Mathematical Models and Tables for Estimating Total Volume of *Lagerstroemia speciosa* (L.) Pers. Grown in Bangladesh

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Abstract

Jarul (*Lagerstroemia speciosa* L. Pers., Family- Lythraceae) is a semi-deciduous medium to large-sized tree with fluted bole, small buttress and slightly flaky bark tropical flowering tree species. It is a common ornamental tree planted along roadsides, gardens and parks in Bangladesh. The main aim of this study is to develop mathematical models for total volume estimation of jarul. To meet the quest we have tested 21 models for volume equation by regression technique. The best-fitted model for studied species have been selected by highest value of R^2 (coefficients of determination), the lowest value of Akaike Information Criterion (AIC) and Root Mean Square Error (RMSE). The selected models also validated by Chi-square test of goodness of fit, Paired t-test, Percent Absolute Deviation (*%AD*) and 45 degree line test. The study appearance that, for one way analyses the model $\ln(V) = a+b\ln(D)$ and for two way analyses $\ln(V)= a+b\ln(D)+c\ln(H)$ appeared to the best model for estimating the standing tree volume of jarul. Conversion factors equation has been determined to estimate under bark volume and under bark volume of different top end girth of 30, 35, 40 and 45 centimeters from these models. The best-fit volume model showed the highest efficiency in volume estimation compared to previous developed volume model of this species in terms of Model Prediction Error (MPE), Model Efficiency (ME) and Root Mean Square Error (RMSE).

mvims‡¶c

জারুল একটি পাতা-ঝরা ছোট থেকে মাঝারি আকারের গাছ যা খাঁজকাটা গুঁড়ি, ছোট ঠেকনা এবং কিছুটা স্তরপূর্ণ ছালযুক্ত গ্রীষ্মমন্ডলীয় ফুল প্রাজাতির গাছ। এটি বাংলাদেশের রাস্তাঘাট, উদ্যান এবং পার্কের পাশে লাগানো একটি সাধারণ শোভাময় বৃক্ষ। এই গবেষণার মূল লক্ষ্য হচ্ছে জারুল গাছের মোট আয়তন নির্ণয়ের গাণিতিক মডেল উন্নয়ন করা। এই গবেষণা কার্য্যটি পরিচালনার জন্য আমরা রিগ্রেশন কৌশল দ্বারা আয়তন নির্ণয়ের ২১ টি মডেল পরীক্ষা করেছি। রিগ্রেশন কৌশলে প্রাপ্ত সর্বোচ্চ R2 (coefficients of determination) মান, সর্বনিম্ন AIC (Akaike Information Criterion) এবং RMSE (Root Mean Square Error) দ্বারা সেরা-যথাযথ মডেল নির্বাচন করা হয়েছে। নির্বাাচিত মডেল গুলি কাই-বর্গ, জোড়া টি-টেস্ট, Percent Absolute Deviation (%AD) এবং ৪৫ ডিগ্রি লাইন পরীক্ষা দ্বারা বৈধতা পরীক্ষা করা হয়েছে। উক্ত গবেষণায় দাঁড়ানো জারুল গাছের একমূখী আয়তন নির্ণয়ে $\ln(V) = a+b\ln(D)$ এবং দ্বিমূখী আয়তন নির্ণয়ে $\ln(V)= a+b\ln(D)+c\ln(H)$ মডেলদ্বয় সেরা মডেল নির্বাচিত হয়েছে। জারুল গাছের বাকলসহ মোট আয়তন হতে বাকল ছাড়া গাছের আয়তন, গাছের ৩০, ৩৫, ৪০ এবং ৪৫ সে.মি. শীর্ষ প্রান্ত পর্যন্ত আয়তন নির্ণয়ের রুপান্তর গুণক নির্ণয়ের সমীকরণও নির্ণয় করা হয়েছে। সেরা ফিট আয়তন নির্ণয়ের মডেলটি মডেল পূর্বাভাস ত্রুটি (MPE), মডেল দক্ষতা

(ME) এবং রুট মিন স্কয়ার ত্রুটি (RMSE) বিবেচনায় পূর্ববর্তী উন্নয়নকৃত মডেলের তুলনায় আয়তন অনুমানের সর্বোচ্চ দক্ষতা দেখিয়েছে।

Keywords: *Lagerstroemia speciosa*, Total Volume, Volume Model, Volume table

Introduction

Jarul is a semi-deciduous medium to large-sized tree with fluted bole, small buttress and slightly flaky bark tropical flowering tree species found in the *Lagerstroemia* species of the Lythraceae family. This tropical flowering tree is one of the most outstanding summer bloomers, which reflect its attractive and colourful flowers. It is called Queen Crape Myrtle because it is the Queen of the Crape Myrtles dominating with larger crinkled flowers. It is also known as Pyinma (Burmese), Pride of India, Banaba (Filipino), Sebokok (Malay), Murutu (Sinhala), Pumarathu (Tamil), Bang-lang nuoc (Vietnamese) (Rahman *et al*. 2011). It is a medium sized to large deciduous tree with a rounded crown distributed throughout Bangladesh (Ghani 1998). *Lagerstroemia speciosa* (L.) Pers is a fast-growing much branched semi deciduous tree generally used boat building, making doors, windows, house posts and different parts for medicine. It is also recognized as an important species for fuel wood, shade tree, ornamental road side avenue tree and in gardens, parks, throughout the country. It is distributed to India, Srilanka, Myanmar, Philippines, Malaysia, China, Vietnam and tropical Australia (Kirtikar 1987). Drigo *et al*. (1988) developed a local two way volume model for *L. speciosa* during inventory of forest resources of southern Sylhet forest division. They developed only two-way volume model by using a total of 74 standing sample trees of *L. speciosa* locally. They were recommended further volume model develop with covered the wide area and wide diameter range. However, volume models for *L. speciosa* are lacking in existing literature while this species is well distributed in Bangladesh (Das and Alam 2001) and neighboring countries (Kirtikar 1987). Considering its economic importance, proper management of this species is necessary. Volume equations play a crucial role in forest management. The importance of volume equations is indicated by the existence of numerous such equations and the constant search for their improvement. For more than a century, researchers have been trying to estimate the volume of different trees over the time. Now days quite a number of volume equations have been used to estimate tree and stand volume, and have played a significant role in forest inventories and management. Studies of tree volume began in the early nineteenth century. A multitude of equations have been published in forest literature (Spurr 1952, Clutter *et al*. 1983, Avery and Burkhart 2002, Abel 2014, Latif and Islam 2014). Because of inherent morphological differences among tree species, it is generally necessary to develop separate standard volume equations for each species or closely related species group (Burkhart and Gregoire 1994). These are simple methods and tools that can be used to obtain individual tree volume and the volumes of entire stands. Such information is vital for forest management. Sustainable forest management requires among others knowledge on the total volume of the growing forest stock. Usually volume is estimated as total volume per unit area, whereby models predicting total tree volume of individual trees are used. The objective of any volume equation is to provide accurate estimates with acceptable levels of local bias over the entire diameter range in the data. Equations that provide accurate predictions of volume without local bias over the entire range of diameter are one of the basic building blocks of a forest growth and yield simulation system (Bi and Hamilton 1998).

Development of sound management practice is one of the major priorities of the forestry sector. The biomass of a tree can be determined by multiplying the volume of the tree by the biomass conversion factor. Hence volume equation provide to the tree biomass and carbon estimation in non-destructive way.

Tree volumes were calculated using formulae such as Huber's, Newton's and Smallian's. The resulting functions mostly predicted volume from a single parameter such as total tree height or diameter/girth at breast height (DBH/GBH), or from a combination of both variables. Normally, a form factor was also included in the equations to account for the variability in tree form (Hush *et al*. 1982; Laasasenaho 1982).

Volume equations have been developed more than forty two different important tree species in Bangladesh (Latif and Islam 2014; Islam *et al*. 2014; Hossain *et al*. 2016). A considerable amount of work on volume has been done by researcher of Bangladesh Forest Research Institute (BFRI). Volume equations and tables of jarul are needed to estimate the quantity of harvest which is necessary for sustainable forest management system, carbon assessment and economic analysis. However, accurate volume equations of this species are not available. This study, therefore, aims to derive volume prediction equations and tables for *L. speciosa* for yield estimation. The results of the study could serve as input information that is necessary in the operation of subsequent forest regulations such as economic rotation, cut allocation and scheduling, and forest development schedules. Generally, such information could facilitate the effective and sound management in the business projection for *L. speciosa* (Islam *et al*. 2014; Hossain *et al*. 2016).

Materials and Methods

Description of the Study area

The study has been conducted in the remnant the natural forest and existence plantation Moulavi Bazar and Kaptai range under Sylhet South and Rangamati South Forest Division, Bangladesh. The study area contains tropical evergreen and semi-evergreen tree species with natural and plantation stands. The study area Lawachara in Moulavi Bazar range geographically, lies between 24°30'–24°32' N and 91°37'–91°47' E. The soil texture of this area is yellowish brown to reddish brown in colour, loam to clay loam and sandy clay loam of Pliocene origin (Hossain *et al*. 2019). Soil is acidic, organic matter and fertility levels are generally low. The moist tropical climate of this study area is generally warm and humid, turning cool in the winter. Moderately cool and lovely, and dry conditions exist from mid-November to the end of February while June to September is the time of the highest precipitation. Average maximum and minimum temperatures are 35 °C and 15 °C, respectively (Khatun *et al.* 2016). The average annual rainfall is 3800 mm, and humidity ranges from 70% to 85% in most parts of the year (Khatun *et al.* 2016). The study area Kaptai range under Rangamati South Forest Division approximately at the intersection 92°13' E and 22°32' N. The soil of this area is mainly yellowish-brown to reddish-brown loams which grade into broken shale or sandstone at a variable depth. The valley soil is mainly acid loams and clays subject to seasonal flooding (Hossain *et al*. 2014). Soil is acidic and organic matter content of the topsoil varies from 0.15 to 3.32%. While, total nitrogen concentration varies from 0.03 to 0.24% (Hossain *et al*. 2014). The average temperature of the study area ranges from 19.9 °C to 28.3 °C, while the average annual rain fall is about 2900 mm and average annual relative humidity is about 78 %. The climate of this region is characterized by mainly three distinct seasons: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October, and a cool, dry winter from October to March (Khatun *et al*. 2016).

Sampling of trees

A sufficient numbers of sample tree were selected on the basis of girth at breast height (GBH) classes and height classes at random. All sample trees were selected to avoid specimens with broken top, hollow trunk, damage caused by natural calamities or animals, and evidence of suppression or disease. We collected 316 individuals (Table 1) in different GBH class to derive the mathematical volume models and tables of jarul. Sample trees were selected purposively and covered existence wide GBH range and height range. Another 30 sample trees at all girth classes were recollected for model validation.

Measurement of trees

Standing sampled jarul trees in representing different girth classes were selected at random for preparation of mathematical volume functions and tables. Trees girth at breast height in cm and total height in meter were measured with diameter tape and Haga-altimeter respectively and the nondestructive method was used to estimate the volume. The girth and bark thickness at one meter intervals in the stem and branches girth were measured by climbing the trees with a ladder. The bark thicknesses of the samples were measured with a bark gauge. To calculate branch volume for bigger branches whose mid-girth ≥30 cm in particular length also taken and smaller branches not taken. The collected fitting data set were categorized on the basis of GBH and height of the trees. The GBH -height class distribution of the sample trees are given in Table 1.

Table 1: Stand table of collected volume table data of *L. speciosa*

Girth class (cm)	**No. of sample trees under different Height Class (m)**						
	<9	9.1 -14	14.1 -18	18.1 -22	22.1 -26	>26	Total
<35	8	1					9
35.1 -45	8	4					12
45.1 -55	4	14	1				19
55.1 -65	2	19	3				24
65.1 -75	2	15	18				35
75.1 -85		5	26	5			36
85.1 -95		6	29	8			43
95.1 -105		1	22	12	6		41
105.1 -115		1	13	8	9		31
115.1 -125			5	18	6		29
125.1 -135		1	3	6	6		16
>135			2	7	10	2	21
Total	24	67	122	64	37	2	316

Compilation of data

Volumes of all sections except top and bottom section were determined by using the mean cross-sectional areas of the two ends of each section following Smalian's formula cubic volume = [(*B*+*b*)/2]L, where *B*= the cross-sectional area at the large end of the log, *b*= the cross-sectional area at the small end of the log, and *L*= log length. In determining the volume of bottom sections, the formulae used for calculating the volume of a cylinder was considered. Assuming the top section as cone the volume was computed to one third of the cylindrical volume of the portion. We considered the top end diameter measurement for each tree as the base diameter of the cone. In computing the under bark volume of the tree the volume of top section i.e. cone was ignored. The total volume of the tree is the sum of the volume of all sections and branches volume found in a tree. The individual tree total volumes (V), GBH (G) and total height (H) were variable in regression techniques using various functions and transformations as required in the models.

Computation of volume function

Multiple regression analysis techniques were used to select the best suited model equations. The following 21 models (Clutter *et al.* 1983; Bi Hamilton 1998; Latif and Islam 2014 and Islam *et al.* 2017) were tested to select the equation of best fit with different variables are given in Table 2.

Table 2: Frequently used volume models

Model No.	Models
1	$V = a + bG$
2	$V = a + bG + cG^2$
3	$V = a + bG^2$
4	$V = aG + bG^2$
5	$V = aG + bG^{-1}$
6	$V = aG + bG^{-2}$
7	$\log(V) = a + bG$
8	$V = a + b\log(G)$
9	$\log(V) = a + b\log(G)$
10	$V = a + bG^2H$
11	$V = a + bG + cH$
12	$V = a + bG + cG^2H$
13	$V = a + bG + cGH$
14	$V = a + bG + cH + dGH$
15	$V = a + bG + cH + dG^2H$
16	$V = a + bG^2 + cH + dGH$
17	$V = a + bG^2 + cH + dG^2H$
18	$V = a + bG^2 + cGH + dG^2H$
19	$V = a + b\log(G) + c\log(H)$
20	$\log(V) = a + b\log(G) + c\log(H)$
21	$V = a + bG^{-1} + cH^{-1}$

Where: V = total volume over bark in cubic meters, G = girth at breast height in centimeters, H = is total height in meters, a is the regression constant and b, c and d are regression coefficients. The logarithmic functions are to the base e.

Following original and transformed variables were used to select the best suited regression models: Dependent variables: *V, Log (V),*

Independent variables: *G, G2, G-1, G-2, H, H-1, GH, G2H, Log (G), Log(H)*

The dependent variables mentioned above were regressed with the independent variables.

The equations of the best fit based on the highest multiple coefficients of determination; F-ratio and lowest residual mean square and AIC value statistic were chosen. Models for estimation of the total volume over bark were selected and the conversion factors to estimate under bark volume and volume to top end girths of approximately 30, 35, 40 and 45 cm were also estimated.

Model validation

The best suited models were tested with a set of data recollected from 30 trees of different diameter class and compiled in the same procedure as earlier. The actual volumes of these trees were collectively compared with the corresponding volume predicted by the selected models. The independent tests for validation were chi-square test of goodness of fit, paired t-test and Percent absolute deviation (*%AD*). This was also compared with 45 degree line test by plotting the observed values and the predicated value in the graph.

Model comparison

Best-fit volume model was compared with the previous developed local volume model of *L.speciosa* by Drigo *et al*. (1988) (Equation 1) in terms of Model Prediction Error (MPE), Model Efficiency (ME), and Root Mean Square Error (RMSE) (Mayer and Butler, 1993). This comparison was conducted with data set which recollected for validation.

The volume model developed by Drigo *et al*. (1988) and comparison tools are given in the equations:

$$\ln(V) = -9.6744 + 2.1065 \times \ln(D) + 0.6675 \times \ln(H) \qquad (1)$$

$$MPE(\%) = \frac{100}{n} \times \sum \left[\frac{(Y_p - Y_0}{Y_0}\right] \qquad (2)$$

$$ME = 1 - \left[\frac{\sum(Y_0 - Y_p)^2}{\sum(Y_0 - \bar{Y})^2}\right] \qquad (3)$$

$$MSE(\%) = 100 \times \sqrt{\frac{1}{n}\sum(Y_p - Y_0)^2} \qquad (4)$$

Where V = Total volume over bark in cubic meter, D = Diameter at breast height in cm, H = Total height in meter, n = Number of trees, Yp = Predicted volume from the model, Yo = Observed volume in field measurement, and $\bar{Y}$ = Mean of the observed volume. Regression between predicted volume (Yp) (in the X-axis) and observed volume (Yo) (in the Y-axis) were also derived for the best-fit volume model, and developed model by Drigo *et al*. (1988) (Equation 1).

Significance of slope (b = 1) and intercept (a = 1) were tested (Pin˜eiro *et al*. 2008) to understand the overestimation or underestimation of each predicted volume value from observed value by using 1:1 line (Sileshi 2014).

Data Analysis

Data collected were organized and screened (removing the outliers) for analysis. Descriptive statistical analysis was further carried out in order to summarize the data. All analysis carried out were conducted using MS Excel 2013, SPSS 17 Inc and EViews (Quantitative Micro Software, LLC) statistical package version 9.

Results

Dependent and independent variables

Total volume over bark have been calculated from total of 316 sample trees of jarul, in this study. Descriptive statistics of dependent and independent variables represent in Table 3.

Table 3: Descriptive statistics for sample trees for volume-girth and height relationships

Variables	No. of Sample	Mean	Minimum	Maximum	Standard Error	Standard Deviation	Confidence Level (95.0%)
GBH (cm)	316	90.3	30.0	178.0	1.7	29.6	3.3
Height (m)	316	16.4	6.5	27.0	0.3	4.5	0.5
Volume (m^3)	316	0.6	0.0	2.6	0.0	0.4	0.0

Volume equations

We have selected volume equations for estimation of total volume over-bark for *L.speciosa*. The regression models number 9 and 20 are best suited for one way and two way volume equations respectively to estimate total volume over bark. The selected volume equations are given in Table 4.

Table 4: Selected best suitable volume equations of *L. speciosa*

Selected models	Fit statistics			
	R^2	*RMSE*	*AIC*	*N*
$\ln(V_{ob}) = -12.0813 + 2.5114 \times \ln(G)$	0.96	0.19	-0.49	316
$\ln(V_{ob}) = -11.6519 + 1.87239 \times \ln(G) + 0.87445 \times \ln(H)$	0.98	0.14	-1.10	316

Where, G is girth at breast height in cm, H is total height in m, V_{ob} is total volume over bark in m^3, and ln is natural logarithm (logarithm on base e).

Most of the times end users and forest managers need the volume under-bark and the volume at different top end girth along the stem. So, this study is also developed mathematical models and tables for predicting conversion factors to estimate under-bark volume and volume at different proportion of stem from over-bark volume for *L. speciosa*. The conversion factors equations to estimate under-bark volume and volume to different top end girths of approximately 30, 35, 40 and 45 cm from stem volume over bark have been determined and selected conversion factor equations are given in Table 5.

Table 5: Selected best suitable conversion factor equations of *L. speciosa*

Selected models	Fit statistics			
	R^2	*RMSE*	*AIC*	*N*
$F_{ub} = G/(3.0086 + 0.99167 \times G + 0.0000932 \times G^2)$	0.78	0.01	-7.23	316
$F_{30} = G/(24.6933 + 0.69134 \times G + 0.00113 \times G^2)$	0.92	0.02	-4.89	316
$F_{35} = G/(64.2948 + 0.23157 \times G + 0.00282 \times G^2)$	0.97	0.22	-4.82	316
$F_{40} = G/(78.3896 + 0.13294 \times G + 0.003268 \times G^2)$	0.93	0.03	-3.98	312
$F_{45} = G/(113.5499 - 0.2076 \times G + 0.004779 \times G^2)$	0.89	0.04	-3.53	308

Where, F_{ub}, F_{30}, F_{35}, F_{40} and F_{45} are conversion factor to estimate total under bark volume, volumes upto 30 cm top end girth, 35 cm top end girth, 40 cm top end girth and 45 cm top end girth respectively from total volume over bark volume.

Model validation

The statistical requirement to best fitted models by considering those equations having the highest R^2 with lowest RMSE, Akaike Information Criterion (*AIC*) were tested. Results were presented in Table 4 and 5.

Independent test

The best suited volume equations for one way and two way were tested with a set of data recollected from 30 trees of different girth class and complied in the same procedure as earlier. The actual volumes of these trees were collectively compared with the corresponding volume predicted by the selected models. The independent tests for validation were the chi-square test, paired t-test, absolute deviation percent (%AD) and 45 degree line test (Islam *et al*. 1992 and Latif and Islam, 2001).

The computed chi-square, t-values, absolute deviation percent and slope (45-dergee line test) of studied tree species are given Table 6.

Table 6: Result of independent test for predicted volume equations of *L. speciosa*

Model Types	***Chi***	***t***	***%AD***	***Slope^o***
One way	0.35	1.02	3.0	44.1
Two way	0.14	1.71	3.4	44.0

Model comparison

The total volume best-fit model showed lowest (−1.603%) MPE and RMSE (6.42%) and highest ME (0.986 close to the reference value 1) compared to the local volume models of Drigo *et al*. (1988) (Table 7). The graphical presentation from 1:1 line indicated that the best-fit volume model was capable to estimate the total volume more accurately. While locally used Drigo *et al*. (1988) model underestimated the total volume for *L. speciosa* compared to the derived best-fit total volume model in this study (Fig. 1).

Table 7: Comparison of best-fit total volume model with the Drigo *et al*. (1988) model

Source	Type	MPE (%)	ME	MSE (%)
Best Fit Model	Nationally (This study)	-1.603	0.986	6.422
Drigo *et al.* (1988)	Locally in Southern Sylhet	1.602	0.979	7.773

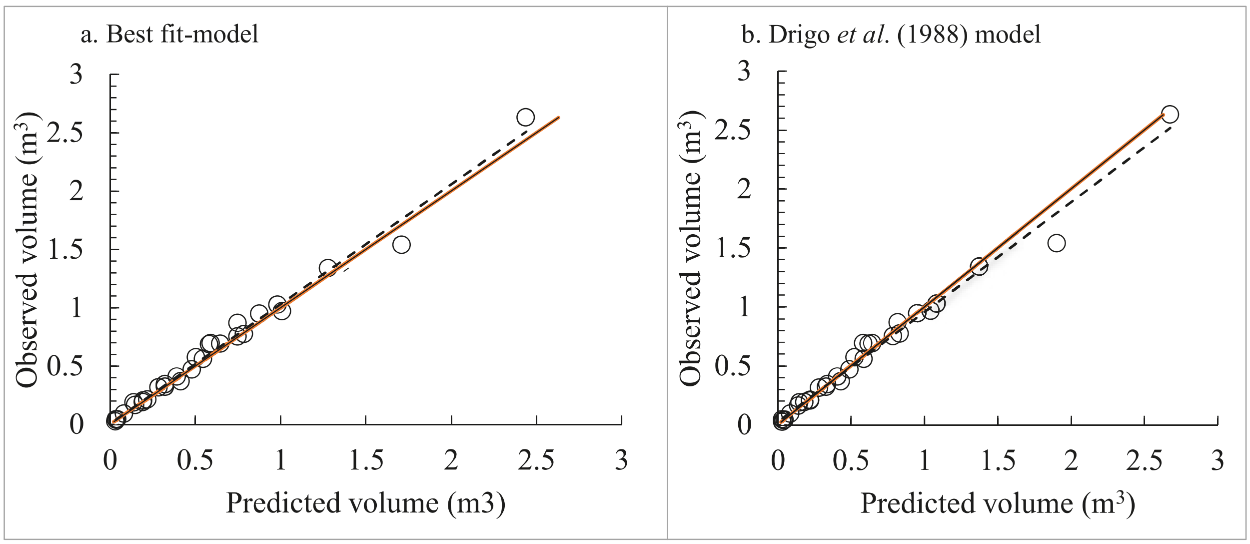

Figure 1: Comparison of best-fit total volume model with Drigo *et al*. (1988) volume model

We have estimated volumes and conversion factors for ready use and are presented in Table 8 and 9. The volume equations and tables are applicable for jarul growing in the different forest areas of Bangladesh.

Table 8: One and Two way volume table for *L. speciosa* grown in Bangladesh

GBH (cm)	One Way	Two-way											
		Height in meter											
		6	8	10	12	14	16	18	20	22	24	26	28
30	0.029	0.024	0.031	0.038	0.045	0.051	0.057	0.064	0.070	0.076	0.082	0.088	0.094
32	0.034	0.027	0.035	0.043	0.050	0.058	0.065	0.072	0.079	0.085	0.092	0.099	0.106
34	0.040	0.031	0.040	0.048	0.056	0.064	0.072	0.080	0.088	0.096	0.103	0.111	0.118
36	0.046	0.034	0.044	0.053	0.063	0.072	0.081	0.089	0.098	0.107	0.115	0.123	0.132
38	0.053	0.038	0.049	0.059	0.069	0.079	0.089	0.099	0.108	0.118	0.127	0.136	0.146
40	0.060	0.042	0.054	0.065	0.076	0.087	0.098	0.109	0.119	0.130	0.140	0.150	0.160
42	0.068	0.046	0.059	0.071	0.084	0.096	0.108	0.119	0.131	0.142	0.153	0.165	0.176
44	0.076	0.050	0.064	0.078	0.091	0.104	0.117	0.130	0.143	0.155	0.167	0.180	0.192
46	0.085	0.054	0.070	0.085	0.099	0.114	0.128	0.141	0.155	0.169	0.182	0.195	0.208
48	0.094	0.059	0.075	0.092	0.107	0.123	0.138	0.153	0.168	0.183	0.197	0.211	0.225

GBH (cm)	One Way	Two-way											
		Height in meter											
		6	8	10	12	14	16	18	20	22	24	26	28
50	0.105	0.063	0.081	0.099	0.116	0.133	0.149	0.165	0.181	0.197	0.213	0.228	0.243
52	0.116	0.068	0.088	0.106	0.125	0.143	0.161	0.178	0.195	0.212	0.229	0.245	0.262
54	0.127	0.073	0.094	0.114	0.134	0.153	0.172	0.191	0.209	0.228	0.246	0.263	0.281
56	0.139	0.078	0.101	0.122	0.143	0.164	0.184	0.204	0.224	0.244	0.263	0.282	0.301
58	0.152	0.084	0.107	0.131	0.153	0.175	0.197	0.218	0.239	0.260	0.281	0.301	0.321
60	0.166	0.089	0.114	0.139	0.163	0.187	0.210	0.233	0.255	0.277	0.299	0.321	0.342
62	0.180	0.095	0.122	0.148	0.174	0.199	0.223	0.247	0.271	0.295	0.318	0.341	0.364
64	0.195	0.100	0.129	0.157	0.184	0.211	0.237	0.263	0.288	0.313	0.338	0.362	0.386
66	0.210	0.106	0.137	0.166	0.195	0.223	0.251	0.278	0.305	0.331	0.358	0.384	0.409
68	0.227	0.113	0.145	0.176	0.206	0.236	0.265	0.294	0.322	0.351	0.378	0.406	0.433
70	0.244	0.119	0.153	0.186	0.218	0.249	0.280	0.310	0.340	0.370	0.399	0.428	0.457
72	0.262	0.125	0.161	0.196	0.230	0.263	0.295	0.327	0.359	0.390	0.421	0.451	0.482
74	0.280	0.132	0.170	0.206	0.242	0.277	0.311	0.345	0.378	0.411	0.443	0.475	0.507
76	0.300	0.139	0.178	0.217	0.254	0.291	0.327	0.362	0.397	0.432	0.466	0.500	0.533
78	0.320	0.145	0.187	0.227	0.267	0.305	0.343	0.380	0.417	0.453	0.489	0.524	0.560
80	0.341	0.153	0.196	0.238	0.280	0.320	0.360	0.399	0.437	0.475	0.513	0.550	0.587
82	0.363	0.160	0.205	0.250	0.293	0.335	0.377	0.418	0.458	0.498	0.537	0.576	0.614
84	0.385	0.167	0.215	0.261	0.306	0.351	0.394	0.437	0.479	0.521	0.562	0.603	0.643
86	0.409	0.175	0.225	0.273	0.320	0.366	0.412	0.457	0.501	0.544	0.587	0.630	0.672
88	0.433	0.182	0.235	0.285	0.334	0.383	0.430	0.477	0.523	0.568	0.613	0.657	0.701
90	0.458	0.190	0.245	0.297	0.349	0.399	0.448	0.497	0.545	0.592	0.639	0.686	0.731
92	0.484	0.198	0.255	0.310	0.363	0.416	0.467	0.518	0.568	0.617	0.666	0.714	0.762
94	0.511	0.206	0.265	0.323	0.378	0.433	0.486	0.539	0.591	0.643	0.693	0.744	0.794
96	0.539	0.215	0.276	0.335	0.393	0.450	0.506	0.561	0.615	0.669	0.721	0.774	0.825
98	0.567	0.223	0.287	0.349	0.409	0.468	0.526	0.583	0.639	0.695	0.750	0.804	0.858
100	0.597	0.232	0.298	0.362	0.425	0.486	0.546	0.605	0.664	0.722	0.779	0.835	0.891
102	0.627	0.240	0.309	0.376	0.441	0.504	0.567	0.628	0.689	0.749	0.808	0.867	0.925
104	0.659	0.249	0.321	0.390	0.457	0.523	0.588	0.652	0.714	0.777	0.838	0.899	0.959
106	0.691	0.258	0.332	0.404	0.474	0.542	0.609	0.675	0.740	0.805	0.868	0.931	0.994
108	0.724	0.268	0.344	0.418	0.491	0.561	0.631	0.699	0.767	0.833	0.899	0.965	1.029
110	0.758	0.277	0.356	0.433	0.508	0.581	0.653	0.724	0.794	0.863	0.931	0.998	1.065
112	0.794	0.286	0.368	0.448	0.525	0.601	0.675	0.749	0.821	0.892	0.963	1.033	1.102
114	0.830	0.296	0.381	0.463	0.543	0.621	0.698	0.774	0.849	0.922	0.995	1.067	1.139
116	0.867	0.306	0.393	0.478	0.561	0.642	0.721	0.799	0.877	0.953	1.028	1.103	1.176
118	0.905	0.316	0.406	0.494	0.579	0.663	0.745	0.825	0.905	0.984	1.062	1.139	1.215
120	0.944	0.326	0.419	0.509	0.598	0.684	0.768	0.852	0.934	1.015	1.095	1.175	1.254
122	0.984	0.336	0.432	0.525	0.616	0.705	0.793	0.879	0.963	1.047	1.130	1.212	1.293
124	1.025	0.347	0.446	0.542	0.635	0.727	0.817	0.906	0.993	1.080	1.165	1.249	1.333
126	1.067	0.357	0.459	0.558	0.655	0.749	0.842	0.933	1.023	1.112	1.200	1.287	1.373
128	1.110	0.368	0.473	0.575	0.674	0.772	0.867	0.961	1.054	1.146	1.236	1.326	1.415
130	1.154	0.379	0.487	0.592	0.694	0.794	0.893	0.990	1.085	1.179	1.273	1.365	1.456
132	1.199	0.390	0.501	0.609	0.714	0.817	0.919	1.018	1.117	1.214	1.310	1.404	1.498

GBH (cm)	One Way	Two-way											
		Height in meter											
		6	8	10	12	14	16	18	20	22	24	26	28
134	1.245	0.401	0.515	0.626	0.735	0.841	0.945	1.047	1.148	1.248	1.347	1.445	1.541
136	1.292	0.412	0.530	0.644	0.755	0.864	0.971	1.077	1.181	1.283	1.385	1.485	1.585
138	1.340	0.423	0.545	0.662	0.776	0.888	0.998	1.107	1.213	1.319	1.423	1.526	1.629
140	1.390	0.435	0.559	0.680	0.797	0.913	1.026	1.137	1.247	1.355	1.462	1.568	1.673
142	1.440	0.447	0.574	0.698	0.819	0.937	1.053	1.167	1.280	1.391	1.501	1.610	1.718
144	1.492	0.459	0.590	0.717	0.841	0.962	1.081	1.198	1.314	1.428	1.541	1.653	1.764
146	1.544	0.471	0.605	0.736	0.863	0.987	1.109	1.230	1.348	1.466	1.582	1.696	1.810
148	1.598	0.483	0.621	0.755	0.885	1.013	1.138	1.262	1.383	1.503	1.622	1.740	1.856
150	1.653	0.495	0.637	0.774	0.907	1.038	1.167	1.294	1.418	1.542	1.664	1.784	1.904
152	1.709	0.507	0.653	0.793	0.930	1.064	1.196	1.326	1.454	1.580	1.705	1.829	1.952
154	1.766	0.520	0.669	0.813	0.953	1.091	1.226	1.359	1.490	1.620	1.748	1.874	2.000
156	1.824	0.533	0.685	0.833	0.977	1.118	1.256	1.392	1.527	1.659	1.790	1.920	2.049
158	1.883	0.546	0.702	0.853	1.000	1.145	1.286	1.426	1.563	1.699	1.834	1.967	2.098
160	1.944	0.559	0.718	0.873	1.024	1.172	1.317	1.460	1.601	1.740	1.877	2.013	2.148
162	2.005	0.572	0.735	0.894	1.048	1.199	1.348	1.494	1.638	1.781	1.922	2.061	2.199
164	2.068	0.585	0.752	0.914	1.072	1.227	1.379	1.529	1.676	1.822	1.966	2.109	2.250
166	2.132	0.598	0.770	0.935	1.097	1.255	1.411	1.564	1.715	1.864	2.011	2.157	2.302
168	2.197	0.612	0.787	0.957	1.122	1.284	1.443	1.599	1.754	1.906	2.057	2.206	2.354
170	2.263	0.626	0.805	0.978	1.147	1.313	1.475	1.635	1.793	1.949	2.103	2.255	2.406
172	2.331	0.640	0.822	1.000	1.173	1.342	1.508	1.671	1.833	1.992	2.150	2.305	2.460
174	2.399	0.654	0.840	1.022	1.198	1.371	1.541	1.708	1.873	2.036	2.197	2.356	2.514
176	2.469	0.668	0.859	1.044	1.224	1.401	1.574	1.745	1.913	2.080	2.244	2.407	2.568
178	2.540	0.682	0.877	1.066	1.250	1.431	1.608	1.782	1.954	2.124	2.292	2.458	2.623

Table 9: Conversion factors to estimate the under bark volumes and different top end girth for *L. speciosa* grown in Bangladesh

GBH (cm)	Conversion factor				
	F_{ub}	F_{30}	F_{35}	F_{40}	F_{45}
30	0.913	0.646	0.407	0.352	0.269
32	0.919	0.667	0.429	0.372	0.286
34	0.923	0.687	0.451	0.392	0.304
36	0.927	0.705	0.472	0.412	0.321
38	0.931	0.722	0.492	0.431	0.338
40	0.934	0.739	0.512	0.450	0.354
42	0.937	0.754	0.532	0.468	0.371
44	0.940	0.768	0.550	0.486	0.387

GBH (cm)	Conversion factor				
	F_{ub}	F_{30}	F_{35}	F_{40}	F_{45}
46	0.942	0.781	0.569	0.503	0.403
48	0.944	0.794	0.586	0.520	0.419
50	0.947	0.805	0.603	0.536	0.434
52	0.948	0.816	0.619	0.552	0.450
54	0.950	0.827	0.635	0.568	0.464
56	0.952	0.836	0.650	0.583	0.479
58	0.953	0.846	0.665	0.597	0.493
60	0.955	0.854	0.679	0.611	0.507
62	0.956	0.862	0.693	0.625	0.521
64	0.957	0.870	0.706	0.638	0.534
66	0.958	0.877	0.718	0.651	0.547
68	0.959	0.884	0.731	0.663	0.560
70	0.960	0.890	0.742	0.675	0.572
72	0.961	0.896	0.753	0.686	0.584
74	0.962	0.902	0.764	0.697	0.595
76	0.963	0.907	0.774	0.708	0.606
78	0.964	0.912	0.784	0.718	0.617
80	0.965	0.917	0.793	0.728	0.627
82	0.965	0.922	0.802	0.737	0.637
84	0.966	0.926	0.810	0.746	0.647
86	0.966	0.930	0.819	0.754	0.656
88	0.967	0.933	0.826	0.763	0.665
90	0.968	0.937	0.834	0.770	0.674
92	0.968	0.940	0.840	0.778	0.682
94	0.969	0.943	0.847	0.785	0.690
96	0.969	0.946	0.853	0.792	0.697
98	0.969	0.949	0.859	0.798	0.705
100	0.970	0.951	0.865	0.804	0.711
102	0.970	0.954	0.870	0.810	0.718
104	0.971	0.956	0.875	0.815	0.724
106	0.971	0.958	0.879	0.820	0.730
108	0.971	0.960	0.884	0.825	0.735
110	0.972	0.961	0.888	0.830	0.741
112	0.972	0.963	0.892	0.834	0.745
114	0.972	0.965	0.895	0.838	0.750
116	0.972	0.966	0.899	0.842	0.754
118	0.973	0.967	0.902	0.845	0.758
120	0.973	0.968	0.904	0.849	0.762

GBH (cm)	Conversion factor				
	F_{ub}	F_{30}	F_{35}	F_{40}	F_{45}
122	0.973	0.969	0.907	0.852	0.766
124	0.973	0.970	0.909	0.854	0.769
126	0.973	0.971	0.911	0.857	0.772
128	0.974	0.972	0.913	0.859	0.774
130	0.974	0.973	0.915	0.861	0.777
132	0.974	0.973	0.917	0.863	0.779
134	0.974	0.974	0.918	0.865	0.781
136	0.974	0.974	0.919	0.867	0.783
138	0.974	0.974	0.920	0.868	0.784
140	0.974	0.975	0.921	0.869	0.786
142	0.975	0.975	0.922	0.870	0.787
144	0.975	0.975	0.922	0.871	0.788
146	0.975	0.975	0.923	0.872	0.788
148	0.975	0.975	0.923	0.872	0.788
150	0.975	0.975	0.923	0.872	0.788
152	0.975	0.975	0.923	0.872	0.788
154	0.975	0.975	0.923	0.872	0.788
156	0.975	0.975	0.923	0.872	0.788
158	0.975	0.975	0.922	0.872	0.788
160	0.975	0.974	0.922	0.872	0.788
162	0.975	0.974	0.922	0.872	0.788
164	0.975	0.973	0.922	0.872	0.788
166	0.975	0.973	0.922	0.872	0.788
168	0.975	0.973	0.922	0.872	0.788
170	0.975	0.973	0.922	0.872	0.788
172	0.975	0.973	0.922	0.872	0.788
174	0.975	0.973	0.922	0.872	0.788
176	0.975	0.973	0.922	0.872	0.788
178	0.975	0.973	0.922	0.872	0.788

Discussion

In the present study, simple linear as well as non-linear models were tested. The use of volume equations to estimate yield in future studies may offer better estimates whilst avoiding destructive sampling (Nunifu and Murchinson 1999). Useful models must be based on easily and cheaply measured tree parameters (Phillips 1995) and ease of operation is an important consideration in the use of volume tables (Perez and Kanninen 2003).

This study selected two volume equations (one and two way) from 21 individual models for jarul grown in Bangladesh. The volume equations predict the total volume over bark and conversion factor equations to predict total volume under bark, under bark volume of different top end girth of 30, 35, 40 and 45 cm from total volume over bark. The data covers different climate regions around the country, represents different types of stands growing on different soil types and thus covers most of the site conditions suitable for forestry in Bangladesh. Regarding the sample trees within these were measured at different girth classes and used in this study. The descriptive statistics of dependent variable (volume) and independent variables (GBH and height) are represented in Table 3 which are performed to develop one way and two way volume equation of *L.speciosa.*

The volume equations were transformed to a logarithmic form, a common procedure to obtain constant variance of the residuals. Volume function [9] for one way [20] for two way which had GBH and H as independent variables gave the best results based on fit and validation statistics and was most suitable according to residual analyses and model comparison for the studies tree species. Fit statistics of each of the equations for each species showed in Table 4. The R^2 values were generally high and acceptable for the equations while *RMSE* values were very low. In this table also shows that *AIC* values are low which are closed to zero. The coefficients of determination for selected one way volume equations is 0.96 and two way volume equations is 0.98. This means that the selected one way models describe over 96% and two way models describe 98% for jarul of the total variations. The best fitted models were selected for estimation of volume on GBH and total height. Islam *et al*. (2012) confirmed the suitability of this two models for estimating total volume of *Albizia richardiana* King and Prain planted in the Southern Part of Bangladesh. The combined variable equation (equation [20]) showed more precision in the estimate as evinced by the values of absolute mean residual, root mean squared error, model efficiency and variance ratio (Table 4) and, hence, was considered the better option for volume prediction. Needless to mention that the combined variable equation, has been well recognised in volume predictions of many tree species with R^2 usually above 95% (Avery and Burkhart 2002). The models were fitted using the method of least squares. Logarithmic volume equations have the advantage of more nearly satisfying the homogeneity of variance assumption of ordinary regression but suffer from the disadvantage that a transformation bias is introduced (Avery and Burkhart 2002).

These volume tables should not be used to estimate volumes of individual trees in a stand. These tables may be used for the mean tree of a stand which may be multiplied by the number of stem to get the total volume of the stand. Estimation of volumes for the trees much outside the height and GBH ranges shown in the stand table should only be done with caution.

The predictive ability of the different equations was assessed using an independent data set (validating data set) for model validation. The volume equations obtained from the fitting data set were applied to the validating data set. The independent tests for validation were the chi-square test, paired t-test, absolute deviation percent (%AD) and 45 degree line test discussed as follows: The computed chi-square values of total volume over bark represented in Table 6 were less than the tabular values $\chi^2_{0.95,29}$=17.71. This implies that there is no significant difference between the actual values from the 30 test sample trees and the corresponding expected values as predicted by the selected models. The result of pared t-test for total volume over bark of studied tree species grown in Bangladesh are given in Table 6 computed t-ratio for all the estimation were less than the tabular values $t_{0.95,29}$=2.045. These imply that there were no significant differences between the observed and predicted values. Thus the prediction models might be accepted. Absolute deviation percent (%AD) between the observed and predicted values for total volume over bark with diameter at breast height and DBH and height for this study species was minimum, which also confirmed validity of the selected models. Graphs comparing the observed values and the predicted values were plotted in the graph paper. The observed values and the predicted values yielded slops very closed to 45 degrees, which have been presented in Table 6. It was observed that the models tend to make an angle 45 degrees with the axes, meaning there were no significant difference between the actual and the predicted values.

The use of Drigo *et al*. (1988) model is estimate local total volume of *L. speciosa* in southern Sylhet which produce variation in volume estimation. The best-fit total volume model of *L. speciosa* has shown a variation in estimating total volume compared to Drigo *et al*. (1988) model. However, the graphical presentation of 1:1 line indicated that our best-fit total volume model is capable to estimate total volume more accurately than other model in comparison (Fig. 1). The variation in estimated volume may be due to the differences in tree species, climatic conditions, site conditions, forest types with its composition and management practices which ultimately influence the architecture of tree and volume partitioning (Hossain *et al*. 2016).

Conclusion

The present study was to develop total tree volume models for *L. speciosa* in Bangladesh based on nondestructive sampling. Although the data were collected from a specific region, and plantation also natural, the volume models constructed can be expected to give a satisfactory estimate for the aggregate standing volume of natural and planted *L. speciosa* stands in Bangladesh. The results showed combined variable equation (model 20) performed well in both the fitting and validation process. Therefore, the developed models in this study are capable to predict total volume for *L. speciosa* in the study area at a higher accuracy. The contrasting results obtained between model fitting and validation emphasise the need for model validation as an important in the model construction process in order to get the best choices. But as with all volume equations, a test of applicability is always necessary if used outside the range of data and/or under other conditions.

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