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TREE FORM FACTOR EQUATION OF BLUE PINE IN WANGDUE, BHUTAN

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ABSTRACT

Accurate assessment of forest growing stock and volume increment predictions are essential for sustainable forest management. The objectives of this research were to determine the artificial form factor of blue pine, to assess the relationship between form factors and other parameters, and to develop a form factor equation for blue pine. The research was carried out in the Wangdue-phodrang district, situated in the west-central region of Bhutan. The study utilized a systematic grid sampling approach to cover a 34.96 ha area of blue pine forest in Khotokha. A sample size of 1.6 ha was selected with 32 circular plots spaced 100 m apart. This study presents the results of a multiple regression analysis aimed at determining the impact of tree diameter at breast height (dbh), mid diameter, and height on the form factor of trees. The findings show that dbh, mid diameter, and height have a significant effect on the form factor. The intercept of the equation (0.186) represents the expected Form Factor of a tree with a height and dbh of zero. The coefficient for height (0.011) suggests that, on average, each additional meter in height increases the tree's total volume by 0.011. In contrast, the coefficient for dbh (-0.001) suggests that each additional centimeter in dbh increases the total volume by 0.001. In the future, this study could provide valuable insights for future research on form factor equations for other tree species.

KEYWORDS: Artificial-form-Factor, Blue-Pine, Forest-Management, Form-factor-Equation, Volume-Prediction.

I. INTRODUCTION

The shape of trees varies due to various factors, such as forest management practices, species mix, climate, genetics, age, size, and dbh. These variations in tree shape emphasize the importance of taking into account stem form when estimating tree volume (Hoyer, 1985). Stem-form refers to the shape of the tree, while stem taper is the rate at which the diameter of the stem changes as it increases in height. To accurately estimate the volume of a tree, it is important to take into account both stem form and stem taper. In Bhutan, a lack of information on tree form factor (FF) has been identified as a practical problem for sustainable forest management. FF is the ratio of the volume of a tree to the product of its basal area and height. Without this information, it is difficult to estimate the volume of timber and develop management plans for economically important tree species (Parresol et al., 1987). To address this issue, it is necessary to establish appropriate tree FF equations that consider the unique characteristics of Bhutan's forests. This will help to improve sustainable forest management and ensure the long-term viability of Bhutan's forest resources (Tenzin and Hasenauer, 2016).

Tenzin and others stated that currently, tree volume is determined by local volume equations and volume tables that rely solely on the diameter at breast height (2017). According to Sharma et al., volume equations are employed to calculate the average amount of wood present in standing trees with different sizes and species (2002). The accuracy of volume estimations is determined by the breadth and scope of the sample data accessible and the degree to which volume equations are compatible with this sample data (Akindele and LeMay, 2006). Species-specific volume tables are produced from the results, which are derived from general volume equations developed during a forest inventory conducted in 1976 (Laumans, 1994). The Forest Resources Development Division of the Department of Forests was responsible for developing the local volume tables (Ministry of Agriculture and Forests, 2019). The local volume tables are currently being used in the country.

However, commonly derived tree volume may be seen as a reduction factor of a cylinder which reduces the accuracy of enumeration by following the existing volume equations (Blackwell, 1935; Tenzin et al., 2017). Existing local volume equations were also developed by measuring a certain number of tree samples. Although, for a specific species estimation could show different volumes for the smaller or bigger trees. Developing species-specific tree FF for determining tree volume in addition to dbh and h suggests adopting the approach to all the tree species where volume calculations derived FF enhance the accuracy of the volume predictions (Adekunle et al., 2013).

II. REVIEW OF LITERATURE

- **Little and Critchfeild (1969)** mentioned that blue pine species can be found across a longitudinal range of 680E to 1000E, a latitudinal range of 250N to 360N, and an altitude range from 1500 meters above sea level (masl) to 3800 masl.
- **Siemon (1973)** explained that tree stems tend to become more cylindrical over time, but the taper in the lower part of the stem does not change much. Undisturbed stands exhibit normally good examples of tree composition.
- **McMahon and Kronauer (1976)** found out that the stem of a tree typically resembles truncated versions of these standard shapes. FF can be different due to several influential factors affecting the trees. FF differs from species to species, region to region, and stand to stand.
- **Goulding and Murray (1976)** stated counting the basal area of a tree, measuring its height, and calculating its cylindrical form factor are necessary steps to determine its volume.
- **Parresol et al. (1987)** described that typically, the volume of trees is determined by measuring the dbh, h, and a form factor. The form factor is used to adjust the volume calculation by accounting for the difference between the actual shape of the tree and a cylinder (with dbh and h).
- **Muhairwe (1994)** mentioned the patterns imply that trees tend to become more cylindrical when the stand density increases and the crown class decreases. To put it differently, while the base of the tree stem tends to be neiloid, the tip tends to be conoid, and the main part of the bole tends to be paraboloid, the inflection points between these shapes are not consistent.
- **Phillip (1994)** explained that the factors are usually determined by using one of the three definitions: (1) the absolute form factor, which is based on the cross-sectional area at the ground level, (2) the normal or Pressler's form factor, which is based on the cross-sectional area at 0.9 of the total height measured from the tip, and (3) the artificial form factor, which is based on the cross-sectional area at breast height and is considered the most practical one.
- **Niklas (1995)** found in heavily thinned stands, taper increases over time, but the shape remains unchanged. To put it simply, the form factor FF of a tree is a measure of its volume relative to a specified geometric solid of similar diameter and height.

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- **Ryan and Yoder (1997)** stated that typically, the FF of a tree is calculated based on a cylinder. This method of enumerating FF is common in different countries.
- **Yadav and Amalava (1997)** found out that the blue pine tree exhibits greater resistance to air pollution compared to most other coniferous trees and possesses a high degree of pollution tolerance. Managing blue pine forests or stands could contribute to the sustainability at large.
- **Lee et al. (1998)** stated that apart from being a source of timber, the blue pine species is also known for its high-quality resin and fuelwood. The economic value of blue pine is increasing and has great importance in the international market.
- **Führer (2000)** described that the services provided by forests have played an essential role in sustaining both rural livelihoods and national development. These services include the production of timber as well as non-wood forest products.
- **Khan (2001)** mentioned that *Pinus wallichiana* commonly known as blue pine, is a commercially valuable tree species found in the mountainous regions of Afghanistan, Pakistan, India, Nepal, Bhutan, Tibet, China, and Burma. The tree species *Pinus wallichiana* is commonly referred to as blue pine, Himalayan Blue pine, Himalayan Pine, or Himalayan White Pine. He also mentioned that blue pine is known for its diversity across its range, which covers the Himalayan Mountains, where the species is exposed to varying climatic, geographic, and soil conditions.
- **Hasenauer et al. (2012)** asserted that ensuring sustainable forest management requires accurate assessment of forest growing stock (stem volume) and volume increment predictions derived from growth models, particularly with the rising demand for timber.
- **United States Global Change Research Program (2014)** accurate volume predictions are necessary for calculating carbon stocks in timberlands, particularly for the development of the United Nations Framework Convention on Climate Change's Reducing Emissions from Deforestation and Forest Degradation (REDD+).
- **Bhavan (2016)** asserted that the shape of different parts of a tree stem approximates common shapes - the base tends to be shaped like a neiloid, the tip like a conoid, and the main part of the bole like a paraboloid.
- **Rahman et al. (2017)** also stated that it is distinguished from other five-needle pines due to its ability to resist rust caused by *Cronartium ribicola* (White-pine blister rust). Blue pine exhibits resistance and can be used in various ways.
- **Naeem et al. (2020)** described to obtain the actual volume of a tree, it is important to establish

ratios that can be used to convert the computed volumes of standard solids into true volumes, based on species-specific form factors for a specific location.

III. OBJECTIVES OF STUDY

The purpose of the study is to develop a form factor equation for Pinus wallichiana, a species of pine tree found in the study area. The form factor is a measure of the shape of a tree and is calculated as the ratio of the volume of a tree to the product of its basal area and height. The form factor is used to estimate the volume of timber that can be obtained from a tree.

The specific objectives of the study are as follows:

A. To determine the artificial form factor of Pinus wallichiana in the study area.
B. To assess the relationship between the form factor and other parameters.
C. To develop a form factor equation for Pinus wallichiana.

IV. RESEARCH METHODOLOGY

A. Study Area

The study was conducted in Khotokha, which falls under two gewogs namely Bjena geowg, and Rubiesa gewog under Wangduephodrang Dzongkhag which lies in the western part of the country. The study area lies at an elevation of 2600 m above sea level and Latitude: 27°25'3.37” N, Longitude 89°59'37.56” E.

B. Sampling Design and Data Collection

Systematic sampling was done, covering 34.96 ha of blue pine forest area with a sample size of 1.6 ha. There were 32 plots where the distance between plots to plot was 100 m. The plot shape was circular with a 12.62 m radius having an area of 500 m². Google Earth was used to map out the study area. The map was drawn using the “add path” option and was exported as kml file. It was later converted to shp file. Plots were laid out using the create fishnet option in the Arc GIS with a distance of 100 m between plots to plot. The plot coordinates were uploaded into the GPS, and a proximity alarm was set to determine the location of the plot to collect the data.

C. Equipment Used

The materials used are GPS handset, Spiegel Relascope with Ranging Rods, Diameter measuring tape, and 100 m measuring tape.

D. Sample Tree Selection Criteria

Trees with a normal height that does not have much variation and diameter development were selected, trees with defects, forked, or broken tops were avoided, trees with dbh 10 cm and above were selected and the data was collected from the following tree parameters height of the trees, mid diameter and diameter at breast height.

E. Tree Height Measurement, and Diameter Measurement

The height of the trees was determined by utilizing a Spiegel Relaskop and 2 ranging rods with red markings on the top, middle, and bottom to aid in visibility within the forest. To correct for slope error, the relaskop was used to sight at the center of the stick, and the scale drum was locked for range finding. The 2 m stick was hung from the tree, and measurements were taken using different scale bars for varying ranges. The readings obtained from the top and bottom of the tree were then added together to obtain the tree's height. Tree mid diameter was also recorded using a relascope. At breast height (1.37 m), the tree's diameter was measured using a diameter tape. This method provided accurate and reliable height and diameter measurements of the trees. The vivid red color markings on the stick ensured that measurements were taken at the correct points on the stick, and the Spiegel Relaskop allowed for the correction of any slope errors that may have occurred.

F. FF Equation

Data was entered and arranged in the MS Excel spreadsheet. Data was explored for errors and normality, finding relationships between the tree parameters and developing the equation was done by SPSS using multiple factor regression. While developing the equation, the form factor of the tree was the dependent variable and the independent variables were dbh and height. The strengths and weaknesses of the ff equation were assessed by the Mean Biased Error (MBE) and Root Mean Square Error (RMSE). The following formula was used to determine these evaluation criteria (Tabari et al., 2013):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}}$$

$$MBE = \frac{\sum (P - O)}{N}$$

Where $\underline{P}$ & $\underline{O}$ are averages of P_i & O_i, P_i is the predicted values and O_i is the observed values, n is the total number of observations. The model took the following multiple regression equation:

Form Factor = β1TP1+…βnTPn + C + E1…En

Where, β1…βn = Coefficients, TP1…TPn =Tree parameters, C = Intercept, and E1…En = random errors of the tree parameters.

V. DATA ANALYSIS AND INTERPRETATION

A. Descriptive Statistics

From the total sample of 555 trees, height ranges from 7 m to 29.2 m. The highest dbh recorded was 60.4 cm and the lowest was 11 cm. The highest form factor recorded was 0.61 and the lowest was 0.11 with a mean value of 0.39.

Table 1: Descriptive Statistics Table for ff, dbh, and height

	N	Minimum	Maximum	Mean	SE	SD
ff	555	0.11	0.617	0.39	0.004	0.09
dbh (cm)	555	11	60.4	32.81	0.473	11.16
height (m)	555	7	29.2	22.64	0.228	5.37

Source: Compiled by Author

B. Plot-Wise Basal Area Comparison

The highest basal of 3.28 m2 from plot number 19 and the lowest of 0.628 m2 from plot number 7.

Sudarshan Research Journal
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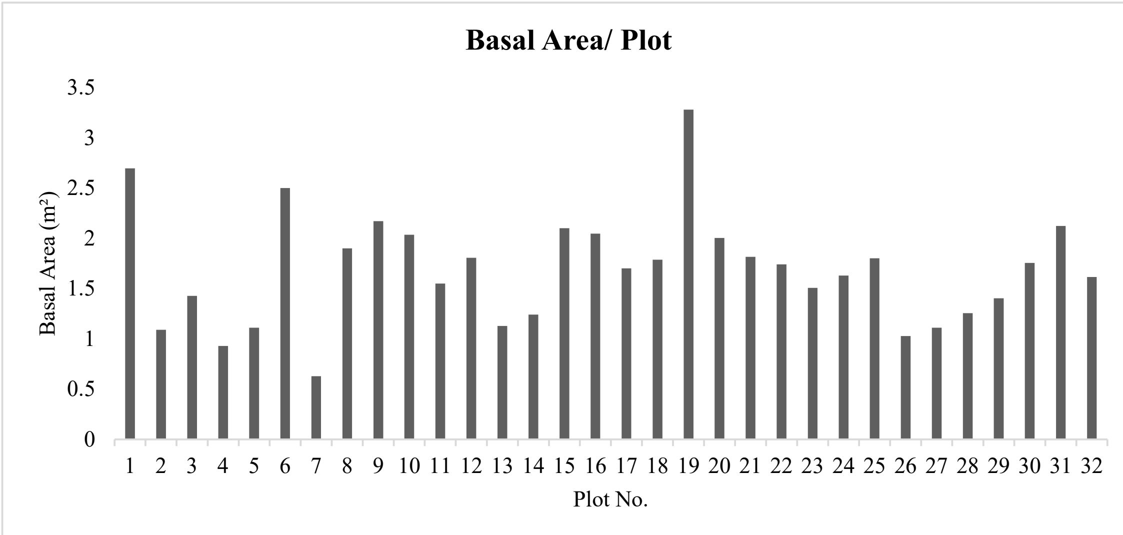
Figure 1: Basal Area for Each Plot



Source: Compiled by Author

The basal area per hectare for plots was 33.69 m22/ha.

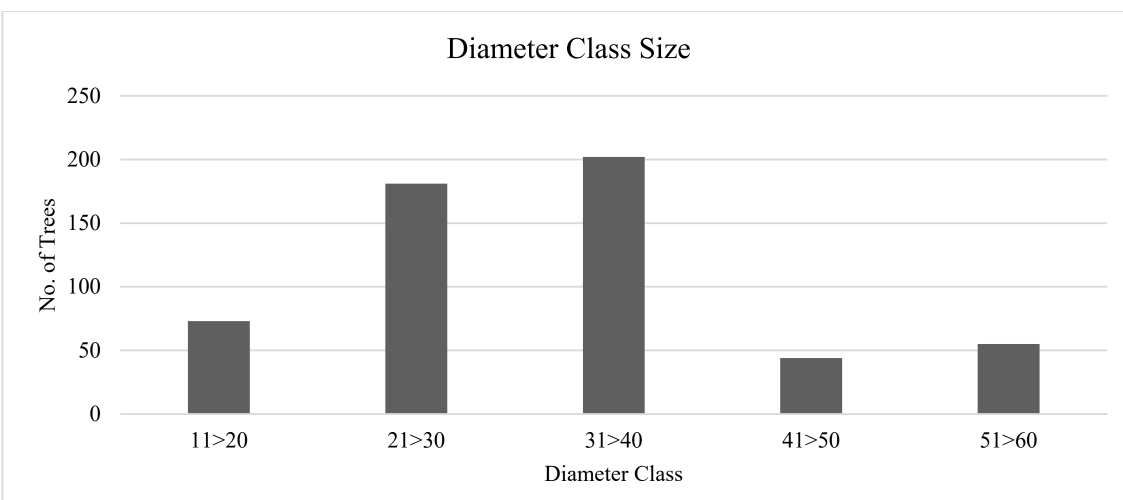
$$\textbf{Basal area (m^2)} = \frac{\sum Basal\ Area(m^2)}{Sample\ size\ ha)} = \frac{53.9}{1.6}$$

$= 33.69\ m^2 2/ha.$

C. Diameter Class Comparison

The highest diameter class observed was 'between' (31-40) with 202 trees. The least diameter class observed was 'between' (41-50) with 44 trees.

Figure 2: Diameter Size Class Graph

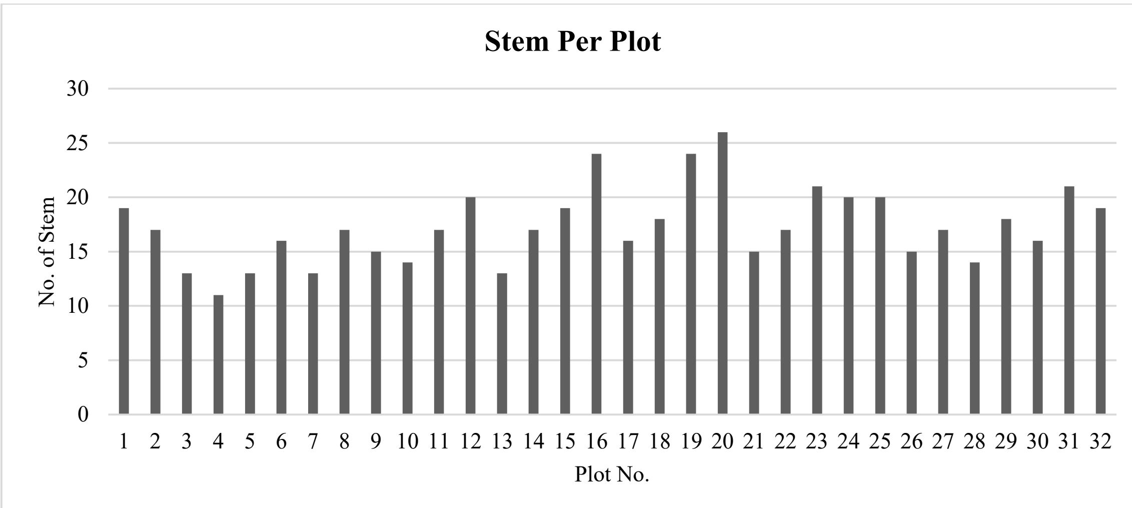


Source: Compiled by Author

D. Plot-Wise Stem Comparison

The plot with the most stems was plot number 20, which had 26 trees, while the plot with the least was plot number 4, which had 11 trees. Stem per hectare was calculated for these plots which were 347 stems per hectare.

Figure 3: No. of Stem for Each Plot



Source: Compiled by Author

$$\text{Stem/ha} = \frac{\sum No.of\ stems}{Sample\ size(ha)} = \frac{555}{1.6}$$

$$= 347\ \text{Stem/ha}$$

E. The Correlation Between dbh, Height, and ff

Table 2: Pearson Correlation between dbh, height, and ff

	dbh (cm)	height (m)	ff
dbh (cm)	1	32	32
height (m)	.821**	1	32
ff	.377**	.511**	1

Source: Compiled by Author

The correlation coefficient between dbh and ff is ($r = .377$, $p > .01$), indicating a moderate positive correlation between these two variables in Table 2, which could be due to factors such as competition for resources or differences in species composition (Parresol et al., 1987). The correlation coefficient between dbh and height is (r = .821, p < .01), indicating a strong positive correlation between these two variables, this relationship is expected since larger trees tend to be taller than smaller trees (King, 1990). The correlation coefficient between height and ff is (r = .511, p > .01), indicating a moderate positive correlation between these two variables, which could be due to factors such as differences in species composition or age structure (Evert, 1969). Overall, the correlation matrix provides insight into the relationships between these three variables, which is useful for forest management and planning.

F. Observed ff, and Predicted ff

The observed ff is 0.395, while the predicted ff based on the model is 0.399. This suggests that the predicted ff is higher than the observed ff, indicating that the model slightly overestimated the volume of the trees. Further research is needed to determine the accuracy of the model and to adjust it accordingly.

G. Relationship between dbh, Height, and ff in a Regression Model

The relationship between two predictor variables dbh, height, and the dependent variable ff is shown in Table 3. The results indicate that there is a positive correlation between the two predictor variables and ff (R = 0.516). The standard error of the estimate (0.8196) represents the typical difference between the predicted values of the ff and the actual values. Which is a measure of the variability of the errors or residuals in a regression model.

Table 3: Regression Model Summary Table

R	R^2	Adjusted R^2	SD
0.516a	0.266	0.264	0.8196

Source: Compiled by Author

a. Predictors: (Constant), height (m), dbh (cm)

b. Dependent Variable: Form Factor

A summary of the regression model's performance in Table 3 explains the dependent variable using the independent variables. It suggests that there is a moderate positive correlation between the two, but the model may not explain as much of the variance in the dependent variable as desired. Tenzin, Wangchuk, et al., in the year 2017, carried out a comparison study between four different form factors among nine commercial tree species in Bhutan which includes blue pine. The study used a non-linear regression model and the R statistical program generated the value of 0.4986 which is observed ff found by a destructive method.

H. Tree ff Based on dbh, and Height: A Regression Model Analysis

In the model shown in Table 4, the intercept is 0.183, which represents the expected value of the dependent variable when all predictor variables are zero. The dbh variable has a negative unstandardized coefficient of -0.001 and a negative standardized coefficient of -0.129, indicating that as dbh increases by one unit, the dependent variable decreases by 0.001 units while controlling for the other predictor variables and that a one-standard-deviation increase in dbh is associated with a 0.129 standard deviation decrease in the dependent variable. The height variable has a positive unstandardized coefficient of 0.011 and a positive standardized coefficient of 0.617, indicating that as height increases by one unit, the dependent variable decreases by 0.011 units while controlling for the other predictor variables and that a one-standard-deviation increase in height is associated with a 0.617 standard deviation decrease in the dependent variable.

Table 4: Multiple Regression Coefficients Table

	Unstandardized Coefficients B	SE	Standardized Coefficients Beta	t	Sig.
(Constant)	0.183	0.015		11.890	0.000
dbh (cm)	-0.001	0.001	-0.129	-2.026	0.000
height (m)	0.011	0.001	0.617	9.667	0.043

Source: Compiled by Author

In Table 4, Height explains 61.7% of the variance in the dependent variable (Y) while holding other independent variables constant. The dbh explains 12.9% of the variance in the dependent variable (Y) while holding other independent variables constant. The intercept of the equation (0.183) represents the expected ff of a tree with a height and dbh of zero. The coefficient for height (0.011) suggests that, on average, for each additional meter in height, the total volume of the tree increases by 0.011. Similarly, the coefficient for dbh (-0.001) suggests that, on average, for each additional centimeter in dbh, the total volume of the tree decreases by 0.001.

I. The ff Equation Development

The ff equation predicts the ff of a tree based on its dbh and height.

ff = 0.183 - 0.001 * dbh (cm) + 0.011 * height (m)

An observation of tree dbh and height from the sample data respectively 41 (cm) and 28.4 (m) was used for the equation (Annexure 1, SL no. 3).

ff = 0.183 - 0.001 * 41 (cm) + 0.011 * 28.4 (m)

Where numbers with (c*m)* and (*m*) units are the tree dbh and height.
This indicates that based on the values of dbh (cm) = 41, and height (m) = 28.4 from the sample data, the predicted value of ff is 0.454p. To find the tree volume using the developed form factor equation an observed tree dbh and height from the sample data of the same can be used. The Volume equation is as follows:

Tree volume = ff * (dbh)^2 * height

Tree volume = 0.454 * (0.41 m) ^2 * 28.4 m

This suggests that the predicted value of the tree volume of 2.44 m^3 is lower than the observed value of 3.7 m^3 based on the regression equation. This equation provides a way to predict the volume of a tree based on the values of the predictor variables. However, it is important to note that the accuracy of the predictions may be limited by the assumptions and limitations of the regression model. In general, the ff of a tree tends to have a negative relation with the dbh (Ek and Monserud, 1979). This means that as the dbh of a tree increases, the ff decreases. Mechanical stability, crown development, and competition for light are a few reasons for this negative relation (Bhandari, 2003, Hemery et al., 2005 James et al., 2006).

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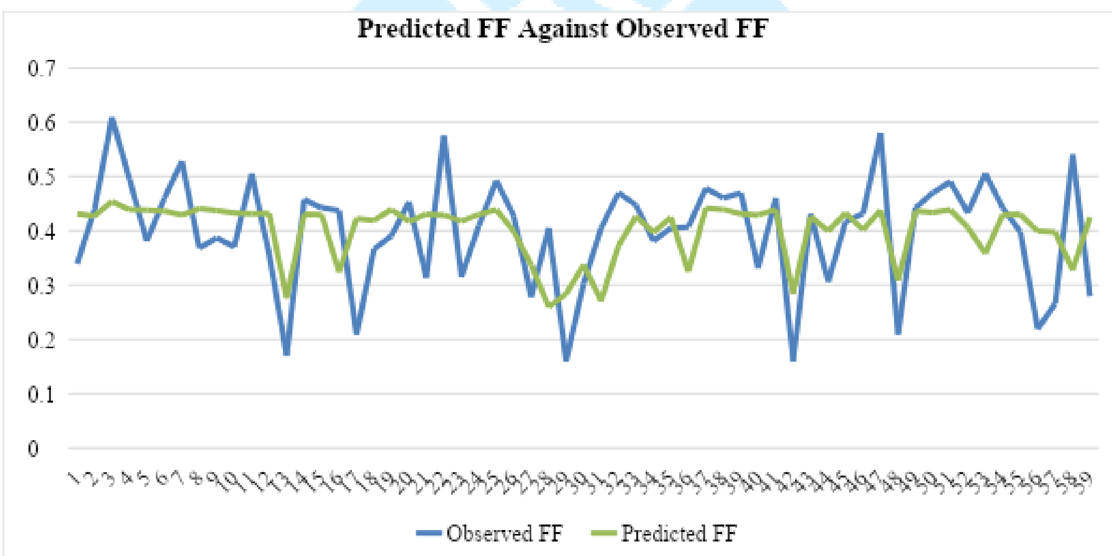
Table 5: RMSE, and MBE Value

RMSE and MBE Formula	Value
$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$	0.0818
MBE= $\frac{\sum(P-O)}{N}$	0.0038

Source: Compiled by Author

The RMSE value of 0.0818 indicates that, on average, the predicted ff is about 8.18% away from the observed ff. The MBE value of 0.0038 indicates that, on average, the predicted form factor is (0.38%) higher than the observed ff. Figure 4 shows the trends of the observed and predicted ff for 59 samples to avoid a compacted chart view. Tenzin, Wangchuk, et al., found out that, among four ff functions Pollanschütz's function, Short Swedish's function, Meyer's function, and Evert's function, the highest value of RSME is 0.0548 which is Evert's function, and the lowest is 0.0499, which is Pollanschütz's function (2017).

Figure 4: Predicted ff Against Observed ff



Source: Compiled by Author

VI. CONCLUSION

The ff equation developed for Blue pine in Khotokha Forest Management Unit, Bhutan, is a significant contribution to the field of forestry. The equation is the first of its kind in the region, providing a species-specific volume assessment. The ff equation for this study is quite weak. Several factors could have contributed to the low R^2 value (= 0.266) observed in the study. The equation could be further developed which allows for consistent volume increment predictions, which are essential information needed for effective forest management. The significance of this study lies in its potential with improvised equations for practical application in forest management practices. In the future, the equation can aid forest managers and policymakers in making informed decisions about forest management practices, including harvesting schedules, growth projections, and carbon sequestration estimates. The ability to predict volume and volume increments accurately and consistently is essential for sustainable forest management, as it ensures the long-term viability of forest resources and supports the attainment of ecological, economic, and social objectives.

Moreover, the study highlights the importance of developing ff equations for other tree species in the region and beyond. By using an artificial ff approach, this study has shown that the equation can be easily recalibrated and/or extended to any other tree species if new calibration data are available. This opens up opportunities for further research and development of ff equations for other tree species, which would enhance the understanding of the regional forest resource and support effective management. Overall, this study provides valuable insights into sustainable forest management and underscores the importance of accurate and consistent volume assessments. The developed equation is a significant contribution to the field and has practical implications for forest management practices in Bhutan.

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