

Development and Validation of Volume Equations for Tree Species in the Tropical Dry Forest Area of Indonesia

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Abstract

The aims of this study is to develop and validate tree volume prediction models of tree species in East Nusa Tenggara tropical dry forest, Indonesia. Data collection in this study was conducted by measuring diameter and height of trees. Tree species volume equation is estimated using models of Berkhout, Kopecky-Gehrhardt and Hohenadl-Krenn. Selection of the best models was based on the values of the coefficient of standar deviation (SD), R² adj, aggregate deviation (AD) and average deviation (AveD), root mean square error (RMSE) and bias. Hohenadl-Krenn and Kopecky-Gehrhardt models were accepted as the best model for tree species in all research sites. The selected volume model for these tree species has Hohenadl-Krenn ($V = 0.572 - 0.033D_{bh} + 0.00106D_{bh}^2$ for Binafun and $V = 0.683 - 0.0366D_{bh} + 0.001278D_{bh}^2$ for Bonmuti) and Kopecky-Gehrhardt models ($V = 0.0502 + 0.000537 D_{bh}^2$ for Letkole and $V = -0.1776 + 0.000677D_{bh}^2$ for Oelbanu).

Keywords: Volume table; Tropical dry forest; Best models; selected model

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1. Introduction

Generally, considerable importance has been given to the development of estimation schemes to predict volume for each individual tree and for the whole stand. Economic aspect is the main reason for this effort. Forest industres and other organizations often need periodic inventories to determine the quantity of wood available for utilization.

It has been a practice for foresters to rely on prepared volume tables [1]. These tables predict the volume of standing trees of given species, diameters and heights that would be obtained if trees where felled, bucked and scaled as logs. Aside from providing cubic volume for the entire main stem, the tables also sometimes give either the volume from

stump to a given merchantable diameter of the volume of cut lumber obtainable from a tree.

There are difficulties that may arise when one depends upon using these prepared volume tables, because: 1) any individual tree may not have the same height, diameter, and form characteristics as those used in the construction of the volume table employed;2) volume tables are constructed for spesific units of measurement and utilization standards, and it is often imposible or unwieldy to try to change to these spesifications;3) any errors in the volume tables are incorporated into the estimate and in most cases no assessment of their magnitude is include. In addition to these difficulties, one must consider that the volume table is based on established estimation schemes which are in turn based on a spesific model. Thus, the reliability of

such tabulations depends upon the model selected as the basis for the construction [1].

The objective of this study is to develop a more accurate volume tabel for tree species in tropical dry forest of East Nusa Tenggara, Indonesia. The tree volume equation is formulated by using models of Berkhout ($V = aD^b$), Kopezky-Gehrhardt ($V = a + bD^2$) and Hohenadl-Krenn ($V = a + bD + cD^2$). Model equation estimators had the best volume with using a scoring system based on the statistical test criteria in the compilation and validation of the model.

2. Materials and methods

2.1. Study area

The study was carried out at the Mutis Timau Protected Forest Management Unit (Mutis Timau PFMU) of East Nusa Tenggara Province, Indonesia, which is covered on Kupang District, Timor Tengah Selatan District and Timor Tengah Utara District (Lat. 90 20' 00" - 90 45' 10" South and long. 123.042'30" - 124.0 20' 00" E) (Fig. 1). Data for this study were collected from 4 dry forest study sites named Binafun, Bonmuti, Letkole and Oelbanu, each study site consisting of two 10.000 m² plots.

The research sites represent the dry forests of East Nusa Tenggara, Indonesia, and surrounding areas are the wettest areas on the island of Timor, the rain fell almost every month with the highest frequency of rainfall occurs during November to July, temperatures range between 14⁰C - 29⁰C, and in extreme conditions can decrease up to 9⁰C. High-speed winds occurred in November until March.

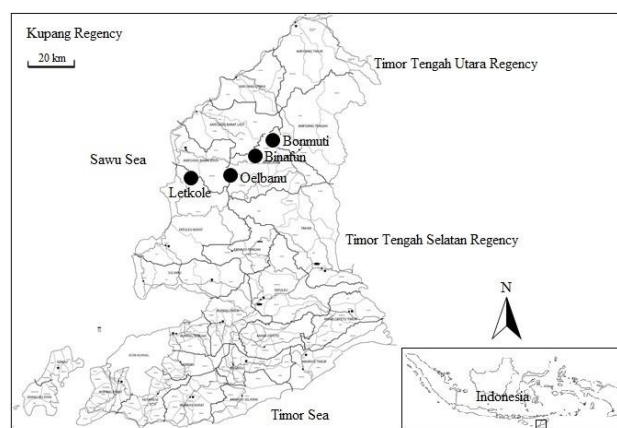


Figure 1. Location of research sites at Mutis Timau PFMU, East Nusa Tenggara province, Indonesia

2.2. Study plot

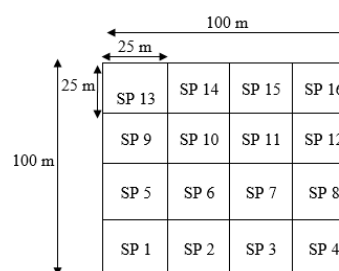


Figure 2. Design of sample plots

In order to know the potential of tree species, two sample plots (100 m x 100 m) was established in each study area. In each sample plot, it divided into 16 sub-plots (SP) with the size of 25 m x 25 m as shown in Figure 2. In each plot, all tree species were measured for species name, height, and diameter at breast height (DBH) ≥ 20 cm (1.3 meters).

2.3. Data analysis

Samples of 516 trees (Binafun=119, Bonmuti=71, Letkole=141 and Oelbanu=185) for developing tree volume model and 372 sample trees (Binafun=98, Bonmuti=45, Letkole=121 and Oelbanu=108) for validating the model were selected randomly from each of the four data sets. The tree volume equation is estimated using models of Berkhout ($V = aD^b$), Kopezky-Gehrhardt ($V = a + bD^2$) and Hohenadl-Krenn ($V = a + bD + cD^2$). Where, V= total tree volume (m³), Dbh=Diameter at breast height (cm), a,b,c=constant.

Appropriate checks are to be made to assess the accuracy of the model. Therefore, I consider the following measures (standard deviation, R^2 adj, aggregate deviation and average deviation, root mean square error and bias):

The formula for the sample standard deviation is

$$SD = \sqrt{\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N-1}}$$

Where; s is standard deviation, x_1, x_2, x_n are the observed values of the sample items, $\bar{x}$ is the mean value of these observations, and N is the number of observations in the sample.

The formula for the adjusted R^2 adj is:

$$R_{adj}^2 = 1 - \left[\frac{(1 - R^2)(n - 1)}{n - k - 1} \right]$$

Where; N is the number of points in your data sample, K is the number of independent regressors, i.e. the number of variables in your model, excluding the constant.

The formula for aggregate deviation and average deviation are

$$AD = \left(\frac{\sum_{i=1}^n Vp - \sum_{i=1}^n Vob}{\sum_{i=1}^n Vp} \right)$$

$$AveD = \left\{ \frac{\left(\sum_{i=1}^n \frac{Vp - Vob}{Vp} \right)}{n} \right\} \times 100\%$$

Where AD is aggregate deviation, AveD is average deviation, Vob is observed tree volume, Vp is prediction tree volume [2].

$$RMSE (\%) = 100 \sqrt{\frac{1}{n} \sum_{i=1}^n \left(\frac{y_i - \hat{y}_i}{y_i} \right)^2}$$

where n is number of trees used for model development, and y_i and $\hat{y}_i$ are observed and predicted tree volume [3].

The model bias was defined as follows: Bias = $(B_{est} - B_{obs}) / B_{obs}$, where B_{est} =bias estimation of tree volume and B_{obs} =bias observation of tree volume.

3. Results and Discussion

3.1. Distribution of tree sample

Descriptive of the sampled trees for each Dbh class, research site, equation development plot and validation plot are given in Table 1. Number of sampled tree was different between site and plot. Totally, number of sampled tree is 217 for Binafun, 116 for Bonmuti, 262 for Letkole and 293 for Oelbanu. All site dominated by tree with Dbh class 20 cm - 49 cm and 50 cm - 79 cm.

Table 1 : Recapitulation of sample tree

Location	Dbh class (cm)	Plot for equation development	Validation plot	Total
Binafun	20 - 49	75	71	146
	50 - 79	31	14	45
	80 - 109	9	8	17
	110 - 139	4	1	5

	140 - 169	0	3	3
	170 - 199	0	0	0
	200 - 229	0	0	0
	230 - 259	0	1	1
	Total	119	98	217
Bonmuti	20 - 49	48	40	88
	50 - 79	14	4	18
	80 - 109	6	1	7
	110 - 139	2	0	2
	140 - 169	1	0	1
	170 - 199	0	0	0
	200 - 229	0	0	0
	230 - 259	0	0	0
	Total	71	45	116
Letkole	20 - 49	109	104	213
	50 - 79	22	13	35
	80 - 109	8	3	11
	110 - 139	1	0	1
	140 - 169	0	0	0
	170 - 199	1	1	2
	200 - 229	0	0	0
	230 - 259	0	0	0
	Total	141	121	262
Oelbanu	20 - 49	170	80	250
	50 - 79	12	24	36
	80 - 109	3	3	6
	110 - 139	0	1	1

140 - 169	0	0	0
170 - 199	0	0	0
200 - 229	0	0	0
230 - 259	0	0	0
Total	185	108	293

3.2. Model of regression for tree volume estimation

In the present study, analysis of equation development shows that all values of R^2 and S was in a good

range for estimating tree volume (Table 2). In Bonmuti, Berkhout model higher values of R^2 (98.69) and lower values of S (0.051). The estimator is to be unbiased (100% accuracy) if the value is equal to zero for S parameter [4].

Tabel 2 : Regression models for estimation of tree volume

Site	Model	Equation	S	R^2 (%)	R^2_{adj} (%)
Binafun	Berkhout	$V = 0.000247Dbh^{2.243}$	0.077	97.23	97.20
	Kopezky-Gehrhardt	$V = -0.318 + 0.000816 Dbh^2$	0.574	95.70	95.66
	Hohenadl-Krenn	$V = 0.572 - 0.033Dbh + 0.00106Dbh^2$	0.540	96.22	96.16
Bonmuti	Berkhout	$V = 0.000411Dbh^{2.185}$	0.051	98.69	98.68
	Kopezky-Gehrhardt	$V = -0.374 + 0.001037Dbh^2$	0.633	97.78	97.74
	Hohenadl-Krenn	$V = 0.683 - 0.0366Dbh + 0.001278Dbh^2$	0.592	98.08	98.02
Letkole	Berkhout	$V = 0.000383Dbh^{2.0924}$	0.116	92.46	92.41
	Kopezky-Gehrhardt	$V = 0.0502 + 0.000537 Dbh^2$	0.531	91.85	91.79
	Hohenadl-Krenn	$V = -0.145 + 0.00735Dbh + 0.000490Dbh^2$	0.529	91.94	91.83
Oelbanu	Berkhout	$V = 0.00023Dbh^{2.217}$	0.077	94.43	94.40
	Kopezky-Gehrhardt	$V = -0.1776 + 0.000677Dbh^2$	0.248	92.60	92.56

Hohenadl-Krenn	$V = 0.5426 - 0.03518Dbh + 0.001019Dbh^2$	0.214	94.51	94.45
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V = Tree volume; Dbh= Diameter at breast height.

In the present study, normal assumptions condition are viewed based on residual plot and normal probability plot as shown in Figure 3-6. Generally, the pattern of relationship between the value of residual and normal probability are varies. Model of normality assumption is fulfilled if the values are spread normally [5]. Based on Figure 3-6, we can see plots

that follow the linear line, ie, Berkhout, Kopezky-Gehrhardt and Hohenadl-Krenn models, and all plot forming like a S letter. The Kolmogorov-smirnov normality test shows that all models meet the normal assumption because they have $P\text{-value} > \alpha (0.05)$. It can be concluded that the normality assumption is fulfilled for all models.

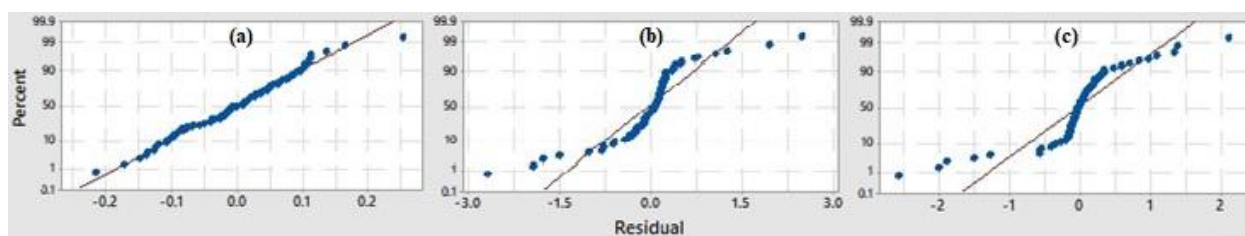


Figure 3. Diagram of normal probability for Binafun tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

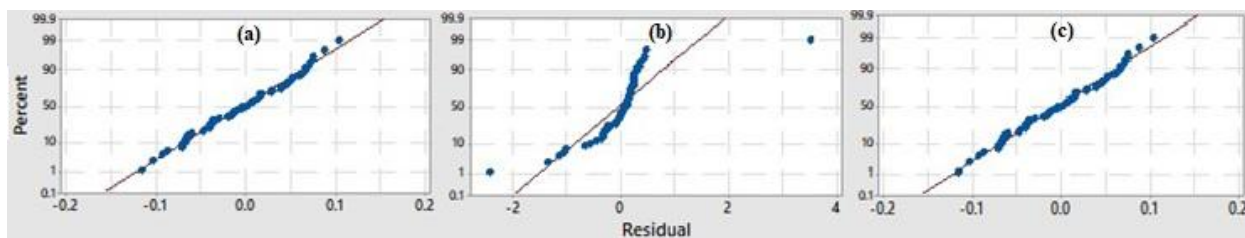


Figure 4. Diagram of normal probability for Bonmuti tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

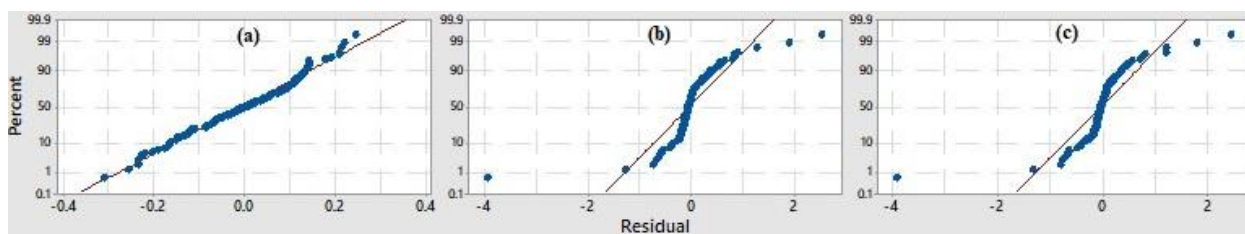


Figure 5. Diagram of normal probability for Letkole tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

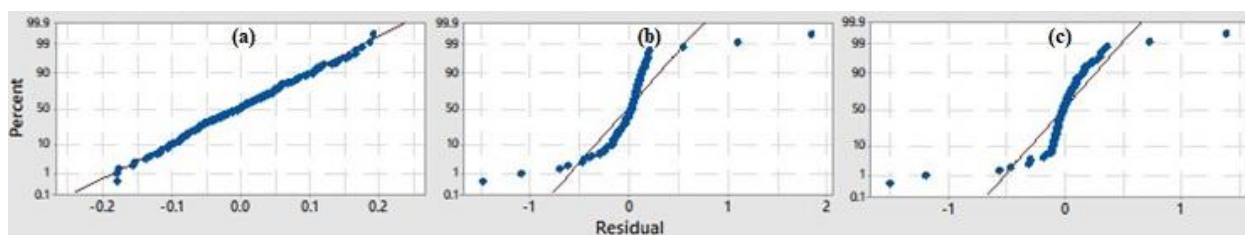


Figure 6. Diagram of normal probability for Oelbanu tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

3.3. Model validation

The result of model validation by using sample data of predefined tree is presented in Table 3. The level of accuracy of tree volume model can be seen from aggregate deviation (SA) and average deviation (SR) values. The range values of SA from -1 to +1

and <10% for SR are a good for volume estimation model [2]. Based on the evidence summarized in Table 3, all model (Berkhout, Kopezky-Gehrhardt and Hohenadl-Krenn) at all sites, fitted with S, SA, SR, RMSE and probability plot. These model also performed well when fitted with optimal scatter plot.

Table 3 : Model validation

Model	Binafun							
	S	R ² adj	AD	AvD	RMSE	Bias	Xcal	Xtable
Berkhout	0.0778	97.2	-0.039	-0.04	0.383	-0.038	5.58E-06	120.989
Kopezky-Gehrhardt	0.5744	95.66	0.01	0.011	0.11	0.011	4.88E-07	120.989
Hohenadl-Krenn	0.54	96.16	-0.057	-0.06	0.551	-0.055	1.13E-05	120.989
Model	Bonmuti							
	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Xtable
Berkhout	0.0509	98.68	-0.039	-0.09	0.567	-0.084	2.48E-05	60.48
Kopezky-Gehrhardt	0.633	97.74	0.025	0.056	0.387	0.057	1.23E-05	60.48
Hohenadl-Krenn	0.592	98.02	-0.074	-0.17	1.034	-0.154	7.96E-05	60.48
Model	Letkole							
	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Xtable
Berkhout	0.116	92.41	-0.175	-0.15	1.359	-0.123	0.0001	146.567

Kopezky-Gehrhardt	0.531	91.79	-0.179	-0.15	1.385	-0.125	0.0001	146.567
Hohenadl-Krenn	0.529	91.83	-0.174	-0.14	1.348	-0.122	0.00017	146.567
Oelbanu								
Model	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Xtable
Berkhout	0.077	94.4	0.215	0.199	2.636	0.253	0.0005	132.144
Kopezky-Gehrhardt	0.248	92.56	0.152	0.141	1.736	0.167	0.0002	132.144
Hohenadl-Krenn	0.214	94.45	0.189	0.175	2.244	0.215	0.0004	132.144

* accepted H₀ significance on $\alpha=0.05$

Based on the results of Table 4, for Binafun and Bonmuti, model Berkhout and Hohenadl-Krenn should be rejected, because, although is adequately fitted, has low for ranking equation. Also, models Berkhout and Hohenadl-Krenn at Letkole and Oelbanu should be rejected, because, although they

have fairly good values for comparison criteria, both for fitting, validation data and their regression coefficients is statistically significant at the level p, all of their validation parameter highest than Kopezky-Gehrhardt.

Table 4 : Scoring and ranking of equation for tree volume estimating

Binafun									
Model	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Sum	Rangking
Berkhout	3	1	2	2	2	2	2	14	2
Kopezky-Gehrhardt	1	3	1	1	3	1	3	13	3
Hohenadl-Krenn	2	2	3	3	1	3	1	15	1
Bonmuti									
Model	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Sum	Rangking
Berkhout	3	1	2	3	2	2	2	15	2
Kopezky-Gehrhardt	1	3	1	1	3	1	1	11	3
Hohenadl-Krenn	2	2	3	2	1	3	3	16	1
Letkole									
Model	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Sum	Rangking

Berkhout	3	1	2	3	2	2	3	16	2
Kopezky-Gehrhardt	1	3	3	3	1	3	3	17	1
Hohenadl-Krenn	2	2	1	1	3	1	1	11	3
Model	Oelbanu								
	S	R ² adj	SA	SR	RMSE	Bias	Xcal	Sum	Rangking
Berkhout	3	2	1	1	1	1	1	10	3
Kopezky-Gehrhardt	1	3	3	3	3	3	3	19	1
Hohenadl-Krenn	2	1	2	2	2	2	2	13	2

Table 5 : Tree volume equation selected

Study site	Model	Equation
Binafun	Hohenadl-Krenn	$V = 0.572 - 0.033Dbh + 0.00106Dbh^2$
Bonmuti	Hohenadl-Krenn	$V = 0.683 - 0.0366Dbh + 0.001278Dbh^2$
Letkole	Kopezky-Gehrhardt	$V = 0.0502 + 0.000537 Dbh^2$
Oelbanu	Kopezky-Gehrhardt	$V = -0.1776 + 0.000677Dbh^2$

V = Tree volume; Dbh = Diameter at breast height

Hohenadl-Krenn model (Binafun and Bonmuti) and Kopezky-Gehrhardt model (Letkole and Oelbanu) performed best in the validation as well as in the fitting phases (Tables 3 and 4). And Kopezky-Gehrhardt (Binafun and Bonmuti), Hohenadl-Krenn (Letkole) and Berkhout (Oelbanu) model was placed lowest during fitting and validation analysis. This analysis exemplifies the importance of model validation so that models can be used with greater confidence [6].

The developed tree species volume models in this study are based on data from one tropical dry forest site, and we know little about how well these data are representing dry forests elsewhere in Indonesia or other country. However, most of the dryforests in the country, including Mutis Timau where our data were collected, are parts of the Mutis Timau Mountains, and similarities regarding growth conditions

and allometry are likely present. As long as the allometry of the trees obviously is not different from that of Mutis Timau Mountains, we therefore believe that our tree species volume models may be applied for dry forests outside this site. However, further testing of the developed models, if data from other tropical dryforest sites in Indonesia or other countries becomes available, is very recommended.

Conclusions

The present study was the first to develop tree species models for dryforests in Indonesia based on un-destructive sampling. The results showed that large parts of volume variation were explained by the models and that they performed relatively well when tested over different tree size classes. When considering the challenges in height measurements in dryforests, we in general recommend applying model

Hohenadl-Krenn model for Binafun and Bonmuti sites, Kopezky-Gehrhardt model for Letkole and Oelbanu sites with dbh only as independent variable.

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