Volume Equations and Tables for Planted and Natural Stands of *Sonneratia apetala* Buch.-Ham. in the Coastal Areas of Bangladesh

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Abstract

Keora (*Sonneratia apetala* Buch.-Ham.) is one of the most important tree species for large scale plantations in the coastal areas of Bangladesh. The aim of this study was to generate a common volume equation and table for predicting the total and merchantable volume of planted and natural stand of *S. apetala* in the coastal areas of Bangladesh. A total of 430 sample trees having different girth classes were sampled from the plantation stands of Chattogram, Noakhali, Bhola and Patuakhali. Twenty one (21) models were tested to derive best-fit models for the volume over bark and under bark. The best fit models were selected based on the highest value of R^2 (co-efficient of determination), the lowest value of Akaike Information Criterion (AIC) and Root Mean Square Error (RMSE). The selected models were validated by Chi-square test of goodness of fit, Paired t-test, Percent Absolute Deviation (% AD) and 45 degree line test. The best-fit one-variable and two-variable basic models were and respectively. The best-fit models showed the highest efficiency in volume estimation compared to previous developed model in terms of Model Prediction Error (MPE), Model Efficiency (ME) and Root Mean Square Error (RMSE).

সারসংক্ষেপ

বাংলাদেশের উপকূলীয় অঞ্চলে ব্যাপক আকারে বৃক্ষরোপণের জন্য কেওড়া একটি গুরুত্বপূর্ণ বৃক্ষ প্রজাতি। এই গবেষণার উদ্দেশ্য হলো সৃজিত ও প্রাকৃতিকভাবে জন্মানো কেওড়া গাছের মোট আয়তন ও বিক্রয়যোগ্য আয়তনের সাধারণ গাণিতিক সমীকরণ নির্ণয় ও সারণী তৈরী করা। এই উদ্দেশ্য বাস্তবায়নের জন্য চট্টগ্রাম, নোয়াখালী, ভোলা এবং পটুয়াখালী উপকূলীয় বনাঞ্চল হতে বিভিন্ন বেড় শ্রেণির ৪৩০ টি দাঁড়ানো গাছের উপাত্ত সংগ্রহ করা হয়। বাকলসহ এবং বাকলছাড়া আয়তন নির্ণয়ের সেরা মডেল বের করার জন্য একুশটি (২১) মডেল পরীক্ষা করা হয়েছে। সর্বোচ্চ R^2 (coefficients of determination) মান, সর্বনিম্ন AIC (Akaike Information Criterion) Ges RMSE (Root Mean Square Error) দ্বারা সেরা-যথাযথ মডেল নির্বাচন করা হয়েছে। নির্বাচিত মডেলগুলি কাই-বর্গ, জোড়া টি-টেস্ট, Percent Absolute Deviation (%AD) এবং ৪৫ ডিগ্রি লাইন পরীক্ষা দ্বারা বৈধতা পরীক্ষা করা হয়েছে। একমূখী আয়তন নির্ণয়ে এবং দ্বিমূখী আয়তন নির্ণয়ে মৌলিক মডেলদ্বয় সেরা মডেল নির্বাচিত হয়েছে। সেরা ফিট আয়তন নির্ণয়ের মডেলগুলি, মডেল পূর্বাভাস ত্রুটি (MPE), মডেল দক্ষতা (ME) এবং রুট মিন স্কয়ার ত্রুটি (RMSE) বিবেচনায় পূর্ববর্তী উন্নয়নকৃত মডেলের তুলনায় আয়তন অনুমানের সর্বোচ্চ দক্ষতা দেখিয়েছে।

Key words: *Sonneratia apetala*, Total volume, Volume model, Volume table.

Introduction

Keora (*Sonneratia apetala* Buch.-Ham, Family-Lythraceae) is the pioneer mangrove species that can attain a height of about 20 m and a diameter of about 80 cm (Siddiqi 2001, Mahmood 2015). *Sonneratia apetala* is a fast growing compared to other mangrove species. It is a strong light demanding species. The tree occurs on newly accreted soil in moderately to strongly saline areas and is considered as a pioneer species in ecological succession (Mahmood 2015). Afforestation Programme along the coastal belt was initiated in 1966 with the primary objective to protect the lives and properties of coastal communities from cyclone and tidal surges by creating mangrove forest cover in the exposed 710 km coastal belt (Das and Siddiqi 1985; Mahmood *et al.* 2020). *Sonneratia apetala* was the most successful tree species in all along the coastal belt and *Avicennia officinalis* was the second most successful species in coastal plantation. A total of 0.192 million hectares of accreted lands were afforested with *S. apetala* that constitutes about 95% of the total coastal plantations.

Volume equations have been used to estimate tree and stand volume, have played a significant role in forest management. The inherent morphological differences among tree species recommend to develop species-specific volume (Burkhart and Gregoire 1994). The volume equations and tables have been developed for more than forty three important tree species in Bangladesh (Latif and Islam 2014; Islam *et al.* 2014; Mahmood *et al.* 2016 and Islam *et al.* 2020). The one-variable (volume-diameter/girth) and two-variable volume tables of *S. apetala* were derived for the young stands located in Patuakhali and Bhola (Islam *et al.* 1992a) and the mature stands located in Chattogram and Patuakhali (Latif 1994). However, these volume equations and tables are not capable to produce accurate volume estimation for all the coastal plantations of *S. apetala* in Bangladesh. Therefore, a common volume equation and table is required for accurate volume estimation that will help in sustainable forest management, assessment of carbon stock and so on. The aim of this study was to generate a common volume equation and table for predicting the total and merchantable volume of planted and natural stands (other than Sundarban) of *S. apetala* in the coastal areas of Bangladesh. .

Materials and Methods

Study area

Bangladesh Forest Department has taken an initiative to expand and popularize afforestation programme in the new accreted char- land in the coastal belt of Bangladesh. *S. apetala* is the common tree species along newly accreted char and coast line of Bangladesh. This study has been conducted in the remnant the existence plantations and natural stands in several forest beat of these forest areas presented in Table 1.

Table 1. Study areas for estimation of volume for the keora grown in Bangladesh.

Forest Division	Range	Beat/area
Chattogram costal	Sador	Halishahar, Kattali and Fouzdarhat
	Sitakunda Mirsarai	Banshbaria and Bogachattar Dumkhali and Mogadia
Noakhali	Jahajmara	Char Osman, Char Kalam and Jahajmara
Patuakhali	Galachipa	Char Kashem, Kankanipara and Ashabaria
	Char Montaj	Sonar Char, Char Taposhi and Char Montaj
Bhola	Kukrimukri	Char Kukrimukri, Char Jamir, Char Dighal and Char Safi

Sampling of trees

The sample size were selected on the basis of girth at breast height (GBH) classes and height classes of *S. apetala.* 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. A total of 430 sample trees belong to different GBH class (Table 2) were selected to derive the volume equations and tables. 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

Girth at breast height and total height of the sampled trees were measured with diameter tape and Haga-altimeter respectively. Sectional diameter of the stem and bigger branches (girth ≥30 cm) were taken at 1 m interval using ladder. At the same time bark thickness was measured from bark chip using a bark gauge. The collected fitting data set were categorized on the basis of GBH and height of the trees. The GBH-height class distribution of the sampled trees are given in Table 2.

Table 2. Stand table of collected volume data of *S. apetala* (keora).

Girth class (cm)	Number of sample trees under different Height Class (m)							
	≤9	9.1 -12	12.1 -15	15.1 -18	18.1 -21	21.1 -24	>24	Total
<35	2	2						4
35.1 -45	5	11	1					17
45.1 -55		8	2	1				11
55.1 -65		7	19	9	1			36
65.1 -75		9	25	24	7	3	2	70
75.1 -85		3	26	50	2	2	2	85
85.1 -95		2	22	36	12	5	5	82
95.1 -105			3	18	18	12	3	54
105.1 -115			2	9	4	11	5	31
115.1 -125			2	3	2	6	8	21
125.1 -135				2	2	1	4	9
>13 5						4	6	10
Total	**7**	**42**	**102**	**152**	**48**	**44**	**35**	**430**

Compilation of Data

Volume of log sections except top and bottom section were estimated 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 = length of the log. 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 analyses technique was adopted to select the best fit models. The following 21 models (Clutter *et al.* 1983; Bi Hamilton 1998; Latif and Islam 2014; Islam and Chowdhury 2017) were tested to select the equation of best fit with different variables are given in Table 3.

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

Table 3. 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 = volume in cubic meters, G = girth at breast height in centimeters, H = 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.

Independent variables: G, G^2, G^{-1}, G^{-2}, H, H^{-1}, GH, G^2H, *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 and under bark selected.

Model validation

The best fit models were validated with another set of 30 trees of different girth class and compiled in the same procedure as earlier. The measured volumes of these 30 trees were compared with their predicted volume. 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 (Latif 1994 and Islam *et al.* 1992a).

Model comparison

The best-fit volume model was compared with the previous developed local volume model of Keora by Latif (1994) and Islam *et al.* (1992a) (Table 4) 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 and terms calculate with statistical tools represent by the following equations.

Table 4. Previous developed local volume models of *Sonneratia apetala* for comparison with best-fit model in this study.

No.	Model	Type	Source
1	$V = -0.0117 + 0.00000283756D^2 \times H$	Locally in Patuakhalį Bhola and Noakhali	Latif (1994)
2	$V = 0.0073 + 0.000003368D^2 \times H$	Locally in Chattogram	
3	$\ln(V) = -9.1937 + 1.7683 \times \ln(D) + 0.7385 \times \ln(H)$	Locally in Patuakhali	Islam *et al.* (1992a)
4	$\ln(V) = -9.2587 + 1.6463 \times \ln(D) + 0.9138 \times \ln(H)$	Locally in Bhola	

Where *V* = volume over bark in cubic meter, *D* = Diameter at breast height in cm, *H* = Total height in meter

The comparison tools are given in the equations

$$\text{MPE}(\%) = \frac{100}{n} \times \sum \left[\frac{(Y_p - Y_0)}{Y_0}\right] \quad (1)$$

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

$$\text{MSE}(\%) = 100 \times \sqrt{\frac{1}{n} \sum (Y_p - Y_0)^2} \quad (3)$$

Where 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 Latif (1994) and Islam *et al.* (1992a) (Table 4). Significance of slope (b = 1) and intercept (a = 1) were tested (Pineiro *et al.* 2008) to understand the over estimation or under estimation of each predicted volume value from observed value by using 1:1 line (Sileshi 2014).

Data analysis

Collected data were organized and screened (removing the outliers) for analysis. Descriptive statistical analysis was further carried out in order to summarize the data. All analysis were carried out 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 430 sample trees in this study. Descriptive statistics of dependent and independent variables represent in Table 5.

Table 5. Descriptive statistics for sample trees for model development.

Variables	No. of sample	Mean	Minimum	Maximum	Standard error	Standard deviation	Confidence level (95.0%)
Gbh (cm)	430	84.0	31.5	171.0	1.1	22.2	2.1
Height (m)	430	17.0	8.0	30.5	0.2	4.4	0.4
Volume (m^3)	430	0.5	0.0	2.6	0.0	0.3	0.0

Volume equations

The volume equations for estimation of total volume over-bark for *S. apetala* were selected. The model 9 and 20 were best fit for one way and two way volume equations respectively to estimate total volume over bark and volume under bark. The selected volume equations were given in Table 6.

Table 6. Selected best fit volume equation of *S. apetala.*

Selected Models	Fit statistics			
	R^2	RMSE	AIC	N
$\ln(V_{ob}) = -11.2916 + 2.354365 \times \ln(G)$	0.90	0.21	-0.38	430
$\ln(V_{ob}) = -11.1083 + 1.752458 \times \ln(G) + 0.878759 \times \ln(H)$	0.94	0.16	-0.97	430
$\ln(V_{ub}) = -11.3602 + 2.361471 \times \ln(G)$	0.90	0.22	-0.36	430
$\ln(V_{ub}) = -11.1771 + 1.76028 \times \ln(G) + 0.877715 \times \ln(H)$	0.94	0.17	-0.98	430

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

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 6.

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 measured volume of these trees were collectively compared with the corresponding predicted volume using best fit 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.* 1992b; Latif and Islam 2001). The computed chi-square, t-values, absolute deviation percent and slope (45-dergee line test) of studied tree species for total volume over bark and under bark equations were given Table 7.

Table 7. Result of independent test for predicted volume equations of *S. apetala.*

Proportion	Model Types	*Chi*	*t*	*%AD*	*Slope* ^{o}
Over bark	One way	1.07	0.33	1.8	43.8
	Two way	0.60	1.00	4.2	44.1
Under bark	One way	1.03	0.35	1.9	44.2
	Two way	0.58	1.03	4.3	43.6

Total volumes over bark were calculated for ready use and presented in Table 9. The volume equations and tables were applicable for keora growing in the different coastal forest areas of Bangladesh.

Model comparison

The total volume best-fit model showed the lowest (-3.24%) MPE and RMSE (11.71%) and the highest ME (0.93), close to the reference value 1) compared to the local volume models of Latif (1994) and Islam *et al.* (1992a) (Table 8). The graphica l presentation from 1:1 line indicated that the best-fit volume model was capable to estimate the total volume more accurately. While locally used Latif (1994) and Islam *et al.* (1992a) model overestimated the total volume for *S. apetala* compared to the derived best-fit total volume model in this study (Fig. 1).

Table 8. Comparison of best-fit total volume over bark model with the Latif (1994) and Islam *et al.* (1992a) model.

Source	Type	MPE (%)	ME	MSE (%)
(A) Best fit model (V_{ob})	This study	-3.24	0.93	11.71
(B) Latif (1994)	Locally in Patuakhali	23.51	0.87	15.99
(C) Latif (1994)	Locally in Chattogram	20.09	0.89	13.64
(D) Islam *et al.* (1992a)	Locally in Patuakhali	32.51	0.53	29.99
(E) Islam *et al.* (1992a)	Locally in Bhola	31.06	0.56	28.83

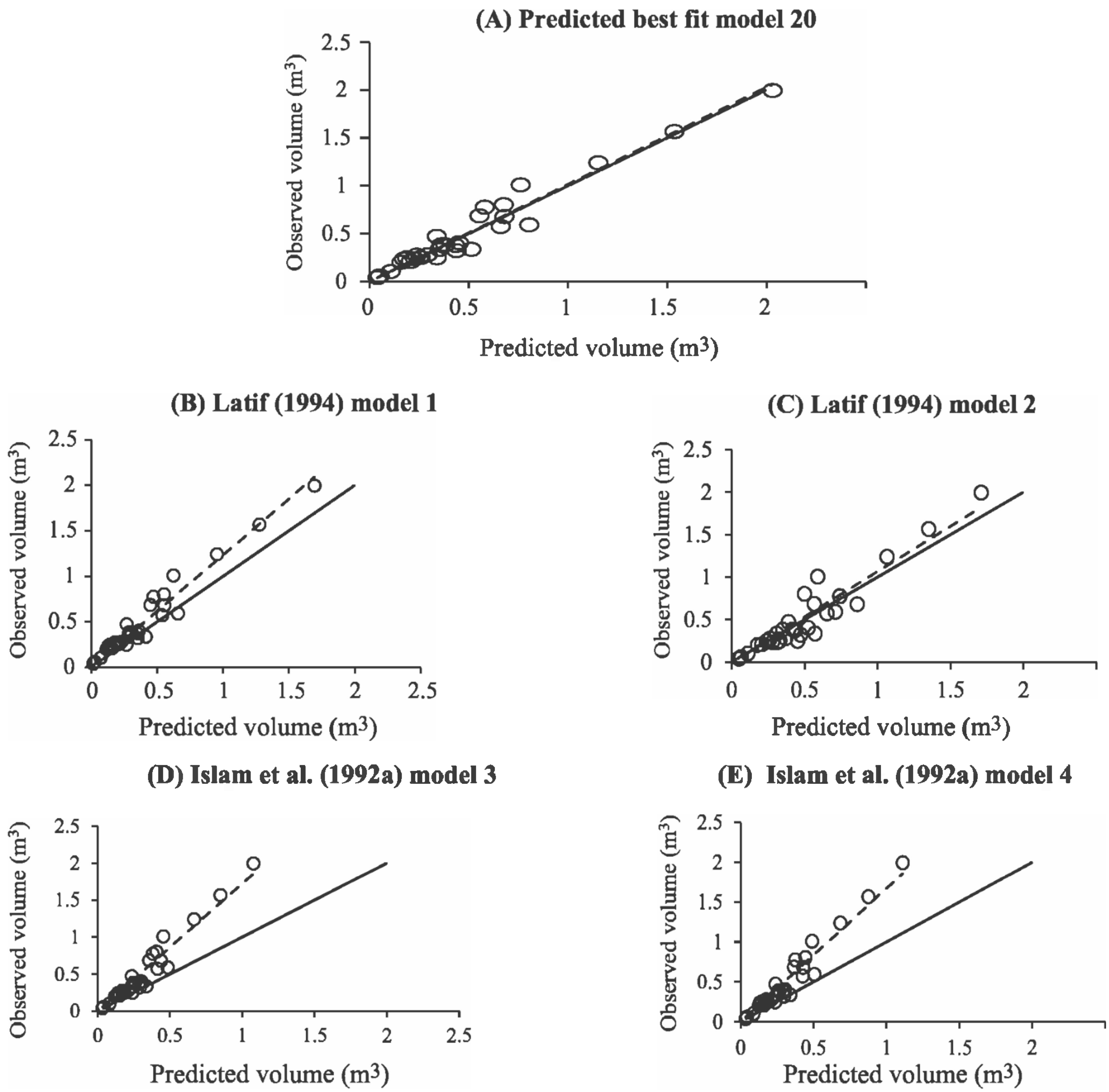

Figure 1. Comparison of best-fit total volume model with Latif (1994) and Islam *et al.* (1992a) volume model.

Table 9. One and Two way volume table for *S. apetala* grown in Bangladesh.

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**
30	0.037	0.028	0.036	0.044	0.052	0.059	0.066	0.074	0.081	0.088	0.095	0.102	0.109
32	0.044	0.031	0.040	0.049	0.058	0.066	0.074	0.083	0.091	0.098	0.106	0.114	0.122
34	0.050	0.035	0.045	0.055	0.064	0.074	0.083	0.092	0.101	0.109	0.118	0.127	0.135
36	0.058	0.039	0.050	0.061	0.071	0.081	0.091	0.101	0.111	0.121	0.131	0.140	0.150
38	0.065	0.042	0.055	0.067	0.078	0.089	0.101	0.112	0.122	0.133	0.144	0.154	0.164
40	0.074	0.046	0.060	0.073	0.085	0.098	0.110	0.122	0.134	0.146	0.157	0.169	0.180
42	0.083	0.051	0.065	0.079	0.093	0.107	0.120	0.133	0.146	0.159	0.171	0.184	0.196
44	0.092	0.055	0.071	0.086	0.101	0.116	0.130	0.144	0.158	0.172	0.186	0.199	0.213
46	0.103	0.059	0.076	0.093	0.109	0.125	0.141	0.156	0.171	0.186	0.201	0.215	0.230
48	0.113	0.064	0.082	0.100	0.118	0.135	0.151	0.168	0.184	0.200	0.216	0.232	0.248
50	0.125	0.069	0.088	0.108	0.126	0.145	0.163	0.180	0.198	0.215	0.232	0.249	0.266
52	0.137	0.074	0.095	0.115	0.135	0.155	0.174	0.193	0.212	0.230	0.249	0.267	0.285
54	0.150	0.079	0.101	0.123	0.145	0.166	0.186	0.206	0.226	0.246	0.266	0.285	0.304
56	0.163	0.084	0.108	0.131	0.154	0.176	0.198	0.220	0.241	0.262	0.283	0.304	0.324
58	0.177	0.089	0.115	0.140	0.164	0.188	0.211	0.234	0.257	0.279	0.301	0.323	0.345
60	0.192	0.095	0.122	0.148	0.174	0.199	0.224	0.248	0.272	0.296	0.320	0.343	0.366

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
62	0.207	0.100	0.129	0.157	0.184	0.211	0.237	0.263	0.288	0.314	0.339	0.363	0.388
64	0.223	0.106	0.136	0.166	0.195	0.223	0.251	0.278	0.305	0.332	0.358	0.384	0.410
66	0.240	0.112	0.144	0.175	0.205	0.235	0.265	0.293	0.322	0.350	0.378	0.405	0.433
68	0.257	0.118	0.152	0.184	0.217	0.248	0.279	0.309	0.339	0.369	0.398	0.427	0.456
70	0.276	0.124	0.160	0.194	0.228	0.261	0.293	0.325	0.357	0.388	0.419	0.449	0.480
72	0.294	0.130	0.168	0.204	0.239	0.274	0.308	0.342	0.375	0.408	0.440	0.472	0.504
74	0.314	0.137	0.176	0.214	0.251	0.288	0.323	0.359	0.393	0.428	0.462	0.495	0.529
76	0.334	0.143	0.184	0.224	0.263	0.301	0.339	0.376	0.412	0.448	0.484	0.519	0.554
78	0.355	0.150	0.193	0.235	0.275	0.315	0.355	0.393	0.431	0.469	0.506	0.543	0.580
80	0.377	0.157	0.202	0.245	0.288	0.330	0.371	0.411	0.451	0.490	0.529	0.568	0.606
82	0.400	0.163	0.210	0.256	0.301	0.344	0.387	0.429	0.471	0.512	0.553	0.593	0.633
84	0.423	0.171	0.220	0.267	0.314	0.359	0.404	0.448	0.491	0.534	0.577	0.619	0.660
86	0.447	0.178	0.229	0.278	0.327	0.374	0.421	0.467	0.512	0.557	0.601	0.645	0.688
88	0.472	0.185	0.238	0.290	0.340	0.390	0.438	0.486	0.533	0.579	0.625	0.671	0.716
90	0.498	0.192	0.248	0.301	0.354	0.405	0.456	0.505	0.554	0.603	0.651	0.698	0.745
92	0.524	0.200	0.258	0.313	0.368	0.421	0.473	0.525	0.576	0.626	0.676	0.725	0.774
94	0.552	0.208	0.267	0.325	0.382	0.437	0.492	0.545	0.598	0.650	0.702	0.753	0.804
96	0.580	0.215	0.277	0.338	0.396	0.454	0.510	0.566	0.621	0.675	0.729	0.782	0.834
98	0.608	0.223	0.288	0.350	0.411	0.470	0.529	0.587	0.644	0.700	0.755	0.810	0.865

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
100	0.638	0.231	0.298	0.363	0.426	0.487	0.548	0.608	0.667	0.725	0.783	0.840	0.896
102	0.668	0.240	0.309	0.375	0.441	0.505	0.567	0.629	0.690	0.751	0.810	0.869	0.928
104	0.700	0.248	0.319	0.388	0.456	0.522	0.587	0.651	0.714	0.777	0.838	0.899	0.960
106	0.732	0.256	0.330	0.402	0.471	0.540	0.607	0.673	0.738	0.803	0.867	0.930	0.992
108	0.765	0.265	0.341	0.415	0.487	0.558	0.627	0.696	0.763	0.830	0.896	0.961	1.025
110	0.799	0.274	0.352	0.428	0.503	0.576	0.648	0.718	0.788	0.857	0.925	0.992	1.059
112	0.833	0.282	0.363	0.442	0.519	0.594	0.668	0.741	0.813	0.884	0.954	1.024	1.093
114	0.869	0.291	0.375	0.456	0.535	0.613	0.689	0.765	0.839	0.912	0.985	1.056	1.127
116	0.905	0.300	0.387	0.470	0.552	0.632	0.711	0.788	0.865	0.940	1.015	1.089	1.162
118	0.942	0.309	0.398	0.485	0.569	0.651	0.732	0.812	0.891	0.969	1.046	1.122	1.198
120	0.980	0.319	0.410	0.499	0.586	0.671	0.754	0.837	0.918	0.998	1.077	1.156	1.233
122	1.019	0.328	0.422	0.514	0.603	0.690	0.776	0.861	0.945	1.027	1.109	1.190	1.270
124	1.059	0.337	0.434	0.529	0.620	0.710	0.799	0.886	0.972	1.057	1.141	1.224	1.306
126	1.099	0.347	0.447	0.544	0.638	0.731	0.822	0.911	1.000	1.087	1.173	1.259	1.344
128	1.141	0.357	0.459	0.559	0.656	0.751	0.845	0.937	1.028	1.117	1.206	1.294	1.381
130	1.183	0.367	0.472	0.574	0.674	0.772	0.868	0.963	1.056	1.148	1.239	1.330	1.419
132	1.227	0.376	0.485	0.590	0.692	0.793	0.891	0.989	1.085	1.179	1.273	1.366	1.458
134	1.271	0.387	0.498	0.606	0.711	0.814	0.915	1.015	1.113	1.211	1.307	1.402	1.497
136	1.316	0.397	0.511	0.621	0.729	0.835	0.939	1.042	1.143	1.243	1.341	1.439	1.536

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
138	1.362	0.407	0.524	0.638	0.748	0.857	0.964	1.069	1.172	1.275	1.376	1.476	1.576
140	1.409	0.417	0.537	0.654	0.767	0.879	0.988	1.096	1.202	1.307	1.411	1.514	1.616
142	1.457	0.428	0.551	0.670	0.787	0.901	1.013	1.124	1.233	1.340	1.447	1.552	1.657
144	1.506	0.439	0.565	0.687	0.806	0.923	1.038	1.151	1.263	1.374	1.483	1.591	1.698
146	1.555	0.449	0.578	0.704	0.826	0.946	1.064	1.180	1.294	1.407	1.519	1.630	1.739
148	1.606	0.460	0.592	0.721	0.846	0.969	1.089	1.208	1.325	1.441	1.556	1.669	1.781
150	1.657	0.471	0.607	0.738	0.866	0.992	1.115	1.237	1.357	1.475	1.593	1.709	1.824
152	1.710	0.482	0.621	0.755	0.886	1.015	1.141	1.266	1.389	1.510	1.630	1.749	1.866
154	1.763	0.493	0.635	0.773	0.907	1.039	1.168	1.295	1.421	1.545	1.668	1.789	1.910
156	1.818	0.505	0.650	0.790	0.928	1.062	1.195	1.325	1.453	1.580	1.706	1.830	1.953
158	1.873	0.516	0.664	0.808	0.949	1.086	1.222	1.355	1.486	1.616	1.744	1.872	1.997
160	1.929	0.527	0.679	0.826	0.970	1.111	1.249	1.385	1.519	1.652	1.783	1.913	2.042
162	1.987	0.539	0.694	0.844	0.991	1.135	1.276	1.415	1.553	1.688	1.823	1.955	2.087
164	2.045	0.551	0.709	0.863	1.013	1.160	1.304	1.446	1.586	1.725	1.862	1.998	2.132
166	2.104	0.563	0.724	0.881	1.034	1.185	1.332	1.477	1.621	1.762	1.902	2.041	2.178
168	2.164	0.575	0.740	0.900	1.056	1.210	1.360	1.509	1.655	1.800	1.942	2.084	2.224
170	2.225	0.587	0.755	0.919	1.079	1.235	1.389	1.540	1.690	1.837	1.983	2.128	2.271

Discussion

Two volume equations (one and two way) were selected from 21 models for *S. apetala* grown in Bangladesh. The volume equations predict the total volume over bark and volume under 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 5 which are performed to develop one way and two way volume equation of *S. apetala*.

The volume equations were transformed to a logarithmic form, a common procedure to obtain constant variance of the residuals. Volume model 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 the species showed in Table 6. 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 both volume equations is 0.90 and two way both volume equations is 0.94. This means that the selected one way models describe over 90% and two way models describe 94% for keora of the total variations. The best fit models were selected for estimation of volume on GBH and total height. Islam *et al.* (2012, 2020) confirmed the suitability of these two models for estimating total volume of *Lagerstroemia speciosa* (L.) Pers and *Albizia richardiana* King and Prain. The combined variable equation (equation 20) showed more precision in the estimate as evinced by the values of absolute mean residual, R^2 values, root mean squared error, model prediction error, model efficiency and variance ratio (Table 6 and 8) and, hence, was considered the better option for volume prediction. Needless to mention that the combined variable equations, 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 were 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 7) were less than the tabular values. 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 7) computed t-ratio for all the estimation were less than the tabular values. 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 and under bark with girth at breast height (GBH) and GBH & 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 7). 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 Latif (1994) and Islam *et al.* (1992a) model are estimated local total volume of *S. apetala* in Chattogram, Bhola and Patuakhali coastal forest which produce variation in volume estimation. The best-fit total volume model of *S. apetala* has shown a variation in estimating total volume compared to Latif (1994) and Islam *et al.* (1992a) model. However, the graphical presentation of 1:1 line indicated that the best-fit volume model is capable to estimate total volume was accurately than other previous developed 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 influenced the architecture of tree and volume partitioning (Mahmood *et al.* 2016).

Conclusion

The present study was to develop total tree volume models for *S. apetala*. 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 *S. apetala* 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 *S. apetala* 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.

Acknowledgements

The authors greatly acknowledge to the Director, Bangladesh Forest Research Institute, Chattogram, Bangladesh for approving to conduct this research. The authors acknowledge to all respective Divisional Forest Officers, Range Officers, Beat Officers and Field Staff of Bangladesh Forest Department in mentioned four coastal forest divisions for their logistics support and for providing all facilities. The authors also acknowledge to Divisional Officer of Plantation Trial Unit Division of BFRI for his continuously logistics support and for providing all facilities. Finally, The authors acknowledge to the staffs of Forest Inventory Division for their assistance in data collection.

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