Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Subir Nandi Sarkar Nayan

Title: Allometric biomass model of *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. For the homestead of Bangladesh

Supervisor(s): Dr. Mahmood Hossain, Professor, Forestry and Wood Technology Discipline, Khulna University

Programme: Bachelor of Science in Forestry

This thesis has been scanned with the technical support from the Food and Agriculture Organization of the United Nations and financial support from the UN-REDD Bangladesh National Programme and is made available through the Bangladesh Forest Information System (BFIS).

BFIS is the national information system of the Bangladesh Forest Department under the Ministry of Environment, Forest and Climate Change. The terms and conditions of BFIS are available at http://bfis.bforest.gov.bd/bfis/terms-conditions/. By using BFIS, you indicate that you accept these terms of use and that you agree to abide by them. The BFIS e-Library provides an electronic archive of university thesis and supports students seeking to access digital copies for their own research. Any use of materials including any form of data extraction or data mining, reproduction should make reference to this document. Publisher contact information may be obtained at http://ku.ac.bd/copyright/.

BFIS's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission you may use content in the BFIS archive only for your personal, non-commercial use. Any correspondence concerning BFIS should be sent to bfis.rims.fd@gmail.com.

Allometric Biomass Model of *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. for the Homestead of Bangladesh.

Subir Nandi Sarker Nayan
STUDENT ID: 140526

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
SCHOOL OF LIFE SCIENCE
KHULNA UNIVERSITY
KHULNA-9208
JULY 2018

Allometric Biomass Model of *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. for the Homestead of Bangladesh.

Subir Nandi Sarker Nayan

STUDENT ID: 140526

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
SCHOOL OF LIFE SCIENCE
KHULNA UNIVERSITY
KHULNA-9208
JULY 2018

Allometric Biomass Model of *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. for the Homestead of Bangladesh.

Course Title: Project Thesis

Course No: FWT-4114

[This thesis paper has been prepared for the partial fulfillment of the requirements of Four Years B.Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh]

Supervisor

Dr. Mahmood Hossain
Professor
Forestry and Wood Technology Discipline
Khulna University, Khulna

Prepared By

Subir Nandi Sarker Nayan
Student ID: 140526

DECLARATION

I, Subir Nandi Sarker Nayan, declare that this thesis is the result of my own work and it has not been submitted or accepted for any degree to other university or institution.

I hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for title and summary to be made available to outside organizations with my approval.

Signature

Nayan 24/9/2018

…………………………………

Subir Nandi Sarker Nayan

APPROVAL

This is to certify that the present project entitled "Allometric Biomass Model of *Mangifera indica* L. and *Artocarpus heterophyllus Lam.* for the Homestead of Bangladesh using Biomass Expansion Factor (BEF)" has been conducted by **Subir Nandi Sarker Nayan** (Student ID: 140526) under my direct supervision and guidance. Project thesis submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh in partial fulfillment of the requirements for the four years professional B.Sc. (Hons.) degree in Forestry. I have approved the style and format of the project thesis.

Supervisor

Hossain 24/09/2018

Dr. Mahmood Hossain

Professor

DEDICATED

TO

MY BELOVED MOTHER

AND

FRIENDS OF FWT'14

Acknowledgement

First of all I would like to thanks and honor to the almighty God for the successful accomplishment of this B.Sc thesis work. I would like to express my heartful gratitude and profound appreciation to my honorable supervisor, **Prof. Dr. Mahmood Hossain** whose sympathetic co-operation, guidance, suggestions, advices help me to complete and submit this paper. I am grateful to **Md. Raqibul Hasan Siddique** for his inspirations, profound suggestions and continuous guidance that help me for conducting this study.

I also greatly acknowledge the Bangladesh Forest Research Institute for the sharing of raw volume data of homestead tree species of Bangladesh. Finally, we like to thank Forestry and Wood Technology Discipline, Khulna University for their logistic supports during the laboratory analysis.

Abstract

Mangifera indica L. and *Artocarpus heterophyllus* Lam. are the common homestead species which can be found all over the Bangladesh. Nationwide second forest inventory is now going on in Bangladesh and it has stratified the tree covers and forests into Hill, Sal, Sundarbans, Coastal and Village zone. One of the objectives of this inventory is to estimate the biomass and carbon stock in trees and forests. Selection of appropriate allometric model of biomass is a challenging issue in accurate estimation of biomass and carbon stock. The objective of this study was to develop a species specific allometric biomass model for *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. for the Village zone of Bangladesh. The allometric models were developed from the volume data of 59 and 64 sample trees of *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. of the village zone respectively. Total above-ground biomass of sample trees was calculated from stem volume, wood density and biomass expansion factor (BEF). Frequently used three linear models (Ln transformed) were tested to derive the best fit allometric model for the total above-ground biomass and stem biomass. Diameter at Breast Height, Total Height and Wood Density were independent variables of the tested allometric models. The best fit allometric models for the total above-ground biomass (TAGB) of *Mangifera indica* and *Artocarpus heterophyllus* were (TAGB) =exp(0.227285+1.8017*Ln(D)) and (TAGB) = exp(-0.897+1.99*Ln(D)); respectively, where D = Diameter at Breast Height, H = Total Height. The best fit TAGB allometric model showed highest efficiency in biomass estimation compared to the frequently used pan-tropical models for the village zone of Bangladesh.

Keywords: Allometry, Biomass, Biomass Expansion Factor, Inventory, Pan-tropical models, Village zone, Forest Reference Emission Levels

List of contents

List of figures

List of tables

Chapter 1: Introduction

1.1. Introduction

The mango (*Mangifera indica* L.) is a juicy stone fruit belonging to the genus Mangifera, consisting of numerous tropical fruiting trees, cultivated mostly for edible fruit. The majority of these species are found in nature as wild mangoes. The mango is native to South Asia e.g. Bangladesh, India, Myanmar from where it has been distributed worldwide to become one of the most cultivated fruits in the tropic (Mehta 2017).

Bangladesh is often recognized as a secondary center of diversity for jackfruit *(Artocarpus heterophyllus* Lam.*)* and is expected to harbor important genetic diversity of this underutilized tree crop. Jackfruit *(A. heterophyllus)* is a giant and unique tropical composite fruit which is grown extensively in equatorial countries in the Indian sub-continent and South-East Asia, such as Myanmar, Bangladesh etc. Many homesteads reported that they had sold most of their large trees for timber and that the naturally growing trees in the forest and fallow lands that were not planted by human had almost disappeared (Khan et al., 2017).

M. indica and *A. heterophyllus* are common homestead trees in Bangladesh. The tree cover in village forests is 2,70,000 hectares which means a reasonable portion of the total demand of forest products is being met from homestead forest. According to the latest inventory report, the village woodlots have a growing stock of 54.7 million cubic meters (Khan et al., 2007).

Trees outside forests e.g. home garden or homestead forests or village forests which support smallholder farmers' livelihoods and play a critical role in the global carbon cycle but for the reason of limited information regarding their extent and inadequate methods for biomass quantification, their contribution to climate change mitigation through carbon storage is not obvious (Kuyah et al., 2014). Forests are large pools of carbon as well as potential carbon sinks and sources to the atmosphere (Giri et al., 2014). To understand the current state of the carbon cycle (Larreta et al., 2017), to assess the mitigation effect on forests on global change, to predict the potential impact of mechanisms to reduce carbon emission and to and to understand how it may evolve with changing land use and climatic conditions, estimation of forest biomass is required accurately (Giri et al., 2014; Ebuy et al., 2011).

Countries may have developed or have access to historical assessments of forest area change for their country, which could be from national, regional or global datasets. Likewise, countries may have already produced and submitted national GHG inventories to the UNFCCC including estimates for their forestry sector. Depending on what data is available, countries may want to first analyze existing historical data when constructing their FRELs and assess its relevance in this context (Angelsen et al., 2012). Trees play a huge role in the carbon cycle on our planet. When trees are cut down, not only does carbon absorption cease but also the carbon stored in the trees is released into the atmosphere as CO2 if the wood is burned or even if it is left to rot after the deforestation process (Werf et al., 2009).

Forests ecologists have developed different methods for biomass estimation (Golley et al., 1975). Allometric biomass models are frequently used to estimate biomass of trees or forests in a non-destructive way (Ketterings et al., 2001; Picard et al. 2012). Many scientists gave efforts to improve the tree allometric models at regional, national or even worldwide scales by using easily measured dimensional variables, such as diameter at breast high (DBH) and tree height (H). However, different models may lead to greatly variation of biomass estimation because of difference in climatic conditions, site quality and forest types (Brown et al., 1989; Ter-Mikaelian and Korzukhin 1997; Chave et al., 2005; Navar 2009; Genet et al., 2011). The species-specific allometric equation has great significance as the carbon balance assessment which is influenced by the forest type, its architectural structure, diameter, height, the type of land-use changes and the selected allometric equation (Kebede 2018, Feldpausch et al., 2011).

Tree species and their DBH, height and wood density ranges of pan tropical models are not similar to the species available in different zones of Bangladesh. So, generalized models sometimes may fail to capture variations in forest type (Chave et al., 2005; Litton 2008). Logically, species specific allometric models should provide a greater level of accuracy at a given location (Ketterings et al., 2001) to assist the assessment of biomass dynamic, net primary productivity, nutrient cycling and budgeting for research purpose (Mahmood et al., 2008; Litton 2008). It is preferable to use species specific regression models for biomass estimation because trees of different species may differ greatly in the tree architecture and wood density (Ketterings et al., 2001; Golley et al., 1975).

Different research and academic institutions and individual researcher have developed volume equations of these two species (Rahman et al., 2012; Islam et al., 2012) but species specific allometric equations for estimating above-ground biomass have not developed yet for these two species in Bangladesh.

1.2. Objective of the study:

1. Development of allometric biomass model for estimating above ground biomass of *Mangifera indica* L. and *Artocarpus heterophyllus* Lam.

Chapter 2: Literature review

2.1. Species description

Mango (*M. indica*) is a commercially important tropical fruit, morphologically belongs to the subtype indeliquescent drupe and contains a single large seed surrounded by fleshy meso-carp. Mango is a dicotyledonous fruit of the family Anacardiaceae, originated in the Indo-Burmese region.

Taxonomy:

The genus Mangifera belongs to the order Sapindales in the family Anacardiaceae, which is a family of mainly tropical species.

1. Kingdom: Plantae
2. Division: Magnoliophyta
3. Class: Magnoliopsida
4. Sub-Class: Rosidae
5. Order: Sapindales
6. Family: Anacardiaceae
7. Genus: Mangifera
8. Species: *Mangifera in*dica

The jackfruit tree is well suited to tropical lowlands and its fruit is the largest tree-borne fruit, reaching as much as 55 kg (120 lb) in weight, 90 cm (35 in) in length, and 50 cm (20 in) in diameter. A mature jackfruit tree can produce about 100 to 200 fruits in a year. The jackfruit is a multiple fruit, composed of hundreds to thousands of individual flowers, and the fleshy petals are eaten (Silver et al. 2016). Bangladesh is often recognized as a secondary center of diversity for jackfruit (*A. heterophyllus*) and is expected to harbor important genetic diversity of this underutilized tree crop (Khan et al., 2010).

Taxonomy:

1. Kingdom: Plantae

2. Division: Magnoliophyta
3. Class: Magnoliopsida
4. Subclass: Hamamelididae
5. Order: Urticales
6. Family: Moraceae
7. Genus: Artocarpus
8. Species: Artocarpus heterophyllus

2.2. Species distribution

Mango is known to be the most important tropical fruit of Asia, grown commercially in more than 87 countries. Mango currently ranks fifth in total production among major fruit crops grown in world wide. The world production of mangoes is estimated to be over 23.4 × 106 MT per anum. India ranks first among world's mango producing countries, accounting for 54.2% of the total mangoes produced worldwide. Other prominent mango producing countries are Bangladesh, China, Thailand, Indonesia, Philippines, Pakistan, and Mexico (Tharanathan et al., 2007).

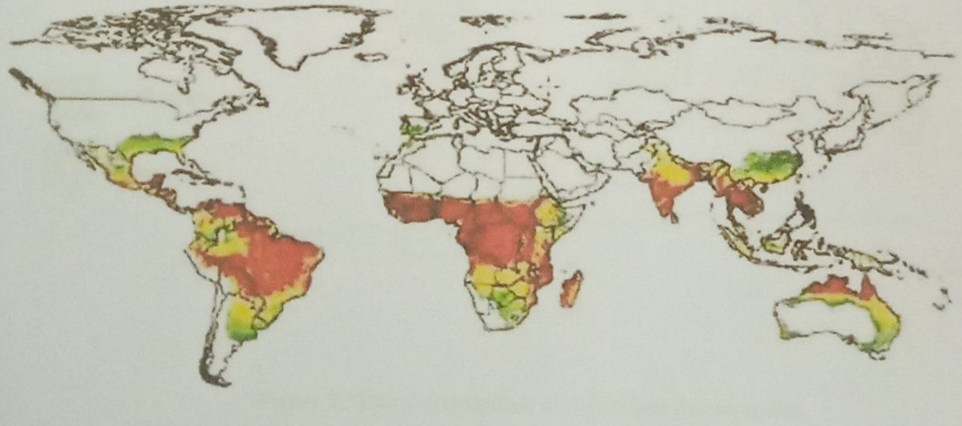


Figure 1: Global distribution of *Mangifera indica*. The red color is indicating the best production area, the yellow is moderate and the green color is indicating the low production area.

The place of origin and wild ancestor of Jackfruit is unknown. Jackfruit has been cultivated for millennia and was referred to as early as 300 B.C.E. by Theophrastus (Hort 1916). It is now so widely cultivated that the region in which it is indigenous and its wild progenitor is unclear. Today it can be found in cultivation at low elevations from the Indian subcontinent through Bangladesh, Myanmar, into southern China, Laos, Vietnam, Cambodia, Thailand, Malaysia, Indonesia and Oceania. It is also commonly cultivated in the Philippines and has been introduced throughout Africa and the Neo-tropics. It has been under cultivation for so long that Jarrett (1959) speculated it would not be possible to identify the wild progenitor. It is, nevertheless, believed to be native to the Indo-Malaysian region (Beddome 1873; Brandis 1906; Gamble 1902; Kanjilal et al. 1940; Talbot 1911; Wight 1843).

Figure 2: Global distribution of *Artocarpus heterophyllus*

2.3 Distribution in Bangladesh

Bangladesh produces a large number of superior varieties of mangos *(M. indica)*, mostly grown in Rajshahi, Nawabganj, and Dinajpur. These have wide demand in the market and are commercially important. Prominent among the elite varieties are Fazli, Langra, Ashini, Gopal-bogh, Laksman-bhog, Mohan-bhog, Raj-bhog, Himsagar, Chok anan, Khirsapat etc (Islam et al., 2013).

Jack fruit *(A. heterophyllus)* grows all over in Bangladesh, mainly on the hilly area of Chittagong, Sylhet and on the highland of Gazipur, Mymensingh, Tangail, Kumilla and Jashore. Jackfruit is native to parts of Southern and Southeast Asia (Khan et al., 2010).

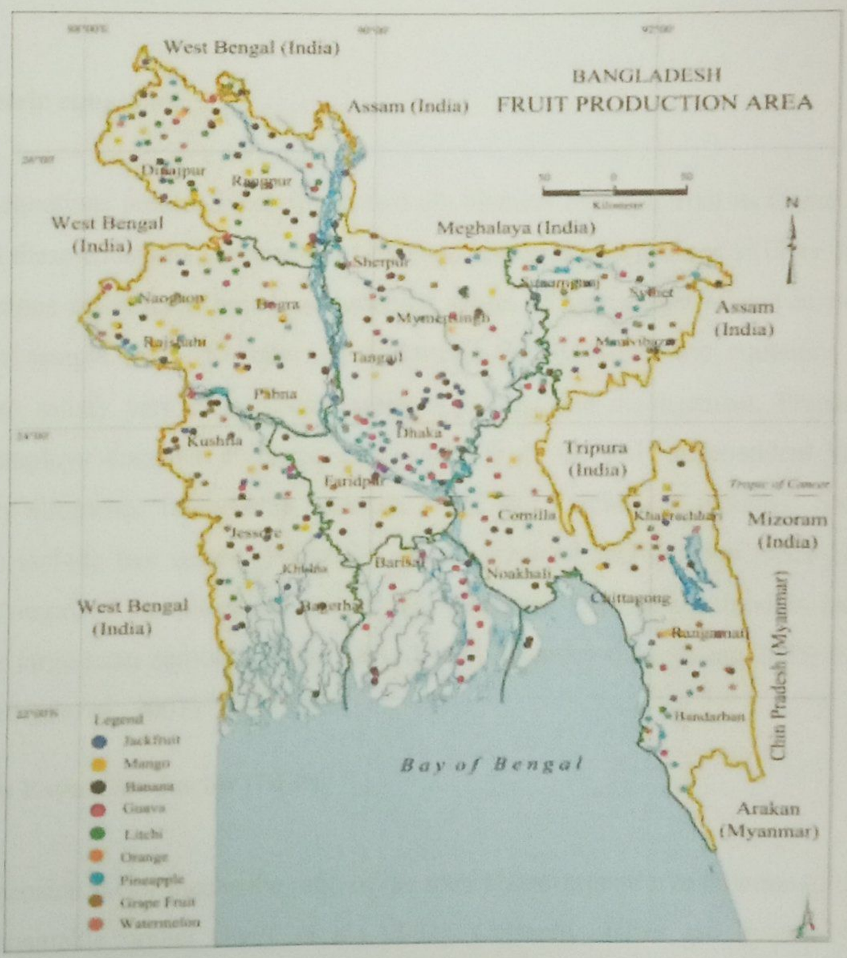


Figure 3: Distribution of common fruits including *Mangifera indica* L. and *Artocarpus heterophyllus* Lam. in Bangladesh

2.4. Biomass

Forest biomass is expressed in terms of dry weight of organic matter which is an important indicator of ecosystem energy potential and productivity (Yaklasimlar 2012). Biomass estimation of the forest ecosystem enables us to estimate the amount of carbon dioxide that can be sequestered from the atmosphere by the forest (Kebede and Soromessa 2018). Relatively 50% of dry forest biomass comprised of carbon (UNFCCC 2010b). Estimating biomass typically involves the use of allometric equations. Such equations are usually derived from destructive sampling of trees to measure biomass directly, after which biomass is correlated with non-destructive measurements, such as diameter and height (Chave et al., 2005; Ngo and Lum 2018).

2.5. Allometric equations

Allometric equations predict the above ground dry biomass of a tree from its diameter or height or both and these equations are needed to estimate carbon stocks in forests (Ebuy et al., 2011). These equations are derived based on measured values of tree weight related to its DBH and height from sample trees (Kebede and Soromessa 2018). Allometric equations have been developed to satisfy various purposes in forest ecology and management. Practically, most allometry employs diameter at breast height (DBH) as the only independent variable and develops an allometric relationship between DBH and component biomass. Some studies proposed to include tree height (H) as the second predictor and develop DBH–H combined equation to improve the precision of biomass estimates. Generalized models have a great potential for large-scale carbon budgets derived from inventory data (Wang 2005; Pastor et al., 1984; Ketterings et al., 2001).

2.6. Biomass Expansion Factor (BEF)

Biomass expansion factor means the ratio of the total above-ground tree biomass to the biomass of the merchantable timber (Levy et al., 2004). Currently, BEFs are frequently used for greenhouse gas reporting because the volumes of growing stock and stem-wood growth are usually the most reliable estimates in traditional forest inventories. But the BEFs were not constant over time. When estimating changes in living biomass at a national scale, it is usually difficult to obtain a reliable value for the whole tree biomass from the stem volume because stem proportion increases with tree size at the expense of branches, foliage, stump and roots (Peterson et al., 2012). To reduce the risk of bias volume-dependent (e.g., Schroeder et al., 1997; Fang et al. 2001) BEFs have been developed, which enables the ratio of whole tree biomass to stem volume to change with tree size (Levy et al., 2004).

BEF = (Weight of total above ground biomass) / (Weight of merchantable stem biomass)

TAGB = Merchantable stem biomass × BEF

2.7. Homestead Forests in Bangladesh

The homestead forest of Bangladesh is described as a multi-storied vegetation of shrubs, bamboos, palms and trees surrounding homesteads that produce materials for a multitude of purposes, including fuel, shelter, structural materials, fruits and other foods, fodder, resins and medicines (Douglas 1981; Rahman et al., 2005). Homestead farming is an age-old practice in Bangladesh (Alam et al., 1988) involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock, within the compounds of individual houses being intensively managed by family labor (Nair et al., 1986). There are no village forests assigned to the villagers under the Forest Act in Bangladesh (Khan et al., 2007). According to the official sources, the total land under forest is about 2.56 million hectares which include classified and unclassified state forest lands, village forest areas and private owned tea and rubber gardens. *Mangifera indica* L. (Am) and *Artocarpus heterophyllus* Lam. (Kanthal) are the fruit bearing trees among the five tree categories of village forest (Khan et al., 2006).

2.8. Forest Reference Emission Level (FREL)

Forest reference emission level is one of the elements to be developed by developing country Parties implementing REDD+ activities. The COP recognized the importance and necessity of adequate and predictable financial and technology support for developing such reference levels. Reference levels are expressed as tones of CO2 equivalent per year for a reference period against which the emissions and removals from a results period will be compared. Thus, reference levels serve as benchmarks for assessing each country's performance in implementing REDD+ activities. Reference levels need to maintain consistency with the country's greenhouse gas inventory estimates (Romijn et al., 2013).

Reference levels should be transparent, taking into account historic data and be flexible so as to accommodate national circumstances and capabilities, while pursuing environmental integrity and avoiding perverse incentives. Developing country Parties implementing REDD+ can use a stepwise approach to construct reference levels, incorporating better data, improved methodologies and, where appropriate, additional pools. They should also update their reference level periodically, taking into account new knowledge, new trends and any modification of scope and methodologies. Developing countries aiming to implement REDD+ activities are invited to submit a reference level to the secretariat, on a voluntary basis and when deemed appropriate. The information contained in the submission should be transparent, complete, consistent with guidance agreed by the COP and accurate. The information provided should be guided by the most recent IPCC guidance and guidelines, as adopted or encouraged by the COP (Angelsen et al., 2012).

2.9. REDD and REDD+

REDD refers to reducing emissions from deforestation and forest degradation and REDD+ refers to conservation of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks. In its most basic form, REDD+ means developed countries paying developing countries to not cut down or re-grow their forests. This counts towards the developed country's carbon offsets. It is based off the assumption that without REDD+, these forests would have been cut down, accelerating climate change (Besten et al., 2014).

Deforestation and forest degradation account for approximately 17 percent of carbon emissions, more than the entire global transportation sector and second only to the energy sector. It is now clear that in order to constrain the impacts of climate change within limits that society will reasonably be able to tolerate, global average temperatures must be stabilized within two degrees

Celsius. This will be practically impossible to achieve without reducing emissions from the forest sector, in addition to other mitigation actions (Phelps et al., 2010)

Reducing emissions from deforestation and forest degradation (REDD+) is a mechanism developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC). It creates a financial value for the carbon stored in forests by offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. Developing countries would receive results-based payments for results-based actions. REDD+ goes beyond simply deforestation and forest degradation and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (Pesket et al., 2009).

Chapter 3: Materials and Methods

3.1. Sources of Data

This study has used summarized stem volume data of *M. indica* and *A. heterophyllus* of Bangladesh Forest Research Institute (BFRI) that have been used to derive volume table of these species. However, the sample trees were collected from home garden of different locations of Bangladesh by the BFRI inventory Division.

3.2. Biomass Expansion Factor (BEF)

A common biomass expansion factor was used to estimate the total above-ground biomass of M. indica and *A. heterophyllus*. The common biomass expansion factor of Mahmood et al. (In press) was followed which was derived from 42 sample trees of *Albizia spp., Artocarpus heterophylus, Mengifera indica, Swietenia macrophylla* and *Syzygium cumini*. The range of Diameter at Breast Height (DBH) and Total Height of the sampled trees were 8.3 to 83.1 cm and 4.9 to 32.9 m respectively.

3.3. Development of Allometric Biomass model

3.3.1. Data collection and compilation

This study used the raw data of stem volume of 59 individuals from *M. indica* and the raw data of stem volume of 64 individuals from *A. heterophyllus* (Latif and Islam, 2000). The summarized volume (m^3) data of individual sample trees of *M. indica* and *A. heterophyllus* were converted to biomass (kg) with the aid of wood density (kg/m^3) of respective tree species as derived by Satter et al. (1999). Finally, the common biomass expansion factor value was multiplied with the stem biomass to get total above-ground biomass of each individual sample tree. Finally, the total above-ground biomass of individual trees was estimated from the stem biomass and BEF of the respective individuals (Soares and Tome, 2012) as derived a common biomass expansion factor by Mahmood et al. (in press).

3.3.2. Allometric model development

The independent variables (Diameter at Breast Height and Total Height, Wood Density) and dependent variable (Total above-ground biomass) were transformed to Ln (natural logarithm) to improve the linearity and homoscedasticity. The total data set of both species was divided in to Data Set A and B. Data Set A contained randomly selected 47 individuals of M. indica and 51 individuals from A. heterophyllus, which was used to derived the allometric model. A total of three frequently used regional and pan-tropical biomass allometric models were tested to derive the allometric model for total above-ground biomass and stem biomass (Table 1).

Table 1 : Most frequently used regional and pan-tropical biomass allometric models

Model no	Formula
1	TAGB=a+ b(log(D)) + c((log(D))^2) + d((log(D))^3) + e(log(H))
2	TAGB=a+ b(log(D))
3	TAGB=a+ b(log(D)) + c(log(H))
4	TAGB=a+ b(log(D2H))

All the tested models were natural logarithm which introduced a systematic bias during biomass estimation. Therefore, a correction factor (CF) was calculated for each equation to minimize the systematic bias during the back transformation to biomass value (Sprugel 1983).

3.3.3. Model selection

The model which has the lowest Akaike Information Criterion (AIC) and Residual Standard Error (RSE); the highest Akaike Information Criterion Weight (AICw) and Coefficient of Determination (R^2) (Sileshi 2014; Picard et al., 2015) and the models which excludes wood density was selected as best fit model because wood density varies within the plant during the life of the plant and between individuals of the same species (Chave 2006). A false sense of confidence during model selection process can arise when the differences among the AIC values are very small. For this reason, to overcome this problem and to describe the relative performance of the models, AICw was calculated (Wagenmakers and Farrel 2004).

The following equation was followed to calculated AICw :

$\text{AICw} = \frac{\exp\left\{-\frac{1}{2}\Delta i(\text{AIC})\right\}}{\sum_{k-1}^{k}\exp\left\{-\frac{1}{2}\Delta k(\text{AIC})\right\}}$ -Equation 1

Where, ΔI AIC is the difference between model having minimum AIC value and AIC of the individual model.

Models having highest and 2^{nd} highest AICw value need to determine the best model in terms of Kullback-Leibler discrepancy and evidence ratio. The calculation of best model based on Kullback-Leibler discrepancy and evidence ratio is as follows (Wagenmakers and Farrel 2004).

Kullback-Leibler discrepanc = $\frac{\text{Highest AICw value}}{\text{Second highest AICw value}}$ - - - - - - - - - - - - - Equation 2 ,

Evidence ratio = $\frac{\text{Higest AICw value}}{\text{Higest AICw value +2nd higest AICw value}}$ - - - - - - - - - - - - - Equation 3

The models containing identical multiple predictors need test of multi co-linearity (Sileshi 2014). Therefore, multi co-linearity among the predictors of models was tested using Variance Influential Factor (VIF). Models having VIF>10 indicate the existence of multi co-linearity among the predictors (Sileshi 2014). VIF was calculated using following formula:

$\text{VIF} = \frac{\text{SD}^2(\text{n}-1)\text{SE}^2}{\text{MSR}}$ -Equation 4

Where, SD = Standard deviation of individual predictor, SE = Standard error of each predictor, (n-1) = Total degree of freedom for the model, MSR= Mean square residual.

3.3.4. Model evaluation and Comparison

Model Prediction Error (MPE), Model efficiency (ME) and Root Mean Square Error (RMSE) are used for existing pan-tropical and regional models to compare and evaluate with the derived best fit TAGB model of the study (Mayer and Butler 1993).

$\text{MPE}(\%) = \frac{100}{n}\sum\left[\frac{(Yp-Yo)}{Yo}\right]$ - Equation 5

$$\mathrm{ME} = 1 - \left[\frac{\sum(\mathrm{Yo}-\mathrm{Yp})^2}{\sum(\mathrm{Yo}-\bar{\mathrm{Y}})^2}\right] \text{------------------------ Equation 6}$$

$$\mathrm{RMSE} = 100 \times \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{Yp}-\mathrm{Yo})^2} \text{ ------------------- Equation 7}$$

Where, n = Number of trees, Yp =Predicted biomass from model, Yo = Observed biomass in field measurement and $\bar{\mathrm{Y}}$ = Mean of the observed biomass.

Only for the best fit TAGB model of this study, regression between Yp (X-axis) and Yo (Y-axis) was derived. Significance of slope (b=1) and intercept (a=1) were also tested in accordance with (Pinerio et al., 2008). The overestimation and underestimation of each predicted biomass can easily be understood graphically from 1:1 line (Sileshi 2014).

Chapter 4: Results

4.1. Biomass Expansion Factor (BEF)

The best fit BEF model for the trees of village zone was BEF = exp(3.8839 - D)^0.1072+exp(0.8791)*D/H^2+1 having lowest RMSE (0.2580) and second lowest AIC (25.3735) value compared to other models (Table 2).

Table 2: **Comparison among the derived models of Biomass Expansion Factor (BEF) for the Village zone**

BEF equation	a	B	c	Adjusted R2	AIC	RMSE
BEF = a + b*D	3.5049	-0.2573		0.2732	35.7229	0.3388
BEF = a*exp(D*b)	2.2125	-0.0136		0.2225	43.1005	0.3504
BEF = a*H^b	5.8501	-0.5375		0.5593	19.2532	0.2638
BEF = a*exp(H*b)	2.7127	-0.0445		0.4668	27.2545	0.2902
BEF =a*(D*H)^b	6.0245	-0.2408		0.4588	27.8840	0.2923
BEF = a - (D*H)^b	3.8316	0.1430		0.3820	33.4559	0.3124
BEF = a*(D/H)^b	1.3904	0.1878		-0.0231	54.6294	0.4019
BEF = a*exp(D/H)^b	1.3504	0.0778		-0.0314	54.9680	0.4036
BEF = exp(a - D)^b + exp(c)*D + 1	12.3520	0.0724	-5.6536	0.3531	43.3777	0.3196
BEF = exp(a - D)^b + exp(c)*D/H^2 + 1	3.8839	0.1072	0.8791	0.5786	25.3735	0.2580

D= Diameter at Breast Height (cm); H= Total Height (m); RMSE=Root Mean Square Error; Source: Mahmood et al. (in press)

4.2. Selection of allometric model for *Mangifera indica* L.

Model 1 (TAGB) = 34.51 -31.49*Ln (D) + 10.645*Ln (D)^2 – 1.102*Ln (D)^3 -0.52*Ln (H)) showed highest adjusted R^2 value (0.940) and lowest RSE (0.248) and lowest AIC (12.364) among the tested four models. But, it showed unaccepted VIF value (VIF > 10) for the three independent variables (D, D^2, D^3). Model 3 (TAGB) = (0.0311 +1.9211*Ln (D) - 0.282Ln(H)) showed 2nd highest adjusted R^2 value (0.872) which is closest to the Model 2, lowest RSE value(0.371) and 2nd lowest AIC value (46.209). Nevertheless, Model 2, (TAGB) =exp(-0.227285+1.8017*Ln(D)) has appeared as best fit allometric model for TAGB with lowest AIC (45.192) and 2nd lowest RSE (0.375) value and highest R^2 (0.873) value among the rest of the models.(Considering Model 1 is unaccepted, the ranking is developed for adjusted R^2, AIC and RSE value) (Table 3).

4.3. Model evaluation and comparison of *Mangifera indica* L.

The model efficiency values of the best fit TAGB Model 2 of this study was 0.873, which was closest to reference value 1, the residual mean square error (RMSE) (11206.03) and the MPE(%) (-6.7505) of the best fit model were lower compared to other regional and pan-tropical models. Nevertheless, among the pan-tropical models, Djomo et al. (2010) ranked the 2nd lowest RMSE (%) (22567.34) and lowest ME(%) (0.974). The graphical presentation from 1:1 line indicated that our best fit TAGB models 2 capable to estimate the total above-ground biomass more precisely. While, overestimated TAGB was observed for the frequently used regional and pan-tropical and regional models compared to ours (Table 4).

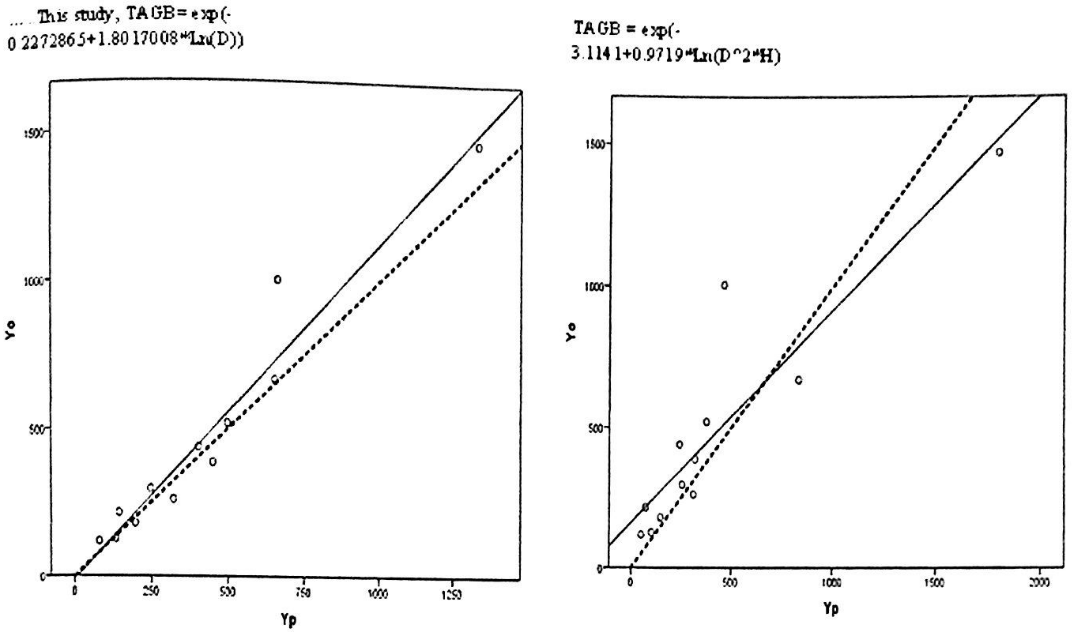
Table 3 : Parameter estimate and comparison among the allometric for Total above ground Biomass (TAGB) of *Mangifera indica*

	Formula	a	b	C	d	e	R^2	RSE	AIC	AICw	CF	VIFa	VIF b	VIFc	VIFd
1	TAGB=a+ b(log(D)) + c((log(D))^2) + d((log(D))^3) + e(log(H))	34.51	-31.49	10.645	-1.102	-0.52	0.94	0.248	12.364	0.999999	1.033	6352.7	2.69	27648.7	7620.43
2	TAGB=a+ b(log(D))	-0.227	1.8017	NA	NA	NA	0.873	0.375	45.192	7.4E-08	1.072				
3	TAGB=a+ b(log(D)) + c(log(H))	0.0311	1.9211	-0.282	NA	NA	0.872	0.371	46.209	4.5E-08	1.073	2.49	2.49		
4	TAGB=a+ b(log(D2H))	-0.727	0.7231	NA	NA	NA	0.841	0.418	55.565	0	1.091				

Note: R^2=co-efficient of determination; RSE=Residual Standard Error; AIC=Akaike Information Criterio; AICw=Akaike Information Criterion weight; CF=Correlation factor; KD=Kullback-Leibler discrepancy; ER=Evidence ratio; VIF=Variance Influential factor

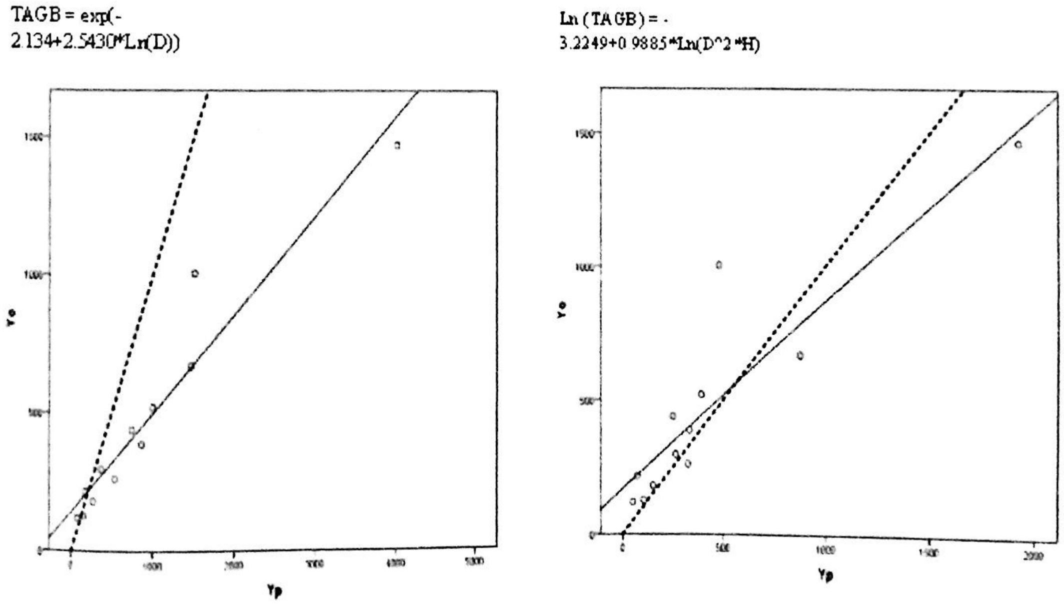
Table 4 : Comparing among the best fit TAGB of *Mangifera indica*. and frequently used pan-tropical and regional models

Model no.	Source	Equation	Type	R^2	MPE (%)	ME	RMSE
	Present Study	TAGB= exp(-0.2272865+1.8017008*Ln(D))		0.873	-6.7505	0.874892	11206.03
1	Brown, 1997 (Moist)	TAGB = exp(-2.134+2.5430*Ln(D))	Pan-tropical		-21.2015	0.7297	20892.21
2	Brown et al. 1989 (Moist)	TAGB = exp(-3.1141+0.9719*Ln(D^2*H)	Pan-tropical	0.97	65.33686	-3.48062	81888.76
3	Djomo et al. 2010	Ln (TAGB) = -3.2249+0.9885*Ln(D^2*H)	Pan-tropical	0.971	-17.8474	0.9748	22567.34



Best fit *(M.indica)*

Brown et al., 1989 *(M.indica)*



Brown 1997 *(M.indica)*

Djomo et al. 2010 *(M.indica)*

Figure 4: Comparing among the best fit TAGB of *Mangifera indica* L. and frequently used pan-tropical and regional models by 1:1 line graph. Here, in case of best fit equation, best fit line and reference line are very close where the difference between predicted value and observed value must be little too.

Note: Yo= Observed value; Yp= Predicted value

4.4. Selection of allometric model for *Artocarpus heterophyllus*

Model 1 (TAGB) = (-0.897+1.9908*Ln(D)) showed highest adjusted R^2 value (0.9528) and 3rd lowest RSE (0.2313) and lowest AIC (-0.6348) among the tested four models. Again Model 2 (TAGB)=(-0.854+2.063Ln(D)-0.123Ln(H)) showed second highest adjusted R^2 value (0.9527) which is closest to Model 1 , 2nd lowest RSE value (2291) and AIC value (0.39342) which is the closest competitor for the best fit model. Nevertheless, Model 1 (TAGB) = (-0.897+1.99*Ln(D)) has appeared as best fit allometric model for TAGB with lowest AIC (-0.6348) and 3rd lowest RSE (0.2313) value and highest R^2 (0.9528) value among the rest of the models (Table 5).

4.5. Model evaluation and comparison of *Artocarpus heterophyllus* Lam

The model efficiency values of the best fit TAGB Model 1 of this study was 0.93, which was closest to reference value 1 and the residual mean square error (RMSE) of the best fit model was the lowest one compared to other regional and pan-tropical models. Nevertheless, among the pan-tropical models, Djomo et al. (2010) ranked the 2nd lowest ME (0.8408) and 2nd lowest RMSE (7721.34). The graphical presentation from 1:1 line indicated that our best fit TAGB models 1 capable to estimate the total above-ground biomass more precisely. While, overestimated TAGB was observed for the frequently used regional and pan-tropical and regional models compared to ours (Table 6).

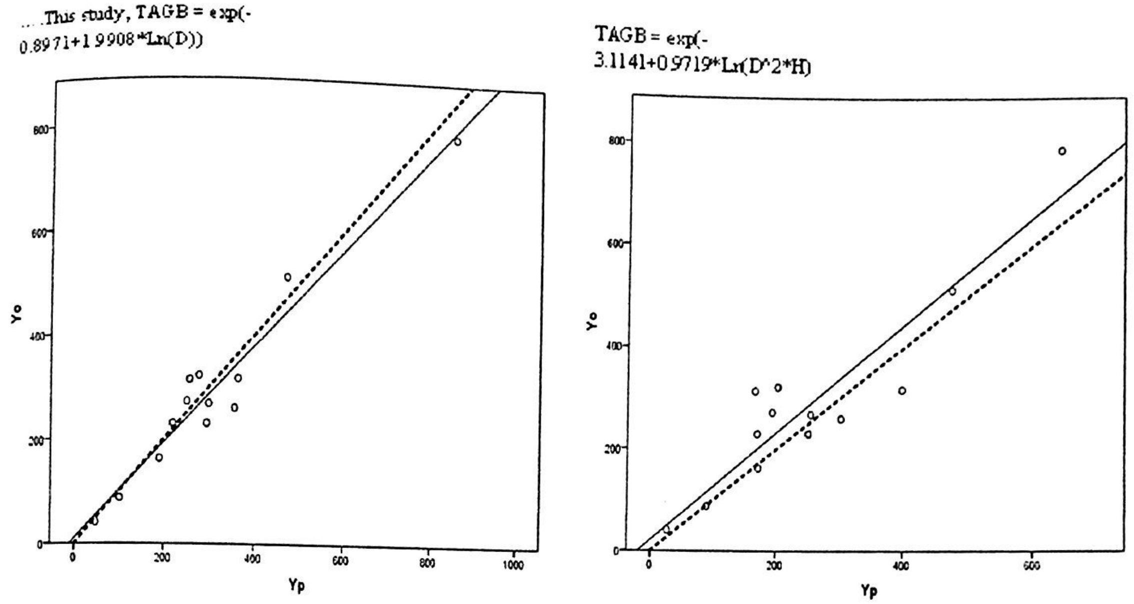
Table 5 : Parameter estimate and comparison among the allometric for Total above ground Biomass (TAGB) of *Artocarpus heterophyllus*

	Formula	a	b	c	d	e	Adj R^2	RSE	AIC	AICw	CF	VIFa	VIF b	VIFc	VIFd
1	TAGB=a+ b(log(D)) + c((log(D))^2) + d((log(D))^3) + e(log(H))	-0.917	0.739	NA	NA	NA	0.9527	0.224	2.230	0.1702	1.0272	4873.3	3.07	19887.4	5239.1
2	TAGB=a+ b(log(D))	-0.897	1.99	NA	NA	NA	0.9528	0.231	-0.634	0.5192	1.0271				
3	TAGB=a+ b(log(D)) + c(log(H))	-0.854	2.063	-0.123	NA	NA	0.9527	0.229	0.393	0.3105	1.0272	2.44	2.44		
4	TAGB=a+ b(log(D2H))	-6.6	8.146	-2.077	0.231	-0.142	0.9086	0.321	33.042	0	1.0531				

Note: R^2=co-efficient of determination; RSE=Residual Standard Error; AIC=Akaike Information Criterio; AICw=Akaike Information Criterion weight; CF=Correlation factor; KD=Kullback-Leibler discrepancy; ER=Evidence ratio; VIF=Variance Influential factor

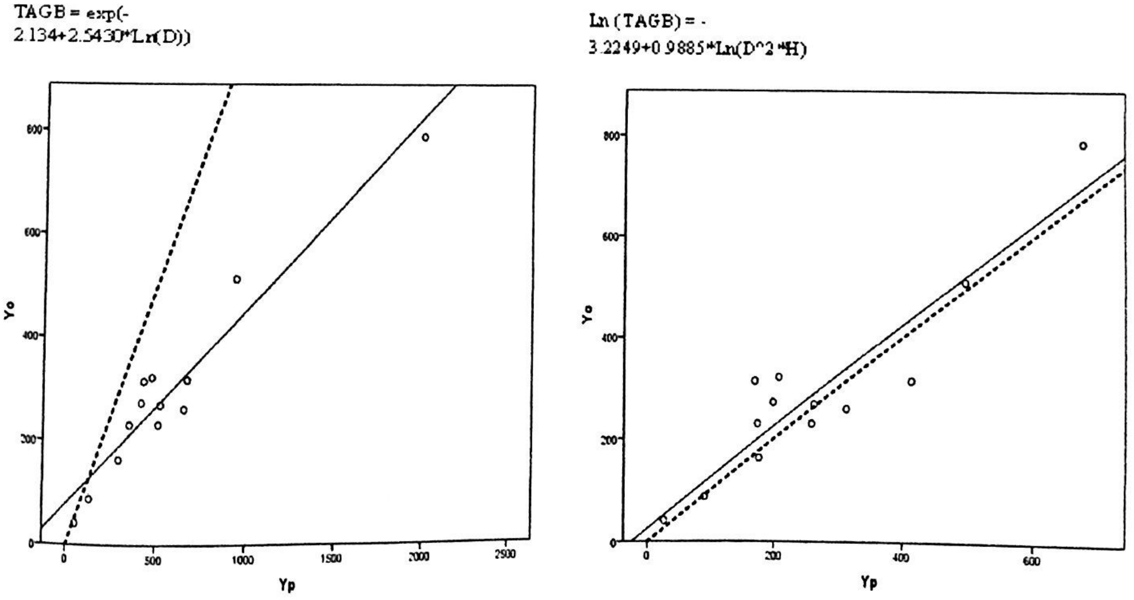
Table 6 : Comparing among the best fit TAGB of *Artocarpus heterophyllus* Lam. and frequently used pan-tropical and regional models.

Model no.	Source	Equation	Type	R^2	MPE (%)	ME	RMSE
	Present Study	TAGB = exp(-0.8971+1.9908*Ln(D))		0.9528	7.66862	0.930	4773.73
1	Brown, 1997 (Moist)	TAGB = exp(-2.134+2.5430*Ln(D))	Pan-tropical		81.983	-4.103	40890.8
2	Brown et al. 1989 (Moist)	TAGB = exp(-3.1141+0.9719*Ln(D^2*H)	Pan-tropical	0.97	-11.421	0.8178	7725.43
3	Djomo et al. 2010	Ln (TAGB) = -3.2249+0.9885*Ln(D^2*H)	Pan-tropical	0.971	-8.3136	0.8408	7721.34



Best fit *(A. heterophyllus)*

Brown et al., 1989 *(A. heterophyllus)*



Brown 1997 *(A. heterophyllus)*

Djomo et al., 2010 *(A. heterophyllus)*

Figure 4 : Comparing among the best fit TAGB of *Artocarpus heterophyllus* Lam. and frequently used pan-tropical and regional models by 1:1 line graph. Here, in case of best fit equation, best fit line and reference line are very close where the difference between predited value and observed value must be little too.

Note: Yo= Observed value; Yp= Predicted value

Chapter 5

Discussion

Development of allometric biomass model is a laborious and time consuming task involving field and laboratory work, and precise statistical analysis (Picard et al. 2015, Mahmood et al. 2017). Selection of best fit allometric biomass model among the set of derived models involves critical analysis of selection criteria (Sileshi 2014). The selection of appropriate model reduces the uncertainty in biomass estimation (Nam et al. 2016). For *Mangifera indica* L., the study selected Model 2, $(\mathrm{TAGB}) = \exp(0.227285+1.8017*\mathrm{Ln}(D))$ as best fit model for TAGB estimation, while Model 3 $(\mathrm{TAGB}) = (0.0311 + 1.9211*\mathrm{Ln}\ (D) - 0.282\mathrm{Ln}(H))$ has been appeared as very close competitor of it. Again, for *Artocarpus heterophyllus* Lam., this study selected Model 1 $(\mathrm{TAGB}) = (-0.897+1.99*\mathrm{Ln}(D))$ as best fit model for TAGB estimation, while Model 2 $(\mathrm{TAGB})=(-0.854+2.063\mathrm{Ln}(D)-0.123\mathrm{Ln}(H))$ has been appeared as very close competitor of it. Considering the value of Kullback-Leibler discrepancy and Evidence ratio, models are selected as best fit models for each of the two species.

Total above-ground biomass of sample trees of Data Set B were estimated using best fit and frequently used pan-tropical allometric models, which was also compared with their observed biomass. All the regional and pan-tropical biomass models have showed lower efficiency in biomass estimation, which indicates poor prediction capacity. Tree species and their architecture, management practices, forest types, site quality, climatic condition are not similar to our studied species and sites, which may influence the efficiency of the compared regional and pan-tropical models (Mugasha et al., 2016). Some recent studies have shown that pan-tropical allometric models produced higher variation in biomass estimation compared to the locally developed models, for instance the biomass study of Kalimantan (Basuki et al., 2009), Sarawak (Kenzo et al., 2009), Columbia (Alvarez et al., 2012), (Ngomanda et al., 2014), Indonesia (Manuri et al., 2014, Maulana et al., 2016), and Vietnam (Nam et al., 2016). However, this variation implies that one should locally check the range of variation or error in using regional and pan-tropical allometric models to estimate biomass of trees and forests (Alvarez et al., 2012, Nam et al., 2014). Unfortunately, such comparison for the regional and pan-tropical allometric model is rare

(Nam et al., 2016). In other way, newly developed best fit allometric model also demands validation and comparison with the existing regional and pan-tropical models to assess their suitability at the local scale (Sileshi 2014, Nam et al., 2014).). However, our derived best fit allometric models have estimated only 10.63% underestimation for Mangifera indica L. and 4.58% overestimation for Artocarpus heterophyllus Lam., which mostly for the individual having observed biomass more than 1000 kg. The context provided by this study and the results presented herein demonstrates that our derived model can accurately estimate the TAGB of the studied species for the Village zone of Bangladesh.

Chapter 6

Conclusion

Comparing with the commonly used regional and pan-tropical models, our study stated that the derived best fit TAGB models can accurately estimate the tree biomass of both *Mangifera indica* L. and *Artocarpus hetrophyluus* Lam.

References

Angelsen, A., Brockhaus, M., Sunderlin, W. D., & Verchot, L. V. (Eds.). (2012). Analysing REDD+: Challenges and choices. Cifor.

Brown, S. (1997). Estimating biomass and biomass change of tropical forests: a primer (Vol. 134). Food & Agriculture Org..

Brown, S., Gillespie, A. J., & Lugo, A. E. (1989). Biomass estimation methods for tropical forests with applications to forest inventory data. Forest science, 35(4), 881-902.

Chave, J. (2006). Measuring wood density for tropical forest trees: a field manual. Sixth Framework Programme, 6.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., ... & Lescure, J. P. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1), 87-99.

Den Besten, J. W., Arts, B., & Verkooijen, P. (2014). The evolution of REDD+: An analysis of discursive-institutional dynamics. Environmental Science & Policy, 35, 40-48.

Djomo, A. N., Ibrahima, A., Saborowski, J., & Gravenhorst, G. (2010). Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa. Forest Ecology and Management, 260(10), 1873-1885.

Ebuy, J., Lokombe, J. P., Ponette, Q., Sonwa, D., & Picard, N. (2011). Allometric equation for predicting aboveground biomass of three tree species. Journal of Tropical Forest Science, 125-132.

Giri, N., Kumar, R., Rawat, L., & Kumar, P. (2014). Development of Biomass Expansion Factor (BEF) and Estimation of Carbon Pool in Ailanthus excelsa Roxb Plantation. J Chem Eng Process Technol, 5, 210.

Hossain, M., 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(6), 539-548.

Hossain, M., Siddique, M. R. H., Saha, S., & Abdullah, S. R. (2015). Allometric models for biomass, nutrients and carbon stock in Excoecaria agallocha of the Sundarbans, Bangladesh. Wetlands ecology and management, 23(4), 765-774.

Huy, B., Kralicek, K., Poudel, K. P., Phuong, V. T., Van Khoa, P., Hung, N. D., & Temesgen, H. (2016). Allometric equations for estimating tree aboveground biomass in evergreen broadleaf forests of Viet Nam. Forest Ecology and Management, 382, 193-205.

Indonesian, R. E. D. D., & Force, T. (2012). REDD+ national strategy. Jakarta, Indonesia: Indonesia REDD+ Task Force.

Islam, M., Khan, M. Z. H., Sarkar, M. A. R., Absar, N., & Sarkar, S. K. (2013). Changes in acidity, TSS, and sugar content at different storage periods of the postharvest mango (Mangifera indica L.) influenced by Bavistin DF. International journal of food science, 2013.

Kabir, M. E., & Webb, E. L. (2009). Household and homegarden characteristics in southwestern Bangladesh. Agroforestry systems, 75(2), 129.

Kebede, B., & Soromessa, T. (2018). Allometric equations for aboveground biomass estimation of Olea europaea L. subsp. cuspidata in Mana Angetu Forest. Ecosystem Health and Sustainability, 4(1), 1-12.

Ketterings, Q. M., Coe, R., van Noordwijk, M., & Palm, C. A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and management, 146(1-3), 199-209.

Khalid, Nafisah, and Juazer Rizal Abdul Hamid. "Development of Allometric Equation for Estimating Aboveground Biomass in Ampang Forest Reserve, Malaysia." Journal of Biodiversity Management & Forestry 2017 (2017).

Khan, M. A. S. A., Uddin, M. B., Uddin, M. S., Chowdhury, M. S. H., & Mukul, S. A. (2007). Distribution and status of forests in the tropics: Bangladesh perspective. Proceedings-Pakistan Academy of Sciences, 44(2), 145.

Khan, R., Zerega, N., Hossain, S., & Zuberi, M. I. (2010). Jackfruit (Artocarpus heterophyllus Lam.) diversity in Bangladesh: land use and artificial selection. *Economic Botany*, *64*(2), 124-136.

Khan, R., Zerega, N., Hossain, S., & Zuberi, M. I. (2010). Jackfruit (Artocarpus heterophyllus Lam.) diversity in Bangladesh: land use and artificial selection. Economic Botany, 64(2), 124-136.

Komiyama, A., Ong, J. E., & Poungparn, S. (2008). Allometry, biomass, and productivity of mangrove forests: A review. Aquatic Botany, 89(2), 128-137.

Kuyah, S., Sileshi, G. W., Njoloma, J., Mng'omba, S., & Neufeldt, H. (2014). Estimating aboveground tree biomass in three different miombo woodlands and associated land use systems in Malawi. biomass and bioenergy, 66, 214-222.

Levy, P. E., Hale, S. E., & Nicoll, B. C. (2004). Biomass expansion factors and root: shoot ratios for coniferous tree species in Great Britain. Forestry, 77(5), 421-430.

Litton, C. M., & Boone Kauffman, J. (2008). Allometric models for predicting aboveground biomass in two widespread woody plants in Hawaii. Biotropica, 40(3), 313-320.

Mehta, I. (2017). History of Mango-King of Fruits. Int. J Engg. Sci. Invention, 6(7), 20-24.

Miah, D., Uddin, M. F., Bhuiyan, M. K., Koike, M., & Shin, M. Y. (2009). Carbon sequestration by the indigenous tree species in the reforestation program in Bangladesh- aphanamixis polystachya Wall. and Parker.

Montagnini, F., & Nair, P. K. R. (2004). Carbon sequestration: an underexploited environmental benefit of agroforestry systems. In New vistas in agroforestry (pp. 281-295). Springer, Dordrecht.

Nair, P. R. (1993). An introduction to agroforestry. Springer Science & Business Media.

Nath, T. K., Aziz, N., & Inoue, M. (2015). Contribution of homestead forests to rural economy and climate change mitigation: a study from the ecologically critical area of Cox's bazar—Teknaf Peninsula, Bangladesh. Small-Scale Forestry, 14(1), 1-18.

Ngo, K. M., & Lum, S. (2018). Aboveground biomass estimation of tropical street trees. Journal of Urban Ecology, 4(1), jux020.

Nogueira, E. M., Fearnside, P. M., Nelson, B. W., Barbosa, R. I., & Keizer, E. W. H. (2008). Estimates of forest biomass in the Brazilian Amazon: New allometric equations and adjustments to biomass from wood-volume inventories. Forest Ecology and Management, 256(11), 1853-1867.

Peng, S., He, N., Yu, G., & Wang, Q. (2017). Aboveground biomass estimation at different scales for subtropical forests in China. Botanical studies, 58(1), 45.

Petersson, H., Holm, S., Ståhl, G., Alger, D., Fridman, J., Lehtonen, A., ... & Mäkipää, R. (2012). Individual tree biomass equations or biomass expansion factors for assessment of carbon stock changes in living biomass–A comparative study. Forest Ecology and Management, 270, 78-84.

Phelps, J., Webb, E. L., & Agrawal, A. (2010). Does REDD+ threaten to recentralize forest governance?. Science, 328(5976), 312-313.

Schroeder, P., Brown, S., Mo, J., Birdsey, R., & Cieszewski, C. (1997). Biomass estimation for temperate broadleaf forests of the United States using inventory data. Forest Science, 43(3), 424-434.

Sileshi, G. W. (2014). A critical review of forest biomass estimation models, common mistakes and corrective measures. Forest Ecology and Management, 329, 237-254.

Ter-Mikaelian, M. T., & Korzukhin, M. D. (1997). Biomass equations for sixty-five North American tree species. Forest Ecology and Management, 97(1), 1-24.

Tharanathan, R. N., Yashoda, H. M., & Prabha, T. N. (2006). Mango (Mangifera indica L.),"The king of fruits"—An overview. Food Reviews International, 22(2), 95-123.

Van der Werf, G. R., Morton, D. C., DeFries, R. S., Olivier, J. G., Kasibhatla, P. S., Jackson, R. B. & Randerson, J. T. (2009). CO 2 emissions from forest loss. Nature geoscience, 2(11), 737.

Vargas-Larreta, B., López-Sánchez, C. A., Corral-Rivas, J. J., López-Martínez, J. O., Aguirre-Calderón, C. G., & Álvarez-González, J. G. (2017). Allometric equations for estimating biomass and carbon stocks in the temperate forests of North-Western Mexico. Forests, 8(8), 269.

Wang, C. (2006). Biomass allometric equations for 10 co-occurring tree species in Chinese temperate forests. Forest Ecology and Management, 222(1-3), 9-16.

Appendix

Data set-A *(A. heterophyllus)*

Species	DBH (cm)	Height (m)	Stem biomass (kg)	BEF	WD (Kg/m3)	TAGB (kg)	Crown biomass (kg)
Artocarpus heterophyllus	8.2	4	10.440	2.864	580	29.902	19.462
Artocarpus heterophyllus	10.8	6	11.600	2.199	580	25.510	13.910
Artocarpus heterophyllus	21.5	14	142.100	1.416	580	201.158	59.058
Artocarpus heterophyllus	8.4	4	10.440	2.881	580	30.077	19.637
Artocarpus heterophyllus	22.8	11	106.140	1.586	580	168.294	62.154
Artocarpus heterophyllus	12.6	6.5	41.760	2.111	580	88.168	46.408
Artocarpus heterophyllus	8.8	5	12.180	2.438	580	29.699	17.519
Artocarpus heterophyllus	10.7	5	18.560	2.513	580	46.635	28.075
Artocarpus heterophyllus	32.1	6	187.340	3.196	580	598.825	411.485
Artocarpus heterophyllus	19.3	9.5	92.220	1.707	580	157.397	65.177
Artocarpus heterophyllus	16.9	6	52.780	2.379	580	125.545	72.765
Artocarpus heterophyllus	42.5	11	347.420	1.862	580	646.901	299.481
Artocarpus heterophyllus	13.8	9	38.280	1.756	580	67.216	28.936
Artocarpus heterophyllus	13	10.5	86.420	1.660	580	143.498	57.078
Artocarpus heterophyllus	15.7	9.5	62.640	1.701	580	106.544	43.904
Artocarpus heterophyllus	19.3	10.5	95.700	1.613	580	154.393	58.693
Artocarpus heterophyllus	22.6	10.5	156.600	1.628	580	254.995	98.395
Artocarpus heterophyllus	28.6	11	155.440	1.640	580	254.935	99.495
Artocarpus heterophyllus	22.3	10	108.460	1.676	580	181.790	73.330
Artocarpus heterophyllus	10.5	6	16.820	2.195	580	36.914	20.094
Artocarpus heterophyllus	19.4	6	60.900	2.488	580	151.499	90.599
Artocarpus heterophyllus	25.1	7.5	133.400	2.178	580	290.516	157.116
Artocarpus heterophyllus	19.4	6	84.680	2.488	580	210.656	125.976
Artocarpus heterophyllus	35.3	8.5	218.660	2.211	580	483.543	264.883
Artocarpus heterophyllus	8.9	5	12.760	2.442	580	31.156	18.396
Artocarpus heterophyllus	26.1	11	175.740	1.612	580	283.301	107.561
Artocarpus heterophyllus	23.9	8	132.820	2.017	580	267.843	135.023
Artocarpus heterophyllus	29.3	14	213.440	1.426	580	304.303	90.863
Artocarpus heterophyllus	27.1	12	143.260	1.536	580	220.103	76.843
Artocarpus heterophyllus	24.3	12	104.980	1.519	580	159.425	54.445
Artocarpus heterophyllus	43.7	12.5	423.400	1.688	580	714.579	291.179
Artocarpus heterophyllus	55.4	9	636.260	2.652	580	1687.048	1050.788
Artocarpus heterophyllus	30.9	8	109.040	2.218	580	241.881	132.841
Artocarpus heterophyllus	30.9	8	158.340	2.218	580	351.242	192.902
Artocarpus heterophyllus	7.8	5	8.700	2.409	580	20.956	12.256
Artocarpus heterophyllus	39.5	12	375.840	1.683	580	632.441	256.601
Artocarpus heterophyllus	36.4	11.5	320.160	1.694	580	542.239	222.079
Artocarpus heterophyllus	29.4	12.5	281.300	1.518	580	427.058	145.758
Artocarpus heterophyllus	27.2	12	212.860	1.537	580	327.203	114.343
Artocarpus heterophyllus	13.2	4.5	37.120	2.939	580	109.082	71.962
Artocarpus heterophyllus	21.6	10	91.640	1.670	580	153.045	61.405
Artocarpus heterophyllus	15.9	8	48.140	1.874	580	90.229	42.089
Artocarpus heterophyllus	15.9	8	48.140	1.874	580	90.229	42.089
Artocarpus heterophyllus	37.9	12.5	294.060	1.610	580	473.550	179.490
Artocarpus heterophyllus	11.1	4.5	15.080	2.782	580	41.950	26.870
Artocarpus heterophyllus	21.1	8	85.840	1.952	580	167.574	81.734
Artocarpus heterophyllus	23.6	14	144.420	1.411	580	203.764	59.344
Artocarpus heterophyllus	18	10.5	73.660	1.614	580	118.854	45.194
Artocarpus heterophyllus	5.9	3	4.060	3.385	580	13.742	9.682
Artocarpus heterophyllus	8.6	3.5	8.700	3.294	580	28.661	19.961
Artocarpus heterophyllus	22.9	7	81.200	2.256	580	183.190	101.990

Data set-B *(A. heterophyllus)*

Species	DBH (cm)	Height (m)	Stem biomass (kg)	BEF	WD (Kg/m 3)	TAGB (kg)	Crown biomass (kg)
Artocarpus heterophyllus	24.8	9	147.320	1.844	580	271.628	124.308
Artocarpus heterophyllus	29.6	10	146.160	1.777	580	259.660	113.500
Artocarpus heterophyllus	26.1	8.5	163.560	1.963	580	321.008	157.448
Artocarpus heterophyllus	46	9	330.600	2.379	580	786.472	455.872
Artocarpus heterophyllus	27.1	10	154.280	1.736	580	267.807	113.527
Artocarpus heterophyllus	25.1	7.5	143.840	2.178	580	313.252	169.412
Artocarpus heterophyllus	23.2	9	126.440	1.816	580	229.627	103.187
Artocarpus heterophyllus	10.9	6	18.560	2.201	580	40.847	22.287
Artocarpus heterophyllus	34.1	12	317.840	1.610	580	511.610	193.770
Artocarpus heterophyllus	21.6	10.5	100.340	1.622	580	162.721	62.381
Artocarpus heterophyllus	15.8	10	52.780	1.659	580	87.585	34.805
Artocarpus heterophyllus	29.9	13	212.280	1.488	580	315.810	103.530
Artocarpus heterophyllus	26.9	10	132.820	1.733	580	230.155	97.335

Data set- A *(M. indica)*

Species	DBH (cm)	Height (m)	Stem biomass (kg)	BEF	WD (Kg/m3)	TAGB (kg)	Crown biomass (kg)
Mengifera indica	62.7	14	682.560	1.772	540	1209.771	527.211
Mengifera indica	46.8	9	645.840	2.402	540	1551.187	905.347
Mengifera indica	43.9	9.5	464.400	2.185	540	1014.914	550.514
Mengifera indica	47.1	12	651.780	1.798	540	1171.653	519.873
Mengifera indica	22.2	9	116.100	1.801	540	209.053	92.953
Mengifera indica	17.8	8.5	56.160	1.818	540	102.127	45.967
Mengifera indica	29.3	12	239.220	1.556	540	372.165	132.945
Mengifera indica	11.1	4.8	17.280	2.622	540	45.307	28.027
Mengifera indica	9.5	6	18.900	2.183	540	41.267	22.367
Mengifera indica	39.2	13.5	464.940	1.541	540	716.388	251.448
Mengifera indica	26.6	10	249.480	1.728	540	431.196	181.716
Mengifera indica	39.9	11	342.900	1.815	540	622.493	279.593
Mengifera indica	37.2	14	338.040	1.485	540	502.098	164.058
Mengifera indica	39.8	8	298.620	2.519	540	752.305	453.685
Mengifera indica	21.5	8	92.340	1.961	540	181.041	88.701
Mengifera indica	15.5	9	38.880	1.749	540	67.997	29.117
Mengifera indica	14.5	8	21.600	1.866	540	40.312	18.712
Mengifera indica	38.2	13	283.500	1.570	540	445.026	161.526
Mengifera indica	38.8	13	354.780	1.577	540	559.393	204.613
Mengifera indica	36.3	14	311.040	1.477	540	459.440	148.400
Mengifera indica	12.7	8.5	35.640	1.812	540	64.585	28.945
Mengifera indica	42.3	10	441.720	2.035	540	898.996	457.276
Mengifera indica	18.1	9	55.080	1.756	540	96.731	41.651
Mengifera indica	28	10	193.320	1.750	540	338.289	144.969
Mengifera indica	27.7	12	248.400	1.541	540	382.847	134.447
Mengifera indica	15.3	7	38.340	2.046	540	78.457	40.117
Mengifera indica	31	10.5	235.980	1.732	540	408.716	172.736
Mengifera indica	47.8	12	421.200	1.809	540	761.793	340.593
Mengifera indica	44.3	8	333.180	2.680	540	893.087	559.907
Mengifera indica	12.2	5	54.540	2.586	540	141.021	86.481
Mengifera indica	27.7	10	136.620	1.745	540	238.420	101.800
Mengifera indica	21	11.5	95.040	1.542	540	146.571	51.531
Mengifera indica	36.2	14	342.360	1.476	540	505.397	163.037
Mengifera indica	54.7	15	540.540	1.590	540	859.416	318.876
Mengifera indica	20.8	9.5	113.940	1.718	540	195.787	81.847
Mengifera indica	19.4	11	84.240	1.576	540	132.745	48.505
Mengifera indica	7.2	7.5	54.540	2.009	540	109.583	55.043
Mengifera indica	7.6	6.5	27.540	2.105	540	57.966	30.426
Mengifera indica	19.9	10	77.760	1.659	540	129.008	51.248
Mengifera indica	54.4	16	898.560	1.516	540	1362.510	463.950
Mengifera indica	13.4	6	27.000	2.257	540	60.946	33.946
Mengifera indica	41.3	13.5	345.600	1.564	540	540.518	194.918
Mengifera indica	33.1	14	280.800	1.450	540	407.289	126.489
Mengifera indica	14.3	6	31.320	2.284	540	71.545	40.225
Mengifera indica	27.1	10	236.520	1.736	540	410.563	174.043
Mengifera indica	35	10.5	325.620	1.800	540	586.221	260.601
Mengifera indica	38.2	15	279.720	1.434	540	401.186	121.466

Data set- B *(M. indica)*

Species	DBH (cm)	Height (m)	Stem biomass (kg)	BEF	WD (Kg/m3)	TAGB (kg)	Crown biomass (kg)
Mengifera indica	60.5	15	889.920	1.650	540	1468.384	578.464
Mengifera indica	41.1	8	391.500	2.565	540	1004.367	612.867
Mengifera indica	23.8	13	203.580	1.458	540	296.725	93.145
Mengifera indica	21	9.5	104.760	1.720	540	180.209	75.449
Mengifera indica	27.5	12	170.100	1.540	540	261.885	91.785
Mengifera indica	33.1	8.5	180.360	2.147	540	387.272	206.912
Mengifera indica	31.2	7.2	175.500	2.503	540	439.324	263.824
Mengifera indica	17.7	6.5	96.120	2.237	540	214.983	118.863
Mengifera indica	12.8	8.5	65.340	1.811	540	118.353	53.013
Mengifera indica	16.9	10	76.680	1.655	540	126.900	50.220
Mengifera indica	35	9	250.560	2.076	540	520.279	269.719
Mengifera indica	40.7	15	460.080	1.455	540	669.446	209.366