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RESEARCH ARTICLE

VOLUME MODELS FOR TROPICAL RAINFOREST ECOSYSTEM IN OGUN STATE, NIGERIA

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ABSTRACT

Tree growth variables were collected at Elephant and Biosphere reserves of Omo Forest Reserve, Ogun State for volume model and form factor development. Ten(10) plots of equal sizes (50 x 50m) were randomly located in each of the forests using the systematic line transect sampling method. Trees with DBH ≥ 20 cm were enumerated. Growth variables measured include diameter at breast height, diameter at the base, diameter at the top, and the diameter at the middle of all living trees using the girth tape and Spiegel relaskop for trees with large buttresses or diameter while the total height was measured with the Spiegel Relaskop. Most of the tress in the Biosphere reserve fall in the diameter class of 20-30cm class. All data were screened with volume calculated using the Newton's formula .Correlation analysis was carried out to examine the linear relationship between volume and other growth variables. Three regression models were developed, assessed and validated. Assessment was based on the correlation coefficient (R), coefficient of determination (R^2), standard error (SE) and F- ratio while validation was done using the residual analysis to examine the plausibility of the models for volume estimation. The tree form factor which is the ratio of the volume of the tree to that of a geometric solid was also estimated with the form factor for the whole forest estimated at 0.74 and the form factor for the Biosphere reserve and Elephant reserve estimated at 0.50 and 0.52 respectively.

INTRODUCTION

The tropical rainforest is one of the major vegetation types in the world and it is the most diverse of all terrestrial ecosystems containing more of animal and plant species than any other known biome (Turner, 2001). However, many tropical forests are under severe anthropogenic pressures and require management intervention to maintain and/or improve their biodiversity conservation, productivity and sustainability (Kumar *et al.,* 2002) as trees are a major source of wide range wood and non-wood products. With characteristics of dense canopy trees and thickets,the tropical rainforest makes it difficult to measure variables needed for volume estimation from trees in the plots which the use of volume equations and variables (diameter at breast height and height) has helped overcome this difficulty using stem volume as a function of Diameter at Brest Height (DBH), height and form factor (Adekunle, 2007). For management and planning purposes, at both national and stand levels it is extremely important to know the volume of the forest resources and their growth rates (Atriell *et al.,* 2010). Volume equations, that is dependent on height and diameter account for tree form differences; only to the extent that form is predictable from height and diameter. Volume also depends on a combination of diameter, height, and form, yet form is rarely included as an additional variable in standard volume equations for forest measurement and research purposes (Hoyer, 1985). Volume estimation though old is avery important forestry practice that requires regular development is used to manage forest stand effectively to avoid unnecessary cost and ensure high level of precision. Volume estimation can either be direct or indirect where direct estimation includes water displacement methods, graphical fittings, height accumulation and is destructive because they require tree felling.Indirect estimation is done when the parts of the tree are represented by solids of revolution (like cylinder, frustum, cone etc.), makes use of volume tables and volume equations (Newton, Smalian and Huber). Adekunle (2007) noted that developing models for natural, tropical forest ecosystem is scarce and limited due to the complex ecosystem and the inability of age determination, thus, basal area or form factor is used asa replacement for the age. Despite the economic and environmental significance of forests, we have only imprecise measurements of the physical variables that determine their valued attributes, whether for natural habitat, timber volume, biomass, or stored carbon. Without accuracy, appraisals of trees will be discredited, assay of biomass will be deceptive, and claims of species diversity will be false. This brings about the need for precise Inventory or Forest Estimation.

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MATERIALS AND METHODS

Study Area: Omo Forest Reserve, created in 1925, was administratively divided into four areas: J1, J3, J4 and J6 and its topography is characterized by an undulating terrain dominated by slopes up to 15% with elevation reaching 150 meters on a few rocky hills (Ogunleye, 2003). The Reserve; located in Ijebu East Local Government area of Ogun State and lies on Latitude 6^o 35' - 7 ^{o} 05'N and Longitudes 4^o 19' - 4^o 40'E (Amusa*et al.,* 2012) was constituted in 1925 as part of a bigger Shasha Forest Reserve. Omo covers about 130,500 hectares, which includes a 460 ha Strict Nature Reserve (Okali and Ola-Adams 1987; NNMC, 2014). Present in the reserve is a Biosphere Reserve (popularly referred to as the Queen's forest) and the Elephant Forest with the Queen's forest having core area and buffer zone of 460 and 14 200 ha respectively, was constituted a Strict Nature Reserve in 1949 and Biosphere Reserve in 1977 (Isichei 1995, Were 2001). Its terrain is undulating with an elevation that is about 300m on some rocky hills. The climate is humid sub-tropical since it is within the tropical rainforest ecological zone with relative humidity during the rainy season ranging from 85 to 100% and less than 60% during the dry season (Fashinmirin and Oguntuase, 2008). The reserve has a mean annual rainfall between (1600 – 2000 mm) and average temperature of 27^{0}C. The average elevation in Omo is 123 m and the soils are predominantly ferruginous tropical, which is 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 both Elephant and Queen/ Biosphere is mainly sandy loam (Onyekwelu *et al.,* 2008).

Data Collection: Six (6) plots of 50 x 50 meters each were located in the Biosphere reserve and four in the Elephant reserve. Enumeration of plots was done using the Non-Probability sampling technique (Systematic Line Transect). Two transects were gotten in the Biosphere reserve and one in the Elephant reserve. Complete enumeration and species identification were limited to trees with dbh 20m. Total height was recorded from ground level to the top of the crown, while commercial or merchantable bole height was the length of the trunk from the ground to the merchantable height of the tree (FAO, 2005)The horizontal distance from the tree was taken into account for the calculation of the height and is the most recommendable (Garcia, 2004).

Data Analysis: All the trees measured were identified with their scientific and common names. All parameters measured were analyzed using Microsoft Excel and SPSS software.

Basal Area Estimation: Basal area of all trees in sample plots is calculated using equation 1:

$$BA=\frac{(\pi D_2)}{4} \tag{1}$$

Where *BA* = Basal area (m^2), D = Diameter at breast height (m) and л = pi (3.142). *Volume Estimation*

The volume of each tree was calculated for all the plots using Newton's formula (equation 2) of Husch *et al* (2003):

$$V=\left(\frac{h}{6}\right)*(Ab+4\ Am+At) \tag{2}$$

Where: *V* = Tree volume (in m^3), *Ab, Am* and *At*= tree cross-sectional area at the base, middle and top of merchantable height, respectively (in m^2) and *h* = total or merchantable or bole height (meters). Bole, in this study, is the main stem of the tree from the soil surface to the place where the first large branch protrudes the stem (Chaidez, 2009).

Plot volumes were also obtained by summing the volumes of all trees in each plot i.e. Vp. Basal area and volume per hectare were obtained by dividing the sum total of basal area and volume respectively from the by the number of sampling plots in each location.

Form factor estimation: Form factor is the ratio of tree volume to the volume of a geometric solid (cylinder). The form factor (real or true form factor) was estimated for all species pooled. Real form factor is the real volume divided by the volume of a cylinder with basal area equivalent to the tree basal area at breast height and height equal to the tree height (Zobeiri, 2000). Form factors were estimated forthe entire stand by pooling all tree growth data together and for individual reserves. The cylindrical volume (Vc) and the form factors of the trees were estimated using equations 3 and 4 respectively:

$$Vc=\frac{\pi D^2}{4}h \tag{3}$$

Where Vt is the tree volume and Vc is the cylindrical volume of trees estimated.

$$f=\frac{Vt}{Vc} \tag{4}$$

Volume model generation: The simple linear, and the logarithm regression models were developed for individual tree growth variables across all sample plots. The generalized allometric equation for mathematics and science and the linear regression models that followed the general Schumacher (1939) yield models were used. The Schumacher model is of the form (equation 5):

$$Y=f(A, SQ, SD) \tag{5}$$

Three other equations used are

$$\ln V=\alpha+\beta \ln BA+\varepsilon \text{ (Simple linear – double logarithm transformed)} \tag{6}$$

$$V=\alpha+\beta BA+\varepsilon \text{ (Simple linear)} \tag{7}$$

$$V=\alpha+\beta(D^2H)+\varepsilon \text{ (Simple linear)} \tag{8}$$

Where Y = function of yield (volume), A = age, SQ = function of site quality e.g. height, and β are regression coefficients to be determined, Ln is the natural logarithm, *D* is DBH (cm), *H* is tree height (m) and ε is an error term. Equation 8 contains two parameters, but the dependence of volume was expressed as a composition of two independent variables, DBH and height, in the form $D^2 \times H$.

Assessment of the models: The models were assessed to test their plausibility and suitability for further use. The following statistical criteria were used:

Significance of regression (F - ratio): - The tabulated critical value of F at $p < 0.05$ was compared with the calculated F-ratio. Where F-calculated exceeded F-tabulated, equations were considered significant and useful for prediction.

Multiple correlation coefficient (R): R values >0.50 indicated a good fit.

Coefficient of determination (R^2): Models were acceptable at R2value >50%.

Adjusted coefficient of determination ($Radj^2$):Models were acceptable at R2value >50%.

The regression standard error: The value must be relatively small for a model to be valid.

Model Validation: Validation of the models was done by comparing the predicted volumes with field results (observed volumes) using statistical indices like Student's t-test, Simple Linear Regression Equation, and graphical analyses.70% of the pooled data was used for generating the models (total and merchantable volume models) and 30% of the data set aside for validation and tests for significant differences. In adopting the simple linear regression equation, the observed volume was the dependent variable while the model output was the independent variable (Adekunle, 2013). For models with good fit, the intercept must approach 0 and the slope approach 1, while the model must be significant (p<0.05 or very high f-ratio value), hence, there must be high correlation between the observed and predicted values; the coefficient of determination values must also be very high (near 100%) and the standard error of estimates must be small (Adekunle *et al.,* 2004; Adekunle, 2013).Residual plots were obtained for all the equations by plotting residual values against the independent variate i.e. the predicted volume (Ajit, 2010) to verify that the residuals are normally distributed and not over or under estimated. While there are many assumptions in the models, the essential multiple least-square regression assumptions are that the residuals should have normal distribution with zero mean and constant variance of the residuals. One-way analysis of variance (ANOVA) was used to test differences in the outputs of the developed models.

RESULTS

In total, 276 trees were encountered in all the sampling plots representing 55 species of 25 families with *Celtis mildbraedii* been the most abundant specie with frequency of 43 stems. This was followed by *Strombosia pustulata* with 20 stems and basal area, volume per hectare recorded at 25.83 m^2 and 682.17 m^3respectively. There was a relatively wide variation between minimum and maximum values for all tree growth variables. The mean DBH ranged from 20.70-161.2 cm while mean total height ranged from 12.75-56.93 m and all the species encountered in sample plots were used to estimate form factors and generating models. The most abundant species in the Elephant forest is *Celtis mildbraedii* having 17 stems, and this was followed by *Cleistopholis patens* having 10 stems. The family Moraceae accounted for the highest number of species (5 species) with basal area and volume per hectare of 12.54 m^2 and 540.34 m^3respectively. In the Biosphere, *Celtis mildbraedii* was the most abundant tree species with 26 stems and the family Ulmaceae had the highest number of species with basal area and volume per hectare of 20.70 m^2 and 464.18 m^3 respectively. The diameter distribution of trees in both the Elephant and Biosphere Reserves is shown in Fig 1where the trees with the highest diameter are between 20-30cm for both the biosphere and elephant reserve and it shows the inverse J-shapedpattern common with tropical natural forest ecosystems.

Figure 2 and 3 showed the residual plot of residual value against predicted value using model 1 for both total volume and merchantable volume. The result showed that there is no upward and downward bias as the data were randomly distributed across the positive and negative axis. Also, the regression line is at zero. This confirms the goodness of fit of the model used for this study.

DISCUSSION

The diversity of tree species observed in this forest reserve is very typical of the tropical rainforest ecosystem which is known as the richest of all ecosystems in the world due to its species diversity(Mulatu *et.al.,* 2017; Zakaria, *et. al.,* 2016) These rainforests are also useful in carrying out some specific roles in the ecosystem which include purification of both air and water, sequestrating carbon, stabilizing climate, moderating extreme temperature, supporting cultural and spiritual functions, supplying various products to improve the livelihood of the forest dependent people (Adekunle *et al.,* 2005). Strict Nature Reserves (SNRs) are one of the *in situ* methods of management intervention that are needed to strictly protect rare habitats that are being disturbed with the influence of human beings. The results of this study revealed that Omo Forest Reserve contains many indigenous tropical hardwood tree species of different families. This is evidenced by the 276 stems (dbh 20 cm) belonging to 55 indigenous hardwood species, distributed in 25 important families. This is within the range reported by Campbell *et al*. (1992) who reported 245-467 stems for tropical rainforests but not as high as the 544 stems for a primary forest in Indonesia reported by Kessler *et al.* (2005), but in the range of 387 stems of 94 tree species distributed among thirty (30) families that was recorded by Adekunle *et al*. (2013) in a similar ecosystem. The Reserve was dominated by the families of *Apocynaceae, Moraceae* and *Sterculiaceae*. This agrees with the findings of Onyekwelu *et al.,* (2008) and Adekunle *et al.,* (2010) that the tropical rainforest ecosystem of Southwest Nigeria is dominated by the families *Moraceae, Sterculiaceae* and *Euphorbiaceae*.

Stand models are useful for estimating growth and yield of any stand as well as projecting values of other parameters like basal area, mean dbh, height and number of trees per hectare (Luo, *et al.* , 2018; Tsega, *et al.* , 2018). Akindele and LeMay (2006) reported that the growing stock in forestry is usually expressed in terms of timber volume and the most common procedure of obtaining this is the use of volume equations based on relationship between volume and variables such as diameter and height. For the estimation of tree volumes using one or more variables, regression equations are efficient and valuable tools to be used. These equations are generated by different authors to predict volumes thereby avoiding stressful and long procedures of data acquisition and volume calculation always (Shifley *et al*., 2017). Since, age structures for un-even aged forests are highly heterogeneous and complex to deduce, it is therefore replaced using other growth parameters like basal area, diameter or height. Models were developed and tested for the estimation of total and merchantable or bole volumes. The coefficient of variation followed the same trend, ranging from 8% to 93%. All the models for merchantable volume prediction were highly significant except the second model. All the assessment criteria revealed that the simulated models had good fit. The statistical fits were generally good. The conformity to regression assumptions when tested with the probability plot of residual

Table 1. List of tree species, families and growth parameters of trees involved in model generation for pooled data

FAMILY	SPECIES	No of stem	MDbh cm)	MHth (m)	BA/ha (m2/ha)	Vol/ha (m3/ha)	CV (m3)
Agavaceae	*Dracaena mannii*	*2*	33.50	24.28	0.08	1.88	5.43
Annonaceae	*Annona arenaria*	2	29.10	28.43	0.05	4.23	0.70
Apocynaceae	*Cleistopholis patens*	13	58.27	31.52	1.81	79.33	163.93
	Alstonia boonei	2	46.30	29.88	0.16	6.49	4.35
	Funtumiaelastica	10	26.52	22.84	0.23	18.80	3.51
	Holarrhena floribunda	6	22.53	20.82	0.10	9.03	1.67
	Rauvolfia vomitoria	1	25.30	23.00	0.02	1.76	1.16
Bignoniaceae	*Voacangaafricana*	7	25.84	17.91	0.15	5.76	3.54
	Kigelia africana	1	27.90	16.40	0.02	1.69	1.00
Bombacaceae	*Spathodea campanulata*	3	35.60	27.81	0.13	8.86	7.90
	Bombaxbuonopozense	1	20.70	14.58	0.01	0.15	0.49
Boraginaceae	*Ceiba pentandra*	2	27.85	19.98	0.05	2.19	1.15
	Cordia milleni	13	58.66	32.52	1.83	31.65	44.72
Caesalpiniaceae	*Cordia platythyrsa*	2	49.95	32.25	0.15	5.61	10.08
	Distemonanthusbenthamianus	1	32.50	28.00	0.03	2.51	2.32
	Anthonotha macrophylla	6	29.77	20.55	0.17	11.92	4.69
	Brachystegia eurycoma	1	47.40	25.00	0.07	3.47	4.41
Capparidaceae	*Dialium guineense*	1	29.30	31.00	0.03	3.20	0.54
	Buchholzia coriacea	2	26.90	23.03	0.05	4.59	0.65
Combretaceae	*Anogeissusleio carpus*	2	57.05	41.62	0.21	6.44	16.44
	Terminalia ivorensis	1	23.70	23.55	0.02	1.82	1.04
Ebenaceae	*Terminalia superb*	3	51.60	30.30	0.30	6.35	8.62
	Diospryos dendo	14	23.99	19.03	0.26	16.41	7.43
Euphorbiaceae	*Diospyros mespiliformis*	10	26.91	19.90	0.23	8.43	8.90
	Croton perduliflorus	1	87.80	47.30	0.24	0.61	0.93
	Drypetes afzelii	2	35.50	26.06	0.08	5.46	1.61
	Drypetes spp	3	50.80	27.88	0.36	16.31	24.08
Guttiferae	*Ricinodendron heudelotii*	16	71.71	38.03	3.56	66.46	114.86
	Allanblackia floribunda	1	51.50	32.84	0.08	4.87	6.73
Meliaceae	*Entandrophragma cylindricum*	1	39.30	28.67	0.05	1.65	0.50
	Khaya ivorensis	2	107.25	56.93	0.96	6.27	13.82
Mimosaceae	*Trichilia monadelpha*	7	28.40	22.46	0.18	9.32	3.72
	Albizia zygia	3	53.37	26.44	0.34	11.99	30.78
Moraceae	*Milicia excels*	4	161.20	34.64	7.74	49.94	1593.41
	Musanga cecropioides	5	43.43	32.14	0.31	16.33	26.32
	Myrianthus arboreus	1	47	29.5	0.07	4.69	6.85
	Treculiaafricana var. nitida	1	71.80	23.75	0.16	2.43	21.76
Myrislicaceae	*Trilepisium madagascariense*	1	22.5	12.75	0.02	0.99	0.51
	Pycnanthus angolensis	4	46.55	28.27	0.36	13.58	16.35
Olacaceae	*Strombosia pustulata*	20	30.67	21.78	0.83	30.3	11.00
Papilionioideae	*Pterocarpus osun*	1	25.60	20.05	0.02	0.076	0.01
Rubiaceae	*Mitiragyna ciliata*	1	47.70	34.50	0.07	5.852	2.61
	Morinda lucida	1	33.90	29.00	0.04	3.196	2.62
Rutaceae	*Pausinystaliajohimbe*	2	53.50	34.60	0.18	9.088	9.07
	Zanthoxylumzanthoxyloides	4	28.40	20.48	0.11	7.792	4.58
Sapotaceae	*Malacantha alnifolia*	4	25.90	17.73	0.09	2.964	2.00
Sterculiaceae	*Cola gigantea*	1	39.50	25.80	0.05	3.088	0.95
	Cola spp	2	22.15	15.09	0.03	1.016	1.20
	Nesogordonia papaverifera	2	27.80	21.02	0.05	0.168	0.03
	Pterygota macrocarpa	9	39.68	27.18	0.50	33.924	17.65
Tiliaceae	*Sterculia rhinopetala*	16	42.36	26.76	1.07	50.204	30.53
	Desplatsiasubericrapa	5	24.32	19.98	0.10	6.772	4.87
Ulmaceae	*Celtis brownii*	1	21.60	24.40	0.02	1.432	0.13
	Celtis mildbraedii	43	28.66	22.75	1.18	45.052	36.96
	Celtis zenkeri	6	59.88	33.61	0.82	27.776	25.44
	TOTAL	276	2306.87	**	**	**	**

Table 3. Spearman correlation matrix for pooled tree growth variables in Omo Forest Reserve

	Dbh (m)	THt (m)	BA(m2)	LnBA(m^2)	Tvol(m^3)	LnTVol(m^3)	MHt (m)
Dbh(m)	1						
TotalHt(m)	0.837	1					
BA(m2)	1.00**	0.837	1				
LnBA(m^2)	1.00**	0.837	1.00**	1			
TVol(m3)	0.699	0.595	0.699	0.699	1		
LnTVol(m3)	0.699	0.595	0.699	0.699	1.00**	1	
MHt(m)	0.819	0.907	0.819	0.819	0.630	0.630	1

**. Correlation is significant at the 0.01 level (1-tailed).

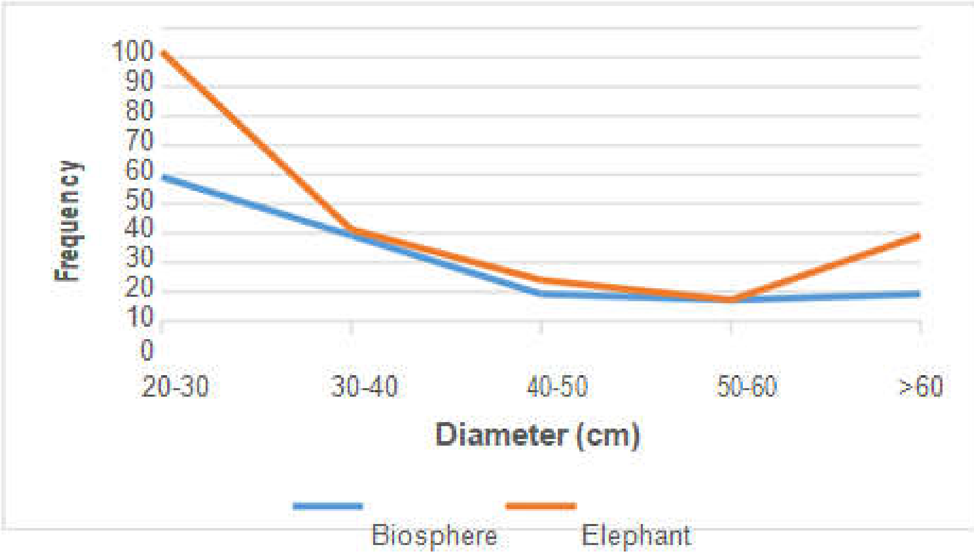

Fig. 1. Diameter distribution curve for Omo Biosphere Reserve and Elephant forest

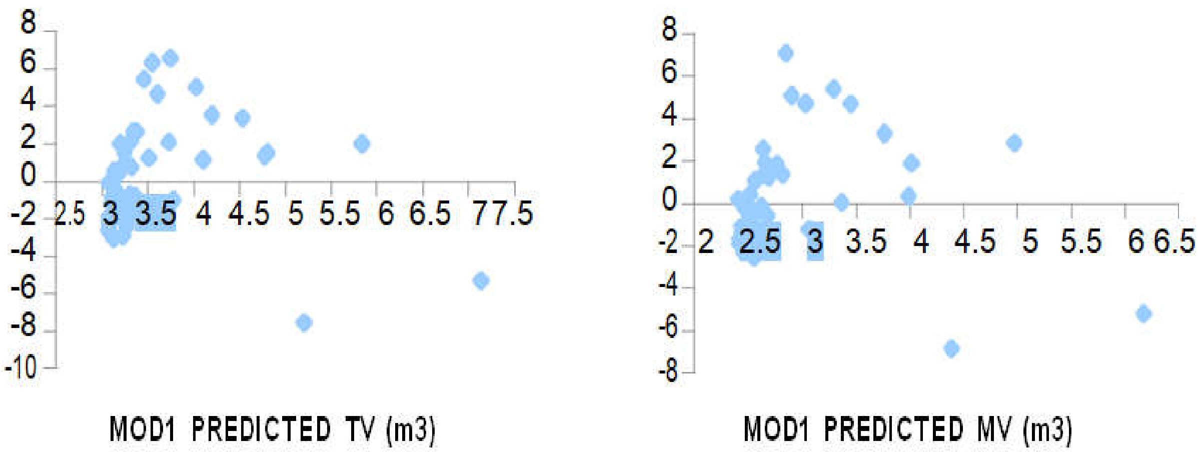

Fig. 2. Predicted total, merchantable V (m3) and Residual plot for allometry model validation for Biosphere reserve

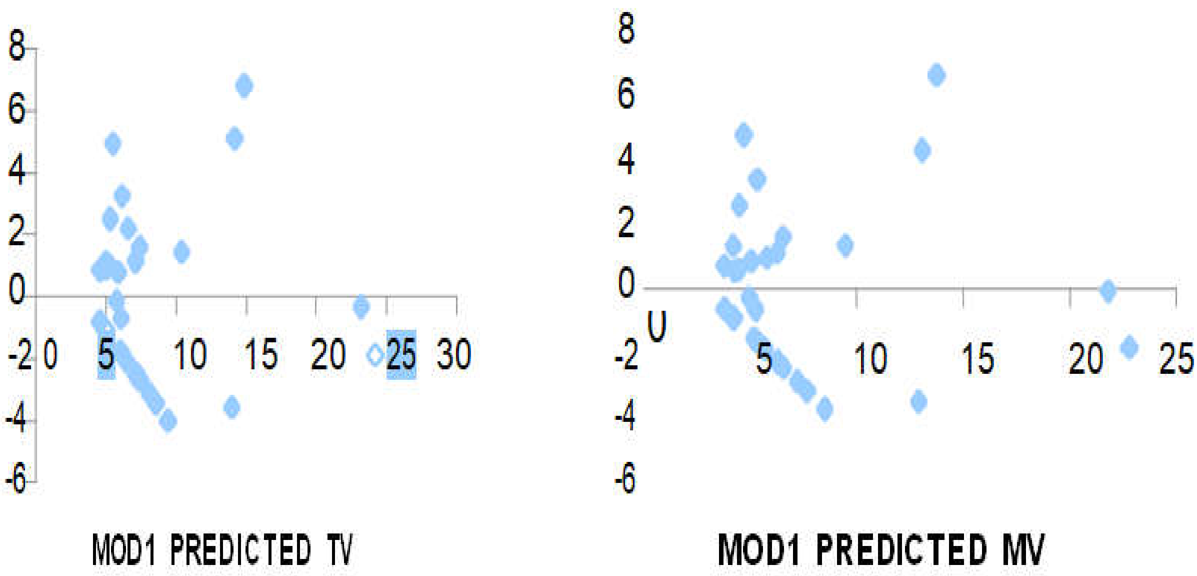

Fig. 3. Predicted total, merchantable V (m3) and Residual plot for allometry model validation for Elephant reserve

and predicted values conformed to the observation of Ajit (2010). The scatter-plots were consistent with the results of other statistical indices for validation. This shows that the regression assumptions were not violated (Adekunle et al., 2013). The best model (Model 1) was validated with the use of residual plot. This confirms the goodness of fit of the best model as the data were randomly distributed. There were no upward and downward bias as the data falls between the positive and negative axes. Also, the regression line is at zero.

Conclusion

Volume estimation is critical to forest resource management. Estimation of this parameter is usually confounded by factors such as lack of equipment for measurement of tree height and upper diameter, difficulties in measurement of tree height in tropical forests, the complex architectural structure of tropical forests and the high cost of inventory work. To avoid this problem, models for total and bole volume estimation were developed in this study.

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