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STATUS OF TREE VOLUME CALCULATION AND DEVELOPMENT OF ALLOMETRIC EQUATIONS IN PAKISTAN

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ABSTRACT

This paper reviews and analyses the biomass and volume allometric models that have been developed for various tree species in forest ecosystem types in Pakistan. The mathematical form of the allometric model, the associated statistical parameters, as well as information about the size (tree diameter and height) and the number of the sample trees used to develop models were collected from various sources published in scientific (both international and national) journals, student thesis and conference presentations. The total number of allometric models that have been reviewed in this paper are 18 consisting of 16 models for estimating biomass of tree components and 2 models for calculating stem volume. The spatial distribution analysis showed that these models have been prepared for dominant species of sub-tropical and coniferous sub-alpine forest ecosystems of Pakistan. These species include *Acacia modesta* (Phulai), *Olea ferruginea* (Kahu), *Pinus roxburghii* (Chir) and *Betula uitlis* (Birch). In biomass models, both above and below ground biomass have been considered. Besides information on model distribution, data coverage, this paper analyses the gaps and proposes strategies to fill the gaps. The collected information on the models provides a basic tool for estimation of forest biomass relevant to its ecosystem. This information also provides input to support the national forest carbon accounting for REDD+.

Key words: REDD+, Allometric models, Biomass, Tree volume, Forest ecosystem, Pakistan.

Introduction

Reliability of the forest carbon and the understanding of the dynamics of carbon in forest ecosystem can be increased by applying the current knowledge concerning tree allometry in the form of volume and biomass allometric models (Jenkins *et al.*, 2003; Zianis and Mencuccini, 2003; Lethonen *et al.,* 2004). The biomass allometric models can be used to directly estimate the stand tree biomass, from tree measurement data (diameter or combination of diameter and height) in forest stand inventory, or by adding specific gravity or wood density and the biomass expansion factor (IPCC, 2003) or the biomass conversion and expansion factor (IPCC, 2006) in using tree volume allometric models.

By using the allometric models that are already formulated, the biomass of one tree can be estimated just by entering the parameters of the results of the measured dimensions of the tree like diameter at breast height (dbh) and height. The stand biomass can be estimated by having information on stem density and then by extrapolating methods.

With Pakistan making attempts to implement REDD+ and fulfil its reporting obligations of GHG emissions for the United Nations Framework Convention on Climate Change (UNFCCC) it is important that the appropriate models that are in accorndance with UNFCCC guidelines are adopted.

Currently, the guidelines or references related to use of allometric models for estimating biomass and C stocks or determining local emission levels in developing countries are given by Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) and United Nations Framework Convention on Climate Change (UNFCCC) *vis a vis* IPCC GPG 2006 are being followed. Few allometric models to estimate tree biomass (including its components, e.g. stem, branches, leaves, twigs and roots) and tree stem volume that have already been developed are for few indigenous species in Pakistan. In order to use these allometric models as reference, a comprehensive study of tree biomass and volume allometric models that already exits is necessary. These models and allometric equations were developed during 2009-2014 with an aspiration to assess the carbon stocks in different forest ecosystem in Pakistan by Nizami *et al.* (2009); Abbas *et al.* (2011); Nizami (2012) and Alam and Nizami (2014).

The biomass and tree volume allometric models of four dominant species (*Acacia modesta, Olea ferruginea, Pinus roxburghii* and *Betula utilis*) of Pakistani Forest have been analysed. There are still many species in different forest types of Pakistan for which allometric equations need to be prepared considering growth in entire rotation.

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The dominant species *Acacia modesta, Olea ferruginea* and *Pinus roxburghii* in sub- tropical forest ecosystem and *Betula utilis* in the coniferous sub alpine forest ecosystem were investigated. The methods described for biomass and carbon assessment developed by FAO 2004 (FAO, 2004) for land use were used in these assessments (Nizami *et al.*, 2009 and Nizami, 2014).

This paper aims to serve as reference in estimating biomass through i) compilation and review on tree biomass and volume allometric models that have been developed for several tree species and forest ecosystem in Pakistan ii) to collect an allometric model development database to know the status of information currently available on tree allometry, identification on gaps of information and modelling methods. This paper also provides basic information on carbon stock assessments in the country and can be used as a supporting document in implementation of REDD+ in the country.

Material and Methods

Data collection

Literature review was conducted and biomass and volume allometric models were compiled in this paper. This included national and international scientific publications, seminar, conferences and university dissertations. The literature review for this paper was limited to the publications till May 2014.

All information related to coordinates of the locations was recorded: i) location or research, details of the province, district or specific name of the forest ii) geographical position (latitude and longitude coordinates) iii) condition of the location (forest type, rainfall, temperature, altitude) and iv) stand condition (dominant tree species, stand age, stand density, stand height, basal area). Apart from this, the time of collection of data (sentence incomplete needed verb e.g Apart form this, the time of data collection was also recorded to capture the seasonal variations. .

For allometric models following information was collected i) method of obtaining the sample tree ii) component or parts of the tree measured (stem, branches, sub branches, leaves, twigs, fruit, flowers and roots) iii) type of tree volume used for volume allometric model (total height, marketable height, etc) iv) methods for formulation of model v) no. of sample trees used to formulate the model vi) size of sample trees (diameter and height) vii) Variable used to formulate models viii) model form (linear, exponential, sigmoidal, quadratic, power, etc) and the ix) statistical parameters resulted from the model.

For biomass, several variables were recorded for measuring the green biomass, taking sub samples from every component for drying and weighing in the laboratory.

All locations of the area from where the models were developed have been shown on the map (Fig. 1)

Evaluation of the model

The main consideration in evaluating the models are statistical values, including i) unit value of the independent variable (X) and independent variable (Y) ii) value of the parameter coefficient iii) value of the standard error of the parameter and iv) the value of the coefficient of determination (R^2) that reflects the proportion of total variation of Y that can be explained by variation of X. Also the use of correction factor in these allometric models was evaluated (Baskerville, 1972; Sprugel, 1983 and Snowden, 1990). The correction factor is primarily needed to eliminate the bias that is introduced when data was transformed (e.g. logarithmic transformation). However information on use of correction factor has not been represented in this paper as the correction factors was found minimal.

Apart from the criteria above, evaluation was also carried out through testing by accounting the biomass values of individual trees based on the diameter of the sample trees used to formulate the model and comparing it with estimated biomass curve obtained from the model. An evaluation of qualitative performance of the model based on biological or logical consideration was also applied.

Results

Geographical and ecosystem location of the allometric model

Each reference and location of the tree biomass and volume allometric model developed in Pakistan was classified according to forest ecosystem type to get information on spatial distribution of the availability of tree biomass and volume allometric model. Out of 19 models, 6 were developed in sub alpine forests at geographical location of 34°30' N and 72°50' E while 13 models were developed in sub-tropical forest ecosystem at location of 33°38' N and 73°00' E.

Scope of the allometric model by species

Of the total number of available biomass allometric models, all were developed for the natural forests. The number of species included in these models is four, namely; *Acacia modesta* (Phulai), *Olea ferruginea* (Kahu), *Pinus roxburghii* (Chir) and *Betula utilis* (Birch). The *P. roxburghii* is the only conifer species while the rest are broadleaved.

Apparently the development of the volume allometric model has been slower than that of biomass

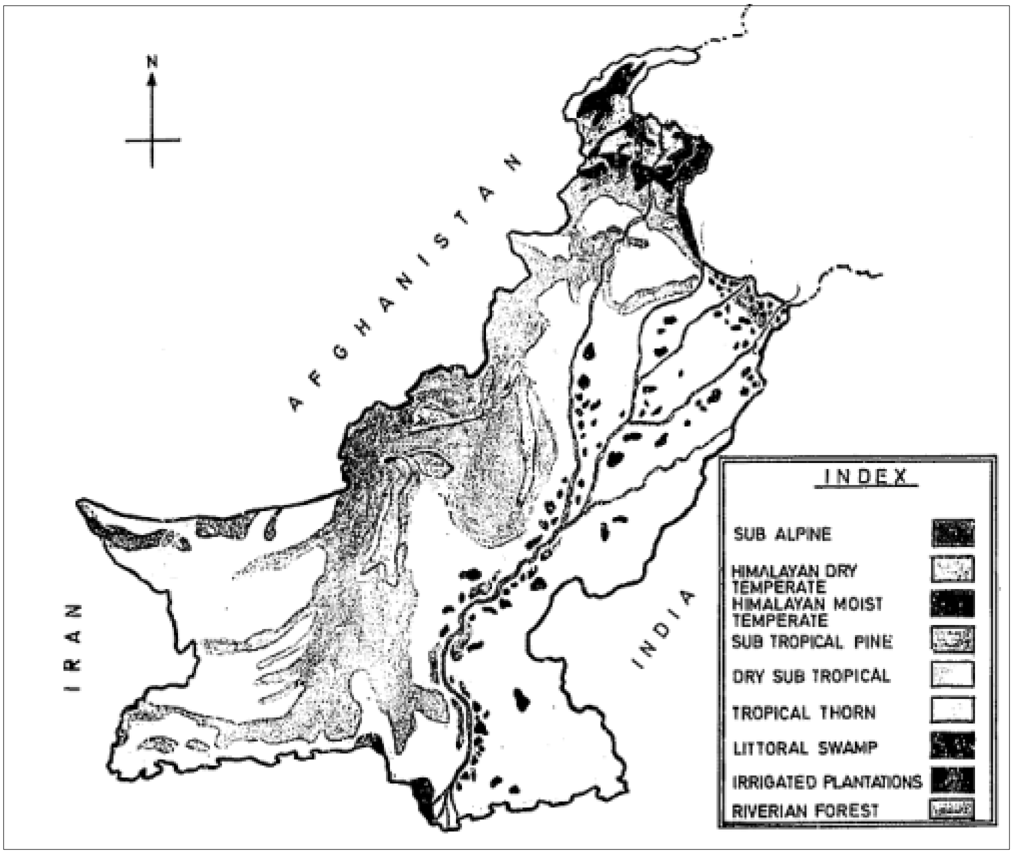

Fig. 1: Forest ecosystem types in Pakistan and models location

allometric models. From the total number of available volume allometric models, half were developed for broadleaved trees and half for conifer species. But all the dominant species were taken into consideration.

Tree biomass allometric models

16 allometric models for biomass are presented. These have been compiled and classified by forest type, tree species and location given in Table 1. Most of the biomass allometric models that have been developed in Pakistan are for estimating above ground biomass of the tree species or the biomass of the individual tree components. There are still a few allometric models for below ground biomass (roots). These models are mainly developed from the sample roots of small trees. This is because the root sampling is difficult and both expensive and time consuming.

Based on the models developed in Pakistan, tree biomass allometric models are usually presented in polynomial quadratic form.

$$y = y_o + ax + bx^2$$

Where y (dependent variable) is the biomass; x (independent variable) is dbh or basal area, y_o regression constant (not equal to 0) and a, b are the regression coefficients. Most of the allometric models for biomass presented in this paper are quadratic but in practice most of the researcher apply logarithmic transformation in fitting the regression model using the least square method in order to create the linear regression relationship and then back transformed into original arithmetic value to estimate the tree biomass. The transformation of biomass values to logarithmic value in the regression with the least square method leads to bias when logarithmic values turned back to original unit (Baskerville, 1972; Sprugel, 1983; Snowden, 1990). Nevertheless this bias can be avoided by multiplying the result with the correction factor (Sprugel, 1983; Perresol, 1999):

$$y = e^{\left(\mu + \sigma^2/2\right)}$$

If using natural logarithmic transformation

Or $$y = e^{\left(\mu + \sigma \ln(10)^2/2\right)}$$

if using base 10 logarithmic transformation

Where y is the estimated biomass value, μ average value of biomass, and σ is the value of error variance.

The other alternative to avoid the linear logarithmic transformation is direct application non-linear regression methods, which can be found in the several statistical softwares. In the present paper, 37.5% of the biomass model used basal area (BA) variable while

Table 1: Biomass Allometric model that can be used for estimating both above and below ground biomass in individual tree components

Ecosystem Type	Tree Species	Location	Tree component	Allometric model	No. of sample	Variable	R^2	Model form	Source
STBLEG	*Olea ferruginea*	Lehterar	Stem	$SB=-1905.25+91.8(x)-.44(x)^2$	5	DBH	0.99	Quardatic	Abbas *et al.,* 2011
STBLEG	*Acacia modesta*	Kherimurat	Stem	$SB= 6.44+2.66(x)$	15	BA	0.0036	Linear	Nizami, 2012
STBLEG	*A. modesta*	Sohawa	Stem	$SB= 2.788+2.461(x)$	15	BA	0.24	Linear	Nizami, 2012
STBLEG	*Olea erruginea*	Kherimurat	Stem	$SB= 2.29+2.49(x)$	15	BA	0.27	Linear	Nizami, 2012
STBLEG	*O.ferruginea*	Sohawa	Stem	$SB= 2.214+1.677(x)$	15	BA	0.28	Linear	Nizami, 2012
STBLEG	*O. ferruginea*	Lehterar	Branches	$BB=547.82-31.13(x)-0.68(x)^2$	5	DBH	0.99	Quardatic	Abbas *et al.,* 2011
STBLEG	*O. ferruginea*	Lehterar	Twigs	$TB=8.87-0.75(x)+1.44(x)^2$	5	DBH	0.99	Quardatic	Abbas *et al.,* 2011
STBLEG	*O. ferruginea*	Lehterar	Leaves	$LB=37.28-3.06(x)+0.07(x)^2$	5	DBH	0.99	Quardatic	Abbas *et al.,* 2011
STBLEG	*O. ferruginea*	Lehterar	Roots	$RB=-43.13+7.13(x)-0.05(x)^2$	5	DBH	0.99	Quardatic	Abbas *et al.,* 2011
STCP	*Pinus roxburghii*	Ghoragali	Stem	$SB=8.64+2.05(x)+5.65(x)^2$	15	BA	0.98	Quardatic	Nizami *et al.*, 2009;
STCP	*P. roxburghii*	Lehterar	Stem	$SB=22.09-0.752(x)+0.119(x)^2$	12	BA	0.98	Quardatic	Nizami *et al.*, 2009;
SA	*Betula utilis*	Kalam	Stem	$SB= 2.18/(1+e^{-(x-28.07/6.358)})$	10	DBH	0.97	Sigmodial	Alam and Nizami, 2014
SA	*B. utilis*	Kalam	Large Branch*	$BB=9.805-2.69(x)+0.25(x)^2$	10	DBH	0.97	Quardatic	Alam and Nizami, 2014
SA	*B. utilis*	Kalam	Sub Branch$^+$	$BB=2.512+0.1746(x)+0.008(x)^2$	10	DBH	0.88	Quardatic	Alam and Nizami, 2014
SA	*B. utilis*	Kalam	Leaves	$LB=0.869-0.031(x)+0.0095(x)^2$	10	DBH	0.97	Quardatic	Alam and Nizami, 2014
SA	*B. utilis*	Kalam	Roots	$RB= 91.51/(1+e^{-(x-26.22/5.922)})$	10	DBH	0.97	Sigmodial	Alam and Nizami, 2014

STBLEG= Sub Tropical Broad leaved Evergreen Forest Ecosystem ; STCP= Sub Tropical Chir Pine Forest Ecosystem ; SA= Sub Alpine Forest Ecosystem; *= Branches having dbh <8cm; + = Branches having dbh >8cm ; BA= Bsala Area, R^2= Coefficent of Determination; SB=stem biomass,TB= Twigs biomass; RB= Roots biomass; LB= Leaves biomass; BB= Branch biomass

62.5% percent used dbh as the biomass estimator. The form of relationship used has been presented in Table 1. The number of sample trees used to develop models varies from 5-15. According to sources of literature all the models were prepared from the sample trees taken from single stand.

The range of diameter used in sample trees 10-24 cm and basal area ranges from 1.26 to 30.38 m^2 ha^{-1}. For the sub-tropical Chir pine forests and Subtropical broad leaved evergreen forests BA was used while in sub alpine forest dbh was used in biomass models (Nizami *et al.*, 2009; Abbas *et al.*, 2011; Nizami, 2012; Alam and Nizami, 2014) .

Tree volume allometric models

The tree volume models that have been developed in Pakistan are presented in Table 2, classified according to ecosystem, tree species and location. In total overall, 2 volume allometric models have been compiled in this paper. Similar to biomass allometric model both the models have been presented in polynomial quadratic form. Among both the developed volume allometric model single variable i.e., dbh was used as volume estimator (Abbas *et al.*, 2011; Alam and Nizami, 2014). Worldwide, the result of the regression analysis of volume allometric models showed that using additional height variable apart from diameter can improve the prediction of 1-3% compared to using diameter variable only (Wahjono *et al.*, 1995; Krisnawati and Bustomi, 2002, 2004). Nevertheless, the additional time, staff and budget required for the application in the field need to be taken into account if tree height variable is to be considered.

In fact, 5 trees were used for volume allometric model development in *Olea ferruginea* species of sub-tropical broad leaved evergreen forest (Abbas *et al.*, 2011) and 10 trees were used for *Betula utilis* species in sub alpine forests (Alam and Nizami, 2014).

The range of diameter (dbh) of the sample tree ranged from 10-24 cm. The trees of exploitable diameter (24 cm) were selected for *O. ferruginea* in sub-tropical broad leaved evergreen forest while the trees of *B.utilis* were categorized into three classes less than or equal to 10, 11 - 20 and greater than or equal to 21 cm.

The value of the determination coefficient (R^2) was greater in both the volume allometric models. It was 0.99 and 0.97 for *O. ferruginea* in sub-tropical broad leaved evergreen forest and *B.utilis* in the sub alpine forest (Abbas *et al.*, 2011; Alam and Nizami, 2014). This shows that over 97% of variation of volume data can be explained by variation of diameter (in case of only variable used as an estimator).

Discussion

The results showed that the tree biomass and volume allometric have been developed for only four species in three forest ecosystem types in Pakistan. From

Table 2 : Volume Allometric model that can be used for estimating the volume of the forest stand

Ecosystem type	Tree species	Location	Tree component	Allometric model	No. of sample	Variable	R^2	Model form	Source
STBLEG	*Olea ferruginea*	Lehterar	Stem	$SV=-.320+0.041(x)-1.44(x)^2$	5	DBH	0.99	Quardatic	Abbas *et al.,* 2011
SA	*Betula utilis*	Kalam	Stem	$SV=0.9589-0.056(x)-0.0013(x)^2$	10	DBH	0.97	Sigmodial	Alam & Nizami, 2014

STBLEG= Sub Tropical Broad leaved Evergreen Forest Ecosystem ; SA= Sub Alpine Forest Ecosystem; SV=Stem volum the literatures that have been reviewed following gap has been identified:

1. The biomass and volume allometric model for the rest of the forest ecosystem type is still lacking. These models are required as the species composition and silvicultural trait significantly varies in all the forest ecosystem types of Pakistan due to terrain conditions and altitude (Walayat, 1988).
2. Availability of the allometric models for all the forest ecosystem is necessary to calculate the growth processes and accumulation of biomass after human land use activities.
3. Biomass data of sample trees above 24 cm dbh is necessary considering that large trees contribute significantly to the total biomass in the forest ecosystem.
4. The stem biomass allometric models in sub-tropical broad leaved evergreen forest ecosystem with dominant species *Acacia modesta* and *Olea ferruginea* need to be redeveloped with variable other than basal area as these models showed very weak relationships in stem biomass and basal area.
5. Investigations are needed on the uncertainty of the quadratic form of models. So counter check of models with national forest inventory data is required.

In order to full fill these gaps, possible strategies required are:

1. Identification of the locations that have not been investigated and identification of new sources of information about the development of allometric models for estimating forest biomass at various locations in Pakistan. Information on spatial distribution of sampling location of allometric models, overlapped with the spatial distribution of forest ecosystem type in Pakistan can be used to identify these gaps. Therefore, to determine the location of the sample trees for measuring biomass in the field is necessary to consider the distribution and representation f the location.
2. The development of general allometric model specific to forest ecosystem type to cope with the diversity of ecological zones that exists in Pakistan.
3. Sample tree data used to develop allometric models should cover the range of tree diameter in the population (representing the existing distribution of diameter class) and the sample should be representative of the trees in order to produce statistically reliable results. Additional samples of large trees are required to expand the scope of available models, especially for tree species and forest ecosystem type for which large trees can still be found in the field.

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