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# Regression Models for Tree Volume Prediction in Pinus Wallichiana Stands of South Western Himalayan Region of Kashmir

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## SUMMARY

This study focuses on assessing tree species diversity and evaluating the efficacy of both linear and non-linear regression models for predicting tree volume. The research was conducted in the slopes of the Pir Panjal range within the Shopian Forest Division, situated in the South-Western Himalayan Region of Kashmir. Data on *Pinus wallichiana* stands, including diameter at breast height (D) and tree height (H), were meticulously collected using appropriate measurement instruments. Employing a multi-stage sampling technique, ten plots of uniform size (10m x 10m) were selected across 20 blocks, and subsequently, 25 trees were randomly chosen from each plot. Six different linear and non-linear regression equations were fitted to the data, and the most suitable equation was identified for volume estimation. To evaluate the performance of the fitted regression models, metrics such as R-squared ($R^2$), adjusted $R^2$, root-mean-square error (RMSE), and Theil's U statistic were employed. Additionally, validation procedures involved using the half-split approach and the Chow test. Upon analysis, it was determined that when employing diameter (D) and considering the joint effect of diameter and height ($D^2H$ (I)) as independent variables, the linear model (V=-1.41+15.12D) and power model ($V=2.301\ I^{0.502}$), quadratic model ($V=1.8726+0.663\ I-0.011\ I^2$) with highest $R^2$, lowest RMSE and Theil's U statistic respectively, emerged as the most suitable for volume estimation, demonstrating superior accuracy compared to alternative models. Consequently, our findings extend beyond academic inquiry, offering practical implications for sustainable forest management and planning in the Western Himalayan Regions of Kashmir. By providing robust volume estimation models tailored to *Pinus wallichiana* stands, our study equips forest managers and policymakers with essential tools for informed decision-making.

*Keywords:* Regression equations; Tree volume; Height-diameter relationship; Pinus wallichiana; Temperate forests; Regression plots; Forest inventory.

## 1. INTRODUCTION

The Eastern Afghanistan regions, encompassing the Himalaya, Karakoram, and Hindu Kush mountain ranges, provide a natural habitat for the distinguished coniferous evergreen species, Pinus wallichiana, a prominent member of the Pinaceae family. Thriving within the heart of these landscapes, Pinus wallichiana attains impressive heights, reaching up to 50 meters, predominantly flourishing in the mountain valleys at altitudes spanning from 1800 to 4300 meters, with occasional occurrences even as low as 1200 meters. This species not only embodies the unique ecological characteristics of these regions but also plays an instrumental role in shaping their distinctive ecosystems (Wikipedia, n.d.).

Amid this tapestry of natural grandeur, Kashmir emerges as an integral geographical entity. Nestled between 32°-17' and 38°-58' north latitude, and 73°-35' and 80°-36' east longitude, this enchanting realm rests as the northwestern bastion of India. The average elevation of 1586 meters above sea level fosters verdant expanses of lush green forests that grace the landscape. These forests, covering an expansive 51% (8118 km²) of the nation's landmass equivalent to approximately 15, 948 km² hold profound significance. Beyond their natural beauty, they assume a vital role in sustaining life within the intricate tapestry of the Kashmir Himalayas, further radiating their impact into the very core of the regional economy (Govt. of J & K Forest Department).

Within the realm of forest inventory and ecosystem evaluation, the dimensions of tree height and diameter assume pivotal roles. These critical variables play an essential role in appraising tree volume, estimating biomass, quantifying carbon storage, and conducting

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survival assessments. The intersection of tree height and diameter enables the establishment of height-diameter (H-D) relationship models, laying the foundation for rapid volume estimations, biomass predictions, and insights into stand dynamics. These estimations, often facilitated by allometric or regression models, provide invaluable insights into the health and trajectory of forest ecosystems. Accurate quantification of tree population and volume holds a fundamental role within the arena of forest management and planning. For this reason, both forest managers and researchers necessitate robust methodologies that cater to both standing and harvested trees, thereby ensuring holistic assessments. Volume equations, regarded as indispensable tools within forest inventory, management, and silvicultural research, stand as a cornerstone for estimating stand volume. The ubiquity of tree and stand volume estimation equations, coupled with persistent endeavors to enhance their accuracy, attests to their significance within the domain of sustainable forest management. Assessing individual tree attributes plays a vital role in estimating growth and yield, aiding decision-making for sustainable forest management (Dau *et al.*, 2015). However, measuring all tree variables individually proves to be both expensive and time-intensive. While variables like diameter at breast height (DBH) and total tree height are commonly measured (Sumida *et al.*, 2013), the measurement of total height is less frequent. Typically, only sample tree heights are directly measured, with the heights of the remaining stand predicted using height-diameter allometry (Peng *et al.*, 2001; Zhang *et al.*, 2014; Bhandari *et al.*, 2021a, 2021b, 2021c). Although DBH measurement is straightforward, determining upper stem diameter at a specific height presents challenges. Taper equations offer a solution by predicting upper stem diameters based on easily measured variables like DBH and total height (Kozak and Smith, 1966; Kozak *et al.*, 1969; Kozak, 2004; Poudel *et al.*, 2018).

Volume models have been used for the estimation of tree volume for over a century, and they have played an important role in forest health planning and management. The volume equation is a set of mathematical statements that are used to determine quantity (Shuaibu, 2014). They're utilized to calculate the average content of trees of various sizes and kinds that are still standing (Avery and Burkhart, 2002). In other words, volume models compute the mean volume of an individual tree of a certain size (Van Laar and Akca, 1997). The diameter, height, and form factor of a tree's stem are all considered independent factors when determining its volume (Clutter *et al.*, 1983; Husch, *et al.*, 2003). Effective forest stand measurements are necessary to evaluate and enhance the quantity and quality of stands in order to increase the supply of timber, poles, and staking materials for socioeconomic development. Foresters must be familiar with every aspect of the forest they are responsible for, including the size, quantity, and quality of available forest assets, as well as how these assets are changing over time. The correlation between tree height and diameter varies across different forest stands, influenced by factors such as site quality, stand age, and silvicultural practices. Moreover, even within a single stand, variations in competitive interactions among trees contribute to the diverse nature of this relationship (Calama and Montero, 2004; Sharma and Parton, 2007; Trincado *et al.*, 2007; Schmidt *et al.*, 2011). This highlights the specificity of the height-diameter relationship, which is highly dependent on-site characteristics and stand density, and can evolve over time within the same stand (Zeide and Curtis, 2002; Pretzsch, 2009).

The objective of this study is to evaluate various regression models for volume estimation in *Pinus wallichiana* stands and identify the most suitable model for accurate prediction and recommend the same for volume table construction. Our hypothesis suggests that certain regression models will outperform others in accurately estimating the volume of *Pinus wallichiana* trees, primarily due to their ability to adequately capture the relationship between tree diameter, height, and volume. This is the first attempt, to our knowledge, to build and compare various H-D relationship models for *Pinus wallichiana* stands in the region. Throughout the distributional range of the selected conifer trees, the models selected in this study would be useful to researchers, managers, and academicians. Caution should be used when projecting heights outside of the size and height ranges, location, and stand conditions used in this study.

## 2. MATERIALS AND METHODS

This work was carried out on the stands of *Pinus wallichiana* which were raised naturally or by plantations and these forests are spread over a large tract in the South Circle of Kashmir Province between 33˚–30 'to 33˚–48' North latitude and 74˚-30 'to 74˚-50' East longitude. The tract under study is a narrow, linear area bordered on the west and south by the massive Pir Panjal Mountains. The Veshav Range of Kulgam Forest Division and Doodh Ganga Range of Pir Panjal Division share the boundary with Shopian Forest Division on the southern and northern sides respectively. The tract is located at an elevation of 1900 meters (Yarwan Karewa's lowest contour) to 4745 meters (sunset peak of Romshi Thung) amsl. The Principal Forest (Tree) belt, however, occurs from 1950 to 3200 amsl (Govt. of J & K Forest Department). The map of the area under study is given in the Fig. 1.

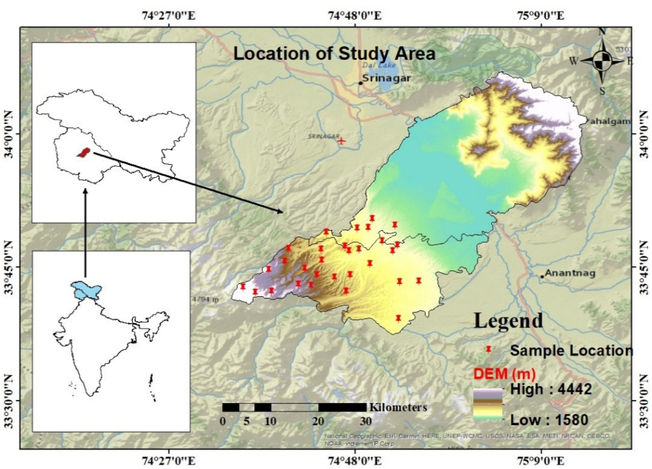


**Fig. 1.** Study area map

## 3. DATA COLLECTION

The study utilized a systematic approach to sample selection, whereby ten plots of identical dimensions (10m × 10m) were meticulously identified within 20 distinct blocks. From each plot, 25 *Pinus wallichiana* trees were randomly selected, resulting in a total of 250 trees for analysis. Precise measurement instruments were employed to record essential parameters including tree diameter and height. The diameter at breast height (DBH) of each tree was accurately measured using a vernier caliper and measuring tape, while tree height was assessed using the Haga Altimeter alongside optical estimations. Employing the methodology outlined by Bitterlich (1984), the volume of standing trees was estimated for further analysis.

$$V = \frac{2}{3} h_1 g$$

Where,

V = volume in cubic meters

$h_1$ = height at which the diameter is half of the dbh

g = basal area in square meters

Fig. 2 and Fig. 3 provide a multi-dimensional view of the measured tree parameters, revealing a discernible linear pattern accompanied by subtle curvilinear trends among the variables. Leveraging diameter and height as key predictors, an array of linear and non-linear models including linear, exponential, quadratic, cubic, logarithmic, and power models were used to predict the volume of *Pinus wallichiana*. Rigorous analysis incorporating ANOVA and the student's t-test served to ascertain the significance of the overarching regression model.

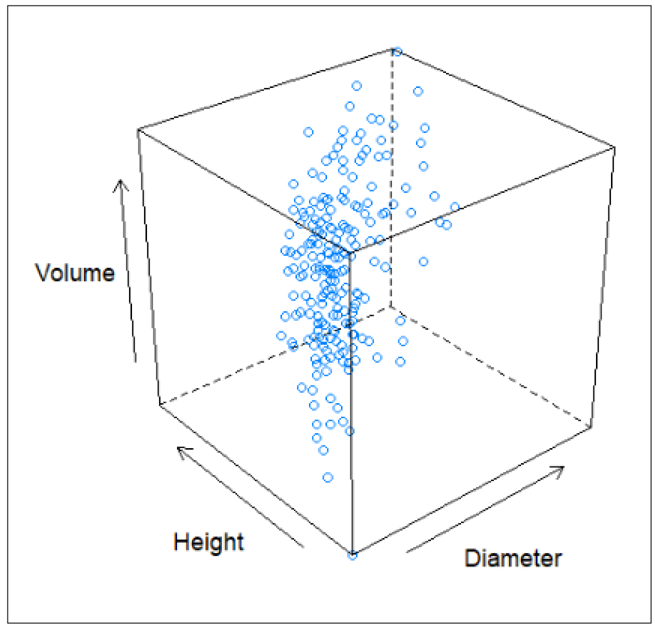


**Fig. 2.** General multi-dimensional view of the parameters

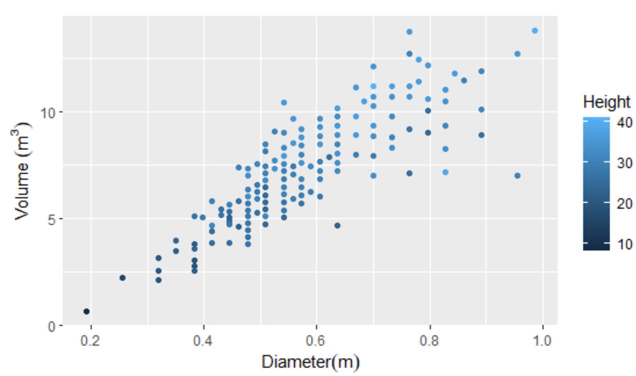


**Fig. 3.** Volume, height and diameter at breast height scatter plot

The process of selecting the most suitable model hinges upon several key criteria, including minimizing the Root Mean Square Error (RMSE), maximizing R-squared ($R^2$) and adjusted R-squared values, and minimizing Theil's U statistic. However, it's important to recognize that model validation requires extensive datasets covering various geographic regions and management scenarios, thereby extending the scope across species' geographical ranges. Given the limitations of the current dataset, future research could explore this avenue further. The ideal model would exhibit the optimal combination of low RMSE and Theil's U statistic, along with high R-squared and adjusted R-squared values. To bolster the validation process, the study employed the half-splitting method and the Chow test. Consequently, the recommended volume models hold significance for constructing volume tables and predicting growth parameters.

## 4. RESULTS AND DISCUSSION

In this study, we present the descriptive statistics for key parameters including diameter, height, and volume of the observed specimens in table 1. The mean diameter was found to be 56.83 cm, with a standard error (SE) of 0.96 cm. The 95% confidence interval (C.I) for diameter ranged from 54.94 cm to 58.72 cm. Notably, the coefficient of variation (C.V) for diameter was calculated to be 26.80%, indicating a moderate level of variability within the dataset.Similarly, the mean height of the specimens was determined to be 28.96 m, with an SE of 0.36 m. The corresponding 95% C.I for height spanned from 28.25 m to 29.68 m. The C.V for height was notably lower at 19.94%, suggesting a relatively lower degree of variability compared to diameter.Furthermore, the mean volume observed was 3.49 $m^3$, with an SE of 0.12 $m^3$. The 95% C.I for volume ranged from 3.11 $m^3$ to 3.91 $m^3$. Interestingly, the C.V for volume was relatively high at 58.35%, indicating a substantial level of variability in volume measurements within the dataset.

**Table 1.** Descriptive statistics of tree growth parameters

| Parameters | Mean | SE | 95% C.I | C.V (%) |
|---|---|---|---|---|
| Diameter (cm) | 56.83 | 0.96 | 54.94-58.72 | 26.80 |
| Height (m) | 28.96 | 0.36 | 28.25-29.68 | 19.94 |
| Volume ($m^3$) | 3.49 | 0.12 | 3.11-3.91 | 58.35 |

## 5. REGRESSION ANALYSIS AND MODEL VALIDATION

The prediction of volume for *Pinus wallichiana* was conducted through the application of various linear and non-linear models. Selection of the most suitable model was contingent upon achieving the highest level of accuracy, determined by performance metrics. The assessment of fitted regression models was conducted based on several metrics, including R-squared ($R^2$), adjusted R-squared ($R^2$adj.), root-mean-square error (RMSE), and Theil's U statistic.

**Table 2.** Regression models for *Pinus wallichiana* utilizing diameter (D) as an independent variable

| Models | Equations | $R^2$ | Adj. $R^2$ | RMSE | Theil's U statistic |
|---|---|---|---|---|---|
| Linear | V=-1.41+15.12D | 0.707 | 0.705 | 1.27 | 0.08 |
| Logarithmic | V=12.2548+ 8.5777D | 0.721 | 0.719 | 1.24 | 0.08 |
| Quadratic | V= 1.4894+ 6.8441D+3.3455D$^2$ | 0.674 | 0.673 | 1.34 | 0.17 |
| Cubic | V=1.745+6.371D+ 4.521D$^2$+ 1.366D$^3$ | 0.667 | 0.666 | 1.36 | 0.17 |
| Power | V=13.6494D$^{1.14}$ | 0.701 | 0.699 | 1.29 | 0.84 |
| Exponential | V=0.5796e$^{2.3365D}$ | 0.656 | 0.654 | 0.22 | 0.56 |

In Table 2, when considering the use of diameter at breast height (D) as an independent variable, the observed root mean square error (RMSE) values of 1.24 and 1.27, along with significant $R^2$ and adjusted $R^2$ values of 0.721, 0.719 and 0.707, 0.705, respectively, as well as the minimal Theil's U-statistic of 0.08, collectively emphasize the suitability of the logarithmic model (V = 12.2548 + 8.5777D) and subsequently the linear model (V = -1.41 + 15.12D) for accurate volume estimation. Previous regression models for a variety of tree species throughout the world indicated similar results (Sharma et. al, 2017; Calama and Montero, 2004; Sharma and Yin Zhang, 2004; Sharma and Parton, 2007; Sharma, 2009).

In Fig. 4, which represents the comparison between observed and predicted volume values using only diameter as an independent variable, the proximity of points to the diagonal line (y=x) serves as an indicator of the model's predictive accuracy. Closer alignment with the diagonal line suggests a more precise estimation of volume values, while deviations from this line signify discrepancies between observed and predicted values. Visual examination of the plots enables an assessment of how effectively the logarithmic and linear regression models capture the inherent pattern were the predicted and observed values closely clustered together and aligning closely with the line.

Furthermore, an exploration into enhanced regression functions involved the incorporation of a novel variable, denoted as $D^2H$ (I), derived from the product of diameter at breast height (D) and tree height

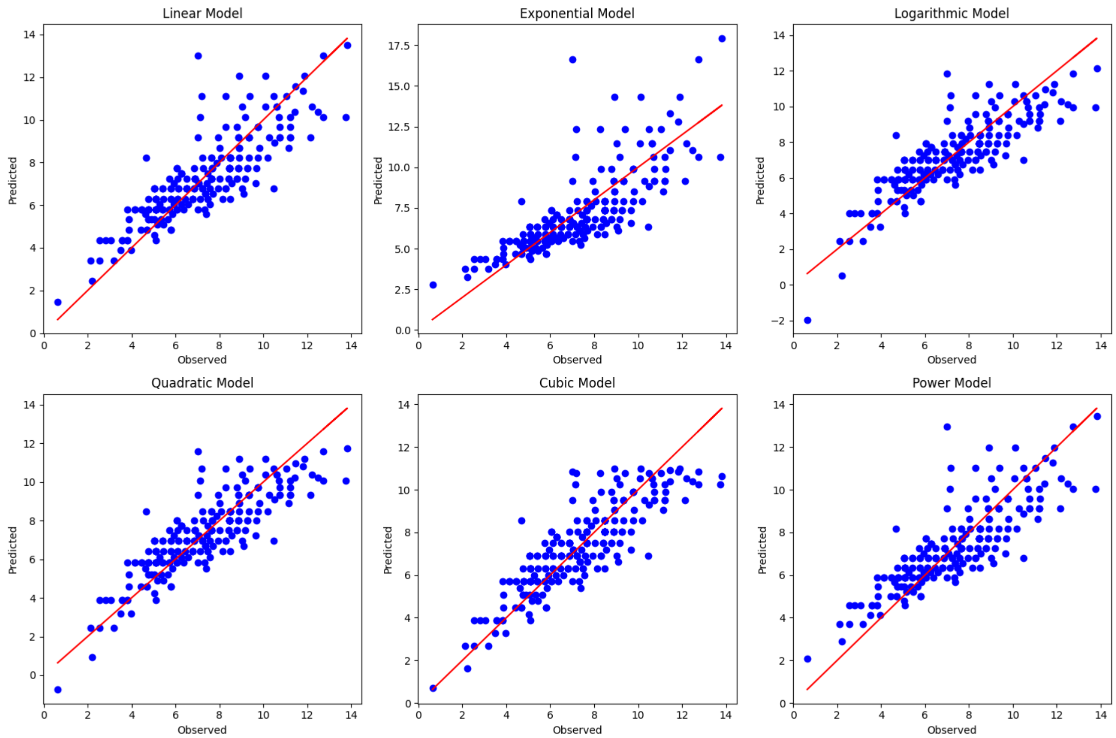


**Fig. 4.** Predicted vs observed volume for different regression models

(H). The study by (Giri *et al.*, 2019, Nurudeen *et al.*, 2014, Spurr, 1952) also provides valuable insights into regression modeling for volume estimation by developing linear regression equations using diameter squared multiplied by height ($D^2H$) as the independent variable and tree volume as the dependent variable, the authors achieved high levels of accuracy for all studied tree species. These findings suggest that the linear and non-linear regression equations based on $D^2H$ offer robust estimates of tree volume without the need for destructive sampling.

**Table 3.** Regression models for *Pinus wallichiana* utilizing $D^2H$ (I) as an independent variable

| Models | Equations | $R^2$ | Adj. $R^2$ | RMSE | Theil's U statistic |
|---|---|---|---|---|---|
| Linear | $V=3.6738+0.3372\ I$ | 0.736 | 0.735 | 1.22 | 0.07 |
| Logarithmic | $V=-0.2595+3.4149\ I$ | 0.783 | 0.782 | 1.09 | 0.07 |
| Quadratic | $V=1.8726+0.663I-0.011\ I^2$ | 0.812 | 0.811 | 1.04 | 0.09 |
| Cubic | $V=-0.759+0.966I-0.033\ I^2+0.001I^3$ | 0.827 | 0.826 | 0.98 | 0.13 |
| Power | $V=2.301\ I^{0.502}$ | 0.805 | 0.804 | 1.02 | 0.06 |
| Exponential | $V=1.3989e^{0.0490\ I}$ | 0.604 | 0.603 | 0.238 | 0.06 |

In Table 3, the power model ($V=2.301\ I^{0.502}$) exhibits the most favorable performance among the models considered, displaying the $R^2$ value of 0.805, closely followed by the quadratic model ($V=1.8726+0.663\ I-0.011\ I^2$) with an $R^2$ of 0.812. The power model also demonstrates a relatively lower root-mean-square error (RMSE) of 1.02 compared to the quadratic model's RMSE of 1.04, suggesting better predictive accuracy. Similarly, the Theil's U statistic for the power model stands at 0.06, indicating less bias compared to the quadratic model's Theil's U of 0.09. Despite the power model exhibiting a lower Theil's U statistic compared to the quadratic model, indicating less bias in predictions, it's crucial to consider the trade-offs between predictive accuracy and explanatory power. While the power model may have a lower Theil's U, its lower $R^2$ value suggests that it explains less of the variance in the data compared to the quadratic model. This implies that although the power model may provide more accurate predictions with less bias, it might not capture the underlying trends in the data as effectively as the quadratic model. Therefore, the choice between the power and quadratic models should consider the balance between prediction accuracy and explanatory power, depending on the specific requirements of the analysis and the context of the study.

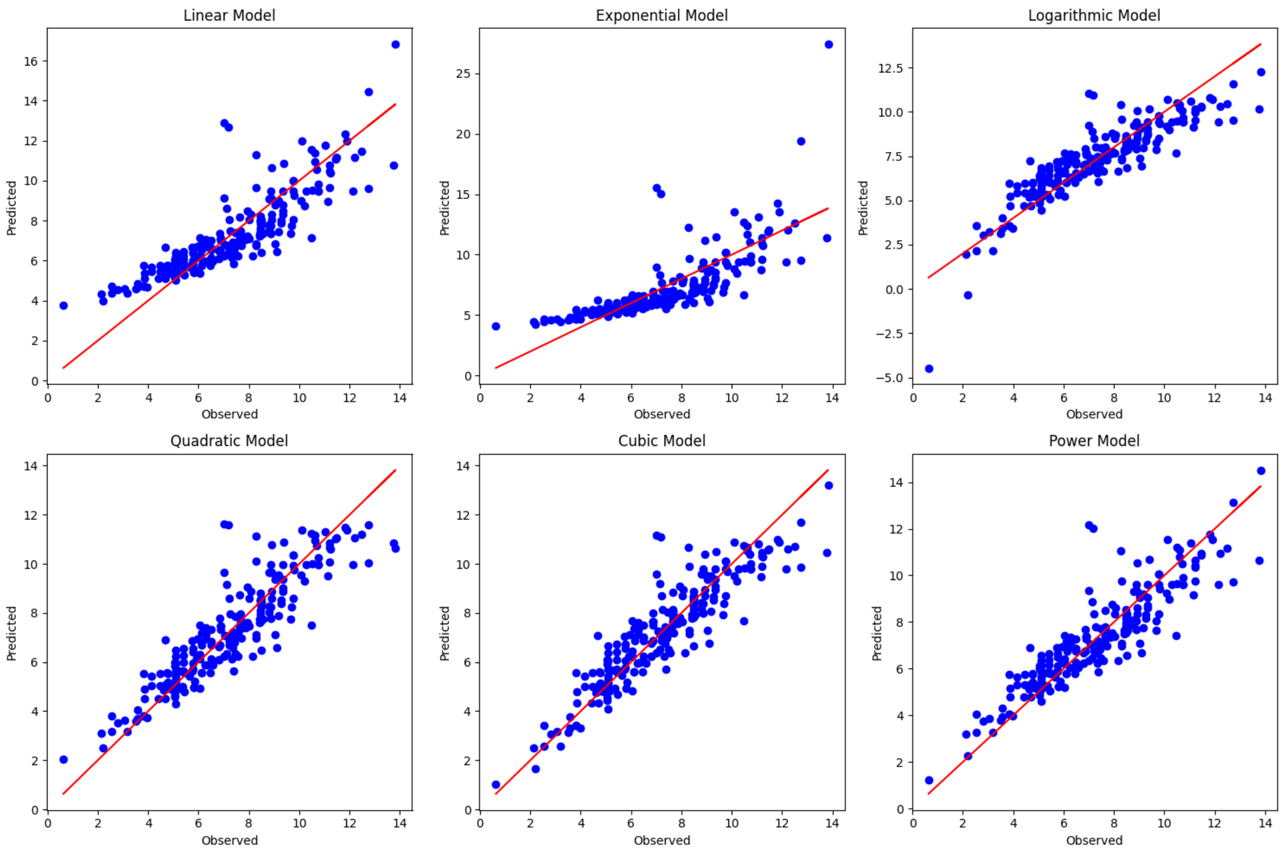


**Fig. 5.** Predicted vs observed volume for different regression models

Sharma and Jain (1977) conducted a study to create regional volume tables for *D. grandiflora* in the Manipur region of Northeast India, employing non-destructive methods. They established a linear regression model $V = a + b D^2H$, achieving a high correlation coefficient (R = 0.993). The regression equation derived from their dataset was $V = 0.081671 + 0.319025 D^2H$. Tewari *et al.*, (2001) suggested the use of combined variable ($D^2H$) for the construction of volume tables which are in line with the present investigation. In our study, this is evidenced by the elevated values of and metrics, alongside diminished root-mean-square error (RMSE) and Theil's U statistic values. The synergistic impact of $D^2H$ (I) becomes apparent upon comparing and contrasting the graphical representations presented in Figures 5, where the power and quadratic model incorporating $D^2H$ (I) exhibits heightened accuracy in volume estimation.

Through a rigorous validation process involving the half-split method and the chow test, the cubic model emerges as the frontrunner, surpassing alternative models. In the case of utilizing only Diameter (D) as the independent variable, the Chow test results indicate that the linear model stands out as the most appropriate choice among the tested models. In table 4 and 5, this conclusion is supported by the non-significant difference observed between the linear model and other models, except the logarithmic model, as revealed by the Chow test (Chow Test F-value: Linear = 0.546, Logarithmic = 31.455, Critical F-value = 4.823). Conversely, when considering $D^2H$ as the independent variable, both the power and quadratic models exhibit non-significant differences according to the Chow test results. Specifically, the Chow test indicates no significant discrepancy between the quadratic and power models (Chow Test F-value: Quadratic = 0.556, Power = 0.294, Critical F-value = 3.946). These findings suggest that for the D-only scenario, the linear model emerges as the optimal choice due to its consistent performance across various model comparisons, while for the $D^2H$ scenario, both the power and quadratic models can be considered equally suitable options based on their non-significant differences in performance.

**Table 4.** Chow Test F-values for the fitted models using diameter (D) as an independent variable

| Variable | Model | Chow Test F-value | Critical F-value | Significant Difference |
|---|---|---|---|---|
| D | **Linear** | **0.546** | **4.823** | **No** |
| | Quadratic | 0.525 | 3.946 | No |
| | Logarithmic | 31.455 | 4.823 | Yes |
| | Cubic | 0.537 | 3.455 | No |
| | Power | 12.036 | 4.823 | No |
| | Exponential | 10.135 | 4.823 | No |

**Table 5.** Chow Test F-values for the fitted models using $D^2H$ (I) as an independent variable

| Variable | Model | Chow Test F-value | Critical F-value | Significant Difference |
|---|---|---|---|---|
| $D^2H$ | Linear | 0.568 | 4.823 | No |
| | **Quadratic** | **0.556** | **3.946** | **No** |
| | Logarithmic | 939.740 | 4.823 | Yes |
| | Cubic | 0.579 | 3.455 | No |
| | **Power** | **0.294** | **4.823** | **No** |
| | Exponential | 590.433 | 4.823 | Yes |

## 6. CONCLUSION

In the pursuit of achieving enhanced accuracy in volume estimation within forest ecosystems, the imperative lies in the evaluation of species-specific and site-specific volume equations or regression models. The conventional method of developing volume equations, reliant on tree felling across diverse diameter classes, is both resource-intensive and time-consuming. This study, however, embraces a non-destructive approach, underscoring its commitment to sustainable practices. Conducted in the temperate natural forests of Shopian Forest Division within the South-Western Himalayan Region of Kashmir, this research ventures into assessing species diversity while probing the efficacy of linear and non-linear regression equations for volume estimation in the context of *Pinus wallichiana*. By meticulously harnessing data from two hundred and fifty trees, this study transcends the limitations of traditional approaches.

This study delves into the synergy between diameter at breast height and the joint influence of diameter and height as predictor variables. The adoption of a non-destructive approach coupled with the selection of best-fitted models for volume estimation showcases a holistic and sustainable approach towards forestry practices. The rapid development of species-specific volume equations through non-destructive means presents a cost-effective and environmentally sustainable alternative to conventional methods. These findings hold promise for forest managers, policy makers, and growth modelers, offering valuable insights for informed decision-making. Ultimately, this study contributes to the refinement of volume estimation techniques and supports comprehensive greenhouse gas inventory data preparation, fostering sustainable forest management practices.

## 7. DECLARATIONS

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**Conflicts of interest/Competing interests:** We the authors declare that we do not have any kind of conflict of interest as all of us have contributed equally.

Authors Contribution:

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

Aqib Gul wrote the overall manuscript text. Statistical analysis of the said research was done by Nageena Nazir and Aqib Gul. Tables and Figures were prepared by Bilal Ahmad Bhat and M. S. Pukhta. All four authors worked together for the review of the manuscript.

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