BIOGENESIS Jurnal Ilmiah Biologi

pISSN 2302-1616, eISSN 2580-2909
Vol 9, No. 2, December 2021, pp. 137-145
Available online http://journal.uin-alauddin.ac.id/index.php/biogenesis
DOI https://doi.org/10.24252/bio.v9i2.22281

Stem volume equation for constructing local volume table of *Pinus merkusii* Jungh et de Vriese in Tana Toraja community forest

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ABSTRACT. *Pinus merkusii* Jungh et de Vriese is a plant with high market and economic values due to providing a variety of products, including wood. Good management is needed to preserve pine forest products. The first step toward effective forest management is developing a management plan based on estimated stock data. The volume table used has a significant impact on the accuracy of the stock potential estimate. This study aims to determine the best equation model for compiling a local volume table for *P. merkusii* Jungh et de Vriese in Tana Toraja Regency. The research was conducted at the community pine forest in Gandang Batu Sillanan and Mengkendek districts, Toraja Regency. The number of sample measured was 100 trees. An analytical method was used to calculate the amount of tree volume on allometric equations. The equation for the stem volume was made using the allometric equation. The research results showed that diameters' mean, standard deviation, and sampling error values were 28.34 cm, 7.39 cm, and 1.45, respectively, heights were 23.77 m, 7.37 m, and 1.44; volume was 1.44 m^3, 0.96 m^3, and 0.19. The regression equation modelling showed that the best equation model for estimating volume *P. merkusii* Jungh et de Vriese based on height and diameter was $V = aD^2H$.

Keywords: allometric equation; forest management; local volume table; pine of South Sulawesi; stem volume

Article History: Received 21 July 2021; Received in revised form 4 August 2021; Accepted 14 November 2021; Available online 30 December 2021
How to Cite This Article: Patabang M, Hardjanto H. 2021. Stem volume equation for constructing local volume table of *Pinus merkusii* Jungh et de Vriese in Tana Toraja community forest. *Biogenesis: Jurnal Ilmiah Biologi*. vol 9(2): 137–145. doi: https://doi.org/10.24252/bio.v9i2.22281.

INTRODUCTION

Pine (*Pinus merkusii* Jungh et de Vriese) is a popular plant that plays an important role in Indonesia (Sadili, 2015). Pine is a marketable and economically valuable tree species due to the numerous products, such as wood and pine sap (Rusdiana & Amalia, 2012). Owing to the high commercial value of pine, it is widely planted in a variety of land uses, such as on Sulawesi Island (Imanuddin *et al*., 2020). According to Cahyono (2011) & Sallata (2013), pine has durable class IV and strong class V wood, and is the only species that grows naturally in Indonesia, including Tana Toraja Regency. Our previous studies (Hardjanto & Patabang, 2019) in Tana Toraja indicates that community forests cover an area of 12510 ha in the Tana Toraja, with the largest pine area being 2702 ha in the Mengkendek District.

The Pine forest in Tana Toraja's community forest exists as a result of reforestation efforts initiated in the 1940s by South Sulawesi Province's forestry officers (Sallata, 2013). Since 2002, the utilization of pine wood from community forests in Tana Toraja as an industrial raw material has begun (Patabang *et al*., 2014). The production of wood from community forests is becoming a more important component of efforts to meet community wood needs, as the production of jungle wood from natural forests continues to decline. Meanwhile, the community pine forest in Tana Toraja has been expanding as a source of wood (Patabang *et al*., 2011). To preserve pine forest products, prudent management is required. Without proper management, fluctuations in the value of pine have the potential to result in the extinction of pine trees in a relatively short period of time (Trivena *et al*., 2019).

The first step toward effective forest management is the development of a management plan based on available data on potential standing stocks (Shrestha *et al*., 2018).

Forest potential inventories can be used to determine the current potential standing stock. The inventory of forest potential is the most critical component of forest planning activities, as the data inventory results serve as the primary basis for forest utilization (Abdurachman, 2012). Volume tables are one of the methods used to implement a forest potential inventory. Volume tables are used to predict the volume of standing trees during the forest inventory process (Shrestha *et al*., 2018). Volume tables are created based on the stem volume's estimated value (Kang *et al*., 2014). According to Liu *et al.* (2019) volume estimation is a very important part of forest management. Estimation of stem volume is necessary for sustainable forest resource planning (Islam & Ullah, 2017). One of the main challenges in forest management is the ability to predict the stem volume of trees accurately and quickly (Soares *et al*., 2011). Stem volume is obtained from modeling in the form of a regression equation which states the relationship between volume and tree diameter and height (Kang *et al*., 2014; Shrestha *et al*., 2018). Modeling the volume equation of a tree can be accomplished using linear, exponential, logarithmic, quadratic, or cubic regression equations (Gonzalez-Benecke *et al*., 2014; Krisnawati, 2016; Islam & Ullah, 2017; Mbangilwa & Jiang, 2019). According to Özçelik & Göçeri (2015), among the various ways to predict tree volume, the modeling method with regression equations is the most accurate approach.

The linear regression equation modelling is the relationship between the volume components as the independent variable, while the diameter and height as the independent variable. Estimating tree volume using linear regression has provided more accurate results than nonlinear regression (Diamantopoulou *et al.,* 2018). Numerous previous researchers have also used this linear regression equation model, with varying results. Mbangilwa & Jiang (2019) stated that the optimal volume equation model is determined by the tree's species and the ecology in which it grows. The relationship between diameter and height and tree volume is always different for each tree species (Wahyudi, 2016). Gonzalez-Benecke *et al.* (2014) showed that the tree height component had a significant effect on volume, while Lee *et al.* (2017) explained that a combination model of diameter and height is the best model for predicting tree volume. On the other hand, Krisnawati (2016) confirmed that the best model is a logarithmic model. The results of regression equation modeling between tree components in the form of diameter, height, and volume were used to compile volume tables in a variety of countries, including Indonesia, Malaysia, China, Pakistan, and Turkey (Abdurachman, 2012; Kang *et al*., 2014; Shrestha *et al*., 2018; Kitikidou *et al*., 2017; Aman & Ismail, 2020). This study aims to determine the best equation model for compiling the volume table of pine in Tana Toraja Regency. The development of stem volume equations can support more effective forest management. The use of the volume table developed in this study will allow for a reduction in the time and cost of forest inventory, as well as the avoidance of damage to forest stands during the inventory's implementation, as destructive methods will be avoided.

MATERIALS AND METHODS

Data collection. Data collection was carried out on *Pinus merkusii* Jungh et de Vriese's stands using non-destructive sampling. The method of selecting samples was carried out using purposive sampling considering the distribution of tree diameters. The location for data collection was carried out in Mengkendek and Gandang Batu Sillanan District, Tana Toraja Regency, as shown in Fig. 1. This location was selected since it retains a fairly large pine forest with the same biophysical condition. The study location is between 3°7’-3°17’ south latitude and 113°-120° east longitude, altitude 974-980 masl, temperature 20°C-23°C, humidity 76-88%, and the number of precipitation 1500-3000 mm per year. The number of sample trees measured was 100. According to Leão *et al*. (2021), the minimum number of samples that can be used to construct volume allometric equations based on height and diameter is 29-39 trees samples. The dimensions of the trees measured included diameter at breast height level (dbh), diameter at the base of the section, diameter at the end of the section, length of the section, and tree height. The diameter and volume referred to in this study are the diameter and volume of wood, including bark (diameter and volume over bark). The diameter of the base and end of the section was measured using a maximum length of 5 m to the end diameter of 6 cm. The diameter and volume referred to in this study are the diameter and volume of wood, including bark (diameter and volume over bark).

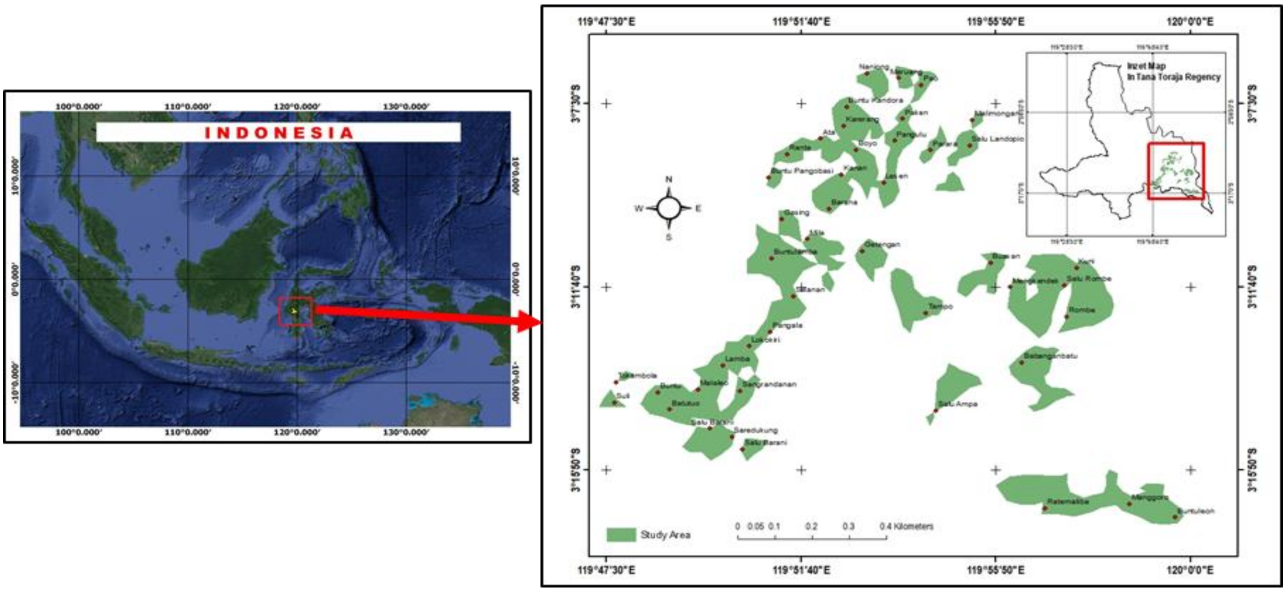

Fig. 1. Research location is in the districts of Mengkendek and Gandang Batu Sillanan, Tana Toraja Regency.

Data analysis. Data analysis was performed by calculating tree volume based on the measurement results of diameter, section length, and tree height. The volume of the tree is calculated using the Smalian equation using equation 1. Other researchers have previously used this equation to calculate tree volume in forestry, including Soares *et al.* (2011), Abdurachman (2012), de León & Valencia (2013), Wahyudi (2016), Fernández *et al.* (2017), García-Espinoza *et al*. (2018), Akpo *et al*. (2020), Aman & Ismail (2020), Coelho *et al.* (2021), and Islam *et al*. (2021).

$$V = \frac{L}{2} \times (B_{ti} + B_{bi}) \quad [1]$$

Note: V= stem volume; L= length of the section (m); B_{ti}= the basal area of the large end of the section (m^2) i^{th}; B_{bi}= the basal area of the small end of the section (m^2) i^{th}.

Further analysis for tree volume was carried out using a regression equation to determine the relationship between tree diameter and height and volume. The regression equation used in this study consisted of diameter at breast height level and total height as the independent variable and volume as the dependent variable. Other researchers have previously used this equation to model tree volume in forestry, including Xia *et al*. (2013), Mate *et al.* (2015), Moulinier *et al.* (2015), Krisnawati (2016), Islam & Ullah (2017), Lee *et al.* (2017), Shrestha *et al.* (2018), Cañadas-López *et al*. (2019), and Mbangilwa & Jiang (2019). The volume equation used is equation 2 to equation 9 as follows:

$$V = aD^b \quad [2]$$
$$V = a + bD^2 \quad [3]$$
$$V = aD + bD^2 \quad [4]$$
$$V = a + bD + cD^2 \quad [5]$$
$$V = aD^bH^c \quad [6]$$
$$V = aD^2H \quad [7]$$
$$V = a + bD^2H \quad [8]$$
$$V = a + bH + cD + dD^2 + eD^2H + fDH \quad [9]$$

Note: V= volume (m^3); D = diameter at breast height level (cm); H= height (m); a, b, c, d are parameters to be estimated in this study.

Validation is carried out to select the best equation model that can be used in compiling volume tables. Selection of the best model is carried out by calculating the value of the coefficient of determination (R^2), coefficient of determination adjust (R^2adj.), t-test, root means square error (RMSE), mean deviation (MD), and mean absolute deviation (MAD) (Xia *et al*., 2013; Gonzalez-Benecke *et al*., 2014; Lee *et al*., 2017; Cañadas-López *et al*., 2019; Hernández *et al*., 2019; Maltamo *et al*., 2019; Saarinen *et al*., 2019; Brūmelis *et al*., 2020; Marzulli *et al*., 2020; Socha *et al*., 2020). This value is calculated as follows, using equations 10 to 15:

$$R^2 = 1 - \left[\sum_{i=1}^{n}\left(V_i - \hat{V}_i\right)^2 / \sum_{i=1}^{n}\left(V_i - \overline{V}_i\right)^2\right] \quad [10]$$

$$R^2{}_{adj} = 1 - (1 - R^2)\left[\frac{n-1}{n-(k+1)}\right] \quad [11]$$

$$t = \frac{b_i}{SE_{bi}} \quad [12]$$

$$RMSE = \sqrt{\sum_{i=1}^{n}\left(V_i - \hat{V}_i\right)^2 / n} \quad [13]$$

$$MD = \sum_{i=1}^{n}\left(V_i - \hat{V}_i\right)/n \quad [14]$$

$$MAD = \sum_{i=1}^{n}\left|V_i - \hat{V}_i\right|/n \quad [15]$$

Note: Vi= measured volume for the i[th] tree; $\hat{V}_i$= predicted volume for the i[th] tree; $\overline{V}$= measured mean tree volume; n= the total number of trees; *k*= the number of independent variables in the regression equation; b = coefficient regression; SE = sampling error.

The volume estimate can be calculated using the best equation obtained and then presented in tabular form known as the volume table. Other researchers have used this method of compiling volume tables, including Abdurachman (2012), Aman & Ismail (2020), Kang *et al.* (2014), Shrestha *et al.* (2018), and Kitikidou *et al.* (2017).

RESULTS AND DISCUSSION

Table 1 summarizes the measurement findings for diameter, height, and volume that were derived using the Smalian equation (Equation 1).

Table 1. Descriptive statistic of tree samples.

	No. of trees	Mean	Minimum	Maximum	SD	Sampling Error
DBH (cm)	100	28.34	16.90	43.00	7.39	1.45
Height (m)	100	23.77	12.14	33.00	7.37	1.44
Volume (m^3)	100	1.44	0.22	3.83	0.96	0.19

According to Table 1, the mean, standard deviation, and sample error values for diameter are 28.34 cm, 7.39 cm, 1.45 cm, respectively, height 23.77 m, 7.37 m, and 1.44, respectively, volume 1.44 m^3, 0.96 m^3, and 0.19, respectively.

These findings suggest that using the Smalian equation to compute volume is quite accurate, as it yields a sampling error value of 0.19, which is lower than the results of Fernández *et al*. (2017). The larger the number of samples, according to de León & Valencia (2013), the more accurate the findings of measurements using the Smalian equation will be. The maximum number of errors utilizing the Smalian formula for n = 30 is 5%, and this error value will decrease as the number of samples investigated increases. The Smalian approach is one that is frequently used in studies to calculate tree volume (Coelho *et al*., 2021). García-Espinoza *et al*. (2018) used the Smalian approach to calculate the volume of trees used to construct the volume equation.

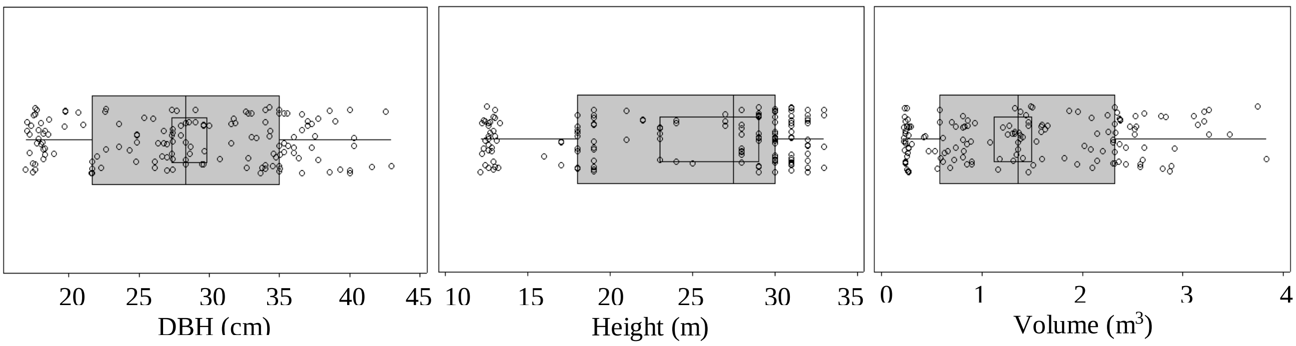

Fig. 2. Data distribution of diameter, height, and volume of samples.

As illustrated in Fig. 2, the distribution patterns of diameter, height, and volume all differ. The distribution of diameter and volume data is more evenly distributed across all sizes, but the distribution of height data is more concentrated on a certain number of measurement. The data from the measurements and calculations are then utilized to generate a regression equation model based on equations 2 to 9 and the results were represented in Table 2.

Table 2. Description of the regression model for estimating volume *Pinus merkusii* Jungh et de Vriese in the study area.

Equation	Parameters						F	Sig.
	a	b	c	d	e	f		
$V = aD^b$	3.66E-5	3.104					3516.804	0.000
$V = a + bD^2$	-0.492	0.002					3102.466	0.000
$V = aD + bD^2$	-0.037	0.003					5412.402	0.000
$V = a + bD + cD^2$	0.144	-0.048	0.003				1609.277	0.000
$V = aD^bH^c$	6,26E-5	1.982	1.020				108905.287	0.000
$V = aD^2H$	6.277E-5						1764417.860	0.000
$V = a + bD^2H$	-0.002	6.284E-5					543454.719	0.000
$V = a + bH + c + dD^2 + eD^2H + fDH$	0.130	-0.004	-0.011	0.001	5.619E-5	0.001	110045.459	0.000

In general, the equation model in Table 2 can be classified into two categories according to the independent variables. The first category includes equations in which diameter is the independent variable (V = f [DBH]) and equations in which diameter and height are both independent variables (V = f [DBH, Height]).

Table 3. Validation of regression equation model.

Equation	Fit Statistic			
	R^2_{adj}	RMSE	MD	MAD
$V = aD^b$	0.960	0.2245	-0.0016	0.1666
$V = a + bD^2$	0.954	0.3128	0.2130	0.2654
$V = aD + bD^2$	0.987	0.2226	-0.0878	0.1512
$V = aD + bD + cD^2$	0.987	0.2186	0.0800	0.1714
$V = aD^bH^c$	0.999	0.0396	-0.0320	0.0320
$V = aD^2H$	0.999	0.0008	0.0007	0.0007
$V = a + bD^2H$	0.999	0.0012	0.0011	0.0011
$V = a + bH + cD + dD^2 + eD^2H + fDH$	0.999	0.3557	-0.3532	0.3532

The results of the F value calculation in Table 2 indicate that there is a significant difference in the value between the first and second category equations. This demonstrates that adding a high component to the equation has an effect on the F value increase. The results of the study in Table 2 indicate that all models have a significant value less than 0.05 (P<0.05). As a result, all models are capable of predicting volume values. However, subsequent testing (t-test) reveal that there is a variable component in equation 9 that has no significant effect (P>0.05). The t-test findings in equation 9 indicate that the four independent variables have no significant effect (P> 0.05) and that only the independent variables have a significant effect (P<0.05). This equation 9 is invalid for estimating the volume of trees. Table 3 details the results of the calculation of these values.

Table 3 shows that the results of statistical test indicate the equations 7 and 8 are the most acceptable for use in this study. The smallest RMSE, MD, and MAD values demonstrate it. According to Lee *et al.* (2017) and Mate *et al.* (2015), the optimal model for estimating volume is equation 8. However, the t-test findings indicate that this equation's constant value has no significant influence (P>0.05), indicating that equation model 7 is the best. This is also demonstrated by the fact that equation 7 has the minimum RMSE, MD, and MAD values.

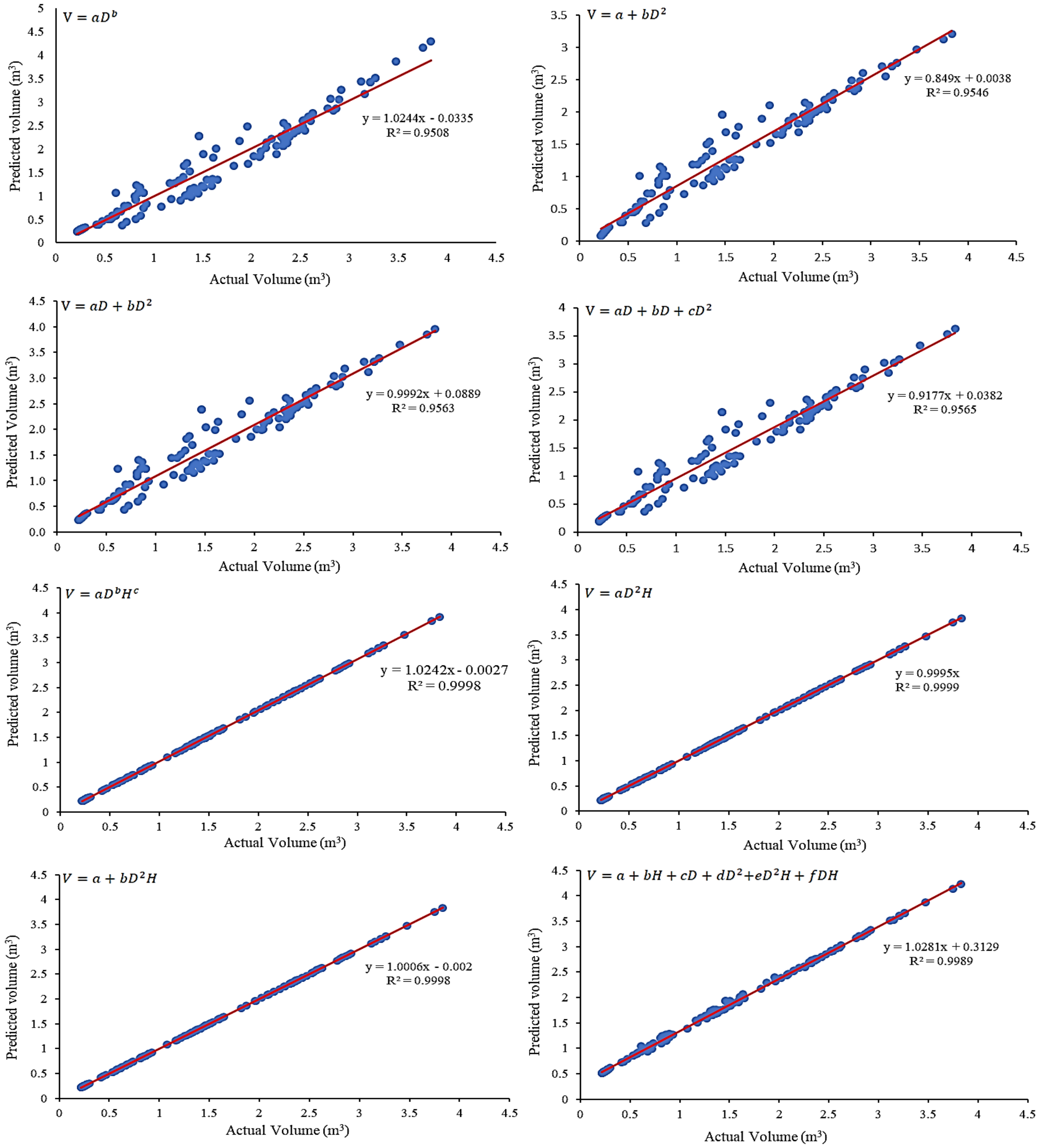

Fig. 3. Relationship between actual and predicted volume.

According to Maltamo *et al.* (2019) and Saarinen *et al.* (2019), the best model can be identified by its lowest RMSE. The findings of this study corroborate Islam & Ullah (2017) assertion that equation 7 is the optimal model for estimating volume based on tree diameter and height. The equations developed as a result of this research are expected to make a significant contribution to the development of tools for forest inventory implementation. Forest managers can use this equation to estimate the standing stocks of pine stand forest. This equation is valid in locations with similar environmental conditions to the research area, but not in areas with significantly different environmental conditions. Environmental factors were not included in the equation as a factor affecting tree growth in this study. Further research is required in a different location with a varied climate, soil type, and nutrient availability.

Table 4. Local volume table (m^3) of *Pinus merkusii* Jungh et de Vriese in research location.

Diam.	Height (m)													
(cm)	8	10	12	14	16	18	20	22	24	26	28	30	32	34
16	0.1286	0.1607	0.1928	0.2250	0.2571	0.2892	0.3214	0.3535	0.3857	0.4178	0.4499	0.4821	0.5142	0.5464
18	0.1627	0.2034	0.2440	0.2847	0.3254	0.3661	0.4067	0.4474	0.4881	0.5288	0.5694	0.6101	0.6508	0.6915
20	0.2009	0.2511	0.3013	0.3515	0.4017	0.4519	0.5022	0.5524	0.6026	0.6528	0.7030	0.7532	0.8035	0.8537
22	0.2430	0.3038	0.3646	0.4253	0.4861	0.5469	0.6076	0.6684	0.7291	0.7899	0.8507	0.9114	0.9722	1.0329
24	0.2892	0.3616	0.4339	0.5062	0.5785	0.6508	0.7231	0.7954	0.8677	0.9400	1.0124	1.0847	1.1570	1.2293
26	0.3395	0.4243	0.5092	0.5941	0.6789	0.7638	0.8487	0.9335	1.0184	1.1032	1.1881	1.2730	1.3578	1.4427
28	0.3937	0.4921	0.5905	0.6890	0.7874	0.8858	0.9842	1.0827	1.1811	1.2795	1.3779	1.4764	1.5748	1.6732
30	0.4519	0.5649	0.6779	0.7909	0.9039	1.0169	1.1299	1.2428	1.3558	1.4688	1.5818	1.6948	1.8078	1.9208
32	0.5142	0.6428	0.7713	0.8999	1.0284	1.1570	1.2855	1.4141	1.5426	1.6712	1.7997	1.9283	2.0568	2.1854
34	0.5805	0.7256	0.8707	1.0159	1.1610	1.3061	1.4512	1.5964	1.7415	1.8866	2.0317	2.1769	2.3220	2.4671
36	0.6508	0.8135	0.9762	1.1389	1.3016	1.4643	1.6270	1.7897	1.9524	2.1151	2.2778	2.4405	2.6032	2.7659
38	0.7251	0.9064	1.0877	1.2690	1.4502	1.6315	1.8128	1.9941	2.1754	2.3566	2.5379	2.7192	2.9005	3.0818
40	0.8035	1.0043	1.2052	1.4060	1.6069	1.8078	2.0086	2.2095	2.4104	2.6112	2.8121	3.0130	3.2138	3.4147
42	0.8858	1.1073	1.3287	1.5502	1.7716	1.9931	2.2145	2.4360	2.6574	2.8789	3.1003	3.3218	3.5432	3.7647
44	0.9722	1.2152	1.4583	1.7013	1.9444	2.1874	2.4305	2.6735	2.9165	3.1596	3.4026	3.6457	3.8887	4.1318
46	1.0626	1.3282	1.5939	1.8595	2.1251	2.3908	2.6564	2.9221	3.1877	3.4534	3.7190	3.9846	4.2503	4.5159
48	1.1570	1.4462	1.7355	2.0247	2.3140	2.6032	2.8924	3.1817	3.4709	3.7602	4.0494	4.3387	4.6279	4.9172
50	1.2554	1.5693	1.8831	2.1970	2.5108	2.8247	3.1385	3.4524	3.7662	4.0801	4.3939	4.7078	5.0216	5.3355

According to Shrestha *et al.* (2018), the best model can also be determined by the relationship between the predicted and actual volume of trees, as illustrated in Fig. 3. The higher the R^2 value, which represents the relationship between the independent and dependent variables, the better, i.e. the larger the R^2 value, the better the outcome. The results of the analysis shown in Fig. 3 indicate that equations 6, 7, and 8 produce the best results. Additionally, Fig. 3 demonstrates that equation 7 has the highest R^2 value. The trend line indicates that equation 6 has an R^2 value of 0.9999, and equation 8 has an R^2 value of 0.9998. However, in the prior analysis, equation 6 outperforms equations 8. Additionally, Fig. 3 demonstrates that only equation 6 has a direct relationship with actual volume, as it lacks a constant value. The findings of this investigation indicate that equation 7 is an excellent choice for compiling volume tables. Table 4 details the local volume table derived from equation 7. It will be useful data to prepare a forest management plan based on potential standing stock. The findings of this study can be used to describe the structure, composition, and volume of pine forests, which will aid foresters in gathering accurate data.

CONCLUSION

The mean, standard deviation, and sampling error values of diameter were 28.34 cm, 7.39 cm, and 1.45, respectively, height 23.77 m, 7.37 m, and 1.44, respectively, and volume 1.44 m^3, 0.96 m^3, 0.19, respectively. The best equation model for calculating volume based on height and diameter was $V = aD^2H$, as determined via regression equation modeling. These findings are the outcome of model validation using statistical testing. This equation can be used as a basis in compiling the local volume table for Pine.

ACKNOWLEDGEMENTS

The authors thank to the Tana Toraja Regency Government and the Dean of the College of Vocational Studies IPB University for their support in implementing this research.

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