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Assessing the Best Fit Volume and Carbon Stock Equation of *Pinus Roxburghii* with Respect to Diameter at Breast Height Using Non-Destructive Method

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Abstract

Pinus roxburghii is dominant timber species in Nepal. However, there is not any model showing correlation of Diameter at breast height (DBH) with Volume and Carbon Stock. Therefore, this study was objectively conducted to show the correlation of diameter with volume and carbon stock. Gaumati community forest was selected as study site for this research. Total 214 sample trees were taken into account for the study. DBH classes were categorized into s 0-10, 11-20, 21-30, and 31-40, 41-50, and DBH > 50 cm to represent the most of the diameter classes. Height and DBH were measured using Clinometer and Diameter tape. Four types of models were developed for volume and carbon stock with DBH viz. linear, logarithmic, power, and exponential. The models were tested, out of which the power equation was found to be the most accurate for both carbon and volume calculations. Power volume and carbon stock equations are $y = 0.00004\ x^{2.8404}$ (y=volume, x=DBH) and $y = 0.0125x^{2.8404}$ (y=carbon stock, x=DBH) respectively. The estimated values of R^2, MAD, MSE, RMSE and AIC were 0.9817, 0.178, 0.093, 0.305 and -41.58 respectively for power volume model and these values of R^2, MAD, MSE, RMSE and AIC were 0.9817, 21.92, 1379.01, 37.13 and 1194.18 respectively for carbon stock calculation. Study shows that, there is a strong correlation between DBH vs. volume and DBH vs. carbon stock. Thus, the volume equation and carbon stock equation will be useful for forest science to calculate the volume and carbon stock of standing plants.

Keywords: AIC; Non-destructive sampling; Power model; Regression equations.

1. Introduction

Volume and carbon modeling is defined as equation showing a given species the average contents of trees, logs or sawn timber for one or more given dimensions and carbon stock (Losi *et al.*, 2003). The dimensions may be, diameter at breast height (DBH) alone, DBH and height including or excluding form factor or taper (Chaturvedi and Khana, 2000; John *et al.*, 2017; Kershaw *et al.*, 2016). Several methods have been used for volume and carbon stock estimation and modeling. Two of the widely used methods are destructive and nondestructive methods (Montes *et al.*, 2000). Destructive methods are time-consuming and costly than non-destructive methods (Liu *et al.*, 2019). Non-destructive methods have now therefore been developed specifically for tree volume estimation and carbon stock modeling (Montès, 2009; Vann *et al.*, 1998). Estimates of aboveground biomass are important measures in ecological studies (Chave *et al.*, 2014). Total harvesting is generally impractical or inappropriate in forest studies, so allometric methods have been developed to estimate volume and carbon from non- destructive surrogate measurements (Vann *et al.*, 1998).

The precise estimation of tree volume and biomass in forest ecosystems is essential for commercial timber extraction and above-ground biomass (AGB) carbon stock assessment. The modeling the diameter at breast height (DBH) with volume is technical requirement to calculate the volume of any tree species (Charles *et al.*, 2018; DFRS, 2015). This provides the estimated volume without felling the trees (Chaudhuri and Pandey, 2016). The volume depends up on the local site quality and climate and non- climatic factors. World wise, this practice is famous to estimate the volume of standing trees (Hyytiäinen *et al.*, 2004; Subedi, 2018). India, Bhutan, Pakistan, China have also been developed the volume equation to estimate the volume of standing trees (Chiung *et al.*, 2019; Demeritt and McIntyre, 1932; Mahmut, 2004). This practice has also initiated in some of parts of Nepal. However, there is still gap to prepare specific volume equation. Assessment of carbon sequestration potential in terrestrial ecosystems using regression models is a commonly used approach. Several regression models have been developed to estimate biomass or carbon stock for forestry species (Avery and Burkhart, 2000; Giri K. *et al.*, 2019).

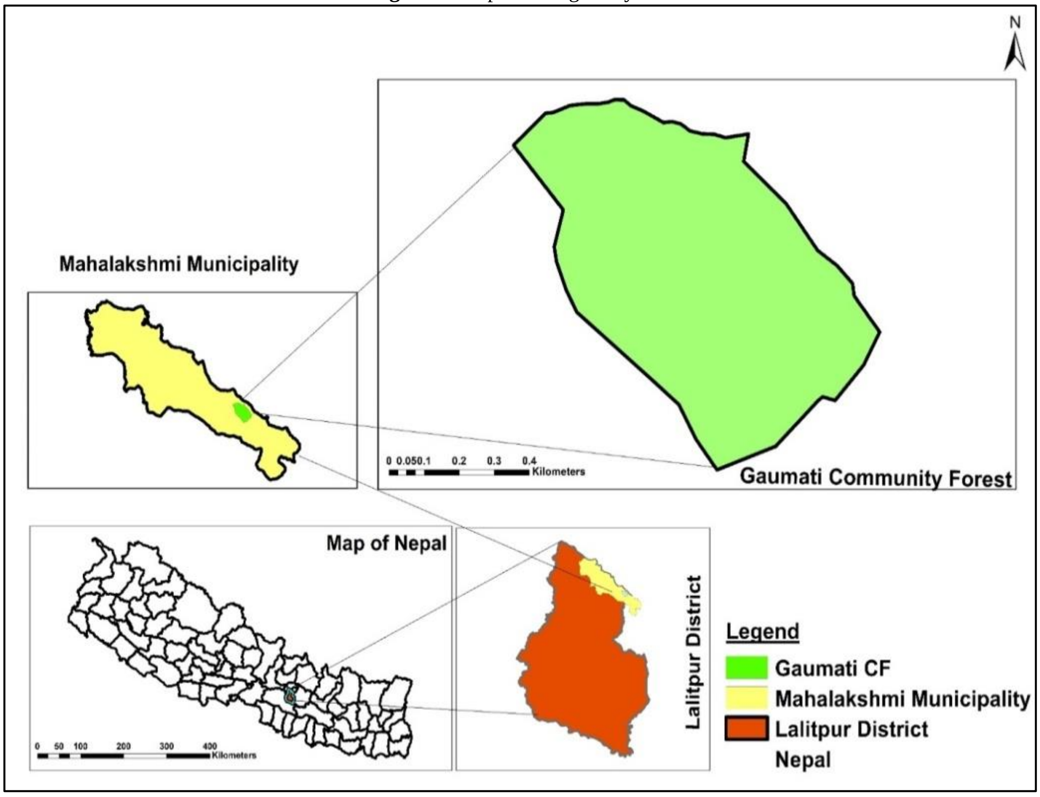
Pinus roxburghii is one of the most common conifers in the sub-tropical region of Nepal and is distributed in all aspects of western Himalaya but is generally found in well-exposed to southern slopes in the central and eastern Nepal. It can grow reasonably well in almost all types of soil and has been proved to be a successful pioneer species even at most degraded sites due to its high survival rate (Tiwari *et al.*, 2020). Chirpine occupies 8.54% of total forest cover, being the fifth most dense tree species in Nepal with 7.05% of total volume in the forest, and has also been an important planted tree species linked with highly successful community forestry program in Nepal. It is reported that it possesses a biomass of 9.09 t/ha in Nepal which accounts for 5.09% of total woody biomass (DFRS, 2015). Although Chirpine is also one of the most important tree species for the local people for its multipurpose uses such as timber, resins, firewood. Thus, precise estimation volume and carbon stock Chirpine is important but there is limited model to estimate the volume and carbon. Thus this study was conducted to show the correlation diameter with volume and carbon stock and evaluate best fit model.

2. Materials and Methods

2.1 Study Area

Lalitpur district is selected as the study site. Lalitpur District lies in Bagmati province, Nepal at latitude 27°32′53.88″ North, longitude 85°20′15.00″ East. The study was conducted in Gaumati community forest of Lalitpur district. Gaumati community forest is distributed in 68 ha area Figure 1). Majority of this community forest is dominated by *Pinus roxburghii* trees with few number of *Alnus nepalensis*. The elevation of study area ranges between 1588 to 2008 m above the mean sea level. Lalitpur receives 2156 mm of precipitation every year. In Lalitpur, the average annual temperature is 25°C. May is the hottest month, with an average temperature of 28°C. The coldest month in Lalitpur is usually January, with an average temperature of 18°C. Major tree species in Lalitpur are *Schima walichii, Castonopsis indica, Myrica spp, Rhododdendron* spp etc.

Figure-1. Map Showing Study Area



2.2. Measurements and Data Collection

2.2.1. Instruments

Linear Tape, Diameter Tape, GPS (Etrex-62s), and Data Sheets were used for Data Collection.

2.2.2. Tree Selection and Measurement

The volume table of *Picea smithiana* was prepared, based on 211 trees (Chaturvedi and Khana, 2000). Altogether 214 trees *Pinus roxburghii* were selected and were categorized into different diameter class 0-10, 11-20, 21-30, 31-40, 41-50, and DBH> 50 cm. The height and diameter at breast height were measured using Diameter tape and Clinometer. The secondary information about the forests in the district was taken from Divisional Forest Office, Lalitpur. The Forest Management Operational Plan of Gaumati Community Forest was consulted for the information regarding the study site.

2.2.3. Analysis of Field Data

The analysis of data was done by using the formula for volume calculation, carbon stock calculation number of data set used for model development, data cleansing, model development and reliability check.

2.2.4. Formulas used for Biomass and Carbon Calculation

Collected data was arranged in sheet of Microsoft excel. Data analyze was completed using different software like Microsoft excel and Statistical Package for the Social Sciences (SPSS). Actual volume of each tree was calculated applying following formula.

The general volume table equation for *Pinus roxburghii* is

Ln (v) = a + b ln(d) + c ln(h)

Where, ln = Natural logarithm to the base 2.71828.

V = Volume (m^3) = exp [a + b×ln(DBH) + c×ln(h)]

d = DBH in cm

h = Total tree height in m

a, b and c are coefficients and their values are -2.9770, 1.9235 ,1.0019 respectively.

The volume is divided by 1000 to convert it into m^3 (Sharma and Pukkala, 1990)

Biomass = Stem volume × wood specific gravity.

The total biomass obtained from such models was further converted into carbon content by multiplying with 0.47 (MacDicken, 1997).

2.2.5. Model Development (Equation Development)

Total 214 trees were measured representing from different diameter class. Out of this, 107 trees from different class were used for development of model equation and remaining data set was used for validation purpose. The volume was estimated based on the height and DBH applying formulae. The assumption of the equation is that same diameter has same height and same volume or carbon of a specific species. The linear regression, natural logarithmic, exponential and power model were used to develop the model.

- **Linear regression model**: linear regression shows the linear relationship between two variables **Y= a+bx**
- Where, Y (Volume/Carbon) is dependent, X (Diameter at breast height) is the independent variable and a, b are the regression coefficients that describe the relationship between x and y
- **Natural logarithmic regression model**: Logarithmic regression is a type of regression used to model situations where growth or decay accelerates rapidly at first and then slows over time. The equation of a logarithmic regression model takes the following form y = **a + b*ln(x)**
- Where, Y= volume/carbon X= diameter. a, b are the regression coefficients that describe the relationship between x and y.
- **Exponential regression model**: The equation of an exponential regression model takes the following form: **$y = ab^x$**
- (Where a is not 0) Y= volume/carbon X= diameter a, b are the regression coefficients that describe the relationship between x and y.
- **Power regression model**: The equation of a power regression model takes the following form: y = axb (where x is not 0)
- Where, Y= volume/carbon X= diameter a, b are the regression coefficients that describe the relationship between x and y.

2.2.6. Parameters for Selection of Best Model

The parameters and fit statistics for each model were estimated in R using the lm, nls, and nlsLM function in the minpack.lm package and evaluated using different criteria including coefficient of determination (R^2); root mean squared error (RMSE), and Akaike Information Criterion (AIC).The best equation was selected based on the values of R^2 (higher the significant), (Ulak *et al.*, 2022) RMSE (lower the significant), and AIC (lower the significant) (Burnham and Anderson, 2002).

$$RMSE = \sqrt{\sum (Xobs - XPre)\ 2}$$

$$RSR = RMSE/Standard\ deviation\ of\ observed\ data$$

$$Standard\ deviation = \sum\sqrt{\frac{(X - X)^2}{N}}$$

Whereas, X indicates the records of the observed data and X is the mean of the observed data set, n is the number of observation.

Percentage bias (PBIAS) $PBIAS = \sum (X_{obs} - X_{pre}) \times 100 / X_{obs}$

Mean absolute deviation (MAD) or Mean Bias (MB)

$MAD = \sum |X_{obs} - X_{pre}| / n$

2.3. Criterion-Based Procedures

Akaike Information Criterion: AIC is a statistical method used for model selection. It helps to compare candidate models and select the best among them. AIC aims to select the model which best explains the variance in the dependent variable with the fewest number of independent variables (parameters).

In general,

AIC= $n \ln \hat{\sigma}^2 + 2l$

where, n is the total number of observations used to fit the models; p the number of model parameters; $l = p + 1$, and $\hat{\sigma}^2$ the estimator of the error variance of the model, the value of which is obtained as follows:

$$\hat{\sigma}^2 = \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{n}$$

Because AIC is on a relative scale, we usually compute the AIC differences (rather than actual AIC values) over all candidate models in the set. Such differences estimate the relative expected K-L differences between f and $g_i(x \mid \theta)$:

$\Delta_i = AIC_i - \min AIC$,

$= E_{\hat{\theta}}\left[\hat{I}(f, g_i)\right] - \min E_{\hat{\theta}}\left[I(f, g_i)\right]$

These Δ_i values are easy to interpret and allow a quick comparison and ranking of candidate models and are also useful in computing Akaike weights and other quantities of interest.

3. Results and Discussion

3.1. Results

3.1.1. Descriptive Statistics of Diameter Distribution

The mean value, standard error of mean, standard deviation, variance and range of diameter distribution is 30.054, 1.0576, 15.47, 239.364 and 54 respectively (Table 1).

Table-1. The descriptive statistics of Diameter, height, volume and carbon distribution

Statistics		
Diameter		
Mean		30.054
Std. Error of Mean		1.0576
Std. Deviation		15.4714
Variance		239.364
Range		54.0
Percentiles	25	18.000
	50	30.000
	75	43.000

3.1.2. Modeling DBH vs Volume of *Pinus roxburghii*

Here, R^2 value of linear model is less and power model is high. Thus power model gives higher precise value of volume than other three models. Similarly aic value of power model is less and high in linear model. Model having less AIC value is precise than other models. Thus, power model is best among other candidate models (Table 1).

The linear equation was developed between diameter at breast height and volume of the tree. The R^2 value was 0.7927. The equation showing correlation between volume (dependent variable) and diameter at breast height (DBH) was **y =** 0.0354x (Table 1), whereas the y stands for dependent variable volume and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.7927, 0.363, 0.167, 0.408 and -36.070 respectively (Table 1).

The exponential equation was developed between diameter at breast height and volume of the tree. The R^2 value was 0.8318.The equation showing correlation between volume (dependent variable) and diameter at breast height (DBH) was y = $0.0098e^{0.1188x}$, whereas the y stands for dependent variable volume and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.8318, 0.593, 1.494 ,1.222 and -7.69 respectively (Table 1).

The logarithmic equation was developed between diameter at breast height and volume of the tree. The R^2 value was 0.6913. The equation showing correlation between volume (dependent variable) and diameter at breast height (DBH) was **y =** 1.0014ln(x) - 2.2844, whereas the y stands for dependent variable volume and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.6913, 0.445, 0.225, 0.5 and -15.51 respectively (Table 1).

The Power equation was developed between diameter at breast height and volume of the tree. The R^2 value was 0. 9817.The equation showing correlation between volume (dependent variable) and diameter at breast height (DBH) y = $0.00004\ x^{2.8404}$, whereas the y stands for dependent variable volume and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.9817, 0.178, 0.093, 0.305 and -41.58 respectively (Table 1).

Table-2. Modeling of Volume of Pinus roxburghii

Types of Model	Equation	R^2	MAD	MSE	RMSE	AIC	Remarks
Linear	y=0.354x	0.79	0.363	0.167	0.408	-36.07	Y= volume (m3) & X= DBH (cm)
Exponential	$y = 0.0098e^{0.1188x}$	0.83	0.593	1.494	1.222	-7.69	
Log model	y = 1.0014ln(x) - 2.2844	0.69	0.445	0.255	0.5	-15.51	
Power model	$y = 0.00004\ x^{2.8404}$	0.98	0.178	0.093	0.305	-41.58	

3.1.3. Modeling of DBH Vs Carbon of *Pinus roxburghii*

Here, R2 value of linear model is less and power model is high. Thus power model gives higher precise value of Carbon Stock than other three models. Similarly aic value of power model is less and high in linear model. Model having less AIC value is precise than other models. Thus, power model is best among other candidate models (Table 2).

The linear equation was developed between diameter at breast height and carbon stock of tree. The R^2 value was 0.7927. The equation showing correlation between Carbon Stock (dependent variable) and diameter at breast height (DBH), y = 11.5x , whereas the y stands for dependent variable Carbon stock and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.7927, 62.227, 6298.7, 79.36 and 1213.32 respectively (Table 2).

The power equation was developed between diameter at breast height and carbon stock of tree. The R^2 value was 0.9817. The equation showing correlation between Carbon Stock (dependent variable) and diameter at breast height (DBH), $y = 0.0125x^{2.8404}$, whereas the y stands for dependent variable Carbon stock and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.9817, 21.92, 1379.01, 37.13 and 1194.18 respectively (Table 2).

The Logarithmic equation was developed between diameter at breast height and carbon stock of tree. The R2 value was 0.6913. The equation showing correlation between Carbon Stock (dependent variable) and diameter at breast height (DBH) y = 325.46ln(x) - 742.43, whereas the y stands for dependent variable Carbon stock and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.6913, 0.1689, 12207.79, 110.48 and 1276.046 respectively (Table 2).

The exponential equation was developed between diameter at breast height and carbon stock of tree. The R2 value was 0.8318. The equation showing correlation between Carbon Stock (dependent variable) and diameter at breast height (DBH) $y = 3.1808e^{0.1188x}$, whereas the y stands for dependent variable Carbon stock and x denotes the independent variable diameter at breast height (cm). The estimated value of R^2, MAD, MSE, RMSE and AIC was 0.8318, 52.074, 6813.11, 82.54 and 1233.808 respectively (Table 2).

Table-2. Model of DBH vs. Carbon stock

Model	R^2	MAD	MSE	RMSE	AIC	Remarks
y =11.5x linear	0.7927	62.227	6298.7	79.36	1213.32	Y=Carbon X=Diameter
$y = 0.0125x^{2.8404}$ power	0.9817	21.92	1379.01	37.13	1194.18	Y=Carbon X=Diameter
y = 325.46ln(x) - 742.43 log	0.6913	-0.1689	12207.97	110.48	1276.046	Y=Carbon X=Diameter
$y = 3.1808e^{0.1188x}$ exponential	0.8318	52.074	6813.11	82.54	1233.808	Y=Carbon X=Diameter

4. Discussion

Among linear, logarithmic, power, and exponential models, power models were found to be the best fit model for both volume and carbon estimation. White and Gould (1965), also showed the significance of the power equation for the quantification of the relationship between the dependent variable and the predictor variable. However, the linear and exponential models were also found to be significant for volume prediction models shown by different research in Nepal (Gupta, 2001; Shrestha *et al.*, 2018a; Subedi, 2018). Power model was found to be significant for carbon factor prediction of *Pinus roxburghii* in Nepal. Giri *et al.* (2018), found that power model is the best fit model for carbon stock calculation i.e. $C = 0.1095\ (DBH)^{2.6606}$. This is similar to the model assessed by this research.

Many variables determine the volume and carbon stock of the tree. The most common use variables are diameter at breast height, height, form factors and site quality (DFRS, 2017; Muukkonen, 2007; Vayreda *et al.*, 2012). Therefore, the volume models and carbon models are based on multiple variables (Rama and Mamtha, 2015; Sharma and Pukkala, 1990), two variables (diameter and height and single variable (diameter). This volume equation was prepared based on diameter. There are different techniques to validate the model of check the performance of the model (Mugasha *et al.*, 2016). Most common methods of checking the reliability of the model are related to error estimation like root mean square error, ratio of root mean square error and so on (Maltamo *et al.*, 2004;

Volkanovski *et al.*, 2009). These all techniques were employed to check the model's performance in this research work.

5. Conclusion and Recommendation

The modeling of various equations in our study shows the maximum significance of the power modeling all conditions over other significant models for the prediction of the volume with the highest adjusted R^2, lowest RMSE, and Lowest AIC values. Similarly the modeling of various equations in our study shows the maximum significance of the power modeling all conditions over other significant models for the prediction of the carbon stock with the highest adjusted R^2, lowest RMSE, and AIC values. Study shows that, there is a strong correlation between DBH vs volume and DBH vs carbon stock. Thus, the volume equation and carbon stock equation will be useful for forest science to calculate and evaluate the volume and carbon stock of standing plants. Same method can be applied to develop the model showing DBH vs volume and DBH vs carbon stock for other species and site.

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