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Tree Slenderness Coefficient Models for Biodiversity Conservation in International Institute of Tropical Agriculture Forest Ibadan, Nigeria

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ABSTRACT

Tree Slenderness Coefficient (TSC) is the ratio of total height to diameter which is used to determine stability of trees to wind throw. There is dearth of information on suitable model for estimating TSC in enhancing species conservation. Suitability of TSC model for conservation was assessed at the International Institute of Tropical Agriculture (IITA) forest, Ibadan, Nigeria. Simple systematic line transect was used to demarcate 16 sample plots (50m x 50m). Tree height and Diameter at Breast Height of trees ≥ 10cm were measured on 389 trees and TSC was computed using standard method. Four TSC models were evaluated. Data were analysed using descriptive statistic and regression at 95% confidence limit. Suitable model was selected using least Root Mean Square Error (RMSE), Akaike Information Criterion (AIC) and highest coefficient of determination (R^2). It was observed that the percentage of tree susceptible to wind-throw damages in the area is 40.10% while moderate and low TSC were 30.59% and 29.31%, respectively. Both the low and moderate TSC totaled 59.9%, indicating that the forest stands have good vigour and has the ability to withstand wind throw. The selected TSC Model was $TSC = \left(\frac{1}{0.004+0.0003DBH}\right)$. The model is therefore recommended for tree slenderness coefficient prediction.

Keyword: IITA Forest - Slenderness coefficient - Tree growth models – Wind throw – Biodiversity conservation.

INTRODUCTION

Tree slenderness coefficient is defined as the ratio of tree total height (H) to diameter at the breast height (DBH) usually measured at 1.3m above the ground, and this coefficient is useful in determining the tree stability to wind throw. Trees in the forest shows a substantial variations and flexibility in their shape and size, crown, height and diameter as reported by Givnish (2002). Navtatil, (1996) and Nivert, (2001) noted that the stability of a stand is mainly determined by physical factor which are directly connected to wind components and biological factors which deals with the species characteristic. Wang *et al.* (1998) also opined that the susceptibility of a stand to wind throw is basically influenced by the tree tapering nature which is based on combination of the tree physical growth characteristics, the stand condition as well as the site soil and quality. Navtatil, (1996); and Chukwu and Chenge, (2018) reveals that wind throw is highly associated with damages to forest which ranges from the bending of the wood, uprooting of a live tree, breakage of stem. Navrtatil *et al.* (1994) classified tree slenderness coefficient into low slenderness coefficient (SC< 70), moderate slenderness coefficient (70 – 99) and high slenderness coefficient (SC> 99). Low slenderness coefficient indicates that the tree has a longer crown, lower centre of gravity and the tree is said to have a better developed root system while trees with high slenderness coefficient are prone to wind damage because their root is not well developed and the tree are often characterized with shorter crown and lower centre of gravity as reported by Oladoye *et al.* (2020). The usefulness of tree slenderness coefficient as an index of tree resistance to wind throw is of great important because the stability of a forest could be determined from the ratio of the tree height to diameter. Little or dearth information has been recorded on tree growth characteristic in many natural forests with respect to ratio of tree height to diameter as well as models to assessed the stability of the forest to wind throw in many natural forest in Nigeria; however various studies focuses only mainly on plantations leaving the natural forest un-worked upon. Knowledge of the relationship between tree and stand slenderness coefficient will help the forest and the management in understanding the structure and stability status of their stand. The International Institute of Tropical Agriculture (IITA) forest Ibadan, Nigeria is one the biodiversity conservation hotspot in Nigeria. As such this study aimed in developing Tree Slenderness Coefficient (TSC) indices model for biodiversity conservation in IITA which could also serve as baseline means of assessing the stability of tree to wind throw in Nigeria natural forest.

MATERIALS AND METHODS

The Study Area

This study was carried out in International Institute of Tropical Agriculture (IITA) Forest (Figure 1). The IITA forest is geographically located in Akinyele Local Government Area of Oyo State Nigeria. It lies between latitudes 7°3 0' 8" and 7° 28' 55.52" North and longitudes 3° 54' 47.50" and 3° 52' 44.49" East in Ibadan. The forest has a humid tropical climate with well-known wet and dry seasons, with the wet season commencing from March and ends in October and dry season that lasts from November to February, it has an average daily temperature of about 21°C to 23°C and the maximum temperature ranges from 28°C to 34°C. The forest used to experience bimodal rainfall pattern between 1300 – 1500mm, which falls between the month of May and September. The mean daily relative humidity ranges between 64 - 83% (Oluyinka, 2020). The forest reserve has a low lying and gentle undulating topography with an elevation ranges between 243m to 292m.

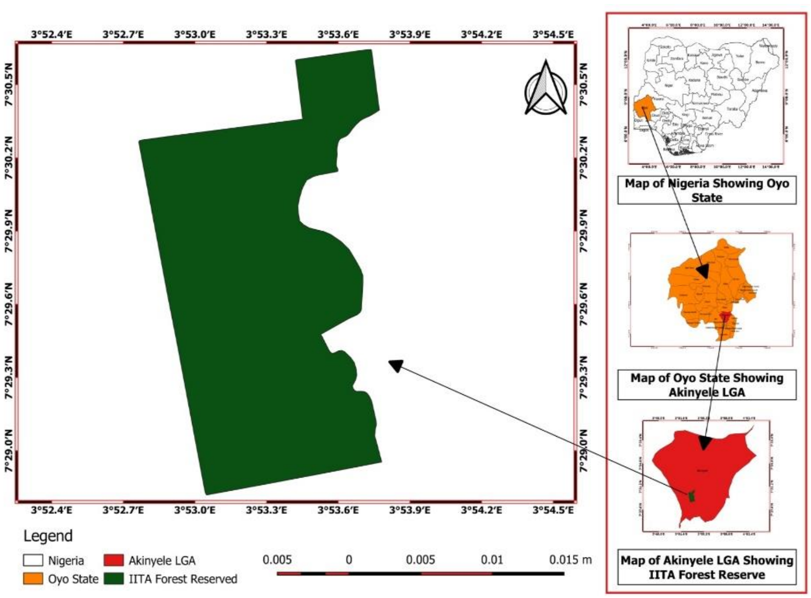

Figure 1: Map of IITA Forest with inserts of Nigerian Map and the Map of Oyo state showing Akinyele Local Government Area

The parent rock materials of the soils are been formed through the underlying crystalline and banded gneiss which weathers to form site-specific soils. In the upland areas clay, quartz gravel and sand are predominant soil types while the bottom of the valley has poorly drained clay and sandy soils. Some part of IITA forest has a highly diverse plant species. The vegetation of this area could be classified as tropical semi- deciduous forest with diverse of vegetation types ranging from derived savanna, secondary forest and riparian types.

Sampling Technique and Data Collection

Simple systematic line transect was adopted for in study for plots laying for data collection. A total of 16 temporary sample plots were used for this research work. Four parallel line transects of 270 m each were delineated at 200m apart, then 4 sample plots of equal size (25m x 25m) were laid alternatively on each transect at 50m interval from each sample plot so as to decrease replication of tree species (Figure 2). On each sample plot, trees with ≥ 10cm Diameter at Breast Height (DBH) were identified, the following variables were measured Diameter at breast height (cm) with the aid of girth tape, diameters at the base using girth tape , Diameter at middle and top measured using the Spiegel relaskop; merchantable height and total height measured using Haga altimeter; Crown diameter measured as the expanse of the crown on the ground at two direction with the aid of ranging pole and meter tape and the crown length of all the trees in each plot were estimated as the difference between tree total height from merchantable height.

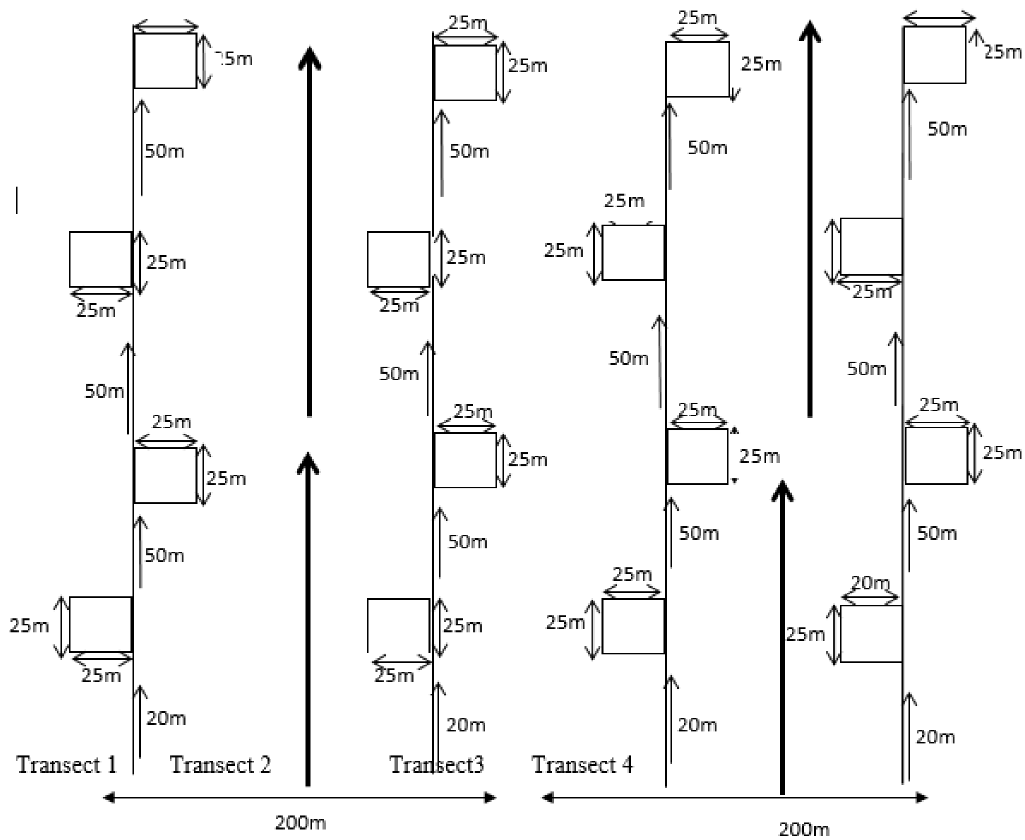

Figure 2: Systematic line transects sampling technique for Plot layout as was established at IITA.

Data Analysis

- Basal Area Estimation

Basal area of each tree was estimated using this formula:

$$BA = \frac{\pi D^2}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where BA = Basal area (m^2), D = Diameter at breast height (cm) and π = Pie (3.142).

- Volume Estimation

The volume of each tree per plot and per hectares was estimated using Newton's formula as used by Hush *et al.* (2003)

$$V = \pi H \left(\frac{Db^2+4Dm^2+Dt^2}{24}\right) \ldots\ldots\ldots\ldots (2)$$

Where V=Stem volume (m^3) H=height (m), Db=Diameter at the base, Dm=Diameter at the middle, Dt = Diameter at the top and π = 3.142

- Crown Diameter

Crown diameter was computed using this formula:

$$CD = \frac{\sum r_i}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: CD is Crown diameter, $\sum r_i$ is the summation of the projected crown radii measured on four axes

- Tree Slenderness Coefficient Indices

Tree slenderness coefficient indices were computed as follows:

$$TSC = \frac{THT}{D} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where; TSC=Tree slenderness coefficient, THT=Tree total height (m), D=Diameter at breast height (cm).

Tree slenderness coefficient values were classified into three categories using Navrtatil *et al.* (1994) slenderness coefficient categorization (Table 1).

Development of the Model

Linear and nonlinear models were developed and tested for predicting the tree slenderness coefficient for the study area using linear and nonlinear regression procedure *lmtools* and *nlstools* packages in R (R Core Team, 2016; Baty and Delignette-Muller (2015)). Forms of models generated are as follows: (Table 2).

Table 1: Tree Slenderness Coefficient classification

S/N	Category	Implication
1	TSC > 99	High slenderness coefficient (prone to wind throw)
2	TSC: 70 – 99	Moderate slenderness coefficient (can withstand wind throw)
3	TSC < 70	Low slenderness coefficient (can withstand wind throw)

Table 2: Tree slenderness Coefficient Model

S/N	Model	Reference
1	$TSC = b_0 * DBH^{-b_1}$	(Wang *et al.*, 1998)
2	$TSC = b_0 * exp^{-b_3 DBH}$	(Wang *et al.*, 1998)
3	$TSC = \frac{1}{b_0 + b_1 DBH}$	(Wang *et al.*, 1998)
4	$TSC = b_0 + b_1 * DBH$	Ige (2017)

Where: TSC= tree slenderness coefficient; DBH= Diameter at Breast Height; b_0, b_1, b_2 and b_3 are the regression parameters

Model Evaluation

Model generated were evaluated with a view to selecting the best estimator for tree slenderness coefficient for the study area. The evaluation was based on graphical and numerical analysis of the residuals and four statistical fit indices listed below were also used to evaluate the model.

Coefficient of Determination (R^2): The R^2 measures the proportion of variation in the dependent variable based on the behavior of the independent variable. Its value was computed using formula (5) below; for model to be considered the best model, its R^2 value must be the highest.

$$R^2 = \frac{SSregression}{SSTotal} \times 100 \ldots\ldots\ldots\ldots\ldots 5$$

Root Mean Square Error (RMSE): This is the sum square of the vertical distances between the data point and its corresponding data point on the regression line. For model to be considered the best model, its RMSE value must be the least.

$$RMSE = \sqrt{\frac{\Sigma(Y_i - Y')^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots 6$$

Bayesian Information Criterion (BIC): For a model to be considered valid its BIC must be relatively low.

$$BIC = n\ ln\left(\frac{rss}{n}\right) + p\ ln \ldots\ldots\ldots\ldots 7$$

Akaike Information Criteria (AIC): This estimates the amount of information lost by a model thereby estimating the quality of the model. For a model to be considered good fit its AIC value must be relatively low.

$$AIC = n\ ln\left(\frac{rss}{n}\right) + 2p \ldots\ldots\ldots\ldots 8$$

Where SS= Sum square, rss = residual sum square, n = sample size, p = number of model fixed parameters, Y_i = the observed value and Y^i = the theoretical value predicted by the model.

Model Validation

Validating of the model was based on the qualitative assessment of the model outputs compared with the real-world data that are independent of the data used in the model construction. In fitting models in forestry, the data obtained from the field are usually divided into two data sets. The Calibration data set and the Validation data set. The first data set was the calibration data (75%) which was used in fitting the models, and the second data set is the Validation data (25%) kept aside for validating the model was used for this purpose. In forest growth models, it has been reported that fewer data are often used for validation while larger data are being used for fitting the models (Adekunle, 2007; Akindele, 2005; Aghimien *et al.*, 2016, Ige *et al.*, 2019). Therefore in this study, 75% of data were used for calibration which was used in fitting the models, and the second data set (25%) were kept aside for validating the model. T-Test was used to test for significant difference between the predicted value of the model fitted and the actual value (Independent data set). Model validation is basically used to shows that the model predicted are close enough to independent data and that the decision made based on the fitted are defensible and realistic. Confidence level of 5% was used for statistical significance. A model is considered acceptable when there is no significant different between the observed and the predicted values. A model with the P-value greater than or equals to 0.05 is considered not significant and acceptable while models with P-value lesser than 0.05 is considered significant and not acceptable.

Two Sample T-Test equations is given as

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{X_1X_2} \cdot \sqrt{\frac{2}{n}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

Where: $S_{X_1X_2} = \sqrt{\frac{1}{2}\left(S_{X_1}^2 + S_{X_2}^2\right)} \ldots\ldots 10$

$\bar{X}_1$ = Means for prediction model
$\bar{X}_2$ = Mean of the data set kept aside for validation
$S_{X1\&X2}$ = Pooled standard deviation.

RESULTS AND DISCUSSION

Results

The statistical summary of the tree growth variables is presented in table 3. The diameter at breast height (DBH) for the study area ranges from 10cm to 170cm with mean value of 25.12±1.03 cm. The tree height ranges from 7.70m to 38.10m with a mean value of 18.55±0.32; volume varied from 0.003m^3 to 24.68m^3 with mean value of 1.04±0.14m^3; and basal area range value of 0.007m^2 to 2.27m^2 with mean of 0.08±0.01m^2. The crown diameter had a mean value of 5.89±0.08m with respective minimum and maximum values of 3 and 13.7m. The crown length and crown ratio had respective mean values of 2.97±0.06 and 0.17±0.004 with their minimum and maximum values of 1.0 and 7.8m; and 0.05and 0.51, respectively. The TSC value had a mean value of 93.14±1.90 with a minimum and maximum values of 22 and 225.

Table 3: Statistical summary of the tree growth characteristics

Stand Growth Variable	Mean	Count	MIN	MAX
DBH (cm)	25.123 ± 1.026	389	10	170
THT (m)	18.548 ± 0.324	389	7.7	38.1
MHT (m)	15.038 ± 0.336	389	3.8	36
VOL (m^3)	1.035 ± 0.136	389	0.003	24.676
BA (m^2)	0.083 ± 0.010	389	0.007	2.270
CL (m)	2.9688 ± 0.059	389	1.00	7.80
CR (m)	0.174 ± 0.004	389	0.051	0.506
TSC	93 .140 ± 1.896	389	22	225
N/ha	442	389	96	704
Dq(cm)	31.488 ± 0.406	389	18.047	52.655
CD(m)	5.894 ± 0.083	389	3	13.7

Where: DBH= Diameter at Breast Height, THT= Tree Total Height, MHT= Merchantable Height, VOL= Volume, BAL= Basal Area, CL= Crown Length, CR= Crown Ratio, TSC= Tree Slenderness Coefficient, N/ha= Numbers of Tree per Hectare, Dq= Quadratic Mean Diameter, CD= Crown Diameter

Table 4 reveals the correlation matrix between TSC and other tree variables in which the TSC has a negative strong correlation coefficient with the entire diameter at different position. The DBH had the highest value of negative correlation coefficient (r = -0.642) indicating that DBH is a better predictor of the slenderness coefficient. The correlation between TSC was also found to be significantly and negatively correlated with the tree total height (r = - 0.046), merchantable height (r = - 0.041), Dt (r = - 0.515), Dm (r = - 0.526) and Db (r = - 0.616).

Table 4: Correlation matrix between tree slenderness coefficient (TSC) and tree Diameters (at the base, breast height, middle and top), Merchantable and Total Heights.

	TSC	*Db*	*DBH*	*Dm*	*Dt*	*MHT*	*THT*
TSC	1						
Db	-0.616*	1					
DBH	-0.642*	0.954*	1				
Dm	-0.526*	0.839*	0.874*	1			
Dt	-0.515*	0.684*	0.718*	0.729*	1		
MHT	-0.041*	0.531*	0.593*	0.641*	0.464*	1	
THT	-0.046*	0.546*	0.608*	0.657*	0.480*	0.983*	1

Where: TSC = Tree Slenderness Coefficient, Db = Diameter at the base, Dbh= Diameter at breast height, Dm= Diameter at the middle, MHT= Merchantable height and THT= Tree total height

However, Figure 3 shows the classification of the TSC into three categories: High, Moderate and Low Slenderness coefficient.

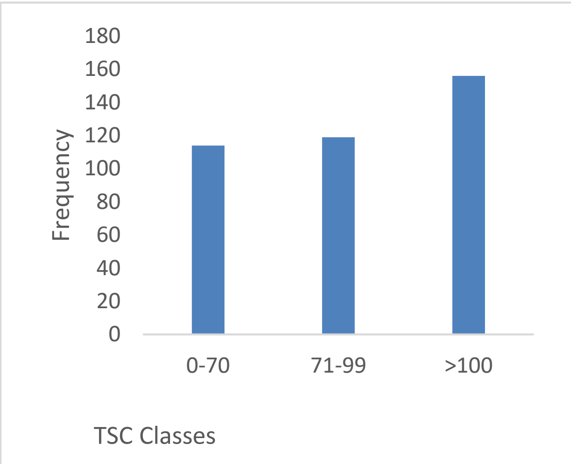

Figure 3: Tree Slenderness Coefficient Classification

High slenderness coefficient (Trees with TSC > 99), Moderate slenderness coefficient (Tree TSC: 70 – 99) Low slenderness coefficient (Tree with TSC < 70), slenderness coefficient categorization. The result shows that 114 trees had a low TSC, 119 trees had a moderate TSC while 156 trees had a high TSC values.

Tree Slenderness Coefficient Model Fitted and Evaluation

Four models that were used in estimating TSC value for the study area are shown in Table 5 with their respective parameter estimates. The result of the fit indices showed in Table 6 revealed that the best model for predicting the TSC is the Model 3 which had the least RMSE, AIC, BIC and highest R^2 values of 25.575, 2725.752, 2736.782 and 0.536, respectively. This was closely followed by Model 1 with RMSE, AIC, BIC and R^2 values of 25.628, 2726.960, 2737.991 and 0.534. Table 7 shows the result of model validation which revealed that the independent data set were not significant at 5% probability level from the predicted slenderness coefficient value.

Table 5: Model Evaluated Parameters

Model Name	Model Function	b_o	b_1
1	$b_0 * DBH^{-b_1}$	571.493	0.617
2	$b_0 * exp^{-b_1 DBH}$	1.665	2.730
3	$\frac{1}{b_0 + b_1 DBH}$	0.0044	0.0003
4	SLC = b_0 + b_1*DBH	121.658	-1.109

Where: b_0, b_1, b_2 and b_3 are the regression parameters

Table 6: Fit Indices

Model No	Fitted Models	RMSE	AIC	BIC	R^2
1	$571.493DBH^{0.617}$	25.628	2726.96	2737.991	0.534
2	$160.993 * exp^{0.0257DBH}$	26.197	2739.791	2750.822	0.513
3	$\frac{1}{0.004 + 0.0003DBH}$	25.575	2725.752	2736.782	0.536
4	125.415 −1.271DBH	28.11	2780.883	2791.913	0.413

Where: RMSE is the root mean square error, AIC is Akaike Information Criteria and Bayesian Information Criteria (BIC), R^2 is the coefficient of determination.

Table 7: Model validation for Tree Slenderness Coefficient Models

Model No	Mean predicted value	Mean Observed value	Validation Predicted vs Observed		Shapiro Wilk Test
			T-Value	P-Value	
1	92.928	93.743	0.183	0.855	$3.164x10^{-05}$
2	92.928	93.463	-0.117	0.907	$3.922x10^{-05}$
3	92.928	93.717	-0.175	0.861	$3.223x10^{-05}$
4	89.134	91.524	-0.509	0.612	8.147e-07

Figures 4 (a-d) and 5 (a-d) show the residual analysis for models 1 and 3 which they had an error variance which was constant across the predicted TSC estimate and the residual, the histogram shows a positively skewed to the right with the value within the range of -50 and 100 in the negative and positive region of the Y-axis.

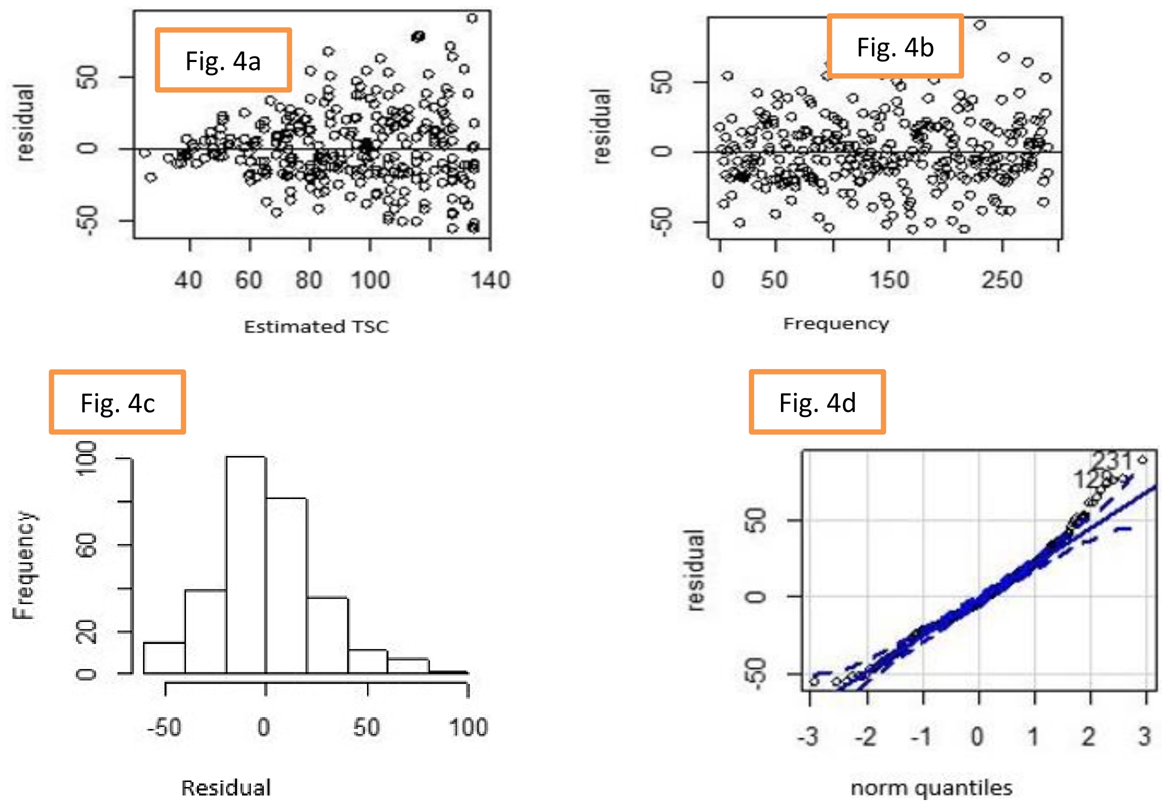

Figure 4 (a – 4d): Residual Plots for Model 1

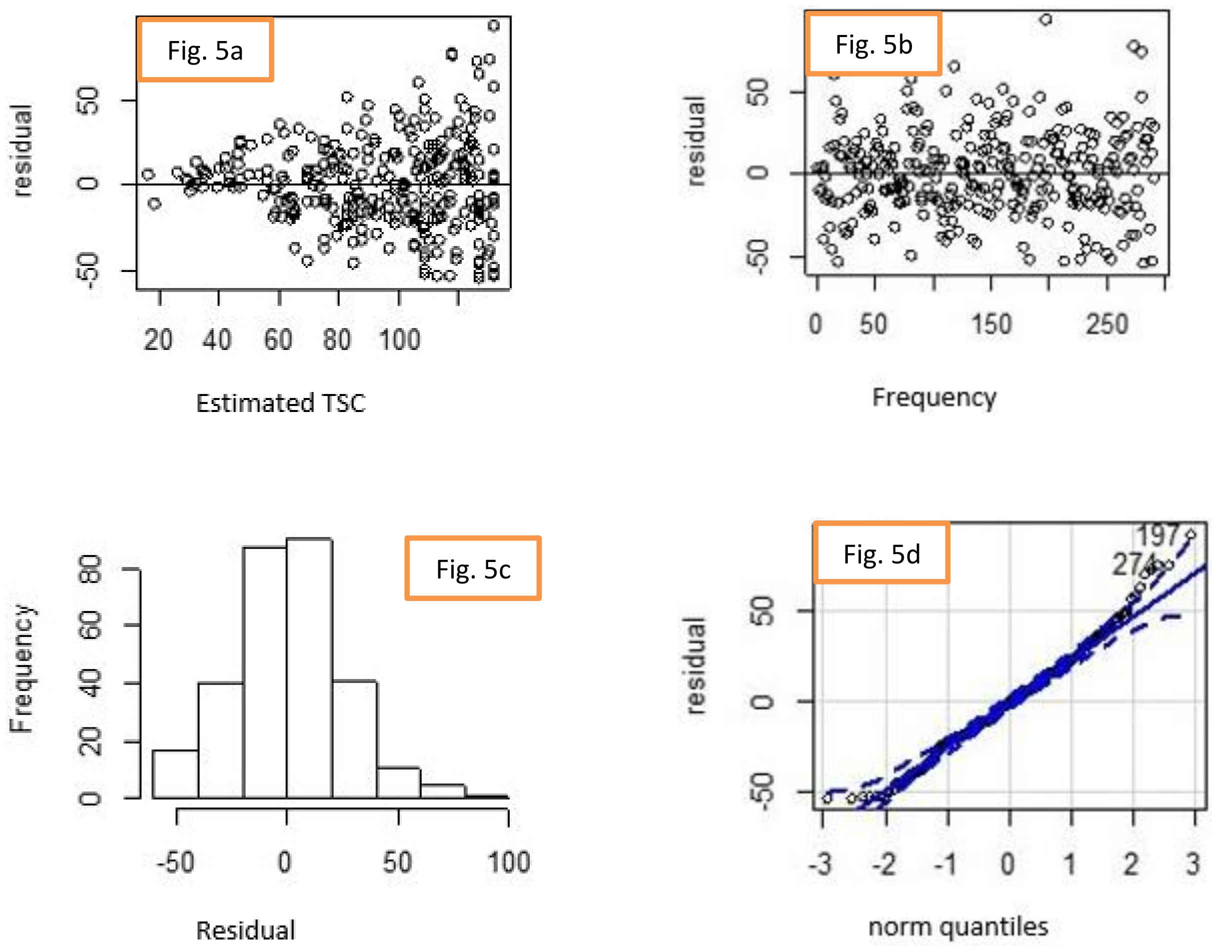

Figure 5 (a – d): Residual Plots for Model 3

DISCUSSION

The Tree Slenderness Coefficient (TSC) was computed for all the tree in the study area. This determines the the ability of the tree to withstnd wind throw. Classification of TSC was done following Navrtatil *et al.* (1994), whose categorization was based on high, moderate and low TSC. The result of TSC was in contrast with what was reported by Aghimien *et al.* (2016) that 98.8% of the trees in this study area had a low TSC as this study observed that 40% of trees per hectare found in the study area had high TSC, while 31% had a moderate TSC and 29% of the trees had a low TSC. This result indicated that larger percentages of the tree are prone to wind throw. However, the disparity found in the TSC of this study and Aghimien *et al.* (2016) studies could be as a result of the species encountered in this study, tree form and the tree growth increment pattern over the years. This was also deduced by Wang *et al.* (1998) where he found out that 50% of the sample trees in boreal mixed wood forest had a TSC greater than 100 an indicator for susceptibility to wind throw which he however noted that this could be as a result of differences in tree form and height growth pattern. Several studies over the year have intensified effort in generating models for assessing tree slenderness coefficient of a tree. The correlation matrix between TSC with DBH at different level, height and crown ratio were found to be negative. This could be as result of the nature of the forest (mixed tropical natural forest). Hence, these findings agree with the findings of Wang *et al.* (1998) in boreal mixed wood forest of Canada and also in agreement with Oladoye *et al.* (2020) findings in a non-linear regression model for tree species in Omo biosphere reserves, South Western Nigeria. Ige, (2017) also reported a negative correlation between the TSC and tree growth characteristics for *Triplochiton scleroxylon* stands in Oniganbari forest reserve, Nigeria (although this is a monoculture forest but could be age induced). All the researchers however based their logical deduction that tree slenderness coefficient values tend to decrease for larger trees and that the smaller DBH often had the largest TSC value. Tree DBH had the highest correlation coefficient values with the TSC compared to other tree growth variable at different levels. This could be adduced to the inclusion of DBH in estimation of TSC. Studies have shown that DBH is a better predictor of TSC (Wang *et al.* 1998, Ige 2017 and Oladoye *et al*. 2020). This study also agrees with this observation because the Correlation coefficient value of DBH with TSC was the highest (-0.642) compared to other growth variables. However, tree with high TSC is easily prone to wind throw and wide movement during windstorm which could result to crash with neighbouring trees and thereby resulting to tree damages. In view to reducing damages caused by wind throw in the forest reserve effort was made and directed to TSC model development and evaluation. Models used by Wang *et al.* (1998) were simply adopted. The model used only one variable (DBH) as the independent variables, this was also in consistence with models used by Ige, (2017) and this was as a result of the high correlation coefficient between the TSC and DBH which is considered as the easiest and most accurate variables that could be obtained in an inventory exercise. Model for TSC for the study area is Model 3. It was observed that the change difference in the R^2, AIC and BIC value of Models 3 and 1 is very small due to the power function of DBH. Hence, this study agrees with what was reported by Ogana (2018) in comparison of a modified log-logistic distribution for tree height prediction in Omo forest reserve, where he stated that judging based on AIC as a common rule of thumbs that two models can be adjudge the same if their AIC value differences is less than two, models 3 and 1 had difference of AIC (ΔAIC) value lesser than 2. Model validation was carried out using the two-sample t-test in order to test the validity and the consistency of the model. The result however shows that there was no significant difference between the observed and the predicted values for the entire model. Therefore, model 3 and 1 developed in this study could be used in assessing the tree slenderness coefficient for the study area.

CONCLUSION AND RECOMMENDATIONS

The result of this study revealed the present assessment of stand growth characteristics and relationship between tree variable and tree slenderness coefficient in International Institute of Tropical Agriculture (IITA) Ibadan. This study has projected the possibility of occurrence of tree susceptible to wind throw and determining the need for enhancing stability in the forest by removing trees that had high slenderness coefficient value in order to reduce tree damages that could resulted from tree being thrown by wind. It was revealed in this study that larger percentages of tree species are susceptible to wind throw damages (40.10%). The percentage of moderate and low slenderness coefficient are in a considerably range. Diameter at breast height (DBH) was the common independent variable used in all the model formulation due to the strong correlation with TSC. Based on the model evaluated for this study Model 3. $\frac{1}{0.004+0.0003DBH}$ can effectively be used in assessing the stability of a tree to wind throw and therefore recommended as tree slenderness coefficient model for IITA forest for further use.

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