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Comparative Evaluation of Huber's, Smalian's and Newton's Volume Estimation Methods for a Young Teak (*Tectona grandis* L.f.) Plantation in Southwestern Nigeria

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Abstract

Tree volume plays a crucial role in forest management as it provides essential data for decision-making regarding timber production, forest sustainability, and economic planning. Understanding tree volume allows forest managers to estimate the amount of usable wood in a forest, which is vital for determining the monetary value of standing timber. This study, therefore, compares volume estimation equations for a young Tectona grandis plantation at Adekunle Ajasin University Campus, Akungba-Akoko, Ondo State, Nigeria. The research assessed key growth variables, including diameter at breast height (DBH), base diameter (DB), middle diameter (DM), top diameter (DT), basal area (BA), and height. It also estimated the association between these growth variables and compared the volume equations. A total of 220 trees were measured in 20m by 20m sample plots in the study area. Three (3) volume estimation models (Huber's, Smalian's, and Newton's) were evaluated for their accuracy in predicting tree volume. Data collected were analysed by descriptive statistics using Microsoft Excel and correlation analysis. Based on the volume estimation models assessed, results of association between the models and growth variables revealed that the correlation coefficient (r) with DBH had 0.726, 0.649, and 0.637, while the correlation coefficient (r) with BA had 0.739, 0.657 and 0.655 for Newton's, Huber's, and Smalian's, respectively. Hence, it was observed that Newton's model had the most accurate values in estimating tree volume based on growth variables assessed. Therefore, the study concluded that accurate estimation of tree volume is emphatically important for sustainable forest management, particularly in optimising timber harvesting and resource allocation in teak plantations.

Keywords*: Tectona grandis, breast height, volume estimation, growth variables, forest management*

1. Introduction

Due to its high international demand, *Tectona grandis* (teak) is a valuable plantation species, offering producers significant income and investment opportunities. Its wood is renowned for its exceptional quality and diverse applications, contributing to its increasing value (Adu-Bredu *et al.,* 2018). To maximize economic returns and ensure sustainability, accurate estimation of teak tree volume is essential for effective timber management. Teak wood demonstrates a combination of beauty, stability, durability, and resistance; is widely used in shipbuilding; and is suitable for luxury outdoor and indoor furniture due to its weathering resistance, seasoning without splitting and cracking, lightness, and strength (Moya *et al.,* 2014). In recent decades, the international market seems to have recognized a higher value for teak plantations, whose log prices have been rising rapidly (IUFRO, 2017). The increasingly competitive timber market requires the development and application of techniques and tools to reduce the costs and waste in the production processes in the forestry undertaking (Bailey *et al.,* 2005). Thus, quantifying forest stocks accurately requires recurrent studies related to the volume of trees, either individually or throughout the stands. Such information guides forest managers in timber valuation as well as in allocation of forest areas for harvest (FORMECU, 1999). For timber production, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions (Fuwape and Akindele, 1997). In order to achieve sustainable management of *Tectona grandis*, tree volume estimation must be developed (Bhat, *et al.,* 2000).

Volume equations play a very crucial role in forest management. The importance of volume equations is indicated by the existence of numerous such equations and the constant search for their improvement (McElhinny *et al*., 2005). Equations that provide accurate predictions of volume without local bias over the entire range of diameter are one of the basic building blocks of a forest growth and yield simulation system (Bhat, *et al.,* 2000; Bi and Hamilton, 1998). The most common procedure is to use volume equations based on relationships between volume and variables such as diameter and height (Fonweban, 1997). According to Avery and Burkhart (2022), volume equations are used to estimate the average content of standing trees of various sizes and species. The reliability of volume estimates depends on the range and extent of the available sample data and how well volume equations fit this sample data. In Nigeria, much work has been done in this regard for plantation species, most of which are exotic (Okojie and Nokoe, 1976; Osho, 1983; Akindele, 1987, 2013; Onyekwelu and Akindele, 1995).

Tree timber volume estimation is necessary for understanding different use standards, especially in sustainable forest management. Timber volume provides key

information about the economic value of a given stand, its health, and its estimated growth and yield. (Akindele and LeMay 2006, Mugasha *et al.,* 2013). Volume is used to estimate the average content for standing trees (Avery and Burkhart, 2022). Different studies have developed models for estimating tree variables from stump diameter in the case of timber trespass. In Nigeria, Osho (1983) developed a volume-estimation model from stump diameter for teak stands in Gambari Forest Reserve. Mugasha *et al.* (2013) also developed volume models from stump diameter for a teak plantation in Nimbia Forest Reserve. Recently, Chukwu *et al.* (2017) developed height-stump diameter prediction models for the teak in the study area at hand. Chukwu *et al*. (2017) also modeled the crown–sump diameter relation for *Parkia biglobosa* Benth. Therefore, this study determines the growth variables and evaluates the possible association between the growth variables and the volume estimation methods for the best adjudged sectional volume estimation procedures for the young *Tectona grandis* (Teak) at Adekunle Ajasin University, Akungba (AAUA) Campus, Ondo State, Nigeria, to ensure sustainable forest management of the plantation.

2. Materials and Methods

2.1 Description of study area

The university is located in Akungba-Akoko, Ondo State, Nigeria. The latitude for Akungba-Akoko is 7°28’58.64”N, and the longitude is 5°45'1.98"E. The climate of Akungba-Akoko falls within the tropical region with rainfall, which varies from 1100 to 2000 mm per annum. The temperature is between 26 and 28°C. The teak plantation is located behind 30CQ along the Faculty of Education. It was raised from the nursery and planted in the year 2018/2019, which is almost six (6) years of age, and it is being managed by the Department of Forestry and Wildlife Management, Faculty of Agriculture. The total area of land is 0.55 hectares.

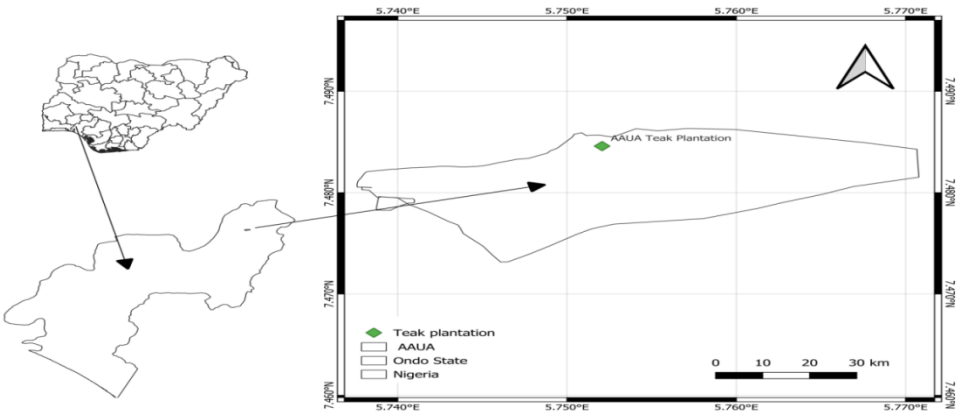


Figure 1: Map of the study area

2.2 Materials and Sampling Procedure

Spiegel Relaskop, girth tape, diameter tape, ranging pole, and a 1.3-m rod were the materials used. The data were collected on the field (teak plantation) through temporary sample plots (TSPs) by constructing 20 m by 20 m sample plots on the plantation; hence, individual trees in the sample plots were measured.

Data collection

Diameter tape was used to measure individual trees' diameter at the base (DB), middle (DM), and top (DT), and the tree height (H) was measured using a Relaskop for *T. grandis* found within the sample plots. Diameter at breast height (DBH) was measured at 1.3 m above the ground level, respectively. The data collected was recorded in an Excel sheet.

Basal area (BA)

The trees' diameter at breast height (DBH) obtained from the plot was used to estimate basal area. The basal area of tree species was estimated using Equation 1.

$BA=\frac{\Pi D^2}{4}$ …….equation 1

Where: Π= 3.142 and D = diameter at breast height (m)

Volume estimation

This formula was chosen, as it has been reported to provide the least biased and most precise estimates of individual tree volume for tropical timber species (Fonweban, 1997) and has been widely used in Nigeria (Adekunle, *et al.,* 2004; Akinsanmi and Akindele, 1995; Forestry Management, Evaluation and Coordinating Unit [FORMECU], 1999; Fuwape and Akindele, 1997; Onyekwelu and Akindele, 1995).

$$V = A_m \times L$$

Huber' formula…….2

$$V = \frac{A_b + A_u}{2} \times L$$

Smalian's formula…….....3

$$V = \frac{A_b + 4A_m + A_u}{6} \times L$$

Newton's formula…….……...4

Where: V = merchantable volume (m^3) H = merchantable height (m) Db = diameter at the base (cm) Dm = diameter at midpoint (cm) Dt = diameter at the top (cm) π = constant (3.142).

3. Results

3.1 The growth variables of Tectona grandis

Table 1 revealed the summary statistics of the dataset used in this research, which included measurements of 220 trees in the sample plots. The distribution of the diameter at breast height (DBH) was 4.5-30.8 cm; the basal area was 0.001-0.073 m²; the base diameter was 15.2-47.7 cm; the middle diameter was 2.44-10.2 cm; the top diameter was 6.7-10.5 cm; and the height was 5.5-13.7 m. The growth variables, as shown in Table 1, revealed that DBH has a mean and standard deviation of 16.25 cm and 5.05. BA has a mean and standard deviation of 0.023 m² and 0.014; DB has a mean and standard deviation of 26.52 cm and 11.69; DM has a mean value and standard deviation of 13.61 cm and 2.44; DT has a mean value of 5.45 cm and 2.10; and height has a mean and standard deviation of 9.0 m and 3.13.

Table 1: Descriptive statistics for tree variables of *Tectona grandis*

Variables	N	Mean	Standard Deviation	Min	Max
DBH	220	16.25	5.05	4.5	30.8
BA	220	0.023	0.014	0.001	0.073
DB	220	26.52	11.69	15.2	47.7
DM	220	13.61	2.44	10.2	18.2
DT	220	5.45	2.10	6.7	10.5
H	220	9.0	3.13	5.5	13.7

DBH-diameter at breast height, BA-basal area, DB-diameter at the base, DM-diameter at the middle,

DT-diameter at the top and H-height

3.2 Estimate of association between the growth variables of Tectona grandis

Table 2 revealed the correlation between DB and BA is r = 0.4669; the correlation between DBH and BA is of a high value, r = 0.9762. This indicates a positive correlation between BA and DBH and a moderate correlation between BA and DB, indicating that basal area rises as DBH and DB increase. Additionally, there is a strong negative correlation between diameter at the top (DT) with a value of r = -0.2544 and height (H) with that value of r = -0.1106 and (BA), suggesting that DT

and height increase with a decrease in BA. This shows that a variable yield 1 when it correlates with itself. These are naturally reasonable and preferably all-inclusive observations.

Table 2: Correlation matrix of pooled growth variable data of *T. grandis*

	BA (m^2)	DBH (cm)	DB(cm)	DM(cm)	DT(cm)	H(m)
BA(m^2)	1					
DBH(cm)	0.9762	1				
DB(cm)	0.4669	0.4193	1			
DM(cm)	0.1492	0.1505	0.0828	1		
DT(cm)	-0.2544	-0.2939	-0.0351	-0.0403	1	
H(m)	-0.1106	-0.1280	-0.1528	0.0568	-0.0343	1

DBH-diameter at breast height, BA-basal area, DB-diameter at the base, DM-diameter at the middle, DT-diameter at the top, and H-height.

3.3 Evaluation of the volume equation estimation methods

Table 3 revealed the association between the method-based estimated volume and the growth variables. The correlation analysis between the growth variables shows that height had a positive correlation with most variables assessed, with the strongest correlation in Huber volume (r = 0.4480), suggesting taller trees have greater volume. However, its correlation with base diameter (DB) is negative (r=0.2752), indicating that shorter trees in the sample may have relatively larger base diameters. The diameter at breast height (DBH) is strongly correlated with basal area (r=0.9883), as expected, since basal area is calculated based on DBH. The DBH also shows a moderate correlation with diameter at the middle, DM (r = 0.7297), suggesting a relationship between these diameters along the tree's length. Basal area (BA) calculated from DBH shows the strongest correlation with DBH (r=0.9883)-reaffirming the connection between DBH and BA in forest measurements, and a strong correlation with DM (r=0.7349). Huber estimated volume shows a strong positive correlation with DM (r = 0.8647) and DBH (r = 0.6496).

Table 3: Correlation matrix between Huber's volume and growth variables of *T. grandis*

	H (m)	**DBH (cm)**	**DB (cm)**	**DM (cm)**	**DT (cm)**	**BA (m^2)**	**Huber Vol (m^3)**
H(m)	1						
DBH(cm)	0.0202	1					
DB(cm)	-0.2177	0.6123	1				
DM(cm)	0.0105	0.7297	0.4173	1			
DT(cm)	0.0715	0.0827	-0.0185	0.1866	1		
BA(m^2)	0.0136	0.9883	0.6243	0.7349	0.0961	1	
Huber V (m^3)	0.4480	0.6496	0.2752	0.8647	0.1627	0.6572	1

DBH-diameter at breast height, BA-basal area, DB-diameter at the base, DM-diameter at the middle, DT-diameter at the top, Huber's V-Huber's volume equation, and H-Height

Table 4 represents the correlation between growth variables and Smalian's volume for *T. grandis*. The results revealed that there was a very weak positive correlation between height and diameter at breast height (r=0.0202), as well as a weak positive correlation between height and Smalian's volume (r=0.2939). This indicates that taller trees tend to slightly influence tree volumes; however, height is not the primary predictor for volume. There was a very strong positive correlation between DBH and basal area (r=0.9883). Similarly, there was a strong positive correlation (r=0.7298) between DBH and diameter at the middle, indicating that trees with larger diameters at breast height are likely to maintain relatively larger diameters along the middle of their stems. The DBH has a strong positive correlation with Smalian's volume (r=0.637); there is a very strong positive correlation between diameter at the base and Smalian's volume (r=0.8018), indicating that base diameter is a critical factor in predicting tree volume, and lastly, there's a strong correlation between basal area and Smalian's volume (r=0.6549), which suggests that basal area can serve as a reliable indicator for tree volume.

Table 4: Correlation matrix between Smalian's volume and growth variables of *T. grandis*

	Height (m)	DBH(cm)	DB(cm)	DM(cm)	DT(cm)	BA (m^2)	Smalian Vol (m^3)

Height (m)	1						
DBH(cm)	0.0202	1					
DB(cm)	0.2177	0.6124	1				
DM(cm)	0.0105	0.7298	0.4173	1			
DT(cm)	0.0715	0.0827	-0.0185	0.1866	1		
BA(m^2)	0.0136	0.9883	0.6243	0.7349	0.0961	1	
Smalian V (m^3)	0.2939	0.6370	0.8018	0.4616	0.1086	0.6549	1

DBH-diameter at breast height, BA-basal area, DB-diameter at the base, DM-diameter at the middle, DT-diameter at the top, Smalian V-Smalian's Volume equation, and H-Height.

Again, Table 5 shows the association of Newton-estimated volume with the growth variables. A weak positive correlation (r=0.4341) between Newton's estimated volume and height was observed, suggesting that taller trees generally result in increased tree volumes; hence, a strong positive correlation between Newton's volume and DBH (r=0.7263) was noted, indicating that trees with larger diameters at breast height tend to have higher volumes. The correlation (r=0.552) between Newton's estimated volume and diameter at the base is moderately strong. This shows that diameter at the base also plays a role in predicting tree volume but is less influential than DBH or middle diameter. The correlation (r=0.7892) between Newton volume and diameter at the middle is the strongest among all diameter measurements. This suggests that diameter at the middle is a critical predictor of tree volume, likely because Newton's formula for volume involves calculating the average of diameters at multiple points along the stem. Lastly, there is a strong positive correlation (r=0.7396) between Newton's estimated volume and basal area. This is expected since basal area is derived from DBH, which was strongly correlated with Newton's estimated volume.

Table 5: Correlation matrix between Newton's volume and growth variables of T. grandis

	Height(m)	DBH(cm)	DB(cm)	DM(cm)	DT(cm)	BA(m^2)	Newton V(m^3)

Height(m)	1						
DBH(cm)	0.0203	1					
DB(cm)	-0.2177	0.6124	1				
DM(cm)	0.0106	0.7297	0.4173	1			
DT(cm)	0.0715	0.0827	-0.0185	0.1866	1		
BA(m^2)	0.0136	0.9883	0.6244	0.7349	0.0962	1	
Newton V(m^3)	0.4341	0.7263	0.5524	0.7892	0.1585	0.7396	1

DBH-diameter at breast height, BA-basal area, DB-diameter at the base, DM-diameter at the middle, DT-diameter at the top, Newton V: Newton's volume equation, and Height.

3.4 Test of significance of the three volume estimation methods

Table 6: Test of significant differences between the three volume estimation methods

	N	Mean	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	F-Ratio	P-value
				Lower Bound	Upper Bound				
Huber-Vol	220	0.2500[a]	0.01131	0.2278	0.2723	0.05	0.81		
Smalian-Vol	220	0.2950[b]	0.01130	0.3542	0.4156	0.01	1.16	28.359	0.00
Newton-Vol	220	0.3849[c]	0.01559	0.2727	0.3173	0.04	0.86		
Total	660	0.3100	0.00775	0.2948	0.3252	0.01	1.16		

Means with the same superscripts along the column are not significantly different from each other @P<0.05

The test of significance between the three (3) estimated volumes using the three methods was presented in Table 6. The result revealed that there was a significant difference between the estimated volume methods (Huber's formula, Smalian's formula, and Newton's formula) with significant observation in the Newton-based estimated volume at $p < 0.00$.

The one-way ANOVA revealed statistically significant differences among the mean volume estimates obtained using Huber's, Smalian's, and Newton's formulas ($F = 28.359$, $p < 0.001$), indicating that the three methods do not produce equivalent estimates of tree volume. Specifically, Newton's formula recorded the highest mean volume (0.3849), followed by Smalian's formula (0.2950), while Huber's formula produced the lowest mean estimate (0.2500).

4. Discussion

The mean DBH (diameter at breast height) for *Tectona grandis* was 16.25 cm, with values ranging from 4.5 to 30.8 cm. The basal area (BA) ranged from 0.001 to 0.073 m^2, with a mean of 0.023 m^2. Heights ranged from 5.5 to 13.7 m, with a mean of 9.0 m. This finding is consistent with study on young teak plantations by Akindele and LeMay (2006), who reported similar DBH values. DBH ranged between 5 and 30 cm, indicating that the teak in both studies was in an early to mid-growth stage. However, the range of tree height in this study (5.5–13.7 m) differs slightly from the report by Perez and Kanninen (2003), who documented greater heights in teak plantations of the same age in Costa Rica, with heights ranging from 8 to 20 m. This discrepancy may be due to differences in environmental conditions such as rainfall and soil type between the study areas as reported by Akinsanmi and Akindele (1995).
Results in Table 2 revealed that there is a high positive correlation (r=0.976) between DBH and basal area, indicating that as DBH increases, so does basal area. A moderate positive correlation (r^2=0.4669) was also found between basal area and diameter at the base (DB). In contrast, there was a weak negative correlation (r=-0.1107) between height and basal area and between diameter at the top and basal area (r=-0.2544). The strong positive correlation between DBH and basal area aligns with previous findings by Henry *et al.* (2011), who observed a similar relationship in tropical forest species, including teak. The strong correlation between these variables is expected since basal area is derived from DBH. The negative correlation between tree height and basal area, however, was in contrast to the study of Mugasha *et al*. (2013), who found a positive correlation between height and basal area in their study on *Tectona grandis* in Tanzania. The difference may stem from variation in the growth stage of the trees, where younger trees (such as in this study) may exhibit weaker correlations between height and basal area compared to older, more established plantations.

The result in table 3 revealed that there is a positive correlation between tree height and Huber volume, which suggests that taller trees tend to have larger volumes, which aligns with the findings of studies by Henry *et al*. (2011). They observed that tree height is a significant factor in estimating tree biomass and volume in tropical forests. There is an exceptionally high correlation between DBH and basal area (r=0.9883), which is expected and in line with standard forest measurement practices. Basal area

is derived directly from DBH, and this relationship is consistently observed in forestry studies. This aligns with Akindele and LeMay (2006), who reported similarly strong correlations in their development of volume equations for Nigerian forests. DBH is often used as the primary predictor for basal area and tree volume estimation across various ecosystems (Clark *et al*., 2001). There is a high correlation between diameter at the middle and Huber volume (0.8647), which suggests that middle diameter is a key predictor for estimating tree volume. Huber's formula uses the diameter measured at the midpoint of the tree to estimate volume, and this strong correlation aligns with findings from Brown (2002), who reported that middle diameter, along with height and DBH, is critical for accurately estimating tree volume in tropical forests. This finding also supports the work of Gschwantner *et al.* (2019), who showed that measurements at different points along the stem can improve volume estimation accuracy in mixed-species forests.

Table 4 revealed the correlation of Smalian's volume with the growth variables. It shows there is a weak positive correlation (r=0.0202) between height and diameter at breast height. This suggests that taller trees in the sample may not necessarily have larger diameters, which may differ from what is commonly expected. In contrast, Chave *et al*. (2014) found a stronger correlation between height and DBH in tropical forests. This weaker correlation might be due to variability in site conditions, species characteristics, or the age of the trees sampled. The DBH has a strong positive correlation (r=0.6370) with Smalian's volume. This confirms that DBH is a key variable in determining tree volume, as noted in numerous studies (Brown, 2002). The correlation between DBH and volume is a key finding in forestry, as it simplifies volume estimation practices in both tropical and temperate regions. Results also show that there is a very strong positive correlation (r=0.8018) between diameter at the base and Smallian volume, indicating that base diameter is a critical factor in predicting tree volume. The comparison of Newton volume with other variables reveals that diameter at the middle (DM) is the strongest predictor of tree volume, followed closely by DBH and basal area (BA). This is consistent with findings in forestry where measuring diameters at multiple points along the tree stem improves volume estimation accuracy (Brown, 2002). The strong correlation between Newton volume and diameter at the middle (r = 0.789) suggests that trees maintain consistent tapering, with the middle portion of the tree having a significant influence on total volume.

The strong association (r=0.726) between DBH and Newton volume also highlights the importance of this measurement in volume estimation models. Studies by Chave *et al*. (2014) and Henry *et al*. (2011) support this finding, where DBH is often used as the primary variable for volume and biomass predictions due to its ease of measurement and consistent association with volume. The weak correlation with diameter at the top (0.158) suggests that the top diameter contributes minimally to

total volume. This also aligns with Chave *et al*. (2014), who noted that the top section of a tree has less impact on overall volume in comparison to the base and middle portions, especially in trees that taper significantly. Thus, the focus for volume estimation should remain on measurements taken at the base, breast height, and middle of the stem. Interestingly, the moderate correlation with height (r=0.434) suggests that while taller trees tend to have larger volumes, height alone is not the most reliable predictor of volume. This finding is supported by Henry *et al*. (2011), who also concluded that height, while useful, should be combined with diameter measurements for accurate volume estimation.

Importantly, the comparative analysis of Newton's, Huber's, and Smalian's formulas reveals a clear hierarchy of accuracy, particularly in the context of tropical forests. While Smalian's formula is the simplest to apply, its tendency to overestimate volume due to its assumption of a linear taper makes it less suitable for precise measurements, especially for irregularly shaped tropical trees (Aminu *et al.,* 2019; Shamaki and Abubakar, 2021). Huber's formula offers an improvement by considering the midpoint diameter, providing better accuracy than Smallian's, but it can still fall short when dealing with highly variable stem forms (Akpo *et al.*, 2021; Mohd-Jamil *et al*., 2019).

Newton's formula consistently emerges as the most accurate method among the three, a finding supported by a substantial body of literature from Nigeria and other tropical regions (Aigbe *et al.,* 2025; Ajayi, 2021; Akinbi, 2022; Aminu *et al.,* 2019). Its strength lies in its ability to integrate three diameter measurements, thereby providing a more nuanced representation of the stem's geometry and taper. This is particularly advantageous in tropical forests where tree forms are often complex and deviate significantly from idealized geometric shapes (Adebusuyi, 2019; Oladoye *et al.,* 2025).

The post hoc grouping (a, b, c) further confirms that each method differs significantly from the others, suggesting that the observed differences were not due to random sampling variation but rather to the computational characteristics of the individual formulae. Consequently, the null hypothesis of no significant difference among the three volume estimation methods was rejected. Similar findings have been reported in forest mensuration studies, where different log-volume formulae consistently produce varying estimates depending on stem taper, log geometry, and measurement precision (Avery and Burkhart, 2022; FAO, 2024). The result therefore demonstrates that the selection of an appropriate volume estimation formula is a critical determinant of inventory accuracy and timber resource assessment.

The superior performance of Newton's formula is theoretically expected because it incorporates measurements from the basal, middle, and upper cross-sectional areas

of the stem, thereby providing a more representative approximation of stem taper than either Huber's or Smalian's formula (Avery and Burkhart, 2022). In contrast, Huber's formula relies solely on the mid-sectional area and may underestimate or overestimate volume when taper deviates from the assumed cylindrical form, while Smalian's formula uses only the end-sectional areas and may introduce bias in irregularly shaped logs. These differences become particularly important in tropical plantations, where stem form is influenced by species characteristics, stand density, site productivity, and silvicultural interventions such as thinning and pruning. Recent advances in tropical forest inventory have emphasized that accurate volume estimation is fundamental for reliable biomass modelling, carbon stock assessment, yield prediction, and sustainable forest management (FAO, 2024; IPCC, 2023). Consequently, statistically significant differences among these formulae should be carefully considered when selecting an appropriate method for operational forest inventories and research applications.

From a management perspective, these findings have important implications for tropical plantation forestry in Southwestern Nigeria and the humid tropics generally. Plantation species such as *Gmelina arborea*, *Tectona grandis*, and *Pinus caribaea* often exhibit variable stem taper resulting from differences in site quality, spacing, age, and silvicultural treatments. Under such conditions, inaccurate volume estimation can lead to errors in timber valuation, harvest scheduling, allowable cut determination, biomass estimation, and carbon accounting. The significantly higher estimates obtained with Newton's formula suggest that it may provide greater accuracy where detailed forest inventories and research measurements are required, although its application requires additional field measurements compared with Huber's and Smalian's methods. Conversely, Huber's and Smalian's formulae remain useful for rapid operational inventories where measurement efficiency is a priority.

For instance, studies evaluating tree volume equations for species like *Gmelina arborea* in Southwestern Nigeria have shown that Newton's formula provides reliable estimates, crucial for sustainable forest management (Oladoye *et al.* 2025; Adekunle, 2016). The application of Newton's formula in carbon sequestration studies at AAUA further underscores its practical utility and accepted accuracy in the region (Ajayi, 2021, 2024). Overall, the present findings reinforce the need for locally calibrated and scientifically validated volume estimation procedures to improve sustainable plantation management, enhance forest productivity assessments, and support climate-smart forestry initiatives in Nigeria and across the tropical region (Avery & Burkhart, 2022; FAO, 2024; IPCC, 2023).

5. Conclusion

Correlation analyses show that DBH and base diameter are the most critical variables for predicting tree volume, as evidenced by their strong correlations with basal area and Smalian volume. The correlation between Newton volume and other variables in this study shows that middle diameter and DBH are the most influential predictors for tree volume estimation. While height has some influence, the diameter measurements, especially at the middle of the tree, are more reliable for volume prediction. Top diameter plays a minimal role in determining volume, reinforcing the need to prioritize measurements at the base, middle, and DBH levels in forestry practices. The results demonstrate the importance of incorporating both diameter at breast height (DBH) and height as key predictors for more reliable volume estimates. This study provides valuable insights for effective forest management practices, particularly in young teak plantations, where accurate volume estimation is crucial for optimizing timber production and ensuring sustainable resource utilization.

While Huber's formula offers a reasonable balance between accuracy and ease of measurement, Smalian's formula is the simplest, and their inherent assumptions about stem geometry often lead to less accurate results in tropical contexts. The consistent use and validation of Newton's formula in recent studies, including those from Adekunle Ajasin University, underscore its importance as a robust tool for quantitative forestry in these challenging environments. Future research should continue to explore the integration of advanced technologies with these classical formulas to further enhance the accuracy and efficiency of tree volume estimation in tropical forests.

6. Recommendations

1. Forest managers and researchers should use the best fit volume equation for more accurate volume estimation in young *Tectona grandis* plantations. This model provides the most reliable predictions and can be applied in similar ecological settings.

2. Continuous monitoring of growth variables such as DBH and height is recommended to ensure accurate volume estimation and better forest management decision-making.

3. Incorporate Modern Technology in Data Collection: The use of advanced technologies such as remote sensing and drones should be encouraged to enhance the accuracy of data collection and improve forest inventory management, especially in large-scale plantations.

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