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VOLUME EQUATIONS FOR FIVE ECONOMIC HARDWOOD SPECIES IN OLUWA FOREST RESERVE, ONDO STATE, NIGERIA

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ABSTRACT

Tropical rainforest remains one of the most complex ecosystems in the world. Tree growth dynamics is a major technique in quantifying the forest composition. However, there is dearth of knowledge on tree volume equations of hardwood tree species in the tropical rainforest especially in Nigeria. Therefore, this study was carried out to develop tree volume equations for selected economic hardwood species (Lovoa trichiliodes, Celtis zenkeri, Picralima nitida, Buchlozia coriacea and Diospyros crassiflora) in Oluwa Forest reserve, Nigeria. Two transect (500m) were laid in the study area, in which distance between each transect was 400m. Systematic sampling technique was adopted to lay four temporary sample plots (TSP) on each transect making a total of Eight TSPs (size 50 x 50m) for the study. All tree species of the aforementioned hardwood species with dbh ≥ 10cm were identified in each TSP. Five models were selected as candidate models for the study. The result revealed that nonlinear model produced the best fit for Buchhlozia coriacea, Celtis zenkeri, Diospyros crassiflora and Picralima nitida while generalized nonlinear model produced a better fit for Lovoa trichiliodes. Residual analysis was carried out to validate the best fitted model for each species. The selected models (Nonlinear and Generalized nonlinear equations) can be very useful for sustainable forest management assessment of Lovoa trichiliodes, Celtis zenkeri, Picralima nitida, Buchhlozia coriacea and Diospyros crassiflora plantations in the study area and similar ecological areas.

Keywords: Volume Equation, nonlinear model, generalized nonlinear model

INTRODUCTION

Tropical Rain Forest (TRFs) is one of the most diversified and a complex ecosystem types in the world (Ojo, 2004). This ecosystem experiences high average temperatures and a significant amount of rainfall yearly. It occupies a total area of 1818.43 million hectares, representing 47% of the total land area occupied by all forest types of the world (Ige *et al*, 2013). Tropical Rain Forests exhibit high levels of biodiversity. TRFs are home to half of all the living animal and plant species on the planet and two-thirds of all flowering plants can be found in rainforests (Wikipedia). It is likely that there may be many millions of species of plants, insects and microorganisms still undiscovered in tropical rainforests. There are very distinct layers of trees in a tropical rain forest. These layers have been identified as the emergent, upper canopy, understory, and forest floor. Each layer is a unique biotic community containing different plants and animals adapted for life in that particular stratum. A report by the Food and Agriculture Organization quoted by Ettah (2008) estimated that tropical countries are losing 127,300 km of forest annually (Jacob *et al* 2015). In view of the great value of the tropical rain forest and the grave consequences of losing it to unregulated logging activities and over-exploitation, it has become the focus of increasing public attention in recent years (Morris, 2010).

Nigeria has a tropical climate with variable rainy and dry seasons, depending on location. The main vegetation patterns run in broad east-west belts, parallel to the Equator. Mangrove and freshwater swamps occur along the coast and in the Niger delta and low rain forest. The most prominent wood industry in Nigeria is the sawmilling industry. In a review of the wood-based industrial sector in

Nigeria, (Ogunwusi, 2014) reported that there were 1300 sawmills in the country. With recent economic reforms and Government efforts i.e. Introduction of the REDD++, Consolidation and expansion of the forest estate and its management for sustained yield, Forest Conservation and protection of the environment; Forest regeneration at a rate greater than exploitation, Reduction of waste in utilizing both the forests and its products, Protection of the forest estates from fires, poachers, trespassers and unauthorized grazer towards poverty reduction, it is likely that this number has increased(Wikipedia).

The wood industries rely mainly on the natural forests as reservoir of wood resources to meet their growing demand. Although large areas of plantations exist, natural forests are of greater attraction to timber contractors due to their wide variety of species and sizes (Fuwape, 2003). Furthermore, many of the well-known indigenous timber species are yet to be established as plantation species on a large scale. Tree volume measurement is a laborious and time consuming task, even for felled trees. In modern forestry practice, one of the most common reasons for taking such measurements is to develop stem volume functions or taper functions, for a particular tree species in a particular forest region. Volume functions allow estimation of the total stem volume of a standing tree from simple measurements, usually its diameter at breast height over bark and its total height (Hernan Attis Beltran *et al*, 2017).Tree volume equations are commonly developed from measurements of tree height and diameter at a number of points along the main stem (Norman *et al* 1998). These are used to predict the content of stems of standing trees, the predictor variables required in order to achieve acceptable accuracy vary by tree form. This form is typical of many conifers and few hardwood species such as yellow poplar (Harold and Margarida, 2012).

Decurrent (also called deliquescent) crown forms result when lateral branches grow as fast or faster than the terminal leader, decurrent crowns are typical of many hardwood species such as elms, oaks and maples. For excurrent forms, the usual predictors for stem volume are diameter at breast height (dbh) and total tree height (Harold and Margarida, 2012)

Total tree height is generally not highly correlated with the volume of the main stem of interest for decurrent tree forms, and a measure of merchantable height may be employed instead. For shrub forms estimation of volume in multiple stems requires additional independent variables, as well as use of diameter at root collar in lieu of diameter at breast height. (Harold and Margarida, 2012). Much of the research on estimating stem volume of trees has been directed towards excurrent forms and involves dbh and total height as predictors. Varying units for the dependent variable have been employed but cubit units are most commonly used, general conclusions reached for estimating cubit volume of stems apply if other measures of volume are used (Burkhart and Tome, 2012).

MATERIALS AND METHODS

Study Area

This study was carried out in Oluwa Forest Reserve, Ondo State, located in the Western part of Nigeria (Fig. 1) on Latitude 6.91°N and Longitude 4.59°E with an area of 827 km^2 and falls within the tropical rainforest. It is 50km east of Omo and 26km from Ore .The topography is undulating with a mean elevation of 90m above sea level, mean relative humidity of 80% and daily temperature of 25˚C. The vegetation of the study area is a mixed/moist semi-evergreen rainforest (Udoakpan, 2013). Although the reserve is biologically unique, it is threatened by logging, hunting and agriculture activities. The natural vegetation of the area in tropical rainforest characterized by emergent with multiple canopies and lianas. The forest comprises of Natural forest and plantations (*Tectona grandis*, *Gmelina arborea* among others) the natural forest is 8km^2 comprising of varieties of indigenous species which includes *Khaya ivorensis*, *Milicia excelsa*, *Afzelia bipindensis*, *Brachystegia nigerica*, *Lophira alata*, *Lovoa trichiliodes*, *Terminalia ivorensis*, *Terminalia superba*, and *Triplochiton scleroxylon.*

The rainy season in the reserves occurs from March to November while the dry season, is from December to February. Annual rainfall ranges from 1700 to 2200 mm. Annual mean temperature is about 26°C. Soils are predominantly ferruginous tropical, typical of the variety found in intensively weathered areas of basement complex formations in the rainforest zone of south-western Nigeria. The soils are well-drained, mature, red, stony and gravely in upper parts of the sequence. The texture of topsoil in the reserves is mainly sandy loam (Onyekwelu *et al.*, 2008; Adeduntan, 2009).

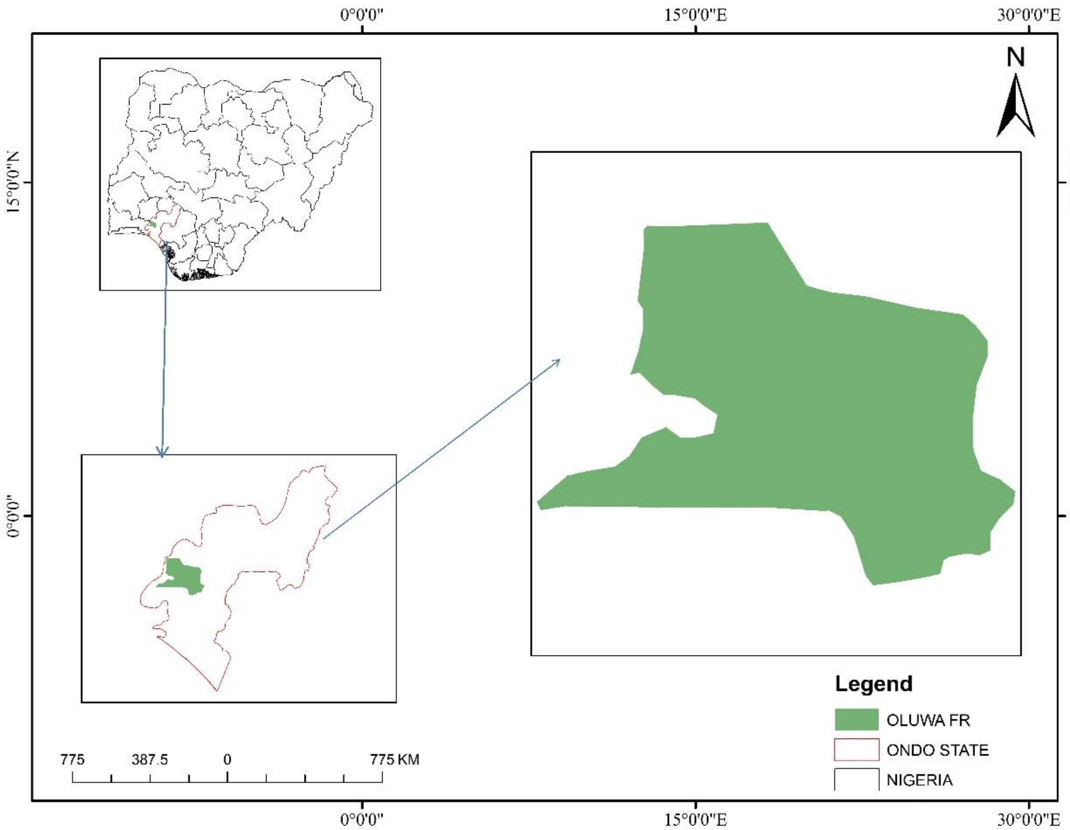

Fig.1: Map of Oluwa Forest Reserve in Ondo State, Nigeria.

Sampling Procedure and data collection
Systematic sampling design was used for the laying of plots. Two transects were laid of 400m apart at the center of the forest. Eight (8) Sample plots of equal size (50 × 50m) were laid in alternate direction along each transect at 100m apart (Fig 2). In each plot, all selected species with diameters ≥ 10cm (diameter at breast height) were identified and diameter at breast height (dbh), diameter (overbark) at base, breast height, middle and top positions along the stem, and stem height to the Crown Point, merchantable and total height were measured.

Data Analysis and Modeling The Tree Volumes were estimated for merchantable portion of the stem because the study is particular about the marketable part of the species selected. The Merchantable volumes for the selected tree species were first computed using the Newton-Simpson's formula (Ige, 2018) expressed as:

$$V = \pi \frac{H}{24}(D_b^2 + 4D_m^2 + D_t^2) \qquad \text{...............} [1]$$

Where: V = merchantable volume, overbark (in m^3),
H = merchantable height (in *m*),
D_b= diameter at the base (in *m*),
D_m = diameter at the middle position along the stem overbark (in *m*), and
D_t = diameter at the top (in *m*).

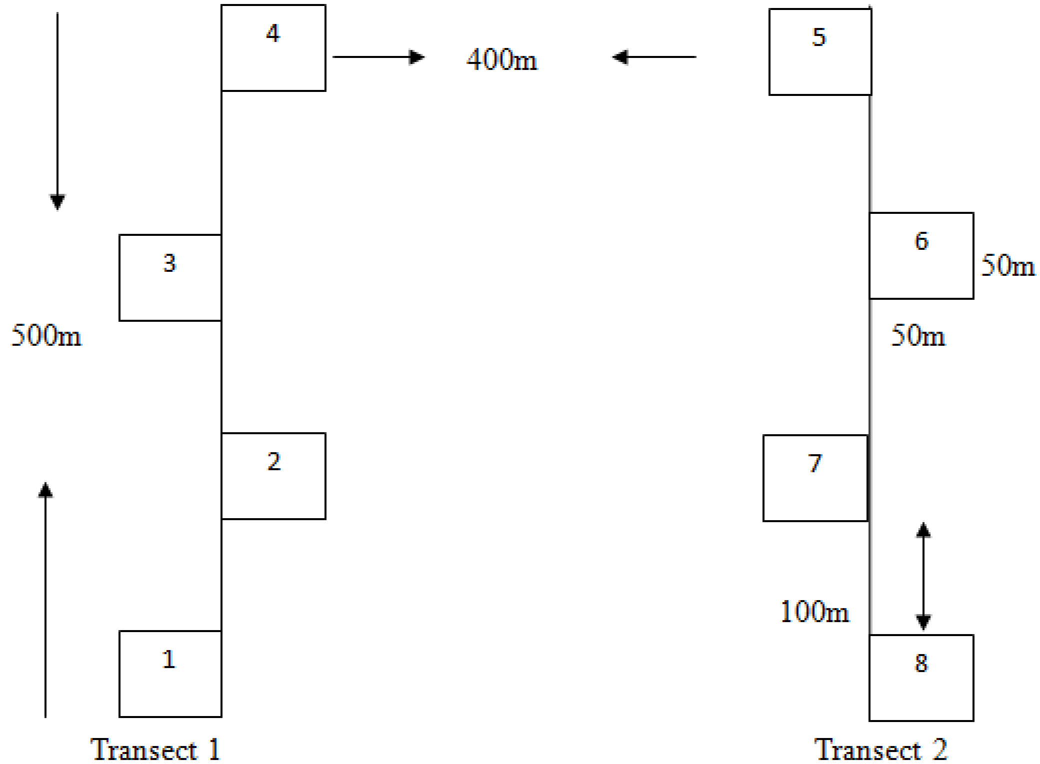

Fig.2: Plots location using systematic sampling

Following the computation of tree volume, the data was divided into two parts and 70% of the data was summarized by computing simple descriptive statistics for each species. The statistics included number of observations, range, mean and standard error of the mean. Graphs were also plotted to examine the relationship between the variables.

Correlation matrix was generated for the predictor variables and the response variable and these helped to determine the predictor variables that correlated more and well with the response variable. Diameter at breast height (DBH) was found to correlate most with the merchantable volume. Residual graphs and scatter diagrams were also plotted to portray the relationship between tree volume and diameter at breast height and Merchantable Volume and Merchantable Height. Series of regression equations were fitted to the data based on the relationship between variables.

The Five (5) modified volume equations were assessed and compared with each species on the basis of their correlation coefficient, coefficient of determination, variance ratio and standard error of estimate and Mean square error. The formulated model was adjudged based on the Co-efficient of determination (R^2), Mean Square Error (MSE) i.e. the model with the highest R^2, and least M.S.E were selected as a suitable model for the tree species.

The remaining 30% data were used on the modified equations for validation, this was to ensure the volume equations are biological plausible. T-test was used to compare the observed and predicted volume at 0.05 level. Generally, for a model to be biological plausible, it is expected that the test should produce a non-significant result (0.05).

Table 1: Modified Volume Equations for Five Economic Hardwood Species in Oluwa Forest Reserve, Ondo State, Nigeria.

Model No	Model type	Modified Model	Equation Numbers
1	Transformed Logarithm	$Ln\,V = b_0 + b_1 \ln \mathrm{D} + b_2 \ln H_i$	**[2]**
2	Constant Form	$V_i = b_1 D_i^2 H_i$	**[3]**
3	Non linear	$V_i = e^{b_1} D_i^{b_2} H_i^{b_3}$	**[4]**
4	Generalized combined	$V_i = b_0 + b_1 D_i + b_2 H_i + b_3 D_i^2 H_i$	**[5]**
5	Generalized Non linear	$V_i = b_0 + b_1\, D_i^{b_2} H_i^{b_3}$	**[6]**

b_0.....b_3= regression constants D=diameter at breast height H= Merchantable Height.

RESULTS

The table below shows the distribution for Five Economic Hardwood Species in Oluwa Forest Reserve, Ondo State, Nigeria. It was observed in Plot 1 and 2 that *Celtis zenkeri* were highly dominated having 13 and 18 stems respectively while for plot 3, 4, and 8 *Picralima nitida* were highly dominated having the same number of stems of 7. Also, in plot 5 *Picralima nitida* has the highest number of stems followed by *Lovoa trichiloides* with 6 and 5 stems respectively. In the case of plot 6, *Celtis zenkeri* and *Picralima nitida* were high dominated with 7 stems.

Table 2: Distribution of Five Economic Hardwood Species in Oluwa Forest Reserve, Ondo State, Nigeria on Plot basis.

	Tree species				
Plot (50m x 50m)	***Buchhlozia coriacea***	***Celtis zenkeri***	***Diospyros crassiflora***	***Lovoa trichilioides***	***Picralima nitida***
1	4	13	7	3	8
2	9	18	5	2	8
3	0	3	1	1	7
4	3	6	2	4	7
5	2	3	1	5	6
6	3	7	5	5	7
7	4	4	3	1	5
8	6	5	1	4	7

Table 3, shows the growth characteristics of the five economic hardwood species in Oluwa Forest reserve. The result of the descriptive statistics shows that *Picralima nitida* has the highest diameter at breast height (Dbh) with 50.2 cm in girth while *Celtis zenkeri* has the lowest with 10cm while for the Stem Height (SHt) i.e. from the stem height to the crown point, *Bucholzia coriacea* has the highest Stem height of 33.6 m with the minimum stem Height of 4.3m also for Volume, *Picralima nitida* has the maximum volume with 3.56m^3 and the minimum volume of 0.008 m^3.

Table 3: Descriptive statistics of five economic hardwood species in Oluwa Forest Reserve, Ondo State, Nigeria.

Species	Tree Variable						
	HD (cm)	**DBH (cm)**	**Dm (cm)**	**Dt(cm)**	**SHt(m)**	**MHt(m)**	**Vol(m^3)**
Buchhlozia coriacea							
Mean	21.5	17.5	12.2	8.7	12.1	8.0	0.156
Standard Error	1.161	1.118	0.938	1.023	1.063	0.778	0.035
Minimum	13.5	10.1	5	2.5	4.3	2.1	0.010
Maximum	35.5	32.3	24.1	25	33.6	24.3	0.865
Celtis zenkeri							
Mean	24.3	20.2	13.8	9.3	15.1	10.8	0.313
Standard Error	1.194	0.998	0.924	0.749	0.672	0.542	0.062
Minimum	11.3	10	5	2.5	5.2	2.6	0.008
Maximum	57.2	42.5	38.6	34.7	30.1	24.2	3.306
Diospyros crassiflora							
Mean	18.0	15.3	11.4	7.5	11.2	7.3	0.140
Standard Error	1.227	0.963	1.100	0.794	0.871	0.770	0.042
Minimum	11.5	10.2	5	2.5	5.1	2.8	0.011
Maximum	30.6	25.2	30	17.4	20.3	16.1	0.910
Lovoa trichilioides							
Mean	26.6	22.3	16.5	12.9	15.9	11.3	0.496
Standard Error	2.451	2.135	1.981	1.966	1.673	1.381	0.125
Minimum	14.2	11.3	5.2	3.1	5.3	3.5	0.015
Maximum	56.2	45.4	41.4	37	41.7	31.3	2.578
Picralima nitida							
Mean	20.9	17.6	12.6	8.8	12.8	9.1	0.219
Standard Error	1.076	0.915	0.797	0.656	0.716	0.693	0.066
Minimum	11.3	10.2	5	2.5	5.1	2.1	0.008
Maximum	59.6	50.2	38.2	22.4	30.9	27.5	3.560

Table 4 shows the model statistics and parameters of volume equations developed for the five economic hardwood species (*Buchhlozia coriacea, Celtis zenkeri, Diospyros crassiflora, Lovoa trichiliodes, and Picralima nitida*) in Oluwa Forest reserve Ondo state. It was discovered that nonlinear logarithm equation produced the best fit for *Buchhlozia coriacea, Celtis zenkeri, Diospyros crassiflora* and *Picralima nitida* while the Generalized Non Linear equations produced a better fit for the *Lovoa trichiliodes*. However, model 2 (constant form equation) performed poorly for all the five hardwood species. This reveals the adequacy of nonlinear logarithm equation over transformed logarithm, constant form, generalized combined functions and Generalized Non Linear equations.

Table 4: Model statistics and parameters estimates of Five Economic Hardwood Species in Oluwa Forest Reserve, Ondo State, Nigeria.

Species	Model type	b_0	b_1	b_2	b_3	M.S.E	R^2
Buchhlozia coriacea,	$V_i = e^{b_1}D_i^{b_2}H_i^{b_3}$	-8.664	1.381	1.301	-	0.004	0.912
Celtis zenkeri	$V_i = e^{b_1}D_i^{b_2}H_i^{b_3}$	-10.554	1.091	2.356	-	0.015	0.800
Diospyros crassiflora	$V_i = e^{b_1}D_i^{b_2}H_i^{b_3}$	-13.121	2.742	1.457	-	0.008	0.863
Lovoa trichiliodes	$V_i = b_0 + b_1\, D_i^{b_2}H_i^{b_3}$	-0.517	0.052	0.686	0.345	0.027	0.871
Picralima nitida	$V_i = e^{b_1}D_i^{b_2}H_i^{b_3}$	-10.586	2.187	1.071	-	0.001	0.969

Key: b_0**…..**$b_{3=}$ regression constants; D=diameter at breast height; H= Merchantable Height; Ln = Natural log V= Volume

DISCUSSION

Akindele (2005) developed volume equations for common timber species in Nigeria's tropical rainforests. The volume equations were fitted for individual species, all species combined, and groups of species. From a series of model-fitting trials, the untransformed generalized logarithmic volume function (also termed Schumacher-Hall's volume function) was found to perform better than other forms of volume functions. The results indicated that the zero-intercept quadratic volume function was the most appropriate function for such single-variable volume prediction.

This is in line with Shamaki and Akindele (2013) who developed five different equations for teak (*Tectona grandis*) plantation in Nimbia forest reserve using stump diameter (Dst) as independent variable. The volume equations developed were linear, logarithm and quadratic in nature. Adjusted coefficient of determination (Adjusted R^2) and root mean square error (RMSE) were used to rank the developed models. The resulting equations were found to be desirable for estimating the merchantable volume for teak in Nimbia forest reserve, Nigeria.

Aigbe *et al*., (2012) developed empirical equations for estimating tree volumes of *Terminalia ivorensis* from stump diameters, by determining relationship between volumes of *Terminalia ivorensis* trees. A series of regression equations were all fitted to the data, the regression equations were fitted for choosing the best model after critical consideration of model diagnostic criteria such as the coefficient of determination (R^2), variance ratio and overall standard error of the various equations. Out of the several regression equations fitted, the non-linear (quadratic) model of stump diameter was considered to be the best. With R^2 =0.69, RMSE = 0.00992 and F- ratio = 85.875; indicating the significant status of the model for predictive purpose. The results showed that stump diameter is appropriate for tree volume estimation and sustainable forest management of *Terminalia ivorensis* in Nigeria.

Wilson *et al*.,(2015) developed Allometric Models for Estimating Tree Volume and Aboveground Biomass in Lowland Forests of Tanzania. This study developed site specific and general models for estimating total tree volume and above ground biomass. Biomass models of trees found in the two study sites. The findings show that site specific ht-dbh model appears to be suitable in estimating tree height.

Daesung *et al*., (2017) also developed the Estimation and validation of stem volume equations for *Pinus densiflora*, *Pinus koraiensis*, and *Larix kaempferi* in South Korea. The combined-variable function was shown to be the best model through the validation of the equation. Also, the model using only DBH was also evaluated to be applicable in the field. These models revealed higher accuracy when compared with previous studies.

Ige *et al*., (2013) also developed Diameter Distribution Models for Tropical Natural Forest trees in Onigambari Forest Reserve. The models were developed using four – parameters Beta functions. Simple linear regression equation was used to fit the models for each of the parameters. The best model from each parameters were selected based on least Values of mean residuals, standard deviation of residuals, sum of squares of residuals, coefficient of variation of residuals; significance and high coefficient of determination.

Ebeniro (2018) developed Height Diameter Modelling Of Mixed Tree Species In Ibadan The study area hosts about 24 tree species dominated by Eucalyptus camaldulensis, Eucalyptus tereticornis, Nauclea diderichi, Terminalia superba, and Terminalia randii. Among the Five models, Shreuder model (M2) demonstrated the best fit and accounted for the greatest proportion of total height variations (R2 = 92.7%).Residual plots were plotted for each model as a means of verifying the validation of the equation.

Yousefpour *et al*., (2012) also predicted logarithmic stem volume equation based on tree height, diameter at breast height (dbh), and tree height and diameter at breast height were determined for Pinus pinaster Ait. Data were measured inkiashahr region of north of Iran. Least relative standard error of the volume estimation by two-variable model was 10%. They found out that transformed Logarithmic model came out as the best model.

John Fonweban *et al*., (2011) also developed variable-top merchantable volume equations for plantation-grown Scots pine (*Pinus sylvestris*) and Sitka spruce (*Picea sitchensis*). Logarithmic expression of timber tree volumegave the best results for total volume.

CONCLUSION

This study focused on developing volume equations for the five hardwood (*Buchhlozia coriacea*, *Celtis zenkeri*, *Diospyros crassiflora*, *Lovoa trichiliodes and Picralima nitida*). Each species was fitted to the five equations i.e. Non Linear logarithm equation, Transformed logarithm, Constant form, Generalized combined functions and Generalized Non Linear equations and the best equation was selected.

RECOMMENDATION

Based on the results from this finding, the following recommendations are made:

- The selected models can be very useful for sustainable forest management assessment of Lovoa *trichiliodes*, *Celtis zenkeri*, *Picralima nitida*, *Buchhlozia coriacea and Diospyros crassiflora* plantations in the study area and similar ecological areas.
- Further research should be carried out in this study area so as to test the validity of these models on some of the other species(*Khaya ivorensis*, *Milicia excelsa, Afzelia Bipindensis, Brachystegia nigerica, Lophira alata, Lovoa trichiliodes, Terminalia ivorensis, Terminalia superba*, and *Triplochiton scleroxylon*) if more datasets are provided perhaps other models may perform better.
- Man-made Plantations should be established in Oluwa Forest reserve to reduce the pressure on hardwood species available.

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