A critical review and database of biomass and volume allometric equation for trees and shrubs of Bangladesh

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Abstract. Estimations of biomass, volume and carbon stock are important in the decision making process for the sustainable management of a forest. These estimations can be conducted by using available allometric equations of biomass and volume. Present study aims to: i. develop a compilation with verified allometric equations of biomass, volume, and carbon for trees and shrubs of Bangladesh, ii. find out the gaps and scope for further development of allometric equations for different trees and shrubs of Bangladesh. Key stakeholders (government departments, research organizations, academic institutions, and potential individual researchers) were identified considering their involvement in use and development of allometric equations. A list of documents containing allometric equations was prepared from secondary sources. The documents were collected, examined, and sorted to avoid repetition, yielding 50 documents. These equations were tested through a quality control scheme involving operational verification, conceptual verification, applicability, and statistical credibility. A total of 517 allometric equations for 80 species of trees, shrubs, palm, and bamboo were recorded. In addition, 222 allometric equations for 39 species were validated through the quality control scheme. Among the verified equations, 20%, 12% and 62% of equations were for green-biomass, oven-dried biomass, and volume respectively and 4 tree species contributed 37% of the total verified equations. Five gaps have been pinpointed for the existing allometric equations of Bangladesh: a. little work on allometric equation of common tree and shrub species, b. most of the works were concentrated on certain species, c. very little proportion of allometric equations for biomass estimation, d. no allometric equation for belowground biomass and carbon estimation, and d. lower proportion of valid allometric equations. It is recommended that site and species specific allometric equations should be developed and consistency in field sampling, sample processing, data recording and selection of allometric equations should be maintained to ensure accuracy in estimation of biomass, volume, and carbon stock in different forest types of Bangladesh.

1. Introduction
Bangladesh is one of the most densely populated countries in the world with only 0.06% of the world’s forest [1] and 0.017 ha of per capita forest land [2]. The huge population (166.3 million) exerts immense pressure on her forest resources for the demand of timber, fuel wood, and other forest products. Measurement of forest biomass and volume are important for estimating forest productivity. Appropriate estimation of forest stocking, productivity, nutrient cycling, nutrient budget, amount of
carbon stock, and prediction of future status are important considerations for the sustainable management of forest resources [3, 4]. Tree biomass and volume can be measured from both destructive (clear-cut) and non-destructive (allometric equation) methods [3, 5]. Allometric method is frequently used for estimating the biomass and volume of forest plant species, which is the most powerful tool of measurement [6, 7, 8, 9]. The use of appropriate equations for estimating biomass and volume will contribute in improving the accuracy of forest resource assessment, and also guide the forest policies and management interventions [10, 11]. Considering this importance, different research and academic institutions and individual researchers have developed biomass and volume allometric equations for estimating biomass and volume stock of a particular forest of Bangladesh.

Choice of allometric equations is one of the key sources of uncertainty in forest biomass estimation. About one-fourth of the published equations contain blunders, oversights, or forecast unrealistic values [12]. Therefore, verification and validation of allometric equation is imperative, before its application in estimation of biomass and volume [13]. Validating and verifying an allometric equation is vast in extent, and diverse in regards to methods, assumptions and conclusions. Recently, [13] proposed a systematic transparent quality control method to quantify the degree of confidence for the allometric equations without involving equation development. Quantitative reviews of available allometric equations have been implemented at a regional scale, but few countries have developed a national database for biomass and volume allometric equations [12]. In South Asia, the first regional database was developed in 2014 [14], while [15] have developed the first database for Bangladesh in 2013. However, these databases were not comprehensive and quality controlled. Repetition of some allometric equations was also observed. The use and development of allometric equations should be specific to the conditions of the country, which is crucial for three reasons. The first is that the assessment of tree and forest resources of a country should be accurate. The second is that country specific models are more efficient, and the third reason is the amount of uncertainty of the models used. However, the overall objective is to improve the quality of estimates for a multitude of purposes including timber volume, wood energy biomass, carbon stocks, etc. in trees and forest resources of Bangladesh. To achieve this overall objective, we have to have the status of the existing tree allometric equations, forest resource estimation methods, and a verified database of tree allometric equations. Therefore, a quality controlled comprehensive database of allometric equations is needed to assess the gaps and scope for the development of new allometric equations with important tree species of different forest types of Bangladesh. The specific objectives of the present study were to: i. develop a compilation with valid allometric equations of biomass, volume and carbon for trees and shrubs of Bangladesh, ii. find out the gaps and scope for further development of allometric equations with different trees and shrubs.

2. Material and Methods

2.1. Collection of Information

Key stakeholders (government departments, research organizations, academic institutions, and potential individual researchers) were identified considering their involvement and experiences in the use and development of allometric equations. A draft list of documents containing allometric equations was prepared through consultation with key stakeholders and online search (Google Scholar) results. This list was updated by taking time and identifying unlisted documents. The listed documents were collected from bibliographic databases such as: Science Direct, Springer Link, CABI, AGRIS, AGRICOLA, JSTOR, ResearchGate. Sometimes personal and official communications were established with identified key stakeholders to obtain their research articles, reports, theses, bulletins, monographs, inventory reports and proceedings papers. Hard and soft copies of the collected documents were maintained for references.
2.2. Compilation of Information

The collected documents were sorted considering relevance and repetition. The information of the allometric equations in the sorted documents was grouped and recorded into 8 different categories. The categories were plant ecology (Population), geographical location, ecoregions (FAO, Udvardy, Bailey, WWF, Holridge and IUCN Biocological zones-Bangladesh), equation parameters (coefficients, constants, variables and ranges), plant components (leaves, Branches, Stump, Stems, Bark, Root, etc.), taxonomical description (Family, Genus, Species), fit statistical information (R2, adjusted R2, RMSE, sample number, bias correction, Akaike information criterion, furnival index) and Bibliography.

2.3. Quality control of the allometric equations

All the allometric equations were tested through a quality control scheme following four types of verification (operational verification, conceptual verification, applicability, statistical credibility) according to [13]. The detail process of verification has been given below:

- Operational verification: Too large or too small predicted biomass or volume values
- Conceptual verification: Predicted biomass or volume are lower than “0” or have negative values
- Applicability: Under which condition the model can be applied (Population ecology, environmental condition of the site where the equation was developed, tree component measured, Taxonomic reference, Range of applicability)
- Statistical credibility: Sample size should be at least 30 trees and the coefficient of determination should be higher than 0.85

3. Results

3.1. Documents of allometric equations

A total of 53 documents were identified that contained the allometric equations for plants of Bangladesh. The collected documents were sorted, considering relevance and repetition, and 50 documents were found (i.e. 96% of the total document of allometric equations). Most of the documents were Journals (52%) followed by reports (24%), bulletins and theses (figure 1). The list of documents containing allometric equations of Bangladesh has been presented as Appendix 1.

![Figure 1. Document type of available literature in percentage.](image)

Most of the documents were prepared during the last decade of the twentieth century (1991-2000). However, the number of studies on the development of allometric equations has increased rapidly
during 2011 to 2016, which contributed 26% of the total allometric documents of Bangladesh (figure 2).

![Figure 2. Year-wise publication of the documents.](image)

### 3.1. Total number of allometric equations

This study recorded a total of 517 allometric equations on volume, biomass, carbon and nutrients for 80 species of tree, shrub, palm and bamboo. Higher preference, about 92% of the total allometric equations, was recorded for trees and 6% for shrubs. Among these equations, 70% equations were for volume estimation and only 6% equations were for oven-dry biomass estimation. Unfortunately, there is not a single equation for below-ground biomass estimation (table 1).

| Category | Volume | Green biomass | Oven-dried biomass | Air-dried biomass | Carbon | Nutrients | Length of split leaf | Total |
|----------|--------|---------------|-------------------|------------------|--------|-----------|---------------------|-------|
| Tree     | 360    | 78            | 11                | 0                | 25     | 3         | 0                   | 477   |
| Shrub    | 1      | 1             | 11                | 0                | 3      | 6         | 0                   | 31    |
| Palm     | 0      | 2             | 0                 | 0                | 0      | 0         | 1                   | 3     |
| Bamboo   | 0      | 3             | 0                 | 3                | 0      | 0         | 0                   | 6     |
| Total    | 361    | 84            | 31                | 3                | 28     | 9         | 1                   | 517   |

### 3.2. Verified allometric equations

Considering operational and conceptual verification, applicability and statistical credibility, the total number of allometric equations was reduced to 222, which was 43% of the total allometric equations. Most of the equations (45%) failed to meet the requirements of statistical credibility and conceptual verification (24%) (table 2). About 97% of the valid allometric equations were for individual species, while only 3% equations for mixed species. Irrespectively, about 77% of allometric equations were for plantation followed by natural forest (15%) and home garden (7%).

| Category | Operational verification | Conceptual verification | Applicability | Statistical credibility | Final validation |
|----------|--------------------------|-------------------------|---------------|------------------------|------------------|
| Valid    | 473                      | 394                     | 517           | 285                    | 222              |
| Not valid| 44                       | 123                     | 0             | 232                    | 295              |
| Total    | 517                      | 517                     | 517           | 517                    | 517              |
Trees contained 196 verified equations which were 41% of the total allometric equations under the tree category. Shrubs contained 26 verified equations which were 84% of the total allometric equations of the shrub category (table 1 and 3). Surprisingly, not a single verified allometric equation was found for palm and bamboo. Under valid allometric equations, about 62% and 12% of the equations were observed for volume and oven-dry biomass respectively (figure 3).

**Table 3.** Number of verified allometric equations according to plant and equation types in Bangladesh.

| Category | Volume | Green biomass | Oven-dried biomass | Carbon | Nutrients | Total |
|----------|--------|---------------|--------------------|--------|-----------|-------|
| Tree     | 138    | 44            | 10                 | 1      | 3         | 196   |
| Shrub    | 0      | 0             | 17                 | 3      | 6         | 26    |
| Palm     | 0      | 0             | 0                  | 0      | 0         | 0     |
| Bamboo   | 0      | 0             | 0                  | 0      | 0         | 0     |
| Grand total | 138 | 44          | 27                 | 4      | 9         | 222   |

**Figure 3.** Percentage of valid allometric equations in different categories.

Thirty-nine species of 18 families and 31 genera have a total of 222 verified allometric equations. But, *Sonneratia apetala, Acacia mangium* and *Acacia auriculiformis* have each of 12 volume equations. *Senna siamea* has 23 allometric equations for green biomass, but other species have few equations under each category. These four species contributed 37% of the total verified allometric equations (Table 4). Species wide valid allometric equations in Bangladesh have been prepared and presented in Appendix 2.
Table 4. List of species with verified allometric equations in Bangladesh.

| Genus        | Species               | Local name | Volume | Green biomass | Oven-dried biomass | Carbon | Nutrient | Remark              |
|--------------|-----------------------|------------|--------|---------------|--------------------|--------|----------|---------------------|
| Acacia       | mangium               | Mangium    | 12     | 12            |                    |        |          |                     |
| Acacia       | auriculiformis        | Akashmon   | 12     | 5             | 1                  |        |          |                     |
| Acacia       | nilotica              | Babla      | 2      |               |                    |        |          |                     |
| Aegialitis   | rotundifolia          | Nuniya     | 2      |               |                    |        |          |                     |
| Aegiceras    | corniculatum          | Khulshi    | 4      | 1             | 3                  |        |          |                     |
| Albizia      | procera               | Koroi      | 2      |               |                    |        |          |                     |
| Albizia      | spp                   | Koroi      | 6      |               |                    |        |          | Mixed species       |
| Albizia      | saman                 | Rain tree  | 6      |               |                    |        |          |                     |
| Albizia      | richardiana           | Rajkori    | 2      |               |                    |        |          |                     |
| Aphanamixis  | polystachya           | Pitraj     | 2      |               |                    |        |          |                     |
| Artocarpus   | chaplasha             | Chapalish  | 2      |               |                    |        |          |                     |
| Artocarpus   | heterophyllus         | Kathal     | 2      |               |                    |        |          |                     |
| Avicennia    | officinalis           | Baen       | 2      |               |                    |        |          |                     |
| Azadirachta  | indica                | Neem       | 2      |               |                    |        |          |                     |
| Breeonia     | chinensis             | Kadam      | 1      |               |                    |        |          |                     |
| Ceriops      | decandra              | Goran      | 5      |               |                    |        |          |                     |
| Dalbergia    | sissoo                | Sissoo     | 5      |               |                    |        |          |                     |
| Dipterocarpus| turbinatus            | Telya      | 3      |               |                    |        |          |                     |
| Eucalyptus   | camaldulensis         | Garjan     | 7      |               |                    |        |          |                     |
| Eucalyptus   | tereticornis          | Eucalyptus | 1      |               |                    |        |          |                     |
| Eucalyptus   | brassiana             | Eucalyptus | 1      |               |                    |        |          |                     |
| Excoecaria   | agallocha             | Gewa       | 5      | 1             | 3                  |        |          |                     |
| Falcataria   | moluccana             | Moluccena  | 2      |               |                    |        |          |                     |
| Gmelina      | arborea               | Gamar      | 2      |               |                    |        |          |                     |
| Hevea        | brasiliensis          | Rubber     | 10     |               |                    |        |          |                     |
| Kandelia     | candel                | Goria      | 5      | 1             | 3                  |        |          |                     |
| Lagerstroemia| speciosa              | Jarul      | 1      |               |                    |        |          |                     |
| Lannea       | coromandelica         | Badi       | 1      |               |                    |        |          |                     |
| Mangifera    | indica                | Am         | 2      |               |                    |        |          |                     |
| Melia        | azadarach             | Bokain     | 2      |               |                    |        |          |                     |
| Mixed        |                       |            | 1      | 4             | 1                  | 1      |          |                     |
| Pinus        | caribaea              | Pine       | 8      |               |                    |        |          |                     |
| Senna        | siamea                | Minjiri    | 8      | 23            |                    |        |          |                     |
| Shorea       | robusta               | Sal        | 7      |               |                    |        |          |                     |
| Sonneratia   | apetala               | Keora      | 12     |               |                    |        |          |                     |
| Swietenia    | macrophylla           | Mahogany   | 6      |               |                    |        |          |                     |
| Syzygium     | cumini                | Kalojam    | 1      |               |                    |        |          |                     |
| Tectona      | grandis               | Teak       | 2      |               |                    |        | 1        |                     |
| Terminalia   | arjuna                | Arjun      | 2      |               |                    |        |          |                     |
A total of 58 verified allometric equations were observed for all over Bangladesh for different species. These allometric equations were developed from sample trees that were collected from different locations of Bangladesh. Therefore, these equations overlap different ecoregions of Bangladesh. Conversely, the other 164 verified allometric equations were found under all categories of ecoregions in Bangladesh as described by FAO, Udvardy, WWF and Bailey (table 5).

Table 5. Numbers of allometric equations and species in different ecoregions of Bangladesh.

| Ecoregion         | Zones                              | Equation number | Species number |
|-------------------|------------------------------------|-----------------|----------------|
| FAO               | Tropical moist Deciduous Forest     | 38              | 12             |
|                   | Tropical rain forest               | 26              | 12             |
| Udvardy           | Tropical humid forests             | 76              | 14             |
|                   | Tropical dry forests / Woodlands   | 12              | 9              |
| WWF               | Tropical humid forest              | 12              | 6              |
|                   | Tropical and subtropical moist broadleaf forests | 10 | 1 |
|                   | Tropical and subtropical dry broadleaf forests | 77 | 20 |
|                   | Mangrove                           | 33              | 5              |
| Bailey            | Rainforest Division                | 101             | 21             |
|                   | Rainforest Regime Mountain         | 12              | 9              |
| Holdridge         | Subtropical moist                  | 13              | 4              |
|                   | Subtropical wet                    | 13              | 10             |
|                   | Tropical moist                     | 10              | 2              |
| Bangladesh IUCN   | Brahmaputra-Jamuna flood plain     | 4               | 2              |
|                   | Chittagong Hills and the CHTs      | 6               | 2              |
|                   | Ganges flood plain                 | 2               | 1              |
|                   | Offshore island                    | 14              | 2              |
|                   | Sundarbans                         | 33              | 5              |
|                   | Surma-Kushia flood plain           | 1               | 1              |
|                   | Sylhet hills                        | 11              | 8              |

* Overlapped ecoregions have not considered in this table.

4. Discussion

Allometric equations for trees and shrubs are fundamental to assess standing volume, biomass or carbon stock, bioenergy, nutrient cycling, payment for environmental services etc. [7, 10, 11]. Inappropriate use and development of allometric equations may give an inaccurate estimate of forest resources that may lead to inappropriate decisions on forest management issues and initiatives [16]. In Bangladesh, 5% species of trees and shrubs have allometric equations for estimating biomass and volume. However, this percentage was reduced to 2.5% considering only the verified equations. Four tree species contributed about 37% of the total valid allometric equations, and 12% verified equations were for oven-dried biomass of 10 species. This scenario pinpointed five gaps in the existing allometric equations of Bangladesh. This situation indicates: a. little work on allometric equations of common tree and shrub species, b. most of the works were concentrated on certain species, c. very little proportion of allometric equations for biomass estimation, d. no allometric equation for below-ground biomass and carbon estimation, and d. lower proportion of valid allometric equations.
Bangladesh Forest Research Institute (BFRI) was usually responsible for the development of allometric equations for estimating volume and biomass since 1971. Forest Department also developed some volume allometric equations in cooperation with BFRI under specific forest inventory from 1971 to 2000. The contribution of individual researchers in developing allometric equations was quite low during that period. Recently (2001-2016), the contribution from the individual researchers has increased. Previously, almost all efforts were given to derived volume equations for different tree species in the natural forest and plantation, to estimate the commercial volume stock of timber in particular forest and species as well. This could be the reason a very small number of biomass allometric equations were found in Bangladesh during 1971 to 2000. Few fuel wood species (*Acacia mangium, Acacia auriculiformis, Senna siamea* and *Sonneratia apetala*) have gotten more emphasis to derive allometric equations.

Development of biomass and volume allometric equations requires extensive planning, field works, sample analysis in the laboratory, and data analysis. These activities are mostly destructive, difficult, and expensive to repeat. Therefore, these activities require consistency in field work and equation selection process. Most of the allometric equations, 45% and 24% of the total allometric equations, failed to meet the requirements of statistical credibility and conceptual verification respectively under quality control scheme. This large proportion of invalid equations (57%) may be from lack of awareness on the quality control scheme of the derived allometric equations. So, it is suggested to include interval of calibration, residual standard deviation, coefficient of regression value, number of sample trees and location of sample tree or data collection in the document to meet the requirements of quality control scheme.

During the last National Forest Assessment in Bangladesh (2005-07), globally available equations and factors were used to calculate the above-ground biomass of forest. The Sundarban Carbon inventory in 2009-10 used the globally available equations for the mangrove species to calculate the carbon stock in the Sundarban Reserved Forest [17]. However, the accuracy can be questionable as they were using some general allometric equations [16, 18]. Therefore, development of allometric equations for local species, considering various factors for different forest types, is essential to ensure accuracy in volume, biomass and carbon estimation [12]. Major species of bamboo natural/homestead, coastal afforestation, fresh water swamp forest, inland chars, mango plantation, associate species of Sal forest, major species of the Sundarbans and tree species outside the forest (table 6) should be given more emphasis during the development of biomass and volume allometric equations in Bangladesh.

**Table 6.** List of recommended species for further development of allometric equations in Bangladesh.

| Acacia catechu | Bombax ceiba | Dendrocalamus longispathus |
| Adina cordifolia | Borassus flabellifer | Dillenia indica |
| Albizia lebbeck | Bruguiera gymnorrhiza | Dillenia pentagyna |
| Albizia odoratissimus | Bruguiera sexangula | Diospyros peregrina |
| Anacardium occidentale | Butea monosperma | Diospyros philippensis |
| Areca catechu | Calophyllum inophyllum | Duabanga grandiflora |
| Avicennia alba | Cassia fistula | Dysoxylum binectariferum |
| Avicennia marina | Cerbera manghas | Erythrina orientalis |
| Avicennia officinalis | Chickrassia tabularis | Excoecaria indica |
| Bambusa arundinacea | Clerodendrum inerne | Feronia limonia |
| Bambusa balcooa | Cocos nucifera | Ficus bengalensis |
| Bambusa longispathata | Cynometra ramiflora | Ficus hispida |
| Bambusa polymorpha | Dalbergia sisoo | Ficus religiosa |
| Bambusa tulda | Dalbergia spinosa | Heritiera fomes |
| Bambusa vulgaris | Dillenia pentagyna | Hibiscus tiliaeus |
| Barringtonia acutangula | Delonix regia | Khaya anthotheca |
| Leucaena leucocephala | Pongamia pinnata | Pithecellobium dulce |
| Litchi chinensis | Psidium guajava | Tamarix indica |
| Lumnitsera racemosa | Rhizophora apiculata | Terminalia belerica |
| Melocanna baccifera | Rhizophora mucronata | Terminalia catappa |
Michelia champca  Schima wallichii  Toona ciliata
Mimosops elengi  Sonneratia apetala  Trema orientalis
Moringa oleifera  Sonneratia caseolaris  Xylocarpus granatum
Nypa fruticans  Spondias dulce  Xylocarpus mekongensis
Phoenix paludosa  Syzygium grandis  Zizyphus mauritiana
Phoenix sylvestris  Tamarindus indica

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Appendix A

| Sl no | Source |
|-------|--------|
| 1 | Alamgir, M., Al-Amin, M. 2008. Allometric models to estimate biomass organic carbon stock in forest vegetation. Journal of Forestry Research 19 (2): 101-106 |
| 2 | Chaffey, D.R., Miller, F.R., Sandom, J.H. 1985. A forest inventory of the Sundarbans, Bangladesh. Project report 140, Overseas Development Administration, Land Resources Development Centre, England |
| 3 | Cox, F.Z. 1984. Volume functions for plantation species and elements for growth models for Teak. Field Document no 2, Assistance to the Forestry Sector of Bangladesh, Food and Agricultural Organization of the United Nations, FAO/UNDP Project BGD/79/017 |
| 4 | Das, N. 2014. Modeling Develops to Estimate Leaf Area and Leaf Biomass of Lagerstroemia speciosa in West Vanugach Reserve Forest of Bangladesh. ISRN Forestry, doi. org/10.1155/2014/486478 |
| 5 | Das, S., Davidson, J., Latif, M.A., Rahman, F., Das, S. 1985. Tree volume tables for Moluccana (Paraserianthes falcataria syn. Albizia falcataria syn. A. moluccana) in Bangladesh. Bulletin no 4, Inventory Division, Bangladesh Forest Research Institute, Chittagong. |
| 6 | Das, S., Rahman, M.F., Reza, N.A., Latif, M.A. 1992. Tree volume tables for Sal (Shorea robusta Gaertn. f.) in the plantations of Bangladesh. Bulletin 7, Forest Inventory Series, Bangladesh Forest Research Institute, Chittagong, 1-11 pp. |
| 7 | Davidson, J., Das, S., Khan, S.A., Latif, M.A., Zashimuddin, M. 1985. Tree volume tables for small Eucalypt round wood in Bangladesh. Bulletin no 4, Silviculturer Research Division, Bangladesh Forest research Institute, Chittagong |
| 8 | Deb, J.C., Halim, M.A., Ahmed, E. 2012. An allometric equation for estimating stem biomass of Acacia auriculiformis in the north-eastern region of Bangladesh. Southern Forests 74(2): 103–113 |
9  Drigo, R., Latif, M.A., Chowdhury, J.A., Shaheduzzaman, M. 1987. The maturing mangrove plantations of the coastal afforestation project. Food and Agricultural Organization of the United Nations, FAO/UNDP Project BDG/85/085, Assistant to the Forestry Sector.

| Sl no | Source |
|-------|--------|
| 10    | Drigo, R., Shaheduzzaman, M., Chowdhury, J.A. 1988. Inventory of forest resources of Southern Sylhet Forest Division. Assistance to Forestry Sector - Phase II, Field Document no 3, Food and Agriculture Organisation of the United Nations, FAO/UNDP Project BGD/85/085 |
| 11    | Hossain, S.M.Y., Martin, A.R. 2013. Merchantable timber production in Dalbergia sissoo plantations across Bangladesh: regional patterns, management practices and edaphic factors. Journal of Tropical Forest Science 25(3): 299-309 |
| 12    | Islam, S.M.Z., Ahmed, K.U., Khan, M.I. 2014. Mathematical models for estimating stem volume and volume tables of Rubber tree. Bulletin 10, Forest Inventory Series, Bangladesh Forest Research Institute, Chittagong. |
| 13    | Islam, S.M.Z., Khan, M.I. Ahmed, K.U. 2012. Volume equations and tables for Rajkoroi (Albizia richardiana King and Prain) planted in the southern part of Bangladesh. Bangladesh Journal of Forest Science 32 (1): 28-39 |
| 14    | Islam, S.S., 1988. Commercial volume table for teak (Tectona grandis) in Bangladesh by regression technique. Bano Biggyan Patrika 17 (1&2): 55-67 |
| 15    | Islam, S.S., Kabir, J., Masum, A.K.M. 2012. Volume Table of Raintree (Samanea saman) in Bangladesh by Regression Technique. Open Journal of Statistics 2: 115-119 |
| 16    | Islam, S.S., Reza, N.A., Hasnin, M., Khan, M.A.S., Islam, M.R., Siddiqi, N.A. 1992. Volume table of young Keora (Sonneratia apetala) trees for the western coastal belt of Bangladesh. Bulletin 1, Plantation Trial Unit Series, Bangladesh Forest Research Institute, Chittagong, 1-23 pp. |
| 17    | Khan, M.N.I., Faruque, O. 2010. Allometric relationships for predicting the stem volume in a Dalbergia sissoo Roxb. plantation in Bangladesh. iForest 3: 153-158 |
| 18    | Kingston, B. 1979. A collation of tree and bamboo volume tables of Bangladesh. Field Document no 15, Food and Agricultural Organization of the United Nations, UNDP/FAO Project BGD/72/005, Forest Research Institute, Chittagong |
| 19    | Latif M.A., Habib, M.A. 1994. Biomass tables for Acacia mangium grown in the plantations in Bangladesh. Journal of Tropical Forest Science 7(2): 296- 302 |
| 20    | Latif, M.A., 1988. Biomass tables for young Eucalyptus grown in Bangladesh. Bano Biggyan Patrika 17 (1 & 2): 46-54 |
| Sl no | Source |
|-------|--------|
| 21    | Latif, M.A., Das, S., Rahman, M.F., Chowdhury, J.A. 1994. Tree volume tables for Baen (Avicennia officinalis L.) in the coastal plantations of Bangladesh. In: Latif, M.A. (ed.), Tree volume table for keora (Sonneratia apetala) and Baen (Avicennia officinalis) in the coastal plantation of Bangladesh. Bulletin 8, Forest Inventory Division, Bangladesh Forest Research Institute, Chittagong, 21-23 pp. |
| 22    | Latif, M.A., Habib, M.A. 1993. Biomass table for Acacia auriculiformis grown in the plantation in Bangladesh. Indian Journal of Forestry 16 (4): 323-327 |
| 23    | Latif, M.A., Habib, M.A. 1994. Biomass tables for minjiri (Cassia Siamea Lam.) grown in the plantations in Bangladesh. Bangladesh Journal of Forest Science 23 (1): 59-64 |
| 24    | Latif, M.A., Habib, M.A., Das, S., 1993. Tree volume tables for Acacia mangium in the plantations of Bangladesh. Bangladesh Journal of Forest Science 22 (1 & 2): 23-29 |
| 25    | Latif, M.A., Islam, M.N. 1984a. Tree volume volume tables for Syzygium grande (Wt.) Wald (Dhakijam). In: Choudhury, J.H., and Davidson, J. (eds.), Tree volume tables for four species grown in plantation in Bangladesh. Bulletin 2, Inventory Division, Bangladesh Forest Research institute. Chittagong, Bangladesh, pp. 25-57. |
| 26    | Latif, M.A., Islam, M.N. 1984b. Tree volume tables for Artocarpus chaplasha Roxb. (Chapalish). In: Choudhury, J.H., and Davidson, J. (eds.), Tree volume tables for four species grown in plantation in Bangladesh. Bulletin 2, Inventory Division, Bangladesh Forest Research institute. Chittagong, Bangladesh, pp. 58-92. |
| 27    | Latif, M.A., Islam, M.N. 1984c. Tree volume tables for Dipterocarpus turbintus Gaertn. F. (Tali Garjan). In: Choudhury, J.H., and Davidson, J. (eds.), Tree volume tables for four species grown in plantation in Bangladesh. Bulletin 2, Inventory Division, Bangladesh Forest Research institute. Chittagong, Bangladesh, pp. 122-128. |
| 28    | Latif, M.A., Islam, M.N. Choudhury, J.H. 1984. Tree volume tables for Gmelina arborea Roxb. (Gamar). In: Choudhury, J.H., and Davidson, J. (eds.), Tree volume tables for four species grown in plantation in Bangladesh. Bulletin 2, Inventory Division, Bangladesh Forest Research institute. Chittagong, Bangladesh, pp. 93-121. |
| 29    | Latif, M.A., Islam, M.N., Islam, S.S. 1985. Tree volume tables for Teak (Tectona grandis) in Bangladesh. Bulletin no 5, Inventory Division, Bangladesh Forest Research Institute, Chittagong. |
| Sl no | Source |
|-------|--------|
| 30    | Latif, M.A., Islam, M.S., Islam, S.M.Z. 1999. Volume tables for sissoo, kori, mahogany, eucalyptus and bokain planted on croplands in the western part of Bangladesh. Bangladesh Forest Research Institute, Chittagong. |
| 31    | Latif, M.A., Islam, M.S., Islam, S.M.Z., 2000. Volume tables for Sissoo, Koroi, Akashmoni, Babla, Mahogany, and Rain tree planted on embankments and road sides in the coastal areas of Bangladesh. Bulletin 9, Forest Inventory Series, Bangladesh Forest Research Institute, Chittagong. |
| 32    | Latif, M.A., Islam, S.M.Z. 2000. Volume tables for 11 important tree species grown in the home gardens of Bangladesh. Forest Inventory Division, Bangladesh Forest Research Institute, Chittagong. |
| 33    | Latif, M.A., Islam, S.M.Z. 2004. Timber and fuelwood volume tables for Acacia auriculiformis, A. mangium, Eucalyptus camaldulensis and Dalbergia sissoo in plantations in Bangladesh. Forestry Sector Project, Bangladesh Forest Department and Bangladesh Forest Research Institute, Chittagong. |
| 34    | Latif, M.A., Islam, S.S., Davidson, J. 1986. Metric volume tables for some tree species found in the natural forests of Bangladesh. Bulletin 6, Inventory Division, Bangladesh Forest Research Institute, Chittagong. |
| 35    | Latif, M.A., Khan, A.F.M.K., Hossain, M.M. 1998. Stump diameter -DBH - volume relationships for Teli Garjan (Dipterocarpus turbinatus), Dhakijam (Syzygium grande) and Teak (Tectona grandis) in Bangladesh. Bangladesh Journal of Forest Science 27 (1): 16-24 |
| 36    | Latif, M.A., Rahman, M.F., Das, S. 1995. Volume table for Acacia auriculiformis, Cassia siamea and Pinus caribaea in Bangladesh. Bangladesh Journal of Forest Science 24 (2): 22-30 |
| 37    | Mahmood, H., Saha, C., Abdullah, S.M.R., Saha, S., Siddique, M.R.H. 2015b. Allometric biomass, nutrient and carbon stock models for Kandelia candel of the Sundarbans, Bangladesh. Trees DOI: 10.1007/s00468-015-1314-0 |
| 38    | Mahmood, H., Shaikh, M.A.A., Saha, C., Abdullah, S.M.R., Saha, S., Siddique, M.R.H. 2016. Above-ground biomass, nutrients and carbon in Aegiceras corniculatum of the Sundarbans. Open Journal of Forestry 6 (2): 72-89 |
| 39    | Mahmood, H., Siddique, M.R.H., Bose, A., Limon, S.H., Chowdhury, M.R.K. Saha, S. 2012. Allometry, above-ground biomass and nutrient distribution in Ceriops decandra (Griffith) Ding Hou dominated forest types of the Sundarbans mangrove forest, Bangladesh. Wetlands Ecology and Management 20: 539-548 |
| Sl no | Source |
|-------|--------|
| 40    | Mahmood, H., Siddique, M.R.H., Saha, S., Abdullah, S.M.R. 2015a. Allometric models for biomass, nutrients and carbon stock in Excoecaria agallocha of the Sundarbans, Bangladesh. Wetlands Ecology and Management 23 (4): 765-774 |
| 41    | Rahman, M.F., Das, S., Latif, M.A. 2001. Volume table for Koroi (albizia procera) and Arjun (Terminalia arjuna) trees planted in the central part of Bangladesh. Bangladesh Journal of Forest Science 30 (1): 39-46. |
| 42    | Rahman, M.F., Das, S., Reza, N.A., Chowdhury, J.A., Latif, M.A. 1994. Tree volume table for Keora (Sonneratia apetala Buch.-Ham) in the coastal plantation of Bangladesh. In: Latif, M.A. (ed.), Tree volume table for keora (Sonneratia apetala) and Baen (Avicennia officinalis) in the coastal plantation of Bangladesh. Bulletin 8, Forest Inventory Division, Bangladesh Forest Research Institute, Chittagong, 1-20 pp. |
| 43    | Rahman, M.M., Kamaluddin, M. 1996. Volume table for natural hybrid trees of Acacia mangium X Acacia auriculiformis in plantations of Bangladesh. Chittagong University Studies, 20 (1): 89-94 |
| 44    | Revilla, J.A.V., Ahmed, I.U., Hossain, A. 1998a. Forest Inventory of the Sundarbans Reserved Forest, Final Report, Volume 1. Mandala Agricultural Development Corporation and Forest Department, Ministry of Environment and Forests, Dhaka, Bangladesh |
| 45    | Revilla, J.A.V., Ahmed, I.U., Saha, U.K. 1998b. Forest Inventory of the Natural Forest and Forest Plantations (Sylhet Forest Division), Final Report. Gob/Wb, Forest Resources Management Project, Technical Assistance Component. (Mandala Agricultural Development Corporation and Forest Department, Ministry of Environment and Forests, Dhaka, Bangladesh). |
| 46    | Roy, B. 2012. Species-specific allometric models for estimation of aboveground stem biomass of three dominant tree species at Satchari National park. Unpublished MS thesis. Department of Forestry and Environmental Science, Shahjalal University of Science and Technology, Sylhet, Bangladesh |
| 47    | Sarker, S.K., Das, N., Chowdhury, M.Q., Haque, M.M. 2013. Developing allometric equations for estimating leaf area and leaf biomass of Artocarpus chaplasha in Raghunandan Hill Reserve, Bangladesh. Southern Forests 75(1): 51-57 |
| 48    | Siddique, M.R.H., Mahmood, H., Chowdhury, M.R.K. 2012. Allometric relationship for estimating above-ground biomass of Aegialitis rotundifolia Roxb. of Sundarbans mangrove forest, in Bangladesh. Journal of Forestry Research 23 (1): 23-28. |
| 49    | Sylvander, R., Latif, M.A., Karlsson, A. 2001. Forest inventory of the Sal forest of Bangladesh, Volume 1, Technical Report, Forestry Sector Project, Forest Department, Ministry of Environment and Forest, Dhaka |
Ullah, M.R., Banik, G.R., RajibBanik. 2014. Developing Allometric Models for Carbon Stock Estimation in Eighteen Year Old Plantation Forests of Bangladesh. Jacobs Journal of Microbiology and Pathology 1(1): 006
### Appendix B

| Genus   | Species | Local name | Family      | Vegetation Component                  | Equation                                                                 | Sample size | R²   | MSE   | Ref. No |
|---------|---------|------------|-------------|---------------------------------------|--------------------------------------------------------------------------|-------------|------|-------|---------|
| Senna   | siamea  | Minjiri    | Leguminosae | Total above-ground green biomass      | \( \log(\text{Green biomass}) = -1.5851 + 2.4855 \times \log(\text{DBH}) \) | 120          | 0.972| 0.0232| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Total above-ground green biomass      | \( \log(\text{Green biomass}) = -4.4303 + 2.4855 \times \log(\text{GBH}) \) | 120          | 0.972| 0.0232| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Total above-ground green biomass      | \( \log(\text{Green biomass}) = -2.0847 + 2.1723 \times \log(\text{DBH}) + 0.5141 \times \log(\text{Height}) \) | 120          | 0.977| 0.0189| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Total above-ground green biomass      | \( \log(\text{Green biomass}) = -4.5714 + 2.1723 \times \log(\text{GBH}) + 0.5141 \times \log(\text{Height}) \) | 120          | 0.977| 0.0189| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem green biomass                    | \( \log(\text{Green biomass}) = -2.1442 + 2.5917 \times \log(\text{DBH}) \) | 120          | 0.966| 0.0313| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem green biomass                    | \( \log(\text{Green biomass}) = -5.1110 + 2.5917 \times \log(\text{GBH}) \) | 120          | 0.966| 0.0313| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem green biomass                    | \( \log(\text{Green biomass}) = -2.7095 + 2.2372 \times \log(\text{DBH}) + 0.5817 \times \log(\text{Height}) \) | 120          | 0.972| 0.0257| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem green biomass                    | \( \log(\text{Green biomass}) = -5.2705 + 2.2372 \times \log(\text{GBH}) + 0.5817 \times \log(\text{Height}) \) | 120          | 0.972| 0.0257| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Branch green biomass                  | \( \log(\text{Green biomass}) = -5.1100 + 2.5917 \times \log(\text{GBH}) \) | 120          | 0.570| 0.3528| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Branch green biomass                  | \( \log(\text{Green biomass}) = -5.5434 + 1.9752 \times \log(\text{GBH}) \) | 120          | 0.570| 0.3528| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Branch green biomass                  | \( \log(\text{Green biomass}) = -3.2955 + 1.3142 \times \log(\text{DBH}) + 1.0521 \times \log(\text{Height}) \) | 120          | 0.585| 0.3355| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Branch green biomass                  | \( \log(\text{Green biomass}) = -4.7999 + 1.3142 \times \log(\text{GBH}) + 1.0521 \times \log(\text{Height}) \) | 120          | 0.585| 0.3355| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Leaves and twigs green biomass        | \( \log(\text{Green biomass}) = -2.1219 + 1.3142 \times \log(\text{DBH}) + 1.0521 \times \log(\text{Height}) \) | 120          | 0.761| 0.1568| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Leaves and twigs green biomass        | \( \log(\text{Green biomass}) = -4.3311 + 1.9299 \times \log(\text{GBH}) \) | 120          | 0.761| 0.1568| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Leaves and twigs green biomass        | \( \log(\text{Green biomass}) = -0.6183 + 2.8726 \times \log(\text{DBH}) - 1.5471 \times \log(\text{Height}) \) | 120          | 0.820| 0.098 | 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Leaves and twigs green biomass        | \( \log(\text{Green biomass}) = -3.9067 + 2.8726 \times \log(\text{GBH}) - 1.5471 \times \log(\text{Height}) \) | 120          | 0.820| 0.098 | 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem and branch green biomass         | \( \log(\text{Green biomass}) = -2.0512 + 2.6006 \times \log(\text{DBH}) \) | 120          | 0.964| 0.0339| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem and branch green biomass         | \( \log(\text{Green biomass}) = -5.0282 + 2.6006 \times \log(\text{GBH}) \) | 120          | 0.964| 0.0339| 23      |
| Senna   | siamea  | Minjiri    | Leguminosae | Stem and branch green biomass         | \( \log(\text{Green biomass}) = -2.9256 + 2.0525 \times \log(\text{DBH}) + 0.8996 \times \log(\text{Height}) \) | 120          | 0.978| 0.0201| 23      |
| Genus          | Species | Local name | Family          | Unit of Y | Vegetation Component | Equation                                           | Sample size | R²       | MSE       | F1       | Ref. No |
|---------------|---------|------------|-----------------|-----------|----------------------|----------------------------------------------------|-------------|----------|-----------|----------|---------|
| *Senna*       | *siamea*| Minjiri    | Leguminosae     | kg        | Stem and branch green biomass | $\log(\text{Green biomass}) = -5.2752 + 2.0525 \cdot \log(\text{GBH}) + 0.8969 \cdot \log(\text{Height})$ | 120         | 0.978    | 0.0201    | 23       |         |
| *Senna*       | *siamea*| Minjiri    | Leguminosae     | kg        | Branch, leaves and twigs green biomass | $\log(\text{Green biomass}) = -2.5173 + 2.281 \cdot \log(\text{DBH}) + 0.494 \cdot \log(\text{Height})$ | 120         | 0.809    | 0.1641    | 23       |         |
| *Senna*       | *siamea*| Minjiri    | Leguminosae     | kg        | Branch, leaves and twigs green biomass | $\log(\text{Green biomass}) = -2.9974 + 1.98 \cdot \log(\text{DBH}) + 0.494 \cdot \log(\text{Height})$ | 120         | 0.811    | 0.1613    | 23       |         |
| *Senna*       | *siamea*| Minjiri    | Leguminosae     | kg        | Branch, leaves and twigs green biomass | $\log(\text{Green biomass}) = -5.264 + 1.98 \cdot \log(\text{GBH}) + 0.494 \cdot \log(\text{Height})$ | 120         | 0.811    | 0.1613    | 23       |         |

| Genus          | Species | Local name | Family          | Unit of Y | Vegetation Component | Equation                                           | Sample size | R²       | MSE       | F1       | Ref. No |
|---------------|---------|------------|-----------------|-----------|----------------------|----------------------------------------------------|-------------|----------|-----------|----------|---------|
| *Sonnerata*   | *apetala*| Keora     | Lythraceae     | m³        | Total volume over bark | $\log(\text{Volume}) = -12.0901 + 2.502194 \cdot \log(\text{GBH})$ | 713         | 0.912    | 42        |         |         |
| *Sonnerata*   | *apetala*| Keora     | Lythraceae     | m³        | Total volume over bark | $\log(\text{Volume}) = -11.6632 + 1.941989 \cdot \log(\text{GBH}) + 0.754839 \cdot \log(\text{Height})$ | 713         | 0.991    | 42        |         |         |
| *Terminalia*  | *arjuna*| Arjun     | Combretaceae   | m³        | Total volume over bark | $\log(\text{Volume}) = -11.1885 + 2.221244 \cdot \log(\text{GBH})$ | 177         | 0.986    | 41        |         |         |
| *Terminalia*  | *arjuna*| Arjun     | Combretaceae   | m³        | Total volume over bark | $\log(\text{Volume}) = -11.3794 + 1.896423 \cdot \log(\text{GBH}) + 0.653558 \cdot \log(\text{Height})$ | 177         | 0.997    | 41        |         |         |
| *Shorea*      | *robusta*| Sal       | Dipterocarpaceae | m³        | Total volume over bark | $\log(\text{Volume}) = -12.0554 + 2.517894 \cdot \log(\text{DBH})$ | 499         | 0.966    | 0.0385    | 0.057    | 38      |
| *Shorea*      | *robusta*| Sal       | Dipterocarpaceae | m³        | Total volume over bark | $\log(\text{Volume}) = -9.615639 + 2.033071 \cdot \log(\text{DBH}) + 0.7361229 \cdot \log(\text{Height})$ | 499         | 0.955    | 0.0077    | 0.088    | 38      |
| *Shorea*      | *robusta*| Sal       | Dipterocarpaceae | m³        | Total volume over bark | $\log(\text{Volume}) = -11.938881 + 2.033071 \cdot \log(\text{GBH}) + 0.7361229 \cdot \log(\text{Height})$ | 499         | 0.955    | 0.0077    | 0.088    | 38      |
| *Shorea*      | *robusta*| Sal       | Dipterocarpaceae | m³        | Total volume over bark | $\log(\text{Volume}) = -12.0554 + 2.517894 \cdot \log(\text{DBH})$ | 499         | 0.966    | 0.0385    | 0.057    | 38      |

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| Species          | Family        | m3    | Total volume under bark | Volume = 0.003255 + 0.0000269 * DBH'^(2) * Height | 499  | 0.962  | 0.0065  | 0.080  | 38 |
|------------------|---------------|-------|--------------------------|-----------------------------------------------------|------|--------|---------|--------|----|
| Shorea robusta   | Dipterocarpaceae | m3    | Total volume under bark  | Volume = 0.003255 + 0.0000027255 * GBH'^(2) * Height | 499  | 0.962  | 0.0065  | 0.080  | 38 |
| Sonneratia apetala | Keora        | m3    | Total volume over bark   | Volume = 0.0052 - 0.0022 * X + 0.0005 * DBH'^(2) | 461  | 0.86   | 0.0000  | 0.009  | 16 |
| Sonneratia apetala | Keora        | m3    | Total volume over bark   | Log (Volume) = -9.1937 + 1.7683 * Log (DBH) + 0.7358 * Log (Height) | 461  | 0.95   | 0.0547  | 0.003  | 16 |
| Sonneratia apetala | Keora        | m3    | Total volume over bark   | Log (Volume) = -9.2587 + 1.6463 * Log (DBH) + 0.9138 * Log (Height) | 464  | 0.94   | 0.0744  | 0.005  | 16 |
| Acacia mangium   | Fabaceae      | m3    | Total volume over bark   | Log (Volume) = -10.7488 + 2.2178 * Log (GBH) | 132  | 0.98   | 0.0152  | 0.006  | 24 |

Note: The table includes equations for calculating the total volume under and over bark for different species. The equations involve variables such as DBH (diameter at breast height) and height, with coefficients and constants provided for each species. The table also includes the coefficients for each variable and the correlation coefficients (r) for the models.
| Genus    | Species   | Local name | Family       | Unit of Y | Vegetation Component | Equation                                                                 | Sample size | R2     | MSE  | FI      | Ref. No |
|----------|-----------|------------|--------------|-----------|----------------------|---------------------------------------------------------------------------|-------------|--------|------|---------|---------|
| Acacia   | mangium   | Mangium    | Fabaceae     | m³        | Total volume over bark | Log (Volume) = -9.1426 + 1.7612 * Log (DBH) + 0.83335 * Log (Height)     | 132         | 0.989  | 0.0091 | 0.0048  | 24      |
| Acacia   | mangium   | Mangium    | Fabaceae     | m³        | Total volume under bark | Log (Volume) = -11.1587 + 1.7612 * Log (GBH) + 0.83335 * Log (Height)     | 132         | 0.989  | 0.0091 | 0.0048  | 24      |
| Acacia   | mangium   | Mangium    | Fabaceae     | m³        | Total volume under bark | Log (Volume) = -10.2221 + 1.74054 * Log (DBH)                             | 132         | 0.977  | 0.0219 | 0.0048  | 24      |
| Acacia   | mangium   | Mangium    | Fabaceae     | m³        | Total volume under bark | Log (Volume) = -11.6633 + 2.3246 * Log (GBH)                             | 132         | 0.977  | 0.0219 | 0.0048  | 24      |
| Mixed    |           | kg         |              |           | Total above-ground green biomass | Log (Green biomass) = -1.3933 + 2.39602 * Log (DBH)                       | 294         | 0.948  |       |         | 20      |
| Mixed    |           | kg         |              |           | Total above-ground green biomass | Log (Green biomass) = -4.136 + 2.39602 * Log (GBH)                       | 294         | 0.948  |       |         | 20      |
| Mixed    |           | kg         |              |           | Total above-ground green biomass | Log (Green biomass) = -2.228 + 1.81492 * Log (DBH) + 0.85007 * Log (Height) | 294         | 0.9575 |       |         | 20      |
| Mixed    |           | kg         |              |           | Total above-ground green biomass | Log (Green biomass) = -4.306 + 1.81492 * Log (GBH) + 0.85007 * Log (Height) | 294         | 0.9575 |       |         | 20      |
| Tectona  | grandis   | Teak       | Lamiaceae    | cft       | Total volume over bark | Volume = 0.084 * DBH^2.263                                                | 635         | 0.88   | 0.23  | 40.79   | 17      |
| Tectona  | grandis   | Teak       | Lamiaceae    | cft       | Total volume under bark | Log (Volume) = -9.1426 + 1.7612 * Log (DBH) + 0.83335 * Log (Height)     | 132         | 0.989  | 0.0091 | 0.0048  | 24      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | kg        | Total above-ground green biomass | Log (Green biomass) = -1.3577 + 2.4177 * Log (DBH)                       | 139         | 0.9674 |       |         | 22      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | kg        | Total above-ground green biomass | Log (Green biomass) = -2.2782 + 1.9736 * Log (DBH) + 0.80131 * Log (Height) | 139         | 0.986  | 0.0084 |         | 22      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | kg        | Stem green biomass     | Log (Green biomass) = -3.1661 + 2.1982 * Log (DBH) + 0.74749 * Log (Height) | 139         | 0.983  | 0.0119 |         | 22      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | m³        | Total volume over bark | Log (Volume) = -8.208 + 2.2389 * Log (DBH)                              | 139         | 0.959  | 0.0061 |         | 36      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | m³        | Total volume over bark | Log (Volume) = -10.7709 + 2.2389 * Log (GBH)                             | 139         | 0.959  | 0.0061 |         | 36      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | m³        | Total volume over bark | Log (Volume) = -9.125 + 1.918 * Log (DBH) + 0.67988 * Log (Height)       | 139         | 0.988  | 0.0648 |         | 36      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | m³        | Total volume over bark | Log (Volume) = -11.3205 + 1.918 * Log (GBH) + 0.67988 * Log (Height)     | 139         | 0.988  | 0.0648 |         | 36      |
| Acacia   | auriculiformis | Akashmon | Leguminosae  | m³        | Total volume under bark | Log (Volume) = -9.187 + 2.468 * Log (DBH)                               | 139         | 0.9688 | 0.0059 |         | 36      |
| Species       | Genus      | Family    | Total volume under bark | Log (Volume)                          | R²   | p-value | n  |
|--------------|------------|-----------|-------------------------|--------------------------------------|------|---------|----|
| *Acacia auriculiformis* Akashmon | Leguminosae | m³ | Total volume under bark | Log (Volume) = -12.0121 + 2.468 * Log (GBH) | 0.9688 | 0.0059 | 36 |
| *Acacia auriculiformis* Akashmon | Leguminosae | m³ | Total volume under bark | Log (Volume) = -10.2398 + 2.100244 * Log (DBH) + 0.780214 * Log (Height) | 0.9773 | 0.0048 | 36 |
| Genus           | Species        | Local name | Family                  | Unite of Vegetation Component | Equation                                                                 | Sample size | $R^2$  | MSE   | FI     | Ref. |
|-----------------|----------------|------------|-------------------------|-------------------------------|---------------------------------------------------------------------------|------------|--------|-------|-------|------|
| Acacia          | auriculiformis | Akashmoni  | Leguminosae             | m3                            | Total volume under bark $\log (Volume) = -12.536 + 2.648 \log (GBH) + 0.783 \log (Height)$ | 139        | 0.977  | 0.004 | 36    |      |
| Senna           | siamea         | Minjiri    | Leguminosae             | m3                            | Total volume over bark $\log (Volume) = -11.165 - 1.871 \log (GBH)$        | 120        | 0.979  | 0.004 | 36    |      |
| Senna           | siamea         | Minjiri    | Leguminosae             | m3                            | Total volume over bark $\log (Volume) = -11.353 - 2.403 \log (GBH)$        | 120        | 0.979  | 0.004 | 36    |      |
| Senna           | siamea         | Minjiri    | Leguminosae             | m3                            | Total volume over bark $\log (Volume) = -9.514 - 1.871 \log (DBH) + 0.897 \log (Height)$ | 120        | 0.989  | 0.005 | 36    |      |
| Senna           | siamea         | Minjiri    | Leguminosae             | m3                            | Total volume over bark $\log (Volume) = -11.656 - 2.403 \log (GBH)$        | 120        | 0.989  | 0.005 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume over bark $\log (Volume) = -8.784 - 2.403 \log (GBH)$         | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume over bark $\log (Volume) = -11.345 - 2.403 \log (GBH)$        | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -11.656 - 2.403 \log (GBH)$      | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -9.334 - 2.483 \log (GBH)$       | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -12.766 - 2.483 \log (GBH)$      | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -10.177 - 2.483 \log (GBH)$      | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -12.539 - 2.483 \log (GBH)$      | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -9.116 - 2.483 \log (GBH)$       | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -11.958 - 2.483 \log (GBH)$      | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -9.751 - 2.483 \log (GBH)$       | 120        | 0.986  | 0.002 | 36    |      |
| Pinus           | caribaea       | Pine       | Pinaceae                | m3                            | Total volume under bark $\log (Volume) = -11.966 - 2.483 \log (GBH)$      | 120        | 0.986  | 0.002 | 36    |      |
| Acacia          | auriculiformis | Akashmoni  | Leguminosae             | m3                            | Total volume over bark $\log (Volume) = -11.839 - 2.403 \log (GBH)$       | 124        | 0.973  | 0.031 | 36    |      |
| Senna           | siamea         | Minjiri    | Leguminosae             | m3                            | Total volume over bark $\log (Volume) = -11.507 - 1.973 \log (GBH) + 0.624 \log (Height)$ | 124        | 0.979  | 0.008 | 36    |      |
| Swietenia       | macrophylla    | Mahogany   | Malvaceae               | m3                            | Total volume over bark $\log (Volume) = -1.8565 - 2.403 \log (GBH)$       | 124        | 0.942  | 0.025 | 36    |      |
| Species          | Common Name | Family    | m³  | Total Volume over bark | Log (Volume) = \(-12.4361459 + 1.8661846 \times \) Log (GBH) + 1.2282822 \times \) Log (Height) |
|------------------|-------------|-----------|-----|------------------------|------------------------------------------------------------------|
| Swietenia macrophylla | Mahogany    | Meliaceae | m³  | Total volume over bark | 245 0.96 \n | Albizia spp | Koroi       | Mimosaceae | m³  | Total volume over bark | 178 0.929 \n
| Genus | Species | Local name | Family | Unite of Y | Vegetation Component | Equation | Sample size | R2  | MSE   | F1  | Ref. No |
|-------|---------|------------|--------|------------|----------------------|----------|-------------|-----|-------|-----|---------|
| Albizia | spp | Koroi | Mimosaceae | m³ | Total volume over bark | \( \text{Log (Volume)} = -12.4 + 1.7131 \times \text{Log (GBH)} + 1.58245 \times \text{Log (Height)} \) | 178 | 0.967 | 31 |
| Dalbergia | sissoo | Sissoo | Fabaceae | m³ | Total volume over bark | \( \text{Log (Volume)} = -12.427775 + 2.6056676 \times \text{Log (GBH)} \) | 202 | 0.902 | 31 |
| Dalbergia | sissoo | Sissoo | Fabaceae | m³ | Total volume over bark | \( \text{Log (Volume)} = -12.5189939 + 1.9800535 \times \text{Log (GBH)} + 1.0775148 \times \text{Log (Height)} \) | 202 | 0.934 | 31 |
| Acacia | nilotica | Babla | Mimosaceae | m³ | Total volume over bark | \( \text{Log (Volume)} = -11.875835 + 1.8829999 \times \text{Log (GBH)} + 1.0819988 \times \text{Log (Height)} \) | 128 | 0.91 | 31 |
| Acacia | nilotica | Babla | Mimosaceae | m³ | Total volume over bark | \( \text{Log (Volume)} = -12.87524 + 2.5086408 \times \text{Log (GBH)} \) | 190 | 0.952 | 31 |
| Albizia | saman | Rain tree | Mimosaceae | m³ | Total volume over bark | \( \text{Log (Volume)} = -12.3213818 + 1.8912934 \times \text{Log (GBH)} + 1.183443 \times \text{Log (Height)} \) | 190 | 0.974 | 31 |
| Ceriops | decandra | Goran | Rhizophoraceae | g | Leaf | Oven-dried biomass = 2.99 \times (\text{Collar girth})^{1.95} | 48 | 0.89 | 0.02 | 39 |
| Ceriops | decandra | Goran | Rhizophoraceae | g | Branch | Oven-dried biomass = 0.23 \times (\text{Collar girth})^{3.09} | 48 | 0.94 | 0.03 | 39 |
| Ceriops | decandra | Goran | Rhizophoraceae | g | Bark | Oven-dried biomass = 0.77 \times (\text{Collar girth})^{2.23} | 48 | 0.97 | 0.01 | 39 |
| Ceriops | decandra | Goran | Rhizophoraceae | g | Stem with bark | Oven-dried biomass = 3.22 \times (\text{Collar girth})^{2.27} | 48 | 0.97 | 0.01 | 39 |
| Ceriops | decandra | Goran | Rhizophoraceae | g | Total above-ground | Oven-dried biomass = 4.70 \times (\text{Collar girth})^{2.41} | 48 | 0.97 | 0.01 | 39 |
| Genus     | Species       | Local name | Family       | Unit of Y | Vegetation Component | Equation                                                                 | Sample size | R2     | MSE    | RMSE   | AIC    | Bias correction | Ref. No |
|-----------|---------------|------------|--------------|-----------|----------------------|---------------------------------------------------------------------------|-------------|--------|--------|--------|--------|-------------------|---------|
| *Aegialitis* rotundifolia | Nuniya       | Plumbaginaceae | g | Leaf     | Oven-dried biomass = 13.96 * (Collar girth) - 12.38 * (Height) - 0.01 * (Height at girth measurement point) + 0.08 * (Collar girth) * (Height) + (Height at girth measurement point) | 50          | 0.88   | 1392.78| 37.32  | 48     |                   | 48      |
| *Aegialitis* rotundifolia | Nuniya       | Plumbaginaceae | g | Branch  | Oven-dried biomass = 3.09 * (Collar girth)^2 - 22.887 * (Height)^2 + 0.13 * (Collar girth) * (Height) * (Height at girth measurement point) | 50          | 0.92   | 8626.98| 92.882 | 48     |                   | 48      |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Leaf    | Log 10 (Oven-dried biomass) = 0.9256 * Log 10 (DBH^2) - 2.133 | 30          | 0.8499 | 0.051  | 0.226  | -86.652 | 1.146             | 40      |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Branch  | Log 10 (Oven-dried biomass) = 1.1656 * Log 10 (DBH^2) - 1.7047 | 30          | 0.9669 | 0.016  | 0.126  | -122.159 | 1.043             | 40      |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Bark    | Log 10 (Oven-dried biomass) = 1.0824 * Log 10 (DBH^2) - 1.7568 | 30          | 0.9933 | 0.003  | 0.052  | -175.484 | 1.007             | 40      |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Stem without bark | Log 10 (Oven-dried biomass) = 1.0927 * Log 10 (DBH^2) - 1.025 | 30          | 0.9937 | 0.003  | 0.051  | -176.616 | 1.007             | 40      |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Total above-ground | Log 10 (Oven-dried biomass) = 1.0996 * Log 10 (DBH^2) - 0.8572 | 30          | 0.9953 | 0.002  | 0.044  | -185.005 | 1.005             | 40      |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Total above-ground | Log 10 (Nitrogen) = 1.0972 * Log 10 (DBH^2) - 3.0845 | 30          | 0.9922 | 0.0032 | 0.0567 | 7       | 1.008583 | 40 |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Total above-ground | Log 10 (Phosphorus) = 1.0947 * Log 10 (DBH^2) - 5.6790 | 30          | 0.9905 | 0.0039 | 0.0623 | 1.01033 | 40 |
| *Excoecaria agallocha* | Gewa          | Euphorbiaceae | kg | Total above-ground | Log 10 (Potassium) = 1.0990 * Log 10 (DBH^2) - 3.0370 | 30          | 0.9929 | 0.0029 | 0.054  | 1.007774 | 40 |
| Genus          | Species     | Local name | Family            | Unit of Y | Vegetation Component | Equation                                                                 | Sample size | R2     | MSE   | RMS   | AIC   | FI   | Bias correction | Ref. No |
|---------------|-------------|------------|-------------------|-----------|----------------------|---------------------------------------------------------------------------|-------------|--------|-------|-------|-------|------|-----------------|----------|
| *Excoecaria*  | agallocha   | Gewa       | Euphorbiaceae     | kg        | Total above-ground   | Log 10 (Carbon) = 1.1 * Log 10 (DBH^2) - 1.1937                        | 30          | 0.9953 | 0.0019 | 0.044 | 1.005136 | 40   |                  |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Leaf                 | Oven-dried biomass = 0.014 * (DBH)^2 + 0.03                             | 25          | 0.89   | 0.004 | 0.06  | -133.53 | 3   | 0.06            | 37       |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Branch               | Sqrt (Oven-dried biomass) = 0.29 * (DBH) - 0.21                         | 25          | 0.87   | 0.03  | 0.16  | -86.947 | 0.23 |                  |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Bark                 | Sqrt (Oven-dried biomass) = 0.66 * sqrt (DBH) - 0.57                    | 25          | 0.86   | 0.01  | 0.1   | -110.07 | 0.11 | 1               | 37       |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Stem without bark    | Sqrt (Oven-dried biomass) = 1.19 * Sqrt (DBH) - 1.02                    | 25          | 0.86   | 0.03  | 0.18  | -80.521 | 0.34 | 5               | 37       |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Total above-ground   | Oven-dried biomass = 0.21 * (DBH)^2 + 0.12                             | 25          | 0.94   | 0.38  | 0.62  | -18.875 | 0.61 | 6               | 37       |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Total above-ground   | Nitrogen = 0.39 * (DBH)^2 + 0.49                                       | 25          | 0.95   |       |       |      |      | 37              |          |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Total above-ground   | Phosphorus = 0.77 * (DBH)^2 + 0.14                                     | 25          | 0.95   |       |       |      |      | 37              |          |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Total above-ground   | Potassium = 0.87 * (DBH)^2 + 0.07                                      | 25          | 0.95   |       |       |      |      | 37              |          |
| *Kandelia*    | candel      | Goria      | Rhizophoraceae    | kg        | Total above-ground   | Carbon = 0.09 * (DBH)^2 + 0.05                                        | 25          | 0.96   |       |       |      |      | 37              |          |
| *Acacia*      | auriculiformis | Akashmoni | Leguminosae       | kg        | Stem biomass         | Oven-dried biomass = 0.092486 * ((DBH)^2 * (Height))^2 + 1.4765         | 600         | 0.9674 |       | -600.02| 1.01066 | 8   |                  |
| *Albizia*     | saman       | Rain tree  | Mimosaceae        | m^3       | Stem volume          | Log (Volume) = - 8.3013 + 2.1746 * Log (DBH)                            | 205         | 0.86   | 0.07  | 0.21  | 0.15  | 5   |                  |
| *Albizia*     | saman       | Rain tree  | Mimosaceae        | m^3       | Stem volume          | Log (Volume) = - 9.1864 + 1.8502 * Log (DBH) + 0.8234 * Log (Height)    | 205         | 0.9    | 0.05  | 0.18  | 0.15  | 5   |                  |
### Above-ground biomass

Oven-dried biomass:

\[ \text{Oven-dried biomass} = 0.696735 + 0.536662 \times \text{(Biomass)}^{0.8720} \]

Carbon:

\[ \text{Carbon} = -0.379625 + 0.500132 \times \text{(Biomass)}^{0.8970} \]

### Vegetation Component Equations

| Genus   | Species | Local name | Family | Unit of Y | Vegetation Component | Equation                                      | Sample size | R²    | MSE   | AIC   | F1   | Bias correction | Ref. No |
|---------|---------|------------|--------|-----------|----------------------|-----------------------------------------------|-------------|-------|-------|-------|------|-----------------|---------|
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Total above-ground green biomass | \( \log(\text{Green biomass}) = -1.4659 + 2.3256 \times \log(\text{DBH}) \) | 132         | 0.979 | 0.019 | 5     | 3    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Total above-ground green biomass | \( \log(\text{Green biomass}) = -4.1281 + 2.3256 \times \log(\text{GBH}) \) | 132         | 0.979 | 0.019 | 5     | 3    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Total above-ground green biomass | \( \log(\text{Green biomass}) = -1.7073 + 2.1922 \times \log(\text{DBH}) + 0.2331 \times \log(\text{Height}) \) | 132         | 0.977 | 0.018 | 2     | 5    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Total above-ground green biomass | \( \log(\text{Green biomass}) = -4.2168 + 2.1922 \times \log(\text{GBH}) + 0.2331 \times \log(\text{Height}) \) | 132         | 0.977 | 0.018 | 2     | 5    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem green biomass           | \( \log(\text{Green biomass}) = -2.2782 + 2.5213 \times \log(\text{DBH}) \) | 132         | 0.955 | 0.043 | 3     | 1    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem green biomass           | \( \log(\text{Green biomass}) = -5.1644 + 2.5213 \times \log(\text{GBH}) \) | 132         | 0.955 | 0.043 | 3     | 1    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem green biomass           | \( \log(\text{Green biomass}) = -2.7344 + 2.2692 \times \log(\text{GBH}) + 0.4406 \times \log(\text{Height}) \) | 132         | 0.958 | 0.039 | 4     | 7    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem green biomass           | \( \log(\text{Green biomass}) = -5.3320 + 2.2692 \times \log(\text{GBH}) + 0.4406 \times \log(\text{Height}) \) | 132         | 0.958 | 0.039 | 4     | 7    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem and branch green biomass | \( \log(\text{Green biomass}) = -1.8493 + 2.3906 \times \log(\text{DBH}) \) | 132         | 0.975 | 0.021 | 1     | 1    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem and branch green biomass | \( \log(\text{Green biomass}) = -4.5859 + 2.3906 \times \log(\text{GBH}) \) | 132         | 0.975 | 0.021 | 1     | 1    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem and branch green biomass | \( \log(\text{Green biomass}) = -2.4276 + 2.0709 \times \log(\text{GBH}) + 0.5586 \times \log(\text{Height}) \) | 132         | 0.981 | 0.015 | 8     | 3    |                 | 19      |
| Acacia  | mangium| Mangiu     | Fabaceae | kg        | Stem and branch green biomass | \( \log(\text{Green biomass}) = -4.7982 + 2.0709 \times \log(\text{GBH}) + 0.5586 \times \log(\text{Height}) \) | 132         | 0.981 | 0.015 | 8     | 3    |                 | 19      |
| Species               | Type      | Stem biomass Log (Oven-dried biomass) = | Regression Coefficients | R²  | SE Intercept | SE Slope  |
|-----------------------|-----------|--------------------------------------|-------------------------|-----|--------------|-----------|
| Artocarpus chaplasha  | Moraceae  | -0.53361 + 0.988759 * Log (DBH) * (Height) * (Wood density) | 101                     | 0.99| -427.62      | 46        |
| Lagerstroemia speciosa| Lythraceae| -1.34008 + 0.83123 * Log (DBH) + 0.47969 * Log (Height) | 312                     | 0.963| -309.79      | 4         |

| Species               | Type      | Leaf Log (Oven-dried biomass) = | Regression Coefficients | R²  | SE Intercept | SE Slope  |
|-----------------------|-----------|--------------------------------|-------------------------|-----|--------------|-----------|
| Artocarpus chaplasha  | Moraceae  | -4.44814 + 2.0483 * Log (DBH) | 200                     | 1.019| 47           | 1         |
| Lagerstroemia speciosa| Lythraceae| -1.34008 + 0.83123 * Log (DBH) + 0.47969 * Log (Height) | 312                     | 0.963| 4            | 1         |
| Genus | Species | Local name | Family | Unit of Y | Vegetation Component | Equation | Sampl e size | R2    | RMS E | AIC     | FI     | Ref No |
|-------|---------|------------|--------|-----------|----------------------|----------|--------------|-------|-------|---------|--------|--------|
| **Tectona grandis** | Teak | Lamiaceae | kg | Stem biomass | Log (Oven-dried biomass) = 0.07908 + 0.83931 * Log ((DBH)^(2) * (Height) * (Wood density)) | 101 | 0.94 | -76.89 | 46 |
| **Albizia richardiana** | Rajkoroi | Leguminosae | m3 | Total volume over bark | Log (Volume) = -10.996396 + 2.247808 * Log (DBH) | 511 | 0.98 | 7 |
| **Albizia richardiana** | Rajkoroi | Leguminosae | m3 | Total volume over bark | Log (Volume) = -10.831293 + 1.699319 * Log (DBH) + 0.813706 * Log (Height) | 511 | 0.98 | 7 |
| **Mixed** |  |  | m3 | Total volume over bark | Log (Volume) = -9.4209 + 1.7480 * Log (DBH) + 0.9310 * Log (Height) | 954 | 0.98 | 4 |
| **Eucalyptus brassiana** |  | Myrtaceae | m3 | Total volume over bark | Log (Volume) = -10.996396 + 2.247808 * Log (DBH) | 101 | 0.94 | -76.89 | 46 |
| **Eucalyptus tereticornis** |  | Myrtaceae | m3 | Total volume over bark | Log (Volume) = -9.4209 + 1.7480 * Log (DBH) + 0.9310 * Log (Height) | 954 | 0.98 | 4 |
| **Eucalyptus camaldulensis** |  | Myrtaceae | m3 | Total volume over bark | Log (Volume) = -9.4209 + 1.7480 * Log (DBH) + 0.9310 * Log (Height) | 954 | 0.98 | 4 |
| **Artocarpus chaplasha** | Chapalish | Moraceae | m3 | Total volume over bark | Log (Volume) = -10.996396 + 2.247808 * Log (DBH) | 511 | 0.98 | 7 |
| **Artocarpus chaplasha** | Chapalish | Moraceae | m3 | Total volume over bark | Log (Volume) = -9.3520 + 1.8055 * Log (DBH) + 0.8590 * Log (Height) | 427 | 0.97 | 3.27 | 26 |
| **Gmelina arborea** | Gamar | Lamiaceae | m3 | Total volume over bark | Log (Volume) = -8.179774 + 2.24074 * Log (DBH) | 427 | 0.97 | 0.03 | 3.27 | 26 |
| **Gmelina arborea** | Gamar | Lamiaceae | m3 | Total volume over bark | Log (Volume) = -8.468706 + 1.63902 * Log (DBH) + 0.784847 * Log (Height) | 486 | 0.96 | 3.68 | 28 |
| **Dipterocarpus turbinatus** | Telyagaran | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -8.9942 + 1.4963 * Log (DBH) + 1.1461 * Log (Height) | 436 | 0.97 | 0.034 | 1.82 | 27 |
| **Hevea brasiliensis** | Rubber | Euphorbiaceae | m3 | Total volume over bark | Log (Volume) = -10.5628 + 2.1502 * Log (DBH) | 583 | 0.95 | 12 |
| **Hevea brasiliensis** | Rubber | Euphorbiaceae | m3 | Total volume over bark | Log (Volume) = -11.2768 + 1.8795 * Log (DBH) + 0.6928 * Log (Height) | 583 | 0.97 | 12 |
| **Hevea brasiliensis** | Rubber | Euphorbiaceae | m3 | Total volume under bark | Log (Volume) = -10.6451 + 2.1607 * Log (DBH) | 583 | 0.95 | 12 |

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| Species       | Rubber        | Family         | Volume Unit | Total volume under bark | Log (Volume) = -11.3509 + 1.8930 \* Log (GBH) + 0.6848 \* Log (Height) | Value | R² | N  |
|---------------|---------------|----------------|-------------|-------------------------|--------------------------------------------------------------------------------|-------|----|----|
| Hevea brasiliensis | Rubber        | Euphorbiaceae  | m³          | Total volume under bark |                                                                                   | 583   | 0.97 | 12 |
| Hevea brasiliensis | Rubber        | Euphorbiaceae  | m³          | Total volume over bark  |                                                                                   | 388   | 0.93 | 12 |
| Genus        | Species       | Local name     | Family            | Unit of V | Vegetation Component | Equation                                                                 | Sample size | R²   | Ref. No |
|--------------|---------------|----------------|-------------------|-----------|----------------------|---------------------------------------------------------------------------|-------------|------|---------|
| Hevea        | brasiliensis  | rubber         | Euphorbiaceae     | m³        | Total volume over bark | Log (Volume) = -11.355075 + 1.90505 * Log (GBH) + 0.67956 * Log (Height) | 388         | 0.96 | 12      |
| Hevea        | brasiliensis  | rubber         | Euphorbiaceae     | m³        | Total volume under bark | Log (Volume) = -10.58495 + 2.14861 * Log (GBH)                           | 388         | 0.93 | 12      |
| Hevea        | brasiliensis  | rubber         | Euphorbiaceae     | m³        | Total volume over bark | Log (Volume) = -11.43443 + 1.92013 * Log (GBH) + 0.670876 * Log (Height) | 388         | 0.96 | 12      |
| Hevea        | brasiliensis  | rubber         | Euphorbiaceae     | m³        | Total volume under bark | Log (Volume) = 0.01097 - 0.00064 * (GBH) + 0.000055 * (GDB)^2            | 195         | 0.96 | 12      |
| Acacia       | auriculiformis| Akashmoni      | Leguminosae       | m³        | Total volume over bark | Volume = 0.027119694 + 0.0000024095 * (GBH)^2                         | 141         | 0.94 | 33      |
| Acacia       | auriculiformis| Akashmoni      | Leguminosae       | m³        | Total volume over bark | Volume = 0.02059085 + 0.00000257258 * (GBH)^2                         | 68          | 0.92 | 33      |
| Acacia       | mangium       | Mangium        | Fabaceae          | kg        | Branch and stem less than 30 cm girth to 10 cm girth green biomass | Green biomass = 17.17526 + 0.011026 * (GBH)^2                            | 68          | 0.85 | 33      |
| Eucalyptus   | camaldulensis | Eucalyptus     | Myrtaceae         | m³        | Timber volume over bark | Volume = 0.003083594 + 0.00000291538 * (GBH)^2                         | 117         | 0.97 | 33      |
| Eucalyptus   | camaldulensis | Eucalyptus     | Myrtaceae         | m³        | Timber volume over bark | Volume = 0.005034521 + 0.00000269095 * (GBH)^2                         | 60          | 0.96 | 33      |
| Eucalyptus   | camaldulensis | Eucalyptus     | Myrtaceae         | m³        | Timber volume over bark | Volume = 0.0076339 - 0.00058066 * (Height) + 0.000016216 * (GBH)^2     | 94          | 0.97 | 33      |
| Eucalyptus   | camaldulensis | Eucalyptus     | Myrtaceae         | m³        | Timber volume over bark | Volume = 0.00444242 + 0.00000274784 * (GBH)^2                         | 94          | 0.97 | 33      |
| Acacia       | mangium       | Mangium        | Fabaceae          | m³        | Total volume over bark | Volume = 0.0379401 - 0.0027469 * (GBH) + 0.000099945 * (GBH)^2          | 44          | 0.93 | 33      |
| Acacia       | mangium       | Mangium        | Fabaceae          | m³        | Total volume over bark | Volume = 0.01368013 - 0.00018226 * (Height) + 0.000005503 * (GBH)^2     | 44          | 0.97 | 33      |
| Acacia       | mangium       | Mangium        | Fabaceae          | m³        | Timber volume over bark | Volume = 0.047423 - 0.00387 * (GBH) + 0.000109 * (GBH)^2               | 37          | 0.90 | 33      |
| Acacia       | mangium       | Mangium        | Fabaceae          | m³        | Total volume over bark | Volume = -0.04085 + 0.00437656 * (Height) + 0.0000627199 * (GBH)^2     | 159         | 0.96 | 33      |
| Acacia       | mangium       | Mangium        | Fabaceae          | m³        | Timber volume over bark | Volume = 0.010632025 + 0.00000280124 * (GBH)^2                         | 133         | 0.95 | 33      |
| Dalbergia    | sissoo        | Sissoo         | Fabaceae          | m³        | Total volume over bark | Volume = 0.012282107 + 0.00168945 * (Height) - 0.000019455 * (GBH)^2    | 80          | 0.97 | 33      |
| Genus   | Species | Local name | Family | Unit of Y | Vegetation Component | Equation | Sample size | R²   | Ref. No. |
|---------|---------|------------|--------|-----------|----------------------|----------|-------------|------|----------|
| Dalbergia | sissoo | Sissoo | Fabaceae | m³       | Total volume under bark | Log (Volume) = -12.14678171 + 2.49978991 * Log (GBH) | 181 | 0.973    | 30   |
| Dalbergia | sissoo | Sissoo | Fabaceae | m³       | Total volume under bark | Log (Volume) = -11.8405276 + 2.460467 * Log (GBH) + 0.6152993 * Log (Height) | 181 | 0.982    | 30   |
| Swietenia | macrophylla | Mahogany | Meliaceae | m³       | Total volume under bark | Log (Volume) = -12.045383 + 2.460647 * Log (GBH) | 120 | 0.979    | 30   |
| Swietenia | macrophylla | Mahogany | Meliaceae | m³       | Total volume under bark | Log (Volume) = -11.716535 + 2.084968 * Log (GBH) + 0.534389 * Log (Height) | 120 | 0.99     | 30   |
| Albizia | spp | Koroi | Mimosaceae | m³       | Total volume under bark | Log (Volume) = -12.093533 + 2.463398 * Log (GBH) | 103 | 0.931    | 30   |
| Albizia | spp | Koroi | Mimosaceae | m³       | Total volume under bark | Log (Volume) = -11.961135 + 1.967741 * Log (GBH) + 0.907724 * Log (Height) | 103 | 0.947    | 30   |
| Eucalyptus | camaldulensis | Eucalyptus | Myrtaceae | m³       | Total volume under bark | Log (Volume) = -11.523307 + 1.91628 * Log (GBH) + 0.738982 * Log (Height) | 151 | 0.945    | 30   |
| Eucalyptus | camaldulensis | Eucalyptus | Myrtaceae | m³       | Total volume under bark | Log (Volume) = -11.041653 + 2.1705 * Log (GBH) | 143 | 0.935    | 30   |
| Melia | azadarach | Bokain | Meliaceae | m³       | Total volume under bark | Log (Volume) = -10.962743 + 1.889575 * Log (GBH) + 0.505435 * Log (Height) | 143 | 0.951    | 30   |
| Mangifera | indica | Am | Anacardiaceae | m³       | Total over bark volume | Log (Volume) = -11.237269 + 2.24506 * Log (GBH) | 343 | 0.975    | 32   |
| Mangifera | indica | Am | Anacardiaceae | m³       | Total over bark volume | Log (Volume) = -11.25377 + 1.96697 * Log (GBH) + 0.52237 * Log (Height) | 343 | 0.981    | 32   |
| Lannea | coromandelica | Badi | Anacardiaceae | m³       | Total over bark volume | Log (Volume) = -11.519102 + 2.01724 * Log (GBH) + 0.56356 * Log (Height) | 87  | 0.971    | 32   |
| Syzygium | cumini | Kalojam | Myrtaceae | m³       | Total over bark volume | Log (Volume) = -11.24854 + 2.24804 * Log (GBH) | 99  | 0.966    | 32   |
| Artocarpus | heterophyllus | Kathal | Moraceae | m³       | Total over bark volume | Log (Volume) = -11.06320 + 2.18208 * Log (GBH) | 119 | 0.97     | 32   |
| Artocarpus | heterophyllus | Kathal | Moraceae | m³       | Total over bark volume | Log (Volume) = -10.99533 + 1.80823 * Log (GBH) + 0.68951 * Log (Height) | 119 | 0.983    | 32   |
| Albizia | spp | Koroi | Mimosaceae | m³       | Total over bark volume | Log (Volume) = -11.50692 + 2.31757 * Log (GBH) | 140 | 0.968    | 32   |
| Albizia | spp | Koroi | Mimosaceae | m³       | Total over bark volume | Log (Volume) = -11.19651 + 1.85690 * Log (GBH) + 0.67878 * Log (Height) | 140 | 0.979    | 32   |
| Swietenia | macrophylla | Mahogany | Meliaceae | m³       | Total over bark volume | Log (Volume) = -11.46122 + 2.29592 * Log (GBH) | 105 | 0.981    | 32   |
| Swietenia | macrophylla | Mahogany | Meliaceae | m³       | Total over bark volume | Log (Volume) = -11.27102 + 1.88064 * Log (GBH) + 0.64629 * Log (Height) | 105 | 0.99     | 32   |
| Azadirachta | indica | Neem | Meliaceae | m³       | Total over bark volume | Log (Volume) = -11.33340 + 2.25814 * Log (GBH) | 36  | 0.974    | 32   |
| Azadirachta | indica | Neem | Meliaceae | m³       | Total over bark volume | Log (Volume) = -11.42823 + 1.89235 * Log (GBH) + 0.71493 * Log (Height) | 36  | 0.985    | 32   |
| Aphanamixis | polystachya | Pitraj | Meliaceae | m³       | Total over bark volume | Log (Volume) = -11.25645 + 2.25821 * Log (GBH) | 105 | 0.973    | 32   |
Aphanamixis polystachya
Pitraj Meliaceae m³ Total over bark volume Log (Volume) = -11.25528 + 1.98544 * Log (GBH) + 0.47163 105 0.987 32

Albizia saman
Rain tree Mimosaceae m³ Total over bark volume Log (Volume) = -11.37623 + 2.26924 * Log (GBH) 153 0.981 32

| Genus       | Species   | Local name | Family       | Unit of Y | Vegetation Component | Equation                                                        | Sample size | R²   | MSE  | RMS  | AIC   | FI  | Ref No |
|-------------|-----------|------------|--------------|-----------|----------------------|-----------------------------------------------------------------|-------------|------|------|------|-------|-----|--------|
| Albizia     | saman     | Rain tree  | Mimosaceae   | m³        | Total over bark volume | Log (Volume) = -11.31983 + 1.91118 * Log (GBH) + 0.63606 * Log (Height) | 153         | 0.99 |      |      |       |     | 32     |
| Breonia     | chinensis | Kadam      | Rubiaceae    | m³        | Total volume over bark | Log (Volume) = -10.4647 + 2.3911 * Log (DBH) + 0.6373 * Log (Height) | 51          | 0.9906 | 5    |      |       |     | 10     |
| Dipterocarpus turbinatus | Telya garjan | Dipterocarpaceae | m³ | Total volume over bark | Log (Volume) = -9.5258 + 2.1229 * Log (DBH) + 0.5993 * Log (Height) | 49          | 0.9666 | 7    |      |       |     | 10     |
| Lagerstroemia speciosa | Jarul | Lythraceae | m³ | Total volume over bark | Log (Volume) = -9.6744 + 2.1065 * Log (DBH) + 0.6675 * Log (Height) | 74          | 0.9862 | 8    |      |       |     | 10     |
| Xylica      | xylocarpa | Lohakat    | Leguminosae  | m³        | Total volume over bark | Log (Volume) = -9.4303 + 2.0988 * Log (DBH) + 0.6042 * Log (Height) | 94          | 0.9872 | 3    |      |       |     | 10     |
| Shorea      | robusta   | Sala       | Dipterocarpaceae | m³ | Total volume over bark | Log (Volume) = -10.0253 + 2.1163 * Log (DBH) + 0.7588 * Log (Height) | 79          | 0.9878 | 7    |      |       |     | 10     |
| Sonneratia  | apetala   | Keora      | Lythraceae   | m³        | Total volume over bark | Log (Volume) = -8.66152 + 1.5856 * Log (DBH) + 0.77152 * Log (Height) | 91          | 0.98 |      |      |       |     | 9      |
| Sonneratia  | apetala   | Keora      | Lythraceae   | m³        | Total volume over bark | Log (Volume) = -9.29715 + 1.70514 * Log (DBH) + 0.95088 * Log (Height) | 236         | 0.98 |      |      |       |     | 9      |
| Sonneratia  | apetala   | Keora      | Lythraceae   | m³        | Total volume over bark | Log (Volume) = -9.23507 + 1.69673 * Log (DBH) + 0.92309 * Log (Height) | 133         | 0.98 |      |      |       |     | 9      |
| Sonneratia  | apetala   | Keora      | Lythraceae   | m³        | Total volume over bark | Log (Volume) = -8.75215 + 1.75034 * Log (DBH) + 0.64233 * Log (Height) | 214         | 0.92 |      |      |       |     | 9      |
| Aegiceras   | corniculatum | Khulshi   | Myrsinaceae  | kg        | Leaf | Log 10 (Oven-dried biomass) = 0.76 * Log 10 ((DBH²) - 1.39) | 29          | 0.93 | 0.02 | 0.12 | -119.05 | 0.0 | 38     |
| Species   | Taxonomy         | Type       | Biomass Parameter                        | Coefficient 1 | Coefficient 2 | Coefficient 3 | Coefficient 4 | R²         | N  | Ref. |
|-----------|------------------|------------|------------------------------------------|---------------|---------------|---------------|---------------|-----------|-----|------|
| *Aegiceras corniculatum* | Myrsinaceae | kg | Bark | Log 10 (Oven-dried biomass) = 1.04 * Log 10 (DBH^2) - 1.80 | 29 | 0.99 | 0.004 | 0.07 | -154.68 | 0.0 | 38 |
| *Aegiceras corniculatum* | Myrsinaceae | kg | Stem without bark | Log 10 (Oven-dried biomass) = 1.04 * Log 10 (DBH^2) - 0.99 | 29 | 0.99 | 0.004 | 0.07 | -154.68 | 0.1 | 38 |
| *Aegiceras corniculatum* | Myrsinaceae | kg | Total above-ground | Sqrt (Oven-dried biomass) = 0.48 * DBH - 0.13 | 29 | 0.99 | 0.03 | 0.18 | -96.57 | 0.6 | 38 |
| *Aegiceras corniculatum* | Myrsinaceae | g | Total above-ground | Sqrt (Nitrogen) = 0.67 * DBH + 0.11 | 29 | 0.99 | 0.09 | 0.31 | -66.27 | 1.8 | 38 |
| *Aegiceras corniculatum* | Myrsinaceae | g | Total above-ground | Sqrt (Phosphorus) = 0.94 * DBH + 0.08 | 29 | 0.98 | 0.19 | 0.43 | -45.94 | 3.6 | 38 |
| *Aegiceras corniculatum* | Myrsinaceae | g | Total above-ground | Sqrt (Potassium) = 1.06 * DBH - 0.18 | 29 | 0.99 | 0.17 | 0.41 | -49.25 | 3.6 | 38 |
| *Aegiceras corniculatum* | Myrsinaceae | kg | Total above-ground | Sqrt (Carbon) = 0.33 * DBH - 0.09 | 29 | 0.99 | 0.02 | 0.13 | -177.67 | 0.3 | 38 |

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References
[1] F 2010 The Food and Agriculture Organization of the United Nations Global Forests Resource Assessment
[2] Altrell D, et al. 2007 National forest and tree resources assessment: 2005 Bangladesh Forest Department, Ministry of Environment and Forests Bangladesh Space Research and Remote Sensing Organization, Ministry of Defense and Food and Agriculture Organization of the United Nations 5 116
[3] Golley B F, et al. 1975 Mineral Cycling in a Tropical Moist Forest Ecosystem University of Georgia Press. Athens
[4] Mahmood H 2014 Carbon pools and fluxes in Bruguiera parviflora dominated naturally growing mangrove forest of Peninsular Malaysia Wet. Ecol. Magt. 22(1) 15
[5] Ketterings Q M, et al. 2001 Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forest For. Ecol. Magt. 146 199
[6] Mahmood H, et al. 2004 Allometric relationships for estimating above and below-ground biomass of saplings and trees of Bruguiera parviflora (Wight and Arnold) Malaysia App. Biol. 33(1) 37
[7] Mahmood H, et al. 2012 Allometry, above-ground biomass and nutrient distribution in Ceriops decandra (Griffith) Ding Hou dominated forest types of the Sundarbans mangrove forest, Bangladesh Wet. Ecol. Magt. 20 539
[8] Komiyama A, et al. 2005 Common allometric equations for estimating the tree weight of mangroves J. Trop. Ecol. 21 471
[9] Komiyama A, et al. 2008 Allometry, biomass, and productivity of mangrove forest: a review Aqu. Bot. 89 128
[10] Morgan W B and Moss P A 1985 Biomass energy and urbanisation: commercial factors in the production and use of biomass fuels in tropical Africa Biomass 6 285
[11] Bombelli A, et al. 2009 Assessment of the status of the development of the standards for the Terrestrial Essential Climate Variables: Biomass Food and Agriculture Organization – Global Terrestrial Observation System 18
[12] Henry M, et al. 2011 Estimating tree biomass of sub-Saharan African forests: a review of available allometric equations Silva Fennica 45(3B) 477
[13] Birigazzi L, et al. 2015 Toward a transparent and consistent quality control procedure for tree biomass allometric equations Xiv World Forestry Congress, Durban, South Africa 7 11
[14] Sandeep S, et al. 2014 Inventory of volume and biomass tree allometric equations for South Asia Food & Agriculture Organization of the United Nations, Rome, Italy
[15] Akhter M, et al. 2013 Tree volume and biomass allometric equations of Bangladesh FD and FAO, Dhaka, Bangladesh
[16] Mahmood H, et al. 2015 Allometric models for biomass, nutrients and carbon stock in Excoecaria agallocha of the Sundarbans, Bangladesh Wet. Ecol. Magt. 23 (4) 765
[17] Rahman M M, et al. 2015 Carbon stock in the Sundarbans mangrove forest: spatial variations in vegetation types and salinity zones Wet. Ecol. Magt. 23 (2) 269
[18] Mahmood H, et al. 2016 Above-ground biomass, nutrients and carbon in Aegiceras corniculatum of the Sundarbans Open J. For. 6 (2) 72