distribution of wood density size classes

Table 1: Estimation of BCS at family level with geometric equation for the truncated cone

Family	**Freq. of Species**	**Biomass (kg)**	**Kg C**	**KgCO$_2$e**	**MgCO$_2$e**	**MgCO$_2$eha^{-1}**
Anacardiaceae	1	1.61	0.76	2.80	0.00	0.00
Apocynaceae	14	30.82	14.64	53.66	0.05	0.00
Clusiaceae	5	13.32	6.33	23.19	0.02	0.00
Combretaceae	6	64.97	30.85	113.11	0.11	0.00
Fabaceae	41	147.21	69.94	256.43	0.26	0.01
Gentianaceae	5	17.56	8.34	30.57	0.03	0.00
Lamiaceae	8	23.21	11.02	40.41	0.04	0.00
Meliaceae	5	37.27	17.61	64.88	0.06	0.00
Moraceae	4	29.19	13.86	50.83	0.05	0.00
Myristicaceae	1	3.24	1.54	5.63	0.01	0.00
Pinaceae	8	76.25	36.20	132.75	0.13	0.01
Rubiaceae	1	53.69	25.49	93.48	0.09	0.00
Rutaceae	1	0.27	0.13	0.47	0.00	0.00
Urticaceae	1	0.09	0.04	0.16	0.00	0.00
Grand Total	**101**	**498.71**	**236.83**	**868.38**	**0.87**	**0.03**

Table 2: Estimation of BCS at family level with Smalian's equation

Family	Freq. of Species	Biomass (Kg)	Kg C	$KgCO_2e$	$MgCO_2e$	$MgCO_2eha^{-1}$
Anacardiaceae	1	1.68	0.71	2.92	0.00	0.00
Apocynaceae	14	35.11	16.71	61.28	0.06	0.00
Clusiaceae	5	13.72	6.52	23.89	0.02	0.00
Combretaceae	6	67.81	32.11	118.05	0.12	0.00
Fabaceae	41	165.84	78.74	288.71	0.29	0.01
Gentianaceae	5	17.78	8.44	30.95	0.03	0.00
Lamiaceae	8	27.83	13.22	48.45	0.05	0.00
Meliaceae	5	42.17	20.02	73.41	0.07	0.00
Moraceae	4	31.70	15.05	55.19	0.06	0.00
Myristicaceae	1	4.114	1.95	7.16	0.01	0.00
Pinaceae	8	89.84	42.65	156.40	0.16	0.01
Rubiaceae	1	60.45	28.70	105.25	0.11	0.00
Rutaceae	1	0.28	0.13	0.49	0.00	0.00
Urticaceae	1	0.10	0.05	0.18	0.00	0.00
Grand Total	**101**	**558.52**	**265.19**	**972.35**	**0.97**	**0.04**

Table 3: Estimation of BCS at family level with Hossfeld's equation

Family	Freq. of Species	Biomass (Kg)	Kg C	$KgCO_2e$	$MgCO_2e$	$MgCO_2eha^{-1}$
Anacardiaceae	1	1.77	0.84	3.08	0.00	0.00
Apocynaceae	14	23.48	11.15	40.88	0.04	0.00
Clusiaceae	5	13.31	6.36	23.33	0.02	0.00
Combretaceae	6	28.40	13.49	49.45	0.05	0.00
Fabaceae	41	115.30	54.75	200.74	0.20	0.01
Gentianaceae	5	9.88	4.69	17.20	0.02	0.00
Lamiaceae	8	13.41	6.37	23.35	0.02	0.00
Meliaceae	5	16.71	7.93	29.09	0.03	0.00
Moraceae	4	19.64	9.32	34.19	0.03	0.00
Myristicaceae	1	2.55	1.21	4.44	0.00	0.00
Pinaceae	8	36.02	17.10	62.70	0.06	0.00
Rubiaceae	1	14.91	7.08	25.97	0.03	0.00
Rutaceae	1	0.59	0.28	1.02	0.00	0.00
Urticaceae	1	0.30	0.14	0.53	0.00	0.00
Grand Total	**101**	**296.37**	**140.72**	**515.96**	**0.52**	**0.02**

Table 4: Descriptive statistics of BCS with three volume techniques

Statistics	Hossfeld equation ($KgCO_2e$)	Truncated cone ($KgCO_2e$)	Smalian's ($KgCO_2e$)
Mean	5.11	8.60	9.63
Standard Error	0.42	1.25	1.42
Standard Deviation	4.20	12.52	14.26
Range	25.54	93.35	105.11
Minimum	0.43	0.13	0.14
Maximum	25.97	93.48	105.25
Confidence Level (95.0%)	0.02	2.47	2.81
Uncertainty	0.82	1.46	1.48

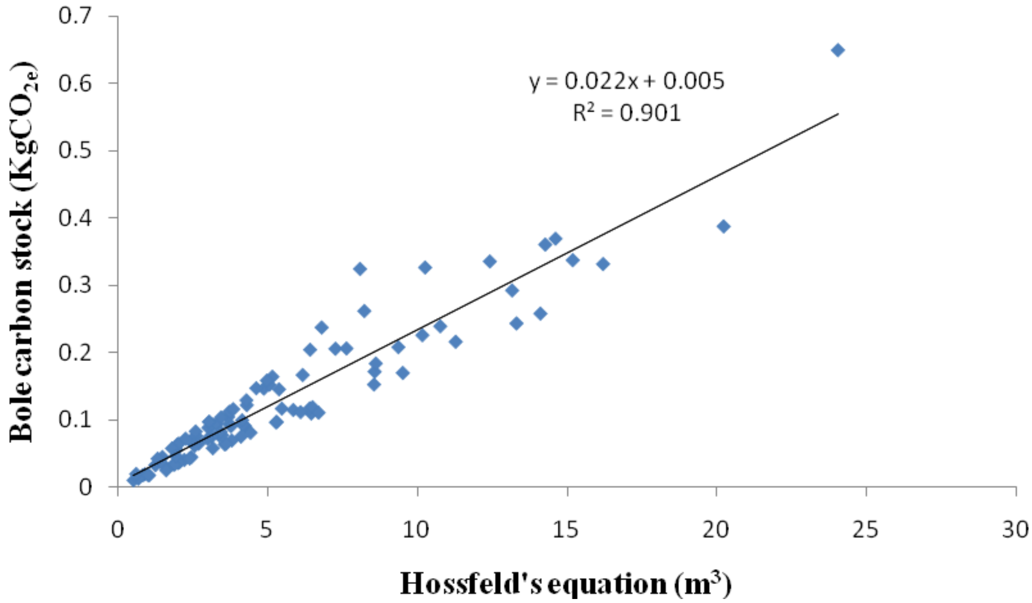

Figure 4: Relationship between above-ground bole carbon stock and Hossfeld equation

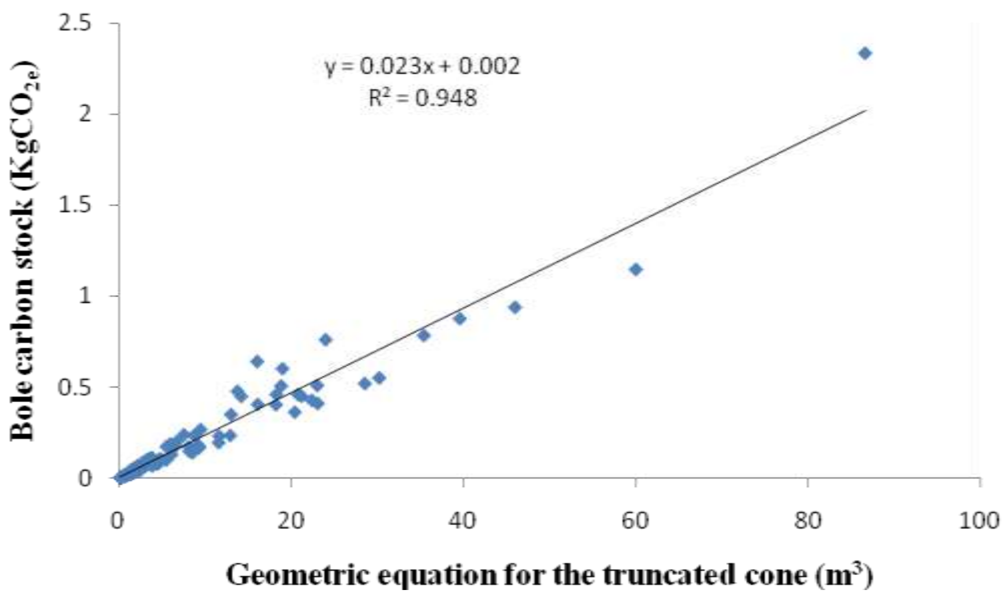

Figure 5: Relationship between above-ground bole carbon stock and Geometric equation for the truncated cone

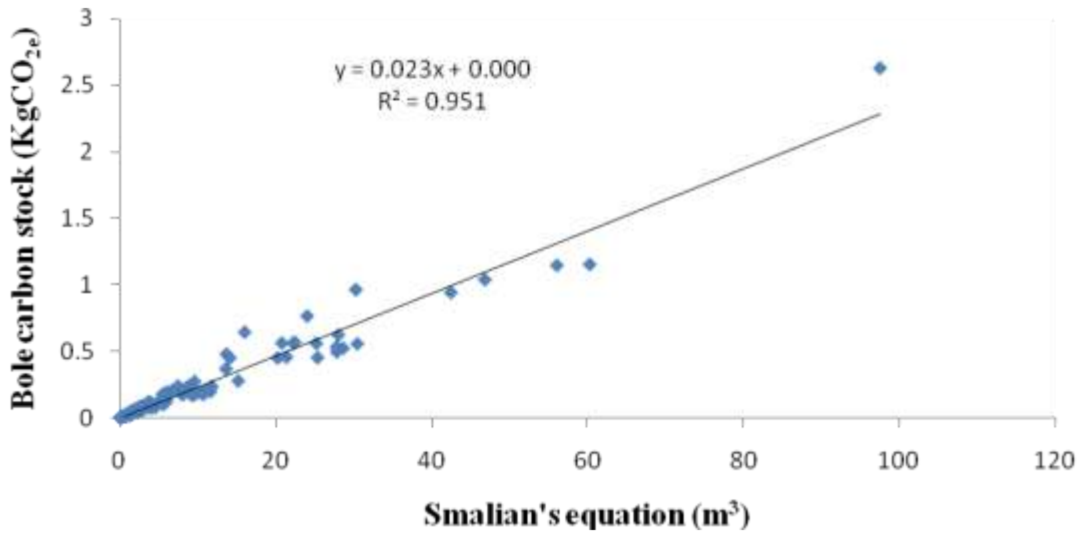

Figure 6: Relationship between above-ground bole carbon stock and Smalian's equation

Table 5: Descriptive statistics with volume (M^3ha^{-1}) techniques used in the estimation of BCS

Statistics	**Hossfeld's equation (M^3ha^{-1})**	**Truncated cone (M^3 ha^{-1})**	**Smalian's equation (M^3 ha^{-1})**
Mean	0.21	0.36	0.41
Standard Error	0.02	0.05	0.06
Standard Deviation	0.18	0.52	0.59
Range	0.94	3.46	3.89
Minimum	0.02	0.01	0.01
Maximum	0.96	3.46	3.90
Confidence Level (95.0%)	0.03	0.10	0.12
Uncertainty	0.82	1.43	1.45
t-Test	0.01[a]	0.00[ab]	0.57[b]
Total bole volume	21.64	36.85	41.33

[a] $p < 0.05$ (Significant), [b] $p < 0.05$ (not significant)

DISCUSSION

Estimation of bole carbon stocks in the study site

The three volume equations (Geometric equation for the truncated cone, Smalian's equation and Hossfeld's equation) techniques were used for the estimation of Bole Carbon Stocks (BCS). The BCS were estimated at family level. The distribution of BCS across family level with geometric equation for the truncated cone as presented in Table 1. The family of Fabaceae sequesters the maximum amount of biomass and carbon stock with values 147.21Kg and 256.43$KgCO_{2e}$ by forty one (41) individual tree species, followed by Pinaceae family with biomass and carbon stock values of 76.25Kg and 132.75$KgCO_{2e}$ by eight (8) individual tree species, while the family of Combretaceae accumulated biomass and carbon stock with values of 64.97Kg and 113.11$KgCO_{2e}$ by six (6) individual tree species, respectively. The bole biomass distribution and carbon storage by the family of Urticaceae had minimum amount with values of 0.09Kg and 0.16$KgCO_{2e}$, while the total accumulation of biomass and carbon stock per hectare in the rainforest ecosystem by tree species at family level had values of 498.71Kg and 0.03$MgCO_{2e}ha^{-1}$, respectively. On the other hand, the highest accumulation of bole biomass and carbon stocks were found in big trees with diameter distribution size classes >45cm. However, maximum bole biomass and carbon stock accumulation in a rainforest ecosystem as presented in Table 1. The distribution of BCS across family level with Smalian's equation is presented in Table 2. The family of Fabaceae sequesters the maximum amount of bole biomass and carbon stock with values of 165.84Kg and 288.71KgCO_{2e} by forty one (41) individual tree species, followed by Pinaceae family with biomass and carbon stock values of 89.84Kg and 156.40KgCO_{2e} by eight (8) individual tree species, while the family of Combretaceae accumulated biomass and carbon stock with values of 67.81Kg and 118.05KgCO_{2e} by six (6) individual tree species and the family of Rubiaceae had biomass and carbon stock values of 60.45Kg and 105.25KgCO_{2e}, respectively. The bole biomass distribution and carbon storage by the family of Urticaceae had minimum amount with values of 0.10Kg and 0.18KgCO_{2e}, while the total accumulation of biomass and carbon stock in the rainforest ecosystem by tree species at family level had values of 558.52Kg and 0.04MgCO_{2e}ha^{-1}. The distribution of BCS across family level with Hossfeld's equation is presented in Table 3. The family of Fabaceae sequesters the maximum amount of biomass and carbon stock with values of 115.30Kg and 200.74KgCO_{2e} by forty one (41) individual tree species, followed by Pinaceae family with biomass and carbon stock values of 36.02Kg and 62.70 KgCO_{2e} by eight (8) individual tree species, while the family of Combretaceae accumulated biomass and carbon stock with values of 28.40Kg and 49.45KgCO_{2e} by six (6) individual tree species. The bole biomass distribution and carbon storage by the family of Urticaceae had minimum amount with values of 0.30Kg and 0.53KgCO_{2e}, while the total accumulation of biomass and carbon stock in the rainforest ecosystem by tree species at family level had values of 296.37Kg and 0.02MgCO_{2e} ha^{-1} .

The descriptive statistics of BCS with the three volume equation were estimated for standard error and uncertainty values of 42% and 82% at confidence level of 2% for Hossfeld's equation, followed by Geometric equation for the truncated cone had standard error and uncertainty values of 125%, 146% at confidence level of 247% and Smalian's equation had an estimate with standard error of 142%, uncertainty value of 148% at confidence level of 281%, respectively.. Unfortunately, above-ground biomass estimates are associated with numerous errors and doubts. Several studies have suggested that the relative errors of the estimates can vary between 5% to 30%, depending on the topographic characteristics of the secondary forest ecosystems, remotely sensed information and their spatial resolutions, approaches used, etc. (Asner *et al.,* 2009; Mascaro *et al.,* 2011). The level of essential precision depends on the scales of the forest management decision. Generally, at regional scales a precision of higher than 90% is preferable while at global and national scales a precision of about 80% may be suitable. Traditionally, the precision of forest biomass estimates is estimated by calculating the Pearson's correlation coefficient, root mean square error of the estimated and observed values as this technique directly accounts for the quality of estimates (Wang and Gertner, 2011).

A preliminary modeling step was used to define a suitable set of functions type that will be used for this study. A linear function was used to fit the data between BCS and three volume equations with a view to identify the most suitable relationship considering model selection criteria. It was observed in Figure 4 that there was a strong positive linear relationship between BCS and Hossfeld's equation with R^2 value of 90%. It was revealed that there was a very strong positive linear relationship between BCS and Geometric equation for the truncated cone with R^2 value of 95% as shown in Figure 5. It was shown that there was a very strong positive linear relationship between BCS and Smalian's equation with R^2 value of 95% as presented in Figure 6. Therefore, the scatter plots shows that the three volume techniques are good predictors for predicting above-ground bole carbon stock in the study site. However, Geometric equation for the truncated cone and Smalian's equation had a very high standard error values. Table 5 shows the descriptive statistics of the three volume equations techniques used for the estimation of AGBC. Hossfeld's equation had the minimum total bole volume, standard error and uncertainty values of 21.64m^{3}ha^{-1}, 2%, and 82% at confidence level of 3%, while Truncated cone had little step up with values of 36.85m^{3}ha^{-1}, 5% and 143% at confidence level of 10%, and Smalian's equation had maximum total bole volume, standard error and uncertainty values of 41.33m^{3}ha^{-1} , 6%, and 145% at confidence level of 12%, respectively as presented in Table 5. Table 5 revealed that Hossfeld's equation was statistically different from Ttruncated cone and Smalian's equation with t-Test value of 0.01, while truncated cone showed statistical difference with Hossfeld's equation with t-Test value of 0.00, with no statistical difference between Smalian's equation and truncated cone with t-Test value of 0.57. However, other studies have produced contrasting results reporting negative relationships (Firn *et al.,* 2007, Jacob et al., 2010), which might have occurred due to the complexity of ecosystem structure and function (Wang *et al.*, 2011).

CONCLUSION

Based on the findings, it was observed that Smalian's equation had the highest bole carbon stocks value of 972.35KgCO_2e, followed by Geometric equation for the truncated cone with carbon stock value of 868.38KgCO_2e, and Hossfeld's equation which had minimum carbon stock value of 515.96KgCO_2e. There were differences in carbon stock with respect to the three volume equations. There were very strong linear relationship between bole carbon stock and three volume equations with R^2 value > 90%. Hossfeld's equation was statistically different from Ttruncated cone and Smalian's equation with t-Test value of 0.01, while Truncated cone showed statistical difference with Hossfeld's equation with t-Test value of 0.00, with no statistical difference between Smalian's equation and Truncated cone with t-Test value of 0.57. Therefore, the scattered plot shows that the three bole volume techniques are good predictors for estimating bole carbon stock in the study site. However, Geometric equation for the truncated cone and Smalian's equation had a very high standard error and uncertainty values. It was observed that CO_2 emission rate, being a measure of environmental pollution, is significant, on the increase, and must be kept low. Hence, this study is important for monitoring and checking of adverse CO_2 emissions in the study site. It is also important to generate CO_2 emissions estimates for all forest types from time to time to keep track of environmental pollution in Edo State, Nigeria.

REFERENCES

Aghimien, E.V**.** and James, T.K. (2019): Above-Ground Bole Carbon Stock Estimation Using Forest Inventory of the Secondary Forest Ecosystem in Ibadan, Nigeria. *Journal of forestry and Management,* 16 (3): 41 – 49

Aghimien E.V., Osikabor, B., Adams, O.T., Adedeji, M.S (2020): Modeling Above-Ground Bole Biomass of Selected Tree Species within the Forest in Forestry Research Institute of Nigeria (FRIN). *Journal of Research in Forestry, Wildlife and Environment,* 12(1): 41 - 52

Aghimien, E.V, Osho, J.S.A, Hauser, S. and Ade-Oni, V.D. (2015): Forest Volume-to-Above-Ground Tree Biomass Models for the Secondary Forest in IITA, Ibadan, Nigeria. *International Journal of Forest Research*, 4 (3): 1 – 11

Asner, G. P., R. F. Hughes, T. Varga, D. Knapp, and T. Kennedy-Bowdoin (2009): "Environmental and Biotic Controls over Above-ground Biomass throughout a Tropical Rain Forest Ecosystems'' 1(2): 261–278

Brown, S., Gillespie, A., and Lugo, A.E. (1989): Biomass estimation methods for tropical forest with applications to forest inventory data. *Forest Science* 3(5): 881–902

Brown, S. (1997): Estimating Biomass and Biomass Change of Tropical Forests; FAO *Forest Resources Assessment Publication*: Roma, Italy, p. 55

Chambers, J.Q.; dos Santos, J.; Ribeiro, R.F. and Higuchi, N. (2001): Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. *Forest Ecology and Management* 15(2):73-84

Condit, R. (2008): Methods for estimating above-ground biomass of forest and replacement vegetation in the tropics. *Center for Tropical Forest Science Research Manuel*, 73 pages

Firn, J.; Erskine, P.D. and Lamb, D. (2007): Woody species diversity influences rates of soil carbon and nitrogen availability in tropical plantations. Oecologia 15(4): 521-533

Husch, B., Beers, T.W. and Kershaw, J.A. Jr. (2003): *Forest mensuration*. John Wiley 8 Sons, Inc., 443 p

IPCC (Intergovernmental Panel on Climate Change) (2000): Land Use Land-Use Change, and

Forestry. Special Report, Summary for Policy Makers, IPCC. Geneva, Switzerland. 20 pages

IPCC (2006): Good practice guidelines for National Greenhouse Gas Inventories. Switzerland: Intergovernmental Panel on Climate Change, 30 pages

Jacob, M.; Leuschner, C and Thomas, F. M (2010): Productivity of temperate broad leaved forest stands differing in tree species diversity. *Annals of Forest Science* 6(7): 503-503.

Kotto-Same, J.; Woomer, P.L.; Appolinaire, M and Louis, Z. (1998): Carbon dynamics in slash-and- burn agriculture and land use alternatives of the humid forest zone in Cameroon. *Agriculture, Ecosystems and Environment* 6(5): 245-256

Kumar, B.M. and Nair, P.K.R. (Editors) (2011): Carbon Sequestration Potential of Agroforestry Systems. Springer, Dordrecht, Netherlands 377 pages

Kishwan, J., Pandey, R. and Dadhwal, V.K. (2009): India's forest and tree cover: contributionas a carbon sink. *Indian Council of Forestry and Education Technical Paper (*ICFRE), Dehradun. 12 pages

Mascaro, J., Detto, M., Asner, G. P., and Muller-Landau, H. C. (2011): Evaluating uncertainty in mapping forest carbon with airborne Lidar. *Remote Sensing of the Environment* 11(5): 3770–3774

Martin, G.J., (1996): Ethnobotany: A method manual. Botanic garden, Kew UK: *Chapman and Hall Press*, New York City. 285p

Murali, K.S.; Bhat. D.M. and Ravmdranath, N.H. (2005): Biomass estimation equation for tropical deciduous and evergreen forests. *International Journal of Agricultural Resources, Governance and Ecology* 1(4):81 -92

Mani. S. and Parthasarathy, N (2007): Above-ground biomass estimation in ten tropical dry evergreen forest sites of peninsular India. *Biomass and Bioenergy* 3(1): 284-290

Wang, G.; Zhang, M.; Gertner, G.Z.; Oyana, T.; McRoberts, R.E.; Ge, H. (2011): Uncertainties of mapping aboveground forest carbon due to plot locations using national forest inventory plot and remotely sensed data. *Scandinavian Journal of Forest Research*, 2(6): 360–373