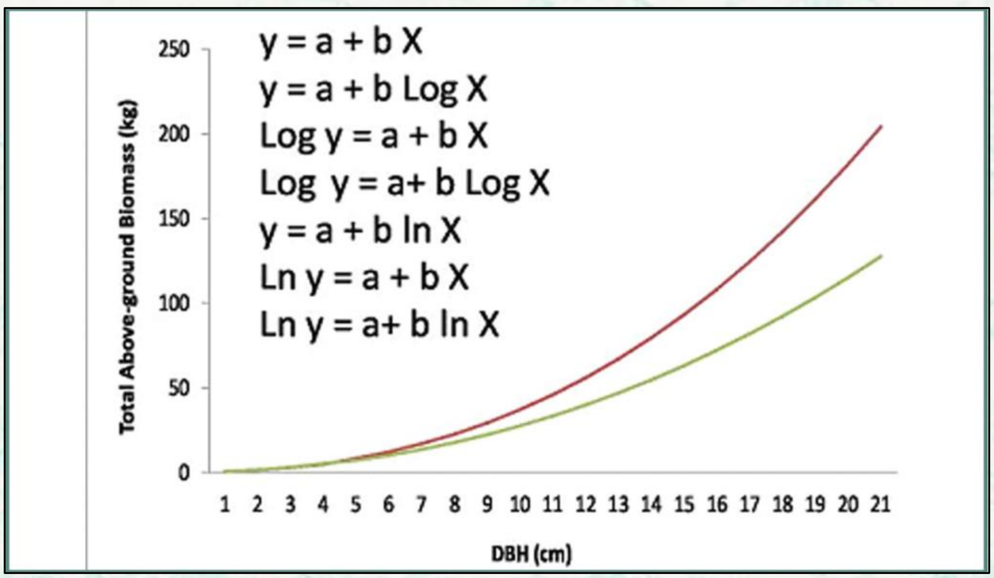
# Improved national tree allometric equation database to support forest monitoring and assessment of Bangladesh




**Bangladesh Forest Department**

**March 2016**

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Food and Agriculture Organization of the United Nations

The Forest Department of Bangladesh leads actions to improve forest management and conservation, adopting forward thinking, innovative approaches in its management of approximately 1.55 million hectares of land across the country.

In 2015, the Forest Department began a process to establish a National Forest Inventory and Satellite Land Monitoring System for improved forest and natural resource management. The process supports national objectives related to climate change mitigation and provides information in support of the UN-REDD programme aimed at Reducing Emissions from Deforestation and Forest Degradation (REDD+). The process also addresses domestic information needs and supports national policy processes related to forests and the multitude of interconnected human and environmental systems that forests support.

The activities implemented under the Bangladesh Forest Inventory process are collaboration between several national and international institutions and stakeholders. National partners from multiple government departments and agencies assist in providing a nationally coordinated approach to land management. International partners, including the United Stated Agency for International Development (USAID) and the Food and Agriculture Organization of the United Nations (FAO) are supporting the development of technical and financial resources that will assist in institutionalizing the process.

The results will allow the Forest Department to provide regular, updated information about the status of trees and forests for a multitude of purposes including for assessment of role of trees for firewood, medicines, timber, and climate change mitigation.

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# Executive Summary

Estimation of forest biomass and volume are important to know the forest stocking and productivity, nutrient cycling and budgeting, amount of carbon stock and prediction of future status of forest resources. Considering this importance, different research and academic institutions and individual researcher have developed biomass and volume allometric equations for estimation of volume stocking and biomass of a particular forest. Therefore, a database and quality control of these allometric equations have appeared as important tasks to assess the gaps and scope for the development of new allometric equations with important tree species of different forest types of Bangladesh.

Development of allometric equations for biomass and volume requires extensive planning, field work, sample analysis in the laboratory, and data compilation and analysis. Most of the cases, these activities are destructive, difficult and expensive to repeat. Measurement of some variables are mandatory for the development of allometric equations, which are linked with the national forest inventory and some other variables may consider as additional information for future forest monitoring. It is certain that the current computing system can be improved and the uncertainty in estimation can be reduced by following a standard field measurement procedure. Some errors were observed in allometric equations which mostly were associated with the use of different methods of field measurement, sample processing, data compilation, statistical analysis, use of different units of measurement. Therefore, development of a field measurement protocol is an important concern to maintain consistency in field measurement activities for the development of allometric equations. This protocol may guide forest technicians, professionals, and students for the development of biomass and volume allometric equations involving both the destructive and semi-destructive activities. Khulna University with the support of Forest Department and FAO have developed a database of allometric equations and also prepared a field measurement protocol that can be used for development of biomass and volume allometric equations, measurement of wood density, and assessment of carbon and other nutrients (N, P and K) in different parts of plants (e.g. Leaves, stem, branches, bark etc.).

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# 1. Introduction

Allometric equations are important for estimating forest biomass and volume, fuel wood and carbon stock etc. which ultimately help to formulate the forest policies for its better management. However, the estimation of these parameters requires careful collection and use of available allometric equations. Inappropriate development and use of equations lead to significant errors and may lead to inappropriate decisions and forest management. Allometric equations are used for a wide range of purposes such as bioenergy, merchantable timber, nutrient cycling, payment for environmental services etc.

Few countries have developed a national database for the biomass and volume allometric equations. In South Asia, the first regional database was developed in 2014 (Sandeep et al., 2014). In Bangladesh, a first database was developed in 2013 (Akhter et al., 2013). However, those tree allometric equation databases were not quality controlled. Indicators for controlling the quality of allometric equations can be the interval of validity, input parameters, and the sample size among other parameters. In addition, other information are necessary to improve tree and forest biomass and volume assessment such as biomass expansion factors, height diameter relationships, plant functional types, wood density among others various types of information are being collected by different national and regional entities and different stakeholders.

Very recently, Khulna University, in collaboration with Forest Department and FAO, has developed a national database for Bangladesh that includes biomass and volume allometric equations, raw data, wood density and their related Meta data. Completion of the database and its accessibility are important national efforts that may improve the estimate of tree and forest resources. Therefore, a national consultation was organized on March 6$^{th}$ 2016 to finalize the national database on biomass and volume allometric equations and manual for field data collection. From this consultation, gaps in the developed allometric equations and needs for the development of new equations considering the forest type/ land uses were identified.

# 2. Objectives

## 2.1 General objective

The general objective of this contract was

**“Improved National Tree Allometric Equation Database to support forest monitoring and assessment”**

## 2.2 Specific objectives

The specific objectives were as follows

- Database of tree allometric equations, wood density, biomass expansion factors and diameter-height relationships for Bangladesh developed

- Gaps, needs for new allometric equations considering forest type, interval of validity, independent variables, architecture, wood density from national consultation identified
- Scientific literature for all tree allometric equations provided
- Field measurement protocol manual developed
- Final report including recommendations for further model development submitted.

# 3. Activities and Deliverables

## 3.1 Develop the national database for tree volume and biomass assessment

A first database for tree allometric equations was developed in 2013 and is available on the web platform Globallometree. Under this activity, the existing database will be updated, all documents and meta-data will be archived and made available to national stakeholders involved in the forest monitoring system. This database will include data on wood density, biomass expansion factors, height-diameter relationships, tree destructive measurement information etc. All equations and data will be quality controlled based on expert judgement and a detailed QC method. Such a method can consider the use of indicators such as the interval of validity, the sample size, the mathematical form of the curve, comparison with other equations to identify whether an equation can be considered as correct or not. The validation of the quality controlled database can be done through the consultation and validation of national experts and comparison with other databases and equations.

## 3.2 Prepare the report based on national consultation on assessing tree and forest volume in Bangladesh

Biometrician and forest technicians involved in the development and use of tree allometric equations will meet and analyse available data, identify gaps and needs and provide recommendations where new equations should be developed taking into consideration forest type, interval of validity, independent variables, architecture, wood density, etc.

## 3.3 Develop a field measurement protocol

Measuring tree biomass through destructive harvesting methods is particularly costly and time consuming. In addition, often, scientist or technicians undertake field measurement in different ways and the results are not consistent. In consequence, this activity will focus on the preparation of a field measurement manual to be used by the various stakeholders to undertake further tree allometric measurement activities.

# 4. Activity 1: Develop the national database for tree volume and biomass assessment

## 4.1 Information collection and data processing

### 4.1.1 Collection of literature

The database on biomass and volume allometric equations was developed from the secondary sources. At the beginning, key stakeholders (government departments, research organizations, academic institutions and potential individual researchers) were identified with experiences on allometric equations. An online search using Google Scholar also helped to identify individual researchers and Institutes.

A list of literatures was prepared from the secondary sources. The listed literatures were searched in the bibliographic database such as Science Direct, Springer Link, CABI, AGRIS, AGRICOLA, JSTOR, ResearchGate. Personal and official communication were established with Forest Department, Bangladesh Forest Research Institute, Academic Institutions and individual researchers to get hard copies of inventory reports, research articles, research bulletin, monograph, proceeding’s paper and thesis which contained quite good number of biomass and volume allometric equations of Bangladesh. Hard and soft copies of the collected literatures were maintained for the development of this database as well as for references (Appendix 1).

### 4.1.2 Literature for allometric equations

The extensive literature survey produced hundreds of documents. These documents were sorted considering relevance and repetition and it yielded 52 documents containing relevant information. Hard and soft copies of these sorted literatures were prepared for the development of this database as well as for references (Appendix 1).

### 4.1.3 Data entry

The information in the sorted documents were interpreted and entered into an Excel database according to FAO requirement. The database consists of 90 variables grouped into 7 different categories as follows:

- Plant ecology (Population and Ecosystem)
- Geographical location (Longitude and Latitude, Ecoregions)
- Equation parameters (Variable characters and ranges)
- Tree vegetation components (Bark, Root, Stump etc.)
- Taxonomical description (Family, Genus, Species, Local name)
- Statistical Information (*R*2, adjusted *R*2, bias correction, RMSE and standard error of mean)
- Bibliography

## 4.2 Validation test of allometric equations

All the allometric equations were tested through a quality control method following four types of verification (Operational verification, Conceptual verification, Applicability and Statistical credibility**)** following Birigazzi et al (2015) and Gamarra et al. (2016)

- Operational verification: Too large or too small predicted biomass or volume values
- Conceptual verification: Predicted biomass or volume are lower than "0" or 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 for trees and coefficient of determination should be higher than 0.85

## 4.3 Biomass and volume allometric equations in Bangladesh

A total of 517 biomass and volume allometric equations for 80 species of trees, shrub, palm and bamboo in Bangladesh were recorded in the database (Tables 1 and 2). About 70% of allometric equations were for volume followed by green biomass (16%) and oven-dried biomass (6%) (Figure 1).

**Table 1:** Allometric equation in Bangladesh

| Category | Number |
|---|---|
| Tree | 477 |
| Shrub | 31 |
| Palm | 3 |
| Bamboo | 6 |
| Grand total | 517 |

**Table 2:** Different categories of allometric equations in Bangladesh

| Category | Volume | Green biomass | Oven-dried biomass | Air-dried biomass | Carbon | Nutrients | Length of split leaf |
|---|---|---|---|---|---|---|---|
| Tree | 360 | 78 | 11 | 0 | 25 | 3 | 0 |
| Shrub | 1 | 1 | 20 | 0 | 3 | 6 | 0 |
| Palm | 0 | 2 | 0 | 0 | 0 | 0 | 1 |
| Bamboo | 0 | 3 | 0 | 3 | 0 | 0 | 0 |
| Total | 361 | 84 | 31 | 3 | 28 | 9 | 1 |

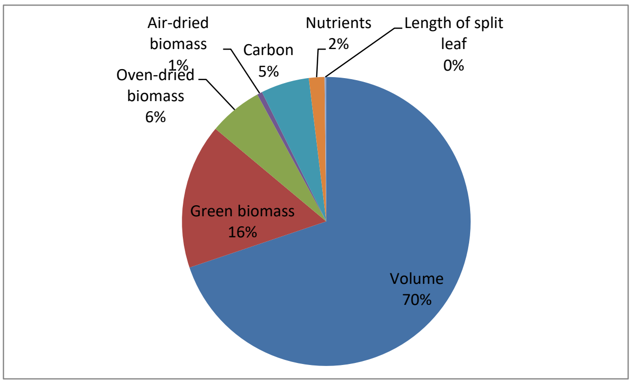



**Figure 1:** Pattern of different categories of allometric equations in Bangladesh

## 4.4 Verified allometric equations in Bangladesh

All the data and allometric equations for biomass and volume of different plant species were tested for validation and only 222 allometric equations of 39 species found to be valid considering statistical credibility, applicability, operational and conceptual verification, which gave only 43% of valid equation of the total database (Table 3 and Figure 2).

**Table 3:** Result of quality control of allometric equations

| Category | Operational verification | Conceptual verification | Applicability | Statistical credibility | Final validation |
|---|---|---|---|---|---|
| Valid | 473 | 394 | 517 | 285 | 222 |
| Not valid | 44 | 123 | 0 | 232 | 295 |
| Total equation | 517 | 517 | 517 | 517 | 517 |

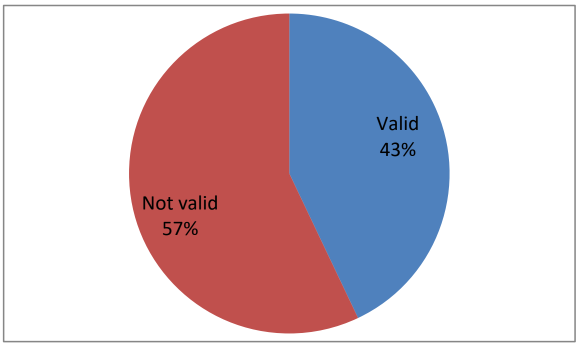



**Figure 2:** Proportion of valid equation for biomass and volume allometric database

Tree contained highest (138) number and proportion (62%) of volume allometric equations followed by green biomass and oven-dried biomass (Table 4 and Figure 3). About 97% valid allometric equations were for individual species while only 3% for mixed species. Irrespectively, about 77% of allometric equations were for plantation followed by natural forest (15%) and home garden (7%) (Figure 4).

**Table 4:** Plant life-form wise valid allometric equations

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

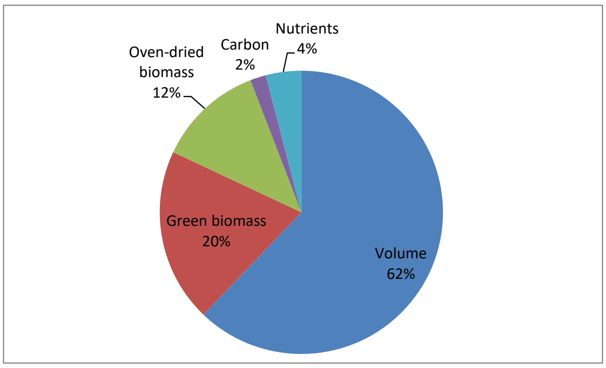
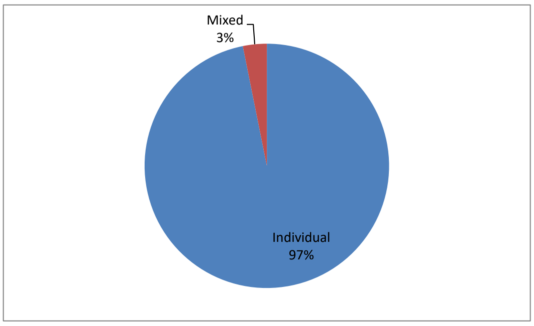



**Figure 3**: Categories of valid allometric equations



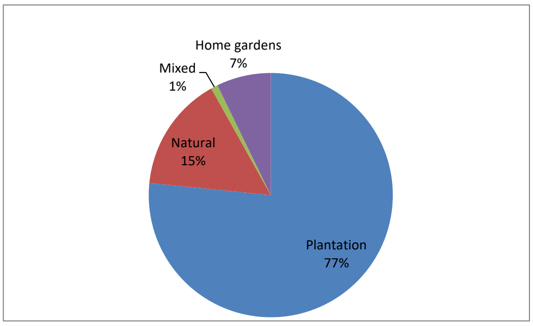




**Figure 4:** Categories of valid allometric equations for individual and mixed species and forest land use pattern

Only 39 species of 18 families and 31 genus have 222 valid equations. However, *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 very few equations under each category (Table 4). Species wise valid allometric equations in Bangladesh have been presented in Appendix 2.

**Table 4:** List of species having valid allometric equations in Bangladesh

| Genus | Species | Local name | Volume | Green biomass | Oven-dried biomass | Carbon | Nutrients | Remark |
|---|---|---|---|---|---|---|---|---|
| *Acacia* | *mangium* | Mangium | 12 | 12 | | | | |
| *Acacia* | *auriculiformis* | Akashmoni | 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* | Rajkoroi | 2 | | | | | |
| *Aphanamixis* | *polystachya* | Pitraj | 2 | | | | | |
| *Artocarpus* | *chaplasha* | Chapalish | 2 | | 2 | | | |
| *Artocarpus* | *heterophyllus* | Kathal | 2 | | | | | |
| *Avicennia* | *officinalis* | Baen | 2 | | | | | |
| *Azadirachta* | *indica* | Neem | 2 | | | | | |
| *Breonia* | *chinensis* | Kadam | 1 | | | | | |
| *Ceriops* | *decandra* | Goran | | | 5 | | | |
| *Dalbergia* | *sissoo* | Sissoo | 5 | | | | | |
| *Dipterocarpus* | *turbinatus* | Telya garjan | 3 | | | | | |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | 7 | | | | | |
| *Eucalyptus* | *tereticornis* | Eucalyptus | 1 | | | | | |
| *Eucalyptus* | *brassiana* | Eucalyptus | 1 | | | | | |
| *Excoecaria* | *agallocha* | Gewa | | | 5 | 1 | 3 | |
| *Falcataria* | *moluccana* | Moluccna | 2 | | | | | |
| *Gmelina* | *arborea* | Gamar | 2 | | | | | |
| *Hevea* | *brasiliensis* | Rubber | 10 | | | | | |
| *Kandelia* | *candel* | Goria | | | 5 | 1 | 3 | |
| *Lagerstroemia* | *speciosa* | Jarul | 1 | | 1 | | | |
| *Lannea* | *coromandelica* | Badi | 1 | | | | | |
| *Mangifera* | *indica* | Am | 2 | | | | | |
| *Melia* | *azadarach* | Bokain, Ghora neem | 2 | | | | | |
| Mixed | | | 1 | 4 | 1 | 1 | | Mixed species |
| *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 | | | | | |
| *Xylia* | *xylocarpa* | Lohakat, Pyinkado | 1 | | | | | |

## 4.5 Geographical distribution of the equations in Bangladesh

Some of the allometric equations were developed from sample trees of different locations (Districts) that overlapped different ecoregions of Bangladesh. However, numbers of allometric equations and species along with the plant components in each ecoregion with specific location species have been presented in the following tables (Tables 5-10) and Figures (Appendix 3).

**Table 5:** Numbers of allometric equations and species in different ecoregion 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-Kushiara flood plain | 1 | 1 |
| | Sylhet hills | 11 | 8 |

* Overlapped ecoregions have not considered in this table

# 5. Activity 2: Reports on national consultation workshop on assessing tree and forest volume in Bangladesh

## 5.1 National consultation workshop on tree allometric equation in Bangladesh

A national consultation workshop on "**Tree Allometric Equations in Bangladesh**" was held on Sunday, March 6, 2016 at NILG Conference Room, 2$^{nd}$ Floor, Main Biulding, Agargaon, Dhaka. The proceedings of this consultation has been prepared, submitted and circulated to the participants and others for their further comments. The general objective of this national consultation was to strengthen the national capacities in developing and using of tree allometric equations and to improve the assessment of tree volume and biomass in Bangladesh. The specific objectives were as follow:

- To present the current and up-to-date knowledge for building allometric equations including courses on the related theory, field operations, fitting and use of the allometric equations.

- To present the current status of developed allometric equations for biomass and volume.

- To propose technical exercises aiming at identifying gaps (knowledge, allometric equations and raw data) to report carbon stocks and carbon stock changes at the country level.

- To get comments and suggestion on the field measurement protocol on tree allometric equation, this will ensure the consistency in field measurement activities for the development of allometric equation in Bangladesh.

- To initiate building a network of experts on allometric equations.

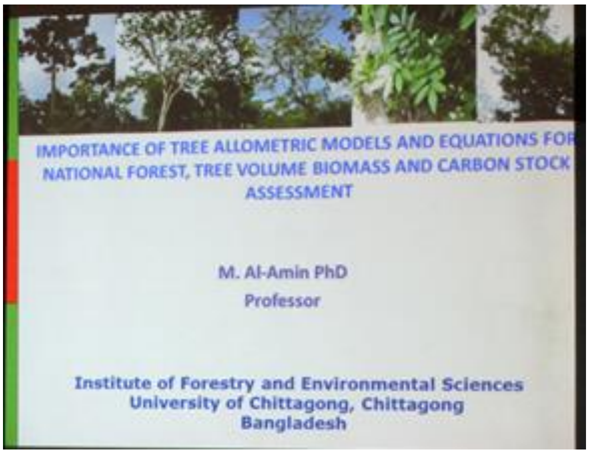
## 5.2 Session 1: Opening session

Mr. Mozaharul Islam, Conservator of Forests and National Project Coordinator delivered the welcome speech. Dr. Laskar Muksudur Rahman, FAO presented the objectives of this national consultation. Mr. Md. Farid Uddin Ahmed, Executive Director, Arannayk Foundation were present as Special Guest and Mr. Md. Yunus Ali, Chief Conservator of Forest, Forest Department was present as the Chief Guest of the national consultation workshop on tree allometric equations. Mr. Md. Yunus Ali, Chief Conservator of Forest, in his speech, highlighted important issues specific to the country and provided valuable guidelines for developing the allometric equation.

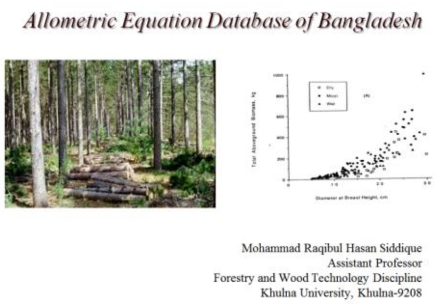

Opening session of the national consultation workshop on tree allometric equations in Bangladesh

## 5.3 Session 2: Status of biomass and volume allometric equations in Bangladesh

Prof. Dr. Al Amin, Institute of Forestry and Environmental Sciences, University of Chittagong presented on “Importance of tree allometric models and equations for national forest, tree volume, biomass and carbon stock assessment”. He mentioned the importance of site and species specific allometric equations for estimation of above-ground biomass and volume in a forest. He has presented the sources of errors in estimating forest biomass. In conclusion, he mentioned that allometric equations are the most easy and authentic way to estimate biomass or volume of trees.




Database on tree allometric equations, wood density, biomass expansion factors and diameter-height relationships for Bangladesh was developed by Khulna University with the support of Forest Department and FAO. As part of this activity, Mr. Mohammad Raqibul Hasan Siddique, Assistant Professor, Forestry and Wood Technology Discipline, Khulna University presented on “Allometric Equation Database of Bangladesh” to visualize the present stratus and gaps in biomass and volume allometric equations in Bangladesh. Validity of all the 515 allometric equations was tested through a quality control method following Birigazzi et al (2015) and Gamarra et al. (2016).



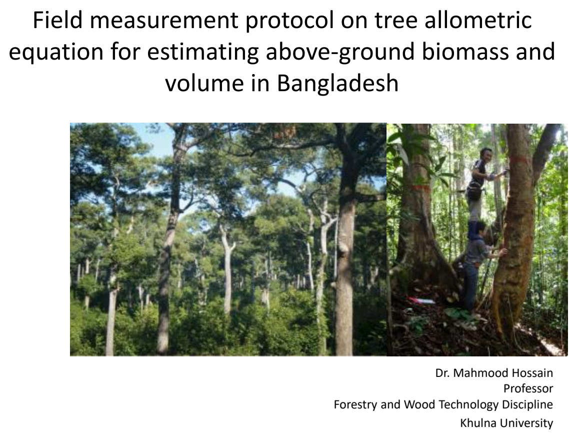

Considering the synthesis of the database of allometric equations, wood density, raw data, diameter and height relationship and biomass expansion factors, Mr. Mohammad Raqibul Hasan Siddique pointed the following gaps:

- Limited species has allometric equations
- Few equations for total above-ground biomass
- Few equations for the estimation of merchantable volume
- BEF are rare and often not adapted
- Few tree species have clear relationship between DBH and other parameters;
- Raw data are rarely accessible.

## 5.4 Session 3: Field measurement protocol

S. M. Zahirul Islam, Research Officer, Bangladesh Forest Research Institute, presented a speech on “Destructive field measurements for tree allometric equation development”. He presented the different mathematical forms used for the development of tree volume and biomass allometric equations. He also presented the destructive and non-destructive measurements for the development of tree volume and biomass allometric equation were also presented.

Dr. Mahmood Hossain, Professor, Forestry and Wood Technology Discipline, Khulna University presented the field measurement protocol on tree allometric equation for estimating above-ground biomass and volume in Bangladesh. In his presentation, he justified the needs and uses of this protocol for different forest types and vegetation forms. This protocol will be updated based on the participant’s contribution. He presented the different steps involved in the development of allometric equation. He presented 44 field and laboratory data forms for recording different measurement of variables and result related to the development of biomass and volume allometric equations for different plant life-form (Trees, Shrubs, Palms, Nypa palm, Liana and Bamboo). The field and laboratory analysis form contained measurements of the basic tree dendrometric measurement and laboratory measurements (fresh weight to oven-dry weight conversion ratio, wood density, carbon and nutrient content) in plant parts. He explained elaborately how semi-destructive method (Branch Cutting) can be used for the development of tree biomass allometric equations.





## 5.5 Group discussion: Identify the gaps in allometric equations and need of new allometric equations and improvement of field measurement protocol

Four groups were formed in the consultation workshop to identify the gaps in the derived allometric equation, need of new allometric equations considering forest types, life form and improvement of field measurement protocol for the development of biomass and volume allometric equations. The outcomes from the group discussion are as follows:

**Group 1:** The findings of group discussion are as follows

- The following forest type have not been covered by allometric equations
  - Fresh water Swamp forest
  - Sal forest (for associates)
  - Sundarbans (partly covered)
  - Coastal afforestation (partly covered)
  - Hill forest (partly covered)
  - Village/ homestead forest (partly)

- The following tree species need better consideration for the development of allometric equation
  - *Acacia catechu*
  - *Adina cordifolia*
  - *Amoora cucullata*
  - *Areca catechu*
  - *Cassia fistula*
  - *Citrus grandis*
  - *Cocos nucifera*
  - *Dalbergia sisoo*
  - *Delonix regia*
  - *Dillenia indica*
  - *Ficis hispida*
  - *Melocanna baccifera*
  - *Michelia champca*
  - *Phoenix sylvestris*
  - *Samanea saman*
  - *Switenia spp*
  - *Syzygium grandis*
  - *Tamarindus indica*
  - *Terminalia belerica*
  - *Terminalia catappa*
  - *Toona ciliata*
  - *Trewia nudiflora*

- The following improvement is needed as recommended by the group members:
  - Pictorial handbook preparation in Bengali

**Group 2:** The findings of group discussion are as follows:

- The following forest types have not been covered by allometric equations:
  - Tree species outside the Forest
  - Mangroves
  - In deciduous forest
  - In Hill forest/Nauaral forest
  - In Swamp

- The following tree species need better consideration for the development of allometric equation:
  - Artocarpus, Guava, Mangifera, Coconut, Areca catechu, Eucalyptus etc.
  - Heritiera, Avicinia, Sonneratia, Xylocarpus, Nypa etc.
  - Shorea, Haldu, Sonalu,
  - Bamboo, Champa, Chikrassi, Chapalish
  - Barringtonia, Pongamia etc.

- The following improvement is needed as recommended by the group members:
  - Some terminologies to be elaborated.

**Group 3:** The findings of group discussion are as follows:

- The following forest types have not been covered by allometric equations:
  - Swamp forest
  - Mango plantation
  - Agor plantation
  - Bamboo
  - Tea garden
  - Shrub land
  - Sand (Inland Char land)
- The following tree species need better consideration for the development of allometric equation:
  - *Areca catechu*
  - *Bambusa balcooa*
  - *Bambusa vulgaris*
  - *Cocos nucifera*
  - *H. fomes*
  - *Melocanna baccifera*
  - *Moringa oleifera*
  - *Phoenix sylvestris*
  - *Psidium guajava*
  - *R. apiculata*
  - *Tamarindus indica*
  - *Terminalia catappa*
  - *X. granatum*
  - *X. mekongensis*
  - *Zizyphus mauritiana*
- The following improvement is needed as recommended by the group members:
  - Title can be changed (improved) in the context of the content. It covers different forms of plants other than trees.

**Group 4:** The findings of group discussion are as follows:

- The following forest types have not been covered by allometric equations:
  - Fresh water swamp forest
  - Tree outside Forest
- The following tree species need better consideration for the development of allometric equation:
  - *Acacia catechu*
  - *Amoora cucullata*
  - *Anthocephalus chinensis*
  - *Areca catechu*
  - *Bambusa balcooa*
  - *Bambusa vulgaris*
  - *Borassus flabellifer*
  - *Cocos nucifera*
  - *Dalbergia sissoo*
  - *Delonix regia*
  - *Erythrina orientalis*
  - *Ficus hispida*
  - *Leucaena leucocephala*
  - *Melocanna baccifera*
  - *Oxytenanthera nigrociliata*
  - *Phoenix sylvestris*
  - *Samanea saman*
  - *Swietenia spp*
  - *Toona ciliata*
  - *Zizyphus mauritiana*
- The following improvement is needed as recommended by the group members:
  - Field testing

# 6. Activity 3: Field measurement protocol on tree allometric equation

Tree biomass and volume can be measured from both destructive (clear-cut) and non-destructive (allometric equation) methods. Allometric method is the most powerful tool of biomass and volume estimation. The use of appropriate equations will contribute to improve the assessment of forest resources which may guide the forest policy and management initiatives. Development of allometric models for biomass and volume requires extensive planning, field work (sampling of forest within each forest strata, sampling of plots within each forest, sampling of plants within each plot; measurement of standing tree dimensions; felling of sampled plant; separating and weighing of different plant parts; sub-sampling of different plant parts for further assessment and data recording), sample analysis in the laboratory, and data analysis. Most of the cases, these activities are destructive, difficult and expensive to repeat. Measurement of some variables are mandatory for the development of allometric equations, which are linked with the national forest inventory and some other variables may consider as additional information for future forest monitoring. This manual aims to guide forest technicians, professionals, and students for the development of biomass and volume allometric equations involving the destructive and semi-destructive activities. The protocol "Field measurement protocol on tree allometric equation for estimating above-ground biomass and volume in Bangladesh" has been developed and submitted as mentioned in LOA.

## 6.1 Content of the protocol

This protocol describes the steps for the development of biomass and volume allometric equations for trees, shrubs, palms, nypa palm, liana and bamboo (Appendix 4). It includes the required formulas for field and laboratory works, required tools and materials.

**Table 6:** Required tools and materials for the measurement of volume and biomass of sampled tree

| **Mandatory tools and materials** | |
|---|---|
| • Hand compass<br>• GPS<br>• Measuring tape (1 cm precision)<br>• Tree caliper<br>• Finnish parabolic caliper<br>• Diameter measuring tape (1 mm precision)<br>• Haga altimeter<br>• Criterion DR 1000<br>• Chain saw<br>• Crosscut saw<br>• Pruning saw<br>• Axe<br>• Debarking knife or bark spud | • Rope<br>• Digital hanging measuring scale 200-500 kg (0.1 kg precision)<br>• Digital measuring scale 50 kg (0.05 kg precision)<br>• Digital laboratory balance 2200 g (0.01 g precision)<br>• Zip poly bag<br>• Woven polypropylene bag<br>• Permanent marker<br>• Pen and pencil<br>• Paint<br>• Field and laboratory data collection tables |
| **Non mandatory tools and materials** | |
| • Digital camera<br>• Measuring rod<br>• 1.3 m long stick (to reduce human error during DBH measurement)<br>• Knives | • Pruning scissor<br>• Paper<br>• Gasoline powered portable winch<br>• Open foris collect software (may be used for data entry and analysis) |

This protocol explains the sampling procedure of plants and dendrometric measurements of plant dimensions (total height, merchantable height, stump height, crown length, crown diameter, crown volume, crown shape and form, DBH, collar diameter, log volume, buttress volume, bark thickness etc.). It also guides the felling operation of the sampled plant, sectioning of bole and bigger branches, and measurement of log diameters at thicker and thinner ends. The separation procedure of plant parts (leaves, flowers, fruits, petioles, rachis and leaflets, smaller branches, bigger branches, log and bark), and measurement of fresh biomass in the field also described here. It contains detailed description of semi-destructive method of volume and biomass measurement for trees (Figure 7).

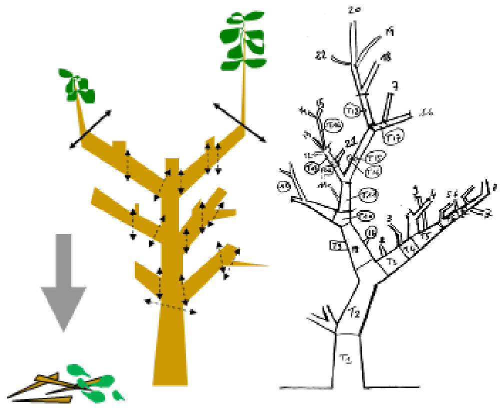


**Figure 5:** measurement of biomass and volume of bigger sized trees using semi-destructive method

This protocol elaborately explains the procedure of sub-sampling of different parts of plant to calculate the fresh to oven-dry weight conversion weight and for the measurement of wood density. It also describes the estimation procedure of carbon, nitrogen, phosphorus, potassium, calcium, magnesium and manganese. Finally, it contains 46 annexes for field data collection and laboratory data recording and analysis.

## 6.2 Table of contents

Detailed section in the protocol can be found from the following table of contents.

**Table 7:** Table of content of the field measurement protocol

# 7. Recommendations for further model development

During last NFA in 2005-07, globally available equations and factors were used for the calculation of AGB for the country. The Sundarban Carbon inventory in 2009-10 used the globally available equations for the mangrove species to calculate the carbon for the Sundarban Reserved Forest. To ensure accuracy in carbon estimation, development of allometric equations for local species considering various factors for different forest types is essential. Major species of the following forest types/ forest land uses have to give more emphasis during the development of biomass and volume allometric equations.

- Agor plantation
- Bamboo natural/ homestead
- Coastal afforestation
- Fresh water swamp forest
- Hill forest plantation/ natural (partly covered)
- Inland Char land
- Mango plantation
- Sal forest (for associate species)
- Sundarbans (Major species)
- Tea garden
- Tree species outside the Forest

A list of 77 species of trees, shrubs, palms has been recommended for the further development of biomass and volume allometric equation. This list has been compiled considering the species with valid allometric equations, forest types/ forest land uses, occurrence of species in NFA (2005-07) and discussion from national consultation workshop on “Tree allometric equations in Bangladesh”.

**Table 8:** Recommended list of plant species for further development of allometric equation

| | | |
|---|---|---|
| *Acacia catechu* | *Bombax ceiba* | *Dendrocalamus longispathus* |
| *Adina cordifolia* | *Borassus flabellifer* | *Dillenia indica* |
| *Albizia lebbeck* | *Bruguiera gymnorrhiza* | *Dillinia pentagyna* |
| *Albizia odoratissimus* | *Bruguiera sexangula* | *Diospyros peregrina* |
| *Anacardium occidentale* | *Butea monosperma* | *Disopyros 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 longispiculata* | *Cynometra ramiflora* | *Ficus hispida* |
| *Bambusa polymorpha* | *Dalbergia sisoo* | *Ficus religiosa* |
| *Bambusa tulda* | *Dalbergia spinosa* | *Heritiera fomes* |
| *Bambusa vulgaris* | *Dellinia pentagyna* | *Hibiscus tiliaceus* |
| *Barringtonia acutangula* | *Delonix regia* | *Khaya anthotheca* |

| | |
|---|---|
| *Leucaena leucocephala* | *Schima wallichii* |
| *Litchi chinensis* | *Sonneratia apetala* |
| *Lumnitzera racemosa* | *Sonneratia caseolaris* |
| *Melocanna baccifera* | *Spondias dulce* |
| *Michelia champca* | *Syzygium grandis* |
| *Mimosops elengi* | *Tamarindus indica* |
| *Moringa oleifera* | *Tamarix indica* |
| *Nypa fruticans* | *Terminalia belerica* |
| *Phoenix paludosa* | *Terminalia catappa* |
| *Phoenix sylvestris* | *Toona ciliata* |
| *Pithecellobium dulce* | *Trema orientalis* |
| *Pongamia pinnata* | *Xylocarpus granatum* |
| *Psidium guajava* | *Xylocarpus mekongensis* |
| *Rhizophora apiculata* | *Zizyphus mauritiana* |
| *Rhizophora mucronata* | |

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# Appendix 2. Species wise valid allometric equations in Bangladesh

| Genus | Species | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Total above-ground green biomass | Log (Green biomass) = -1.5851 + 2.4855 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Total above-ground green biomass | Log (Green biomass) = -4.4303 + 2.4855 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Total above-ground green biomass | Log (Green biomass) = -2.0847 + 2.1723 * Log (DBH) + 0.5141 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Total above-ground green biomass | Log (Green biomass) = -4.5714 + 2.1723 * Log (GBH) + 0.5141 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem green biomass | Log (Green biomass) = -2.1442 + 2.5917 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem green biomass | Log (Green biomass) = -5.1110 + 2.5917 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem green biomass | Log (Green biomass) = -2.7095 + 2.2372 * Log (DBH) + 0.5817 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem green biomass | Log (Green biomass) = -5.2705 + 2.2372 * Log (GBH) + 0.5817 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch green Biomass | Log (Green biomass) = -2.2732 + 1.9752 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch green Biomass | Log (Green biomass) = -4.5343 + 1.9752 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch green Biomass | Log (Green biomass) = -3.2955 + 1.3142 * Log (DBH) + 1.0521 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch green Biomass | Log (Green biomass) = -4.7999 + 1.3142 * Log (GBH) + 1.0521 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Leaves and twigs green biomass | Log (Green biomass) = -2.1219 + 1.9299 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Leaves and twigs green biomass | Log (Green biomass) = -4.3311 + 1.9299 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Leaves and twigs green biomass | Log (Green biomass) = -0.6183 + 2.8726 * Log (DBH) - 1.5471 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Leaves and twigs green biomass | Log (Green biomass) = -3.9067+ 2.8726 * Log (GBH) - 1.5471 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem and branch green biomass | Log (Green biomass) = -2.0512 + 2.6006 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem and branch green biomass | Log (Green biomass) = -5.0282 + 2.6006 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem and branch green biomass | Log (Green biomass) = -2.9256 + 2.0525 * Log (DBH) + 0.8996 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Stem and branch green biomass | Log (Green biomass) = -5.2752 + 2.0525 * Log (GBH) + 0.8996 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch, leaves and twigs green biomass | Log (Green biomass) = -2.5173 + 2.281 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch, leaves and twigs green biomass | Log (Green biomass) = -2.9974 + 1.98 * Log (DBH) + 0.494 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | kg | Branch, leaves and twigs green biomass | Log (Green biomass) = -5.264 + 1.98 * Log (GBH) + 0.494 * Log (Height) |

| Genus | Species | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Volume =  0.0117 + 0.0000280056 * DBH^(2) * Height |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Volume =  0.0117 + 0.00000283756 * GBH^(2) * Height |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Volume under bark | Volume = 0.0041 + 0.0000246325 * DBH^(2) * Height |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Volume under bark | Volume = 0.0041 + 0.00000249579 * GBH^(2) * Height |
| *Avicennia* | *officinalis* | Baen | Aviceniaceae | m3 | Total volume over bark | Volume =  0.0089 + 0.0000264 * DBH^(2) * Height |
| *Avicennia* | *officinalis* | Baen | Aviceniaceae | m3 | Total volume over bark | Volume =  0.0089 + 0.00000267 * GBH^(2) * Height |
| *Albizia* | *procera* | Koroi | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -12.0901 + 2.502194 * Log (GBH) |
| *Albizia* | *procera* | Koroi | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -11.6632 + 1.941989 * Log (GBH) + 0.754839 * Log (Height) |
| *Terminalia* | *arjuna* | Arjun | Combretacear | m3 | Total volume over bark | Log (Volume) = -11.1885 + 2.222144 * Log (GBH) |
| *Terminalia* | *arjuna* | Arjun | Combretacear | m3 | Total volume over bark | Log (Volume) = -11.3794 + 1.896423 * Log (GBH) +  0.653558 * Log (Height) |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -9.1727759 + 2.5178944 * DBH |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -12.0554 + 2.5178944 * Log (GBH) |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -9.615639 + 2.033071 * Log (DBH) + 0.7361229 * Log (Height) |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -11.938881 + 2.033071 * Log (GBH) + 0.7361229 * Log (Height) |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume under bark | Volume = 0.0032556 + 0.0000269 * DBH^(2) * Height |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume under bark | Volume = 0.003255 + 0.0000027255 * GBH^(2) * Height |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Volume = 0.0052 - 0.0022 * X + 0.0005 * DBH^(2) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Log (Volume) = -9.1937 + 1.7683 * Log (DBH) + 0.7358 * Log (Height) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Volume = 0.0042 - 0.0017 * DBH + 0.0005 * DBH^(2) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Log (Volume) = -9.2587 + 1.6463 * Log (DBH) + 0.9138 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Log (Volume) = -8.209 + 2.2178 * Log (DBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Log (Volume) = -10.7488 + 2.2178 * Log (GBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Log (Volume) = -9.1426 + 1.7612 * Log (DBH) + 0.83335 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Log (Volume) = -11.1587 + 1.7612 * Log (GBH) + 0.83335 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume under bark | Log (Volume) = -9.00226 + 2.3246 * Log (DBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume under bark | Log (Volume) = -11.6633 + 2.3246 * Log (GBH) |

| Genus | Species | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume under bark | Log (Volume) = -10.2221 + 1.74054 * Log (DBH) + 1.07596 * Log (Height) |
| *Mixed* | | | | kg | Total above-ground green biomass | Log (Green biomass) = -1.3933 + 2.39602 * Log (DBH) |
| *Mixed* | | | | kg | Total above-ground green biomass | Log (Green biomass) = -4.136 + 2.39602 * Log (GBH) |
| *Mixed* | | | | kg | Total above-ground green biomass | Log (Green biomass) = -2.228 + 1.81492 * Log (DBH) + 0.85007 * Log (Height) |
| *Mixed* | | | | kg | Total above-ground green biomass | Log (Green biomass) = -4.306 + 1.81492 * Log (GBH) + 0.85007 * Log (Height) |
| *Tectona* | *grandis* | Teak | Lamiaceae | cft | Total volume over bark | Volume = 0.084 * DBH^(2.263) |
| *Tectona* | *grandis* | Teak | Lamiaceae | cft | Total volume over bark | Volume = 0.000465 * DBH^(1.58) * Height^(1.603) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | kg | Total above-ground green biomass | Log (Green biomass) = -1.3577 + 2.4177 * Log (DBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | kg | Total above-ground green biomass | Log (Green biomass) = -2.2782 + 1.9736 * Log (DBH) + 0.8113 * Log (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | kg | Stem green biomass | Log (Green biomass) = -2.3176 + 2.6075 * Log (DBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | kg | Stem green biomass | Log (Green biomass) = -3.1661 + 2.1982 * Log (DBH) + 0.7477 * Log (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume over bark | Log (Volume) = -8.208 + 2.2389 * Log (DBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume over bark | Log (Volume) = -10.7709 + 2.2389 * Log (GBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume over bark | Log (Volume) = -9.125 + 1.918 * Log (DBH) + 0.67988 * Log (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume over bark | Log (Volume) = -11.3205 + 1.918 * Log (GBH) + 0.67988 * Log (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume under bark | Log (Volume) = -9.187 + 2.468 * Log (DBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume under bark | Log (Volume) = -12.0121 + 2.468 * Log (GBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume under bark | Log (Volume) = -10.2398 + 2.100244 * Log (DBH) + 0.780214 * Log (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume under bark | Log (Volume) = -12.6440 + 2.100244 * Log (GBH) + 0.780214 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume over bark | Log (Volume) = -8.602 + 2.4038 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume over bark | Log (Volume) = -11.3536 + 2.4038 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume over bark | Log (Volume) = -9.514 + 1.871 * Log (DBH) + 0.897 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume over bark | Log (Volume) = -11.6557 + 1.871 * Log (GBH) + 0.897 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume under bark | Log (Volume) = -9.334 + 2.55686 * Log (DBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume under bark | Log (Volume) = -12.2632 + 2.55686 * Log (GBH) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume under bark | Log (Volume) = -10.1766698 + 2.0641847 * Log (DBH) + 0.8290937 * Log (Height) |
| *Senna* | *siamea* | Minjiri | Leguminosae | m3 | Total volume under bark | Log (Volume) = -12.5396 + 2.064187 * Log (GBH) + 0.8290937 * Log (Height) |

| Genus | Species | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume over bark | Log (Volume) = -8.7854 + 2.410755 * Log (DBH) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume over bark | Log (Volume) = -11.545 + 2.410755 * Log (GBH) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume over bark | Log (Volume) = -9.39412 + 1.867386 * Log (DBH) + 0.839034 * Log (Height) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume over bark | Log (Volume) = -11.5317 + 1.867386 * Log (GBH) + 0.839034 * Log (Height) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume under bark | Log (Volume) = -9.11552 + 2.483187 * Log (DBH) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume under bark | Log (Volume) = -11.9580 + 2.483187 * Log (GBH) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume under bark | Log (Volume) = -9.7505 + 1.935397 * Log (DBH) + 0.851715 * Log (Height) |
| *Pinus* | *caribaea* | Pine | Pinaceae | m3 | Total volume under bark | Log (Volume)= -11.9660 + 1.935397 * Log (GBH) + 0.851715 * Log (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume over bark | Log (Volume) = -11.839665 + 2.404568 * Log (GBH) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Total volume over bark | Log (Volume) = -11.506528 + 1.973377 * Log (GBH) + 0.623823 * Log (Height) |
| *Swietenia* | *macrophylla* | Mahogany | Meliaceae | m3 | Total volume over bark | Log (Volume) = -12.52620808 + 2.5653795 * Log (GBH) |
| *Swietenia* | *macrophylla* | Mahogany | Meliaceae | m3 | Total volume over bark | Log (Volume) = -12.4361459 + 1.8661846 * Log (GBH) + 1.2282822 * Log (Height) |
| *Albizia* | *spp* | Koroi | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -12.8715358 + 2.6994968 * Log (GBH) |
| *Albizia* | *spp* | Koroi | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -12.4 + 1.7131 * Log (GBH) + 1.58245 * Log (Height |
| *Dalbergia* | *sissoo* | Sissoo | Fabaceae | m3 | Total volume over bark | Log (Volume) = -12.427775 + 2.6056676 * Log (GBH) |
| *Dalbergia* | *sissoo* | Sissoo | Fabaceae | m3 | Total volume over bark | Log (Volume) = -12.5189939 + 1.9800535 * Log (GBH) + 1.0775148 * Log (Height) |
| *Acacia* | *nilotica* | Babla | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -11.2782859 + 2.34743 * Log (GBH) |
| *Acacia* | *nilotica* | Babla | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -11.875835 + 1.8823999 * Log (GBH) + 1.0819988 * Log (Height) |
| *Albizia* | *saman* | Rain tree | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -12.287524 + 2.5086408 * Log (GBH) |
| *Albizia* | *saman* | Rain tree | Mimosaceae | m3 | Total volume over bark | Log (Volume) = -12.3213818 + 1.8912934 * Log (GBH) + 1.183443 * Log (Height) |
| *Ceriops* | *decandra* | Goran | Rhizophoraceae | g | Leaf | Oven-dried biomass = 2.99 * (Collar girth)^(1.95) |
| *Ceriops* | *decandra* | Goran | Rhizophoraceae | g | Branch | Oven-dried biomass = 0.23 * (Collar girth)^(3.09) |
| *Ceriops* | *decandra* | Goran | Rhizophoraceae | g | Bark | Oven-dried biomass = 0.77 * (Collar girth)^(2.23) |
| *Ceriops* | *decandra* | Goran | Rhizophoraceae | g | Stem with bark | Oven-dried biomass = 3.22 * (Collar girth)^(2.27) |

| Genus | Species | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Ceriops* | *decandra* | Goran | Rhizophoraceae | g | Total above-ground | Oven-dried biomass = 4.70 * (Collar girth)^(2.41) |
| *Aegialitis* | *rotundifolia* | Nuniya | Plumbaginaceae | g | Leaf | Oven-dried biomass = 13.96 * (Collar girth) - 12.38 * (Height)^(2)- 0.01 * (Height at girth measurement point)^(2) + 0.08 * (Collar girth) * (Height) * (Height at girth measurement point) |
| *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) |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Leaf | Log 10 (Oven-dried biomass) = 0.9256 * Log 10 (DBH^(2)) - 2.133 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Branch | Log 10 (Oven-dried biomass) = 1.1656 * Log 10 (DBH^(2)) - 1.7047 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Bark | Log 10 (Oven-dried biomass) = 1.0824 * Log 10 (DBH^(2)) - 1.7568 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Stem without bark | Log 10 (Oven-dried biomass) = 1.0927 * Log 10 (DBH^(2)) - 1.0275 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Total above-ground | Log 10 (Oven-dried biomass) = 1.0996 * Log 10 (DBH^(2)) - 0.8572 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Total above-ground | Log 10 (Nitrogen) = 1.0972 * Log 10 (DBH^(2)) - 3.0845 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Total above-ground | Log 10 (Phosphorus) = 1.0947 * Log 10 (DBH^(2)) - 5.6790 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Total above-ground | Log 10 (Potassium) = 1.0990 * Log 10 (DBH^(2)) - 3.0370 |
| *Excoecaria* | *agallocha* | Gewa | Euphorbiaceae | kg | Total above-ground | Log 10 (Carbon) = 1.1 * Log 10 (DBH^(2)) - 1.1937 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Leaf | Oven-dried biomass = 0.014 * (DBH)^(2) + 0.03 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Branch | Sqrt (Oven-dried biomass) = 0.29 * (DBH) - 0.21 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Bark | Sqrt (Oven-dried biomass) = 0.66 * sqrt (DBH) - 0.57 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Stem without bark | Sqrt (Oven-dried biomass) = 1.19 * Sqrt (DBH) - 1.02 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Total above-ground | Oven-dried biomas = 0.21 * (DBH)^(2) + 0.12 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Total above-ground | Nitrogen = 0.39 * (DBH)^(2) + 0.49 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Total above-ground | Phosphorus = 0.77 * (DBH)^(2) + 0.14 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Total above-ground | Potassium = 0.87 * (DBH)^(2) + 0.07 |
| *Kandelia* | *candel* | Goria | Rhizophoraceae | kg | Total above-ground | Carbon = 0.09 * (DBH)^(2) + 0.05 |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | kg | Stem biomass | Oven-dried biomass = 0.092486 * ((DBH) * (Height))^(1.4765) |
| *Albizia* | *saman* | Rain tree | Mimosaceae | m3 | Stem volume | Log (Volume) = -8.3013 + 2.1746 * Log (DBH) |

| *Genus* | *Species* | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Albizia* | *saman* | Rain tree | Mimosaceae | m3 | Stem volume | Log (Volume) = -9.1864 + 1.8502 * Log (DBH) + 0.8234 * Log (Height) |
| *Mixed Shrub* | | | | g | Above-ground biomass | Oven-dried biomass = 0.696735 + 0.536662 * (Biomass) |
| *Mixed Shrub* | | | | g | Above-ground biomass | Carbon = -0.379625 + 0.500132 * (Biomass) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Total above-ground green biomass | Log (Green biomass) = -1.4659 + 2.3256 * Log (DBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Total above-ground green biomass | Log (Green biomass) = -4.1281 + 2.3256 * Log (GBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Total above-ground green biomass | Log (Green biomass) = -1.7073 + 2.1922 * Log (DBH) + 0.2331 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Total above-ground green biomass | Log (Green biomass) = -4.2168 + 2.1922 * Log (GBH) + 0.2331 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem green biomass | Log (Green biomass) = -2.2782 + 2.5213 * Log (DBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem green biomass | Log (Green biomass) = -5.1644 + 2.5213 * Log (GBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem green biomass | Log (Green biomass) = -2.7344 + 2.2692 * Log (DBH) + 0.4406 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem green biomass | Log (Green biomass) = -5.3320 + 2.2692 * Log (GBH) + 0.4406 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem and branch green biomass | Log (Green biomass) = -1.8493 + 2.3906 * Log (DBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem and branch green biomass | Log (Green biomass) = -4.5859 + 2.3906 * Log (GBH) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem and branch green biomass | Log (Green biomass) = -2.4276 + 2.0709 * Log (DBH) + 0.5586 * Log (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | kg | Stem and branch green biomass | Log (Green biomass) = -4.7982 + 2.0709 * Log (GBH) + 0.5586 * Log (Height) |
| *Artocarpus* | *chaplasha* | Chapalish | Moraceeae | kg | Leaf | Log (Oven-dried biomass) = -4.44814 + 2.0483 * Log (DBH) |
| *Lagerstroemia* | *speciosa* | Jarul | Lythraceae | kg | Leaf | Log (Oven-dried biomass) = -1.34008 + 0.83123 * Log (DBH) + 0.47969 * Log (Height) |
| *Artocarpus* | *chaplasha* | Chapalish | Moraceeae | kg | Stem biomass | Log (Oven-dried biomass) = -0.53361 + 0.988759 * Log ((DBH)^(2) * (Height) * (Wood density)) |
| *Tectona* | *grandis* | Teak | Lamiaceae | kg | Stem biomass | Log (Oven-dried biomass) = 0.07908 + 0.89315 * Log ((DBH)^(2) * (Height) * (Wood density)) |
| *Albizia* | *richardiana* | Rajkoroi | Leguminosae | m3 | Total volume over bark | Log (Volume) = -10.996396 + 2.247808 * Log (GBH) |
| *Albizia* | *richardiana* | Rajkoroi | Leguminosae | m3 | Total volume over bark | Log (Volume) = -10.831293 + 1.699319 * Log (GBH) + 0.813706 * Log (Height) |
| *Mixed* | | | | m3 | Total volume over bark | Log (Volume) = -9.4209 + 1.7480 * Log (DBH) + 0.9310 * Log (Height) |

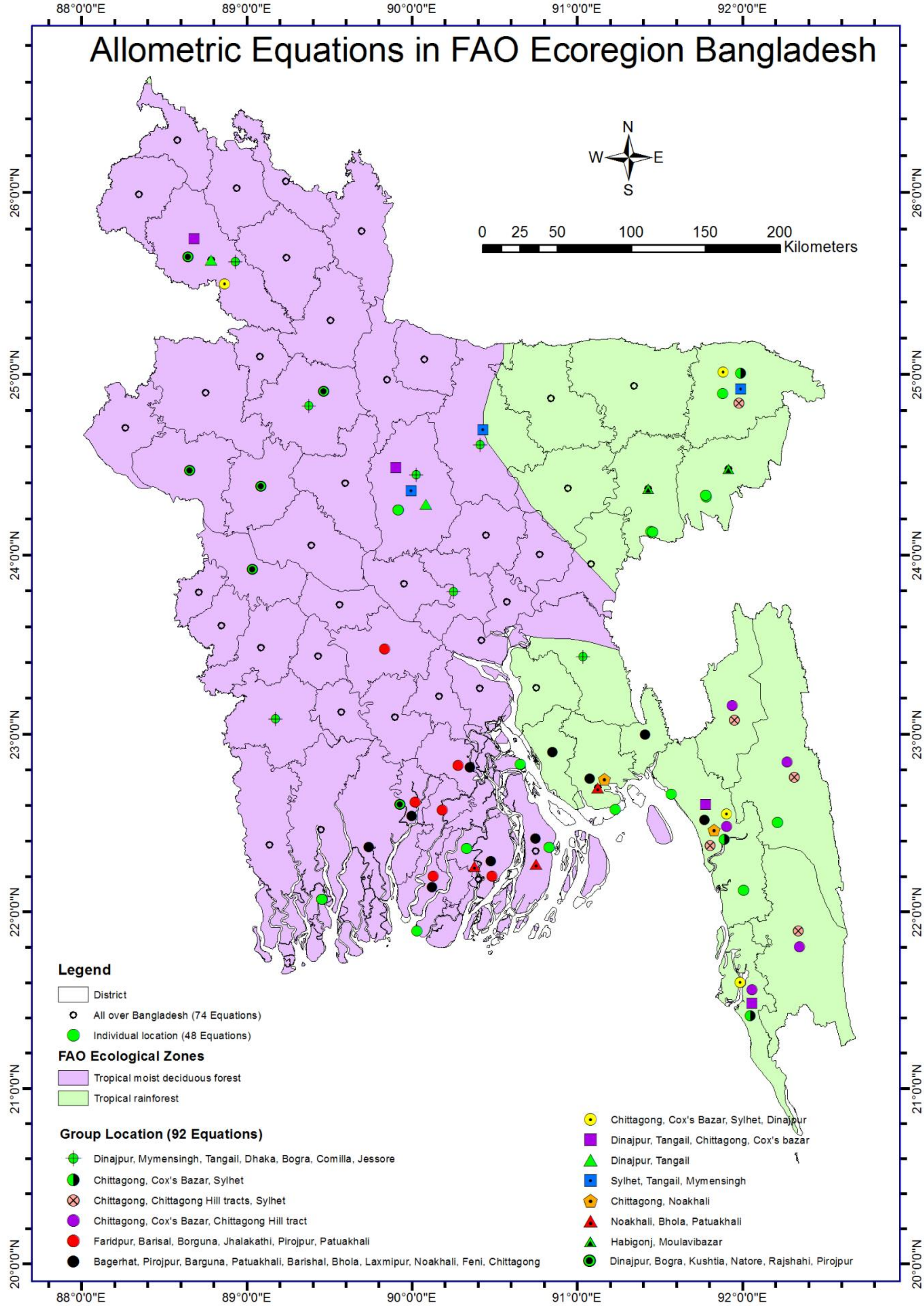
| *Genus* | *Species* | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Eucalyptus* | *brassiana* | Eucalyptus | Myrtaceae | m3 | Total volume over bark | Log (Volume) = -9.5783 + 1.6783 * Log (DBH) + 1.0483 * Log (Height) |
| *Eucalyptus* | *tereticornis* | Eucalyptus | Myrtaceae | m3 | Total volume over bark | Log (Volume) = -9.4264 + 1.6850 * Log (DBH) + 0.9840 * Log (Height) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Total volume over bark | Log (Volume) = -9.3520 + 1.8055 * Log (DBH) + 0.8590 * Log (height) |
| *Artocarpus* | *chaplasha* | Chapalish | Moraceeae | m3 | Total volume over bark | Log (Volume) = -8.179774 + 2.24074 * Log (DBH) |
| *Artocarpus* | *chaplasha* | Chapalish | Moraceeae | m3 | Total volume over bark | Log (Volume) = -8.9449526 + 1.82851 * Log (DBH) + 0.735381 * Log (Height) |
| *Gmelina* | *arborea* | Gamar | Lamiaceae | m3 | Total volume over bark | Log (Volume) = -7.9022697 + 2.1472 * Log (DBH) |
| *Gmelina* | *arborea* | Gamar | Lamiaceae | m3 | Total volume over bark | Log (Volume) = -8.4687076 + 1.63502 * Log (DBH) + 0.784847 * Log (Height) |
| *Dipterocarpus* | *turbinatus* | Telya garjan | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -8.5116354 + 2.35556 * Log (DBH) |
| *Dipterocarpus* | *turbinatus* | Telya garjan | Dipterocarpaceae | m3 | Total volume over bark | Volume = 0.000390878 + 0.00064549776 * (DBH)^(2) + 0.0001478277 * (DBH) * (Height) + 0.00002407 * (DBH)^(2) * (Height) |
| *Falcataria* | *moluccana* | Moluccna | Leguminosae | m3 | Stem Volume over bark | Log (Volume) = -8.9942 + 1.4963 * Log (DBH) + 1.1461 * Log (Height) |
| *Falcataria* | *moluccana* | Moluccna | Leguminosae | m3 | Stem Volume over bark | Log (Volume) = -10.707106 + 1.4963 * Log (GBH) + 1.1461 * Log (Height) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume over bark | Log (Volume) = -10.5628 + 2.1502 * Log (GBH) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume over bark | Log (Volume) = -11.2768 + 1.8795 * Log (GBH) + 0.6928 * Log (Height) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume under bark | Log (Volume) = -10.6451 + 2.1607 * Log (GBH) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume under bark | Log (Volume) = -11.3509 + 1.8930 * Log (GBH) + 0.6848 * Log (Height) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume over bark | Log (Volume) = -10.4946 + 2.1365 * Log (GBH) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume over bark | Log (Volume) = -11.355075 + 1.90505 * Log (GBH) + 0.67956 * Log (Height) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume under bark | Log (Volume) = -10.58495 + 2.14861 * Log (GBH) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume under bark | Log (Volume) = -11.43443 + 1.92013 * Log (GBH) + 0.670876 * Log (Height) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume over bark | Volume = 0.01097 - 0.00064 * (GBH) + 0.000055 * (GDB)^(2) |
| *Hevea* | *brasiliensis* | Rubber | Euphorbiaceae | m3 | Total volume under bark | Volume = 0.016931 - 0.00085 * (GBH) + 0.000055 * (GBH)^(2) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Timber volume over bark | Volume = 0.027119694 + 0.00000240953 * (GBH)^(2) * (Height) |

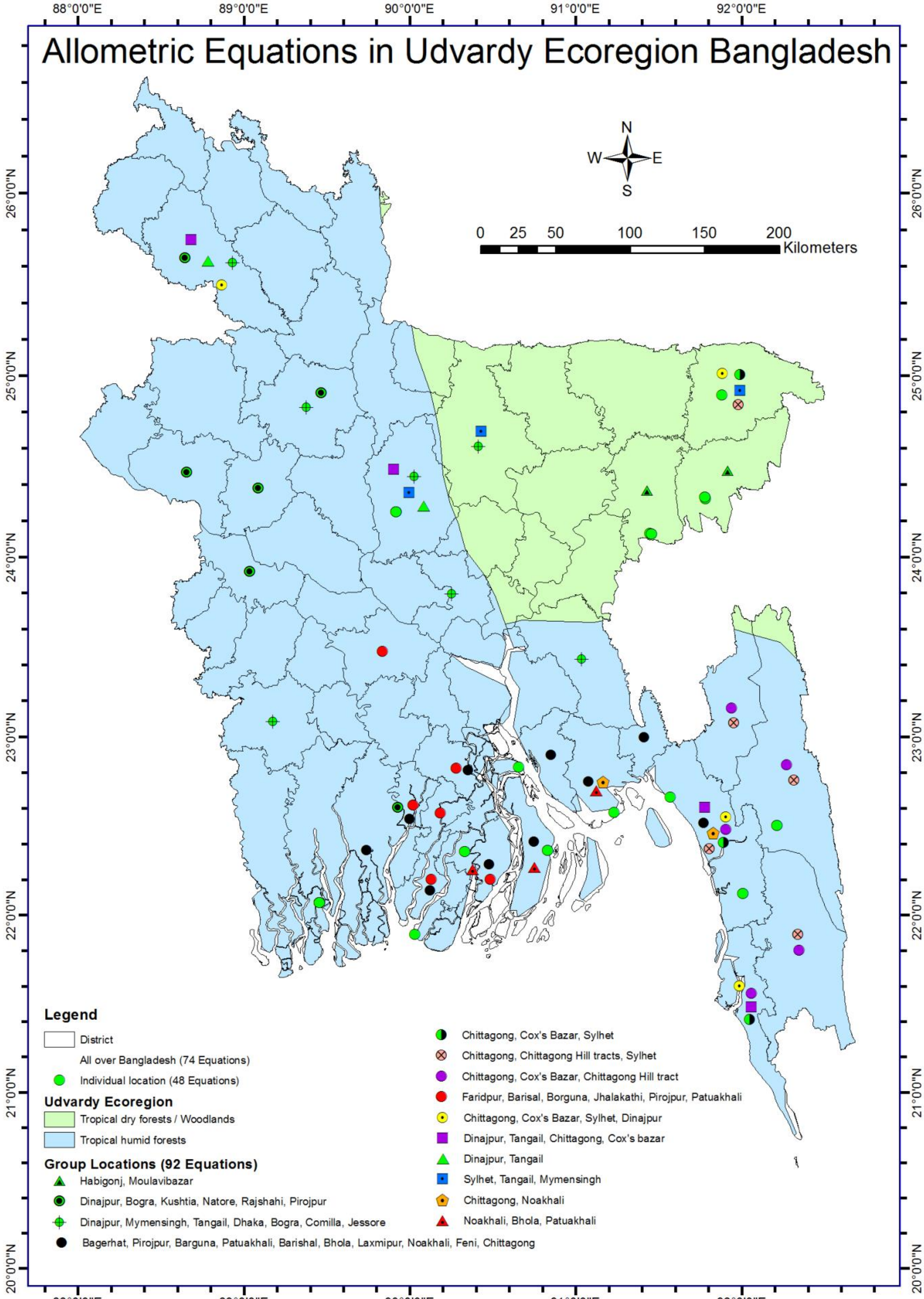
| *Genus* | *Species* | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | m3 | Timber volume over bark | Volume = 0.02059085 + 0.00000257258 * (GBH)^(2) * (Height) |
| *Acacia* | *auriculiformis* | Akashmoni | Leguminosae | kg | Branch and stem less than 30 cm girth to 10 cm girth green biomass | Green biomass = 17.17526 + 0.011026 * (GBH)^(2) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Timber volume over bark | Volume = 0.003083594 + 0.00000291538 * (GBH)^(2) * (Height) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Timber volume over bark | Volume = 0.005034521 + 0.00000269095 * (GBH)^(2) * (Height) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Total volume over bark | Volume = 0.076339 - 0.00058066 * (Height) + 0.000016216 * (GBH)^(2) + 0.0000032565 * (GBH)^(2) * (Height) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Timber volume over bark | Volume = 0.00444242 + 0.00000274348 * (GBH)^(2) * (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Volume = 0.0379401 - 0.0027469 * (GBH) + 0.000099945 * (GBH)^(2) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Volume = 0.01368013 - 0.00018226 * (Height) + 0.000005503 * (GBH)^(2) + 0.00000352188 * (GBH)^(2) * (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Timber volume over bark | Volume = 0.047423 - 0.00387 * (GBH) + 0.000109 * (GBH)^(2) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Total volume over bark | Volume = -0.04085 + 0.00437656 * (Height) + 0.0000627199 * (GBH)^(2) + 0.00000248335 * (GBH)^(2) * (Height) |
| *Acacia* | *mangium* | Mangium | Fabaceae | m3 | Timber volume over bark | Volume = 0.010632025 + 0.00000289124 * (GBH)^(2) * (Height) |
| *Dalbergia* | *sissoo* | Sissoo | Fabaceae | m3 | Total volume over bark | Volume = 0.012282107 + 0.00168945 * (Height) - 0.000019455 * (GBH)^(2) + 0.00000392037 * (GBH)^(2) * (Height) |
| *Dalbergia* | *sissoo* | Sissoo | Fabaceae | m3 | Total volume under bark | Log (Volume) = -12.14678171 + 2.49978991 * Log (GBH) |
| *Dalbergia* | *sissoo* | Sissoo | Fabaceae | m3 | Total volume under bark | Log (Volume)= -11.8405276 + 2.07000287 * Log (GBH) + 0.6152993 * Log (Height) |
| *Swietenia* | *macrophylla* | Mahogany | Meliaceae | m3 | Total volume under bark | Log (Volume) = -12.045383 + 2.460647 * Log (GBH) |
| *Swietenia* | *macrophylla* | Mahogany | Meliaceae | m3 | Total volume under bark | Log (Volume) = -11.716535 + 2.084968 * Log (GBH) + 0.534389 * Log (Height) |

| *Genus* | *Species* | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Albizia* | *spp* | Koroi | Mimosaceae | m3 | Total volume under bark | Log (Volume) = -12.093533 + 2.463398 * Log (GBH) |
| *Albizia* | *spp* | Koroi | Mimosaceae | m3 | Total volume under bark | Log (Volume) = -11.961135 + 1.967741 * Log (GBH) + 0.907724 * Log (Height) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Total volume under bark | Log (Volume) = -11.177929 + 2.297689 * Log (GBH) |
| *Eucalyptus* | *camaldulensis* | Eucalyptus | Myrtaceae | m3 | Total volume under bark | Log (Volume) = -11.523307 + 1.911628 * Log (GBH) + 0.738982 * Log (Height) |
| *Melia* | *azadarach* | Bokain, Ghora neem | Meliaceae | m3 | Total volume under bark | Log (Volume) = -11.041653 + 2.1705 * Log (GBH) |
| *Melia* | *azadarach* | Bokain, Ghora neem | Meliaceae | m3 | Total volume under bark | Log (Volume) = -10.962743 + 1.888957 * Log (GBH) + 0.505435 * Log (Height) |
| *Mangifera* | *indica* | Am | Anacardiaceae | m3 | Total over bark volume | Log (Volume) = -11.27269 + 2.24506 * Log (GBH) |
| *Mangifera* | *indica* | Am | Anacardiaceae | m3 | Total over bark volume | Log (Volume) = -11.25377 + 1.96697 * Log (GBH) + 0.52237 * Log (Height) |
| *Lannea* | *coromandelica* | Badi | Anacardiaceae | m3 | Total over bark volume | Log (Volume) = -11.519102 +2.01724 * Log (GBH) + 0.56356 * Log (Height) |
| *Syzygium* | *cumini* | Kalojam | Myrtaceae | m3 | Total over bark volume | Log (Volume) = -11.24854 + 2.24804 * Log (GBH) |
| *Artocarpus* | *heterophyllus* | Kathal | Moraceeae | m3 | Total over bark volume | Log (Volume) = -11.06320 + 2.18203 * Log (GBH) |
| *Artocarpus* | *heterophyllus* | Kathal | Moraceeae | m3 | Total over bark volume | Log (Volume) = -10.99533 + 1.80823 * Log (GBH) + 0.68951 * Log (Height) |
| *Albizia* | *spp* | Koroi | Mimosaceae | m3 | Total over bark volume | Log (Volume)= -11.50692 + 2.31757 * Log (GBH) |
| *Albizia* | *spp* | Koroi | Mimosaceae | m3 | Total over bark volume | Log (Volume) = -11.19651 + 1.85690 * Log (GBH) + 0.67878 * Log (Height) |
| *Swietenia* | *macrophylla* | Mahogany | Meliaceae | m3 | Total over bark volume | Log (Volume) = -11.46122 + 2.29592 * Log (GBH) |
| *Swietenia* | *macrophylla* | Mahogany | Meliaceae | m3 | Total over bark volume | Log (Volume) = -11.27102 + 1.88064 * Log (GBH) + 0.64629 * Log (Height) |
| *Azadirachta* | *indica* | Neem | Meliaceae | m3 | Total over bark volume | Log (Volume) = -11.33340 + 2.25814 * Log (GBH) |
| *Azadirachta* | *indica* | Neem | Meliaceae | m3 | Total over bark volume | Log (Volume) = -11.42823 + 1.89235 * Log (GBH) + 0.71493 * Log (Height) |
| *Aphanamixis* | *polystachya* | Pitraj | Meliaceae | m3 | Total over bark volume | Log (Volume) = -11.25645 + 2.25821 * Log (GBH) |
| *Aphanamixis* | *polystachya* | Pitraj | Meliaceae | m3 | Total over bark volume | Log (Volume) = -11.25528 + 1.98544 * Log (GBH) + 0.47163 * Log (Height) |
| *Albizia* | *saman* | Rain tree | Mimosaceae | m3 | Total over bark volume | Log (Volume) = -11.37623 + 2.26924 * Log (GBH) |
| *Albizia* | *saman* | Rain tree | Mimosaceae | m3 | Total over bark volume | Log (Volume) = -11.31983 + 1.91118 * Log (GBH) + 0.63606 * Log (Height) |
| *Breonia* | *chinensis* | Kadam | Rubiaceae | m3 | Total volume over bark | Log (Volume) = -10.4647 + 2.3911 * Log (DBH) + 0.6373 * Log (Height) |
| *Dipterocarpus* | *turbinatus* | Telya garjan | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -9.5258 + 2.1229 * Log (DBH) + 0.5993 * Log (Height) |
| *Lagerstroemia* | *speciosa* | Jarul | Lythraceae | m3 | Total volume over bark | Log (Volume) = -9.6744 + 2.1065 * Log (DBH) + 0.6675 * Log (Height) |

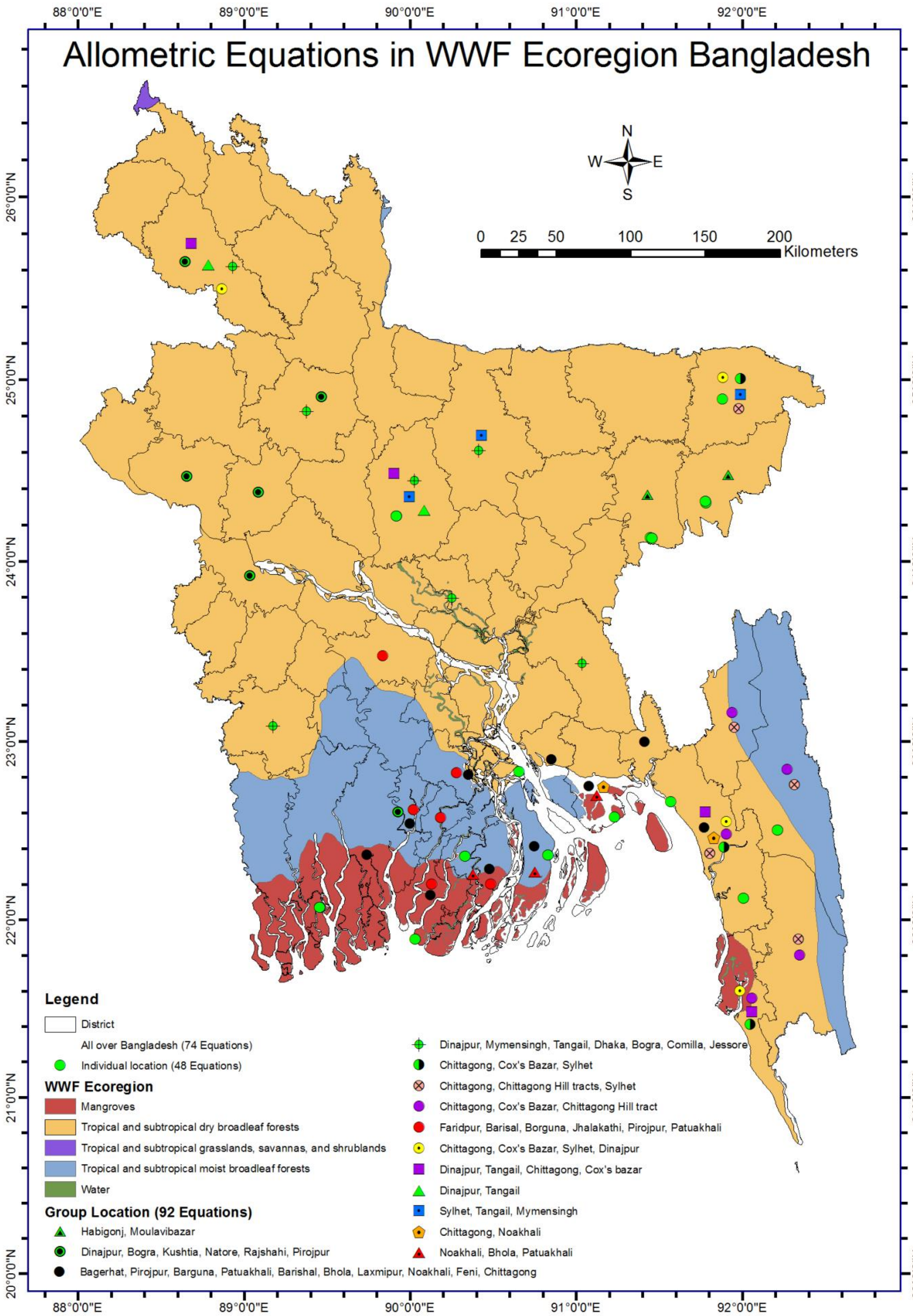
| *Genus* | *Species* | Local name | Family | Unite of Y | Vegetation Component | Equation |
|---|---|---|---|---|---|---|
| *Xylia* | *xylocarpa* | Lohakat, Pyinkado | Leguminosae | m3 | Total volume over bark | Log (Volume) = -9.4303 + 2.0988 * Log (DBH) + 0.6042 * Log (Height) |
| *Shorea* | *robusta* | Sal | Dipterocarpaceae | m3 | Total volume over bark | Log (Volume) = -10.0253 + 2.1163 * Log (DBH) + 0.7588 * Log (Height) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Log (Volume) = -8.66152 + 1.5856 * Log (DBH) + 0.77152 * Log (Height) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Log (Volume) = -9.29715 + 1.70514 * Log (DBH) + 0.95088 * Log (Height) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Log (Volume) = -9.23507 + 1.69673 * Log (DBH) + 0.92309 * Log (Height) |
| *Sonneratia* | *apetala* | Keora | Lythraceae | m3 | Total volume over bark | Log (Volume) = -8.75215 + 1.75034 * Log (DBH) + 0.64233 * Log (Height) |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | kg | Leaf | Log 10 (Oven-dried biomass) = 0.76 * Log 10 ((DBH^(2)) - 1.39 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | kg | Bark | Log 10 (Oven-dried biomass) = 1.04 * Log 10 ((DBH^(2)) - 1.80 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | kg | Stem without bark | Log 10 (Oven-dried biomass) = 1.04 * Log 10 ((DBH^(2)) - 0.99 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | kg | Total above-ground | Sqrt (Oven-dried biomass) = 0.48 * DBH - 0.13 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | g | Total above-ground | Sqrt (Nitrogen) = 0.67 * DBH + 0.11 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | g | Total above-ground | Sqrt (Phosphorus) = 0.94 * DBH + 0.08 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | g | Total above-ground | Sqrt (Potassium) = 1.06 * DBH - 0.18 |
| *Aegiceras* | *corniculatum* | Khulshi | Myrsinaceae | kg | Total above-ground | Sqrt (Carbon)= 0.33 * DBH - 0.09 |

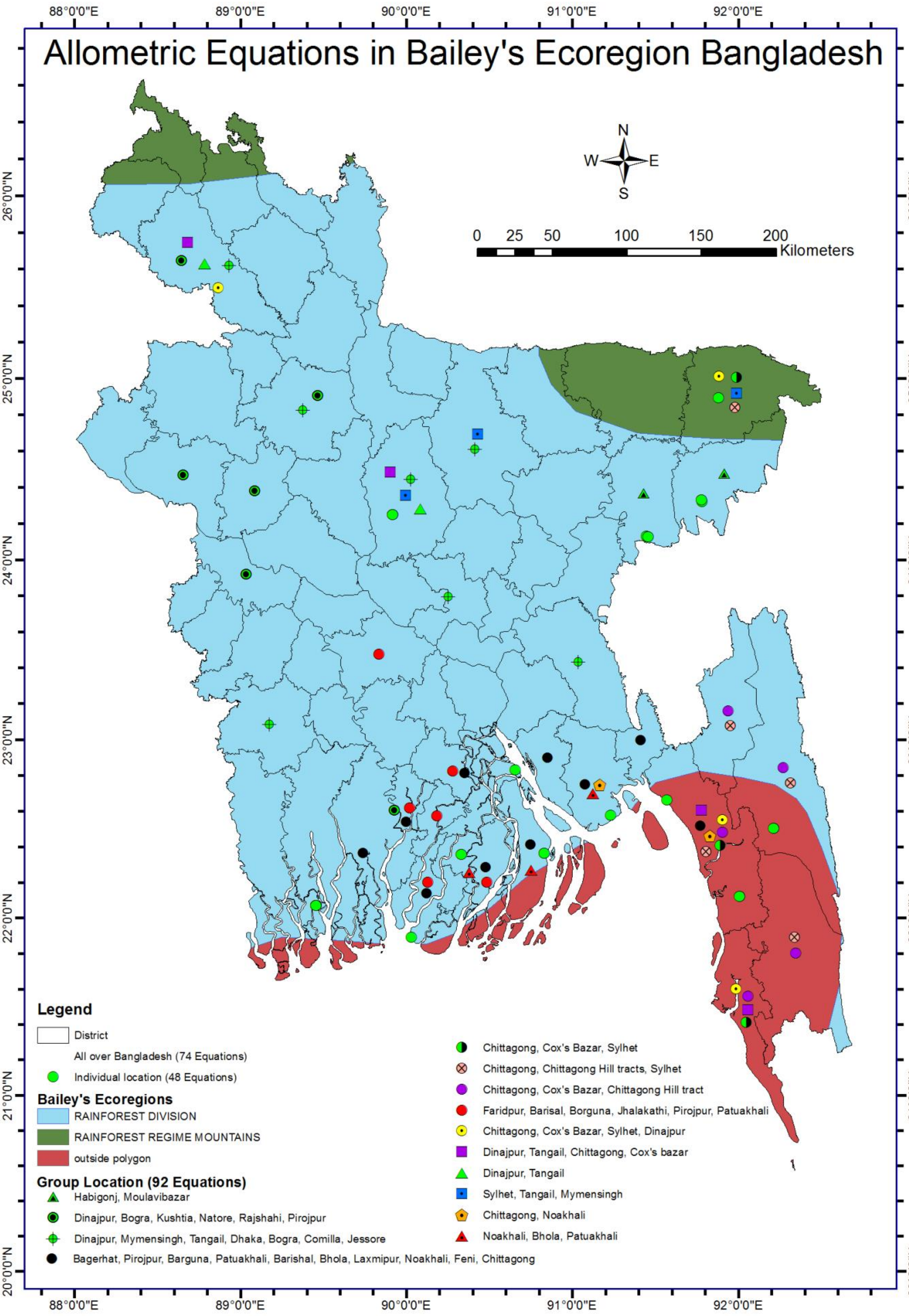
## Appendix 3. Distribution of allometric equations in different ecoregions of Bangladesh

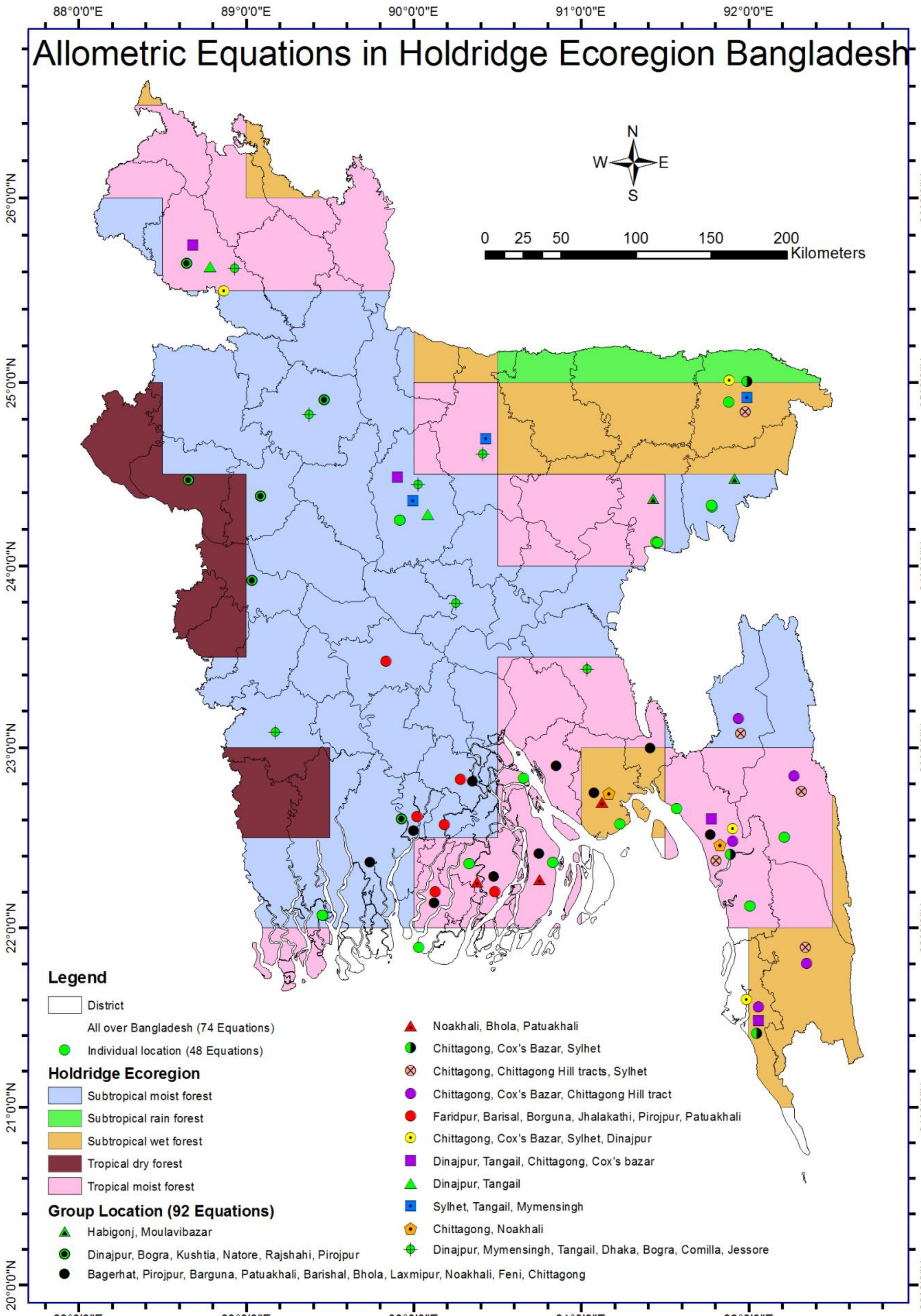


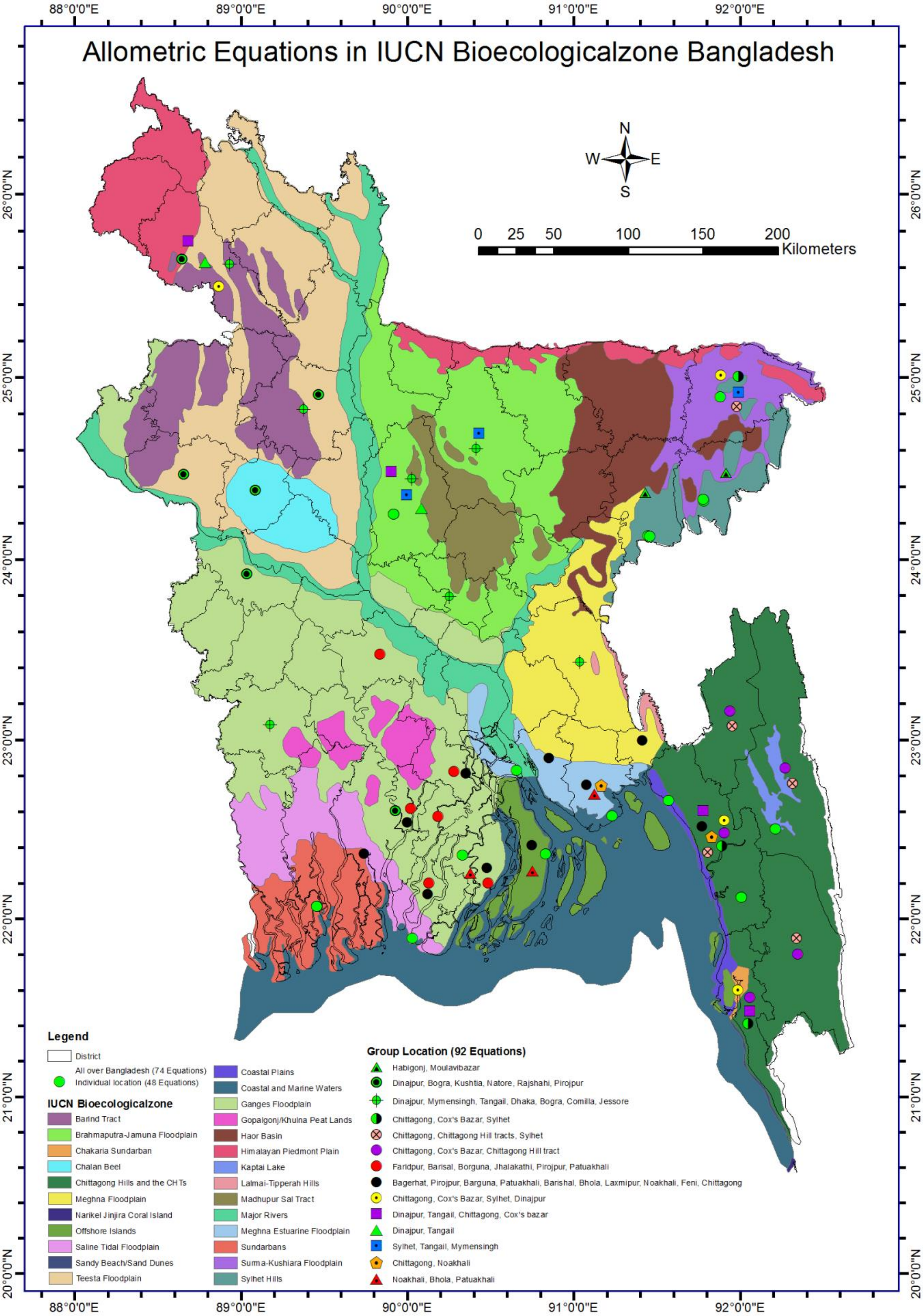


Allometric Equations in Udvardy Ecoregion Bangladesh
88°0'0"E
89°0'0"E
90°0'0"E
91°0'0"E
92°0'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
20°0'0"N
N
W
E
S
0 25 50 100 150 200
Kilometers
Legend
District
All over Bangladesh (74 Equations)
Individual location (48 Equations)
Udvardy Ecoregion
Tropical dry forests / Woodlands
Tropical humid forests
Group Locations (92 Equations)
Habigonj, Moulavibazar
Dinajpur, Bogra, Kushtia, Natore, Rajshahi, Pirojpur
Dinajpur, Mymensingh, Tangail, Dhaka, Bogra, Comilla, Jessore
Bagerhat, Pirojpur, Barguna, Patuakhali, Barishal, Bhola, Laxmipur, Noakhali, Feni, Chittagong
Chittagong, Cox's Bazar, Sylhet
Chittagong, Chittagong Hill tracts, Sylhet
Chittagong, Cox's Bazar, Chittagong Hill tract
Faridpur, Barisal, Borguna, Jhalakathi, Pirojpur, Patuakhali
Chittagong, Cox's Bazar, Sylhet, Dinajpur
Dinajpur, Tangail, Chittagong, Cox's bazar
Dinajpur, Tangail
Sylhet, Tangail, Mymensingh
Chittagong, Noakhali
Noakhali, Bhola, Patuakhali


Allometric Equations in WWF Ecoregion Bangladesh
88°0'0"E
89°0'0"E
90°0'0"E
91°0'0"E
92°0'0"E
20°0'0"N
21°0'0"N
22°0'0"N
23°0'0"N
24°0'0"N
25°0'0"N
26°0'0"N
N
S
E
W
0 25 50 100 150 200 Kilometers
Legend
District
All over Bangladesh (74 Equations)
Individual location (48 Equations)
WWF Ecoregion
Mangroves
Tropical and subtropical dry broadleaf forests
Tropical and subtropical grasslands, savannas, and shrublands
Tropical and subtropical moist broadleaf forests
Water
Group Location (92 Equations)
Habigonj, Moulavibazar
Dinajpur, Bogra, Kushtia, Natore, Rajshahi, Pirojpur
Bagerhat, Pirojpur, Barguna, Patuakhali, Barishal, Bhola, Laxmipur, Noakhali, Feni, Chittagong
Dinajpur, Mymensingh, Tangail, Dhaka, Bogra, Comilla, Jessore
Chittagong, Cox's Bazar, Sylhet
Chittagong, Chittagong Hill tracts, Sylhet
Chittagong, Cox's Bazar, Chittagong Hill tract
Faridpur, Barisal, Borguna, Jhalakathi, Pirojpur, Patuakhali
Chittagong, Cox's Bazar, Sylhet, Dinajpur
Dinajpur, Tangail, Chittagong, Cox's bazar
Dinajpur, Tangail
Sylhet, Tangail, Mymensingh
Chittagong, Noakhali
Noakhali, Bhola, Patuakhali


Allometric Equations in Bailey's Ecoregion Bangladesh
88°0'0"E
89°0'0"E
90°0'0"E
91°0'0"E
92°0'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
20°0'0"N
N
W
E
S
0 25 50 100 150 200
Kilometers
Legend
District
All over Bangladesh (74 Equations)
Individual location (48 Equations)
Bailey's Ecoregions
RAINFOREST DIVISION
RAINFOREST REGIME MOUNTAINS
outside polygon
Group Location (92 Equations)
Habigonj, Moulavibazar
Dinajpur, Bogra, Kushtia, Natore, Rajshahi, Pirojpur
Dinajpur, Mymensingh, Tangail, Dhaka, Bogra, Comilla, Jessore
Bagerhat, Pirojpur, Barguna, Patuakhali, Barishal, Bhola, Laxmipur, Noakhali, Feni, Chittagong
Chittagong, Cox's Bazar, Sylhet
Chittagong, Chittagong Hill tracts, Sylhet
Chittagong, Cox's Bazar, Chittagong Hill tract
Faridpur, Barisal, Borguna, Jhalakathi, Pirojpur, Patuakhali
Chittagong, Cox's Bazar, Sylhet, Dinajpur
Dinajpur, Tangail, Chittagong, Cox's bazar
Dinajpur, Tangail
Sylhet, Tangail, Mymensingh
Chittagong, Noakhali
Noakhali, Bhola, Patuakhali


Allometric Equations in Holdridge Ecoregion Bangladesh
88°0'0"E
89°0'0"E
90°0'0"E
91°0'0"E
92°0'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
20°0'0"N
N
W
E
S
0 25 50 100 150 200 Kilometers
Legend
District
All over Bangladesh (74 Equations)
Individual location (48 Equations)
Holdridge Ecoregion
Subtropical moist forest
Subtropical rain forest
Subtropical wet forest
Tropical dry forest
Tropical moist forest
Group Location (92 Equations)
Habigonj, Moulavibazar
Dinajpur, Bogra, Kushtia, Natore, Rajshahi, Pirojpur
Bagerhat, Pirojpur, Barguna, Patuakhali, Barishal, Bhola, Laxmipur, Noakhali, Feni, Chittagong
Noakhali, Bhola, Patuakhali
Chittagong, Cox's Bazar, Sylhet
Chittagong, Chittagong Hill tracts, Sylhet
Chittagong, Cox's Bazar, Chittagong Hill tract
Faridpur, Barisal, Borguna, Jhalakathi, Pirojpur, Patuakhali
Chittagong, Cox's Bazar, Sylhet, Dinajpur
Dinajpur, Tangail, Chittagong, Cox's bazar
Dinajpur, Tangail
Sylhet, Tangail, Mymensingh
Chittagong, Noakhali
Dinajpur, Mymensingh, Tangail, Dhaka, Bogra, Comilla, Jessore


Allometric Equations in IUCN Bioecologicalzone Bangladesh
88°0'0"E
89°0'0"E
90°0'0"E
91°0'0"E
92°0'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
20°0'0"N
N
W
E
S
0 25 50 100 150 200
Kilometers
Legend
District
All over Bangladesh (74 Equations)
Individual location (48 Equations)
IUCN Bioecologicalzone
Barind Tract
Brahmaputra-Jamuna Floodplain
Chakaria Sundarban
Chalan Beel
Chittagong Hills and the CHTs
Meghna Floodplain
Narikel Jinjira Coral Island
Offshore Islands
Saline Tidal Floodplain
Sandy Beach/Sand Dunes
Teesta Floodplain
Coastal Plains
Coastal and Marine Waters
Ganges Floodplain
Gopalgonj/Khulna Peat Lands
Haor Basin
Himalayan Piedmont Plain
Kaptai Lake
Lalmai-Tipperah Hills
Madhupur Sal Tract
Major Rivers
Meghna Estuarine Floodplain
Sundarbans
Surma-Kushiara Floodplain
Sylhet Hills
Group Location (92 Equations)
Habigonj, Moulavibazar
Dinajpur, Bogra, Kushtia, Natore, Rajshahi, Pirojpur
Dinajpur, Mymensingh, Tangail, Dhaka, Bogra, Comilla, Jessore
Chittagong, Cox's Bazar, Sylhet
Chittagong, Chittagong Hill tracts, Sylhet
Chittagong, Cox's Bazar, Chittagong Hill tract
Faridpur, Barisal, Borguna, Jhalakathi, Pirojpur, Patuakhali
Bagerhat, Pirojpur, Barguna, Patuakhali, Barishal, Bhola, Laxmipur, Noakhali, Feni, Chittagong
Chittagong, Cox's Bazar, Sylhet, Dinajpur
Dinajpur, Tangail, Chittagong, Cox's bazar
Dinajpur, Tangail
Sylhet, Tangail, Mymensingh
Chittagong, Noakhali
Noakhali, Bhola, Patuakhali

# Appendix 4. Steps in the development of biomass and volume allometric equations