Volume models for Sal (*Shorea robusta* Gaertn.) in far-western Terai of Nepal

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Sal (*Shorea robusta* Gaertn.) is one of the most important commercial tree species in Nepal and far-western Terai is renowned for its forest. This study was carried out in far-western Terai to develop volume models of Sal at tree level using destructive sampling. Out of 99 sample trees, 81 data were used to develop the models and 18 data for validation of the selected models. Over bark stem diameters were measured at an interval of 0.5 m in lowermost three sections, at an interval of 1 m for one section and at an interval of 2 m in upper part of the trunk from the ground level. Smalian's formula was used to compute tree volume. Seven regression models were tested using DBH as a predictor variable. Cross validation of the independent data set was used to validate the selected models. The graphical analysis and fit statistics of the models were evaluated to select the best fit model. The selected model for total over bark stem volume is ln V = - 8.04674 + 2.26641 ln DBH with R^2 of 92 % and standard error of 0.18. Similarly, the selected models for over bark volume up to 10 and 20 cm top diameter have R^2 of 82.41% and 79.97% and standard errors of 0.35 and 0.42, respectively. The prediction error of the selected model was found to be less than 6%. Forest managers can use the recommended model in estimation of timber volume of Sal in a particular forest area of this region for effective forest management.

Key words: Destructive sampling, far-western Terai, fit statistics, regression equation

Tree volume provides vital information in forest management for estimating current and future stock of forest. However, direct measurement of volume is a tedious and impractical in the field. Thus, models or mathematical functions are necessary to estimate the volume using some measurable variables such as height, diameter and form of the tree. Further, volume models have been used as one of the best means to estimate trees and stand volume and have played vital role in forest inventory, management and silvicultural research (Ozçelik *et al*., 2010).

In principle, height and diameter are measured in the routine forest measurement. However, height measurement is not always practical due to more time consuming and cost and possibility of being less accurate (Wagle and Sharma, 2011; Sharma and Pukkala, 1990b; Chaturvedi and Khanna, 1982). On one hand, the possibility of error increases more in the dense forest measuring tree height, on the other, DBH can be measured more easily and accurately with less time and cost. Further, volume table produced using a model with predictor variable DBH only is particularly useful for quick timber inventory. It can be tallied with species and only DBH (Sharma and Pukkala, 1990a; Chaturvedi and Khanna, 1982; Özçelik, 2008).

Department of Forest Research and Survey (DFRS) have been involved in producing various volume and biomass models (Sharma and Pukkala, 1990a; Laamanen *et al,* 1995, Tamrakar, 2000; Acharya *et al*., 2003) of tree species required for forest management for long time. The general volume tables of 21 tree species and two species groups were developed in 1990 using data collected in 1960s (Sharma and Pukkala, 1990a). During 1990s there were few studies on general volume and growth models of Sal, especially in central Bhabar forests of Nepal (Laamanen *et al.,*

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1995). In addition to this, DFRS has developed biomass and volume models of some trees and bamboo species and some forest types. However, the diameter used in developing the models was ≤ 35 cm and the data were collected from thinning operation applied in trial plots may not represent the natural forest and again, the data were from only central part of the country *(*Acharya and Acharya, 2004; Acharya *et al*., 2003; Tamrakar, 2000; Pukkala *et al*, nd.*)*.

S. robusta Gaertn*.,* only one species found in Nepal of tropical family Dipterocarpaceae, is a multipurpose tree species. Sal is a valuable and important timber species for construction, and fuel wood. Sal seeds are used as raw material in industries and leaf used for making plates and as fodder for livestock (Jackson,1994). It is still most predominant species in the terai of Nepal (DFRS, 2014). It is found from Terai region to 1500 m but common up to 1000 m. It occurs mostly in Terai, Siwalik and low land of hilly areas. In most areas, almost pure Sal forest can be found or in association with *Terminalia alata*. In some places, it grows along with broadleaved species. The Sal forests in the Terai (plain area) are mostly large and differ from hill Sal forest. In higher rainfall and moist areas, it is replaced by mixed forest. Dobremez (1976) listed nine types of *Shorea* forests, but Champion and Seth (1968) listed more than that, most of them are expected to be found in Nepal (cited by Jackson,1994).

The climate of far-western terai is drier than other parts of the country. Out of the total forest area of Kailali district, 32.16% is covered by Sal forest and 31.39% by Terai Mixed Hardwood (TMH) with Sal (DDC Kailali, 2015). The Sal forest in far-western Terai is similar with minor variations due to topographic and climatic similarity. Thus, DFRS, 2014 described as far-western forest clusters, which is different from those in other parts of the country because its climate is drier than other parts of the country. Therefore, the volume models based on one variable *viz*. DBH alone will be applicable.

In recent years, efforts have been made towards the scientific forest management in Nepal. However, there is lack of appropriate technical tool for volume and biomass estimation of timber. There is need for precise and site specific volume estimation equations using easily and accurately measurable independent variables of the trees. Realizing the situation, Department of Forests has called for preparing district wise local volume tables to estimate the timber quantity (DoF, 2014). Therefore, preparation of local volume equations of this species for the natural forest of far-western Terai is essential. The purpose of the study was to prepare local volume models of *S. robusta* for specific heights of tree trunk in far-western Terai.

Materials and methods

Study area

The study site is Balchaur area located at the eastern part of Kailali district and other sites such as Bani, Banka, Motipur, Gwalabari, Krishnapur, Basahan, Singapurur, etc. located at eastern and southern part of Kanchanpur district (Fig. 1).

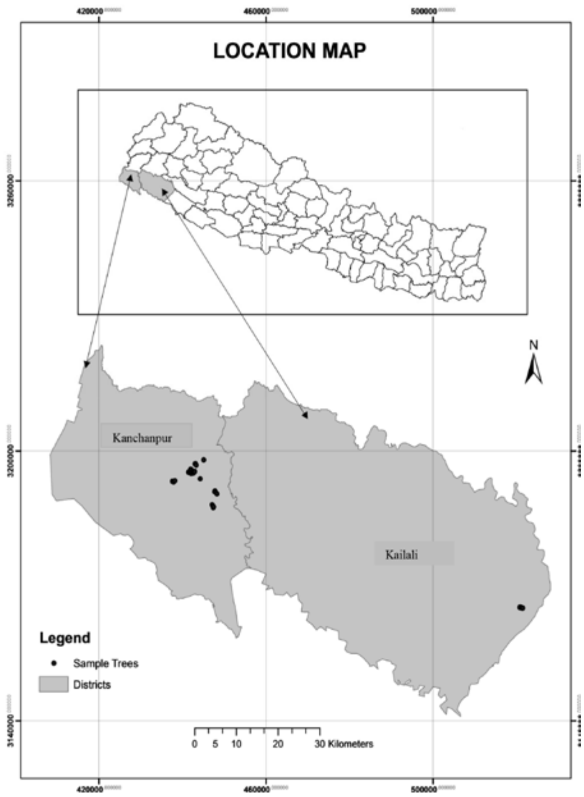

Fig 1: Map of the study area

These sites are in an altitudinal range of 109 m to 200 m above the mean sea level. Kailali district has an area of 3,235 sq. km, in which 40 per cent is covered by Terai (flat land) and 60 per cent by Chure hills. The total area of Kanchanpur district is 1610 sq. km in which 11.7 percent covered by Chure region, 55 percent is covered by forest and streams and 548.5 sq. km. of wildlife reserves and its buffer zone area. The far-western Terai forest extends from the Karnali River in the east to the western border of Nepal. It covers 97,622 ha forest outside the protected area (DFRS, 2014). Sal forest, Terai Mixed Hardwood forest, Sal with Terai Mixed Hardwood forest and Khair-Sissoo forest are the dominant types of forest in this area (DFRS, 2014).

The southern parts of the districts consist of plain area with deep fine sandy loamy soil. The climate is generally sub-tropical. The precipitation and temperature from Dhangadhi and Mahendranagar stations represent eastern and western study sites, respectively. The data of precipitation and temperature in Dhangadhi are average figures of 25-years and 6-years, respectively. The data of precipitation and temperature in Mahendranagar are average figures of 10-years and 4-years, respectively. Average annual precipitation ranges from 1547 mm in Mahendranagar to 1725 mm in Dhangadhi. Average monthly temperature ranges from 23.7^{o} C in Dhangadhi to 23.6^{o} C in Mahendranagar. Absolute maximum temperature is 43.5^{o} C whereas absolute minimum temperature is 2.0^{o} C in Dhangadhi. Absolute maximum temperature is 43.0^{o} C whereas absolute minimum temperature is 2.6^{o} C in Mahendranagar. Dhangadhi annual autumn temperature is maximum 43^{o} C to minimum 24^{o} C and winter temperature is maximum 19^{o} C to minimum 2^{o} C. In this way, average temperature is found as 30.5^{o} C. These climatic data taken from Department of Hydrology and Meteorology/Department of Irrigation, Hydrology and Meteorology are stated by Jackson (1994).

Data collection

According to the Forest Act (1993), plants above 30 cm diameter are regarded as tree and selected as samples for the study. The data of selected sample trees were collected above 30 cm DBH to develop models particularly for estimation of Sal timber. The data were collected from the forests of far-western Terai. The trees above 30 cm diameter were divided into 10 cm diameter class up to 90 cm and one class above this. For each diameter class, at least 10 trees were selected for developing a model. The data were collected from different forest types, quality class, crown class and density to represent all the possible local minor variations of natural forest. The forest type, quality class, crown class and density were measured as in FRA (2010). The representative sample trees with respect to size (diameter) were chosen randomly among the available trees from all parts of the selected area. Twenty-one sample trees were selected from pure Sal forest, 23 from Sal-Asna mixed forest and 37 from Terai Mixed Hardwood forest to develop the model . The crown cover of these forests ranged from 30 to 85% having median of 60% crown cover. Similarly, the selected sample trees to develop the model were 67 from predominant, 12 from co-dominant and two from suppressed trees. In this way, 81 (32 from Kailali and 49 from Kanchanpur) sample trees were selected to develop the model. Similarly, 18 sample trees were selected from representative study area for validation of the models.

The basic characteristics of the site and sampled trees were recorded before felling the sample trees. After measuring DBH, trees were felled and over bark diameters were measured at an interval of 0.5 m in lowermost three sections, at an interval of 1 m for one section and at an interval of 2 m in upper part of the trunk (Sharma and Pukkala, 1990a; Eerikainen, 2001). Further the height of the sampled tree up to 10 cm and 20 cm over bark top diameters were recorded. The over bark diameters were measured by a diameter tape with an accuracy of 0.1 cm. Sectional volume was calculated using Smalian's formula and then total volume and volume up to top 10 and 20 cm diameters were obtained by summing up sectional volumes (Laamanen *et al*.,1995, Segura and Kanninen, 2005 Özçelik, 2008, Ozçelik *et al*., 2010).

Data structure and model development

The average DBH and height of the sample trees were approximately 59 cm and 30 m (Table 1). The detailed descriptive statistics of 81 sample trees is given in table 1.

Table 1: Descriptive statistics of data of sample trees

Variables	Number of sample trees	Minimum	Median	Mean	Maximum	Standard deviation
Total height (m)	81	19.00	30.05	29.91	41.20	5.05
DBH (cm)	81	30.10	57.50	59.21	108.50	16.86
Height diameter ratio	81	0.38	0.50	0.53	0.76	0.10
Crown height (m)	72	3.40	12.20	12.39	23.30	5.28
Total volume (m^3)	81	0.58	2.90	3.69	11.20	2.35
Volume up to 20 cm (m^3)	81	0.38	2.80	3.59	11.14	2.36
Volume up to 10 cm (m^3)	81	0.56	2.89	3.67	11.18	2.35

The following different models were tested using R statistical software (R core Team, 2012).

$V = a + b * D$ ....(i)
$\ln V = a + b * \ln D$........................(ii)
$V = a + b * \ln D$............................(iii)
$\ln V = a + b * D$............................(iv)
$V = a + b * D_2$...............................(v)
$V = a + b*D + c*D_2$.......................(vi)
$V = aDb$..(vii)

Moreover, the following models were tested for predicting the volume of the proportion of sample tree in top 10 cm and top 20 cm over bark diameter (Sharma and Pukkala, 1990a; Laamanen *et al*., 1995).

$\ln V_1 / V = a + b * \ln D$ ....(viii)
$\ln V_2 / Vt = a + b * \ln D$ ....(ix)

where,
a, b and c are parameters to be estimated,
V is total volume of tree,
V_1 is volume beyond 10 cm top diameter,
V_2 is volume between top 10 and 20 cm diameter,
Vt is volume up to 10 cm top diameter,
DBH is diameter at breast height and ln is the natural logarithm.

Model selection and validation

T-test and F-test were used for testing the significance of the parameters and whole equation, respectively. The best fit model was selected based on residual analysis (whether the model fulfilled regression assumption or not), and fit statistics (standard error, bias and coefficient of determination). The back transformation was done with bias correction by adding exp ($SE^2/2$) to the intercept (Sprugel, 1983).

The method of cross validation technique was used (Hawkins, 1987; Kozak and Kozak, 2003). The models were evaluated by testing cross validation of separate data sets of 18 trees. The prediction statistics was estimated using following equation and percentage error were plotted against the explained variable (Hawkins,1987; Acharya *et al.,* 2003; Ducey and Williams, 2011).

$$(\text{bias} = \sum_{n}^{i}(yi - y\hat{}) / n \text{ ....(x)}$$

$$\text{RMSE} = \sqrt{\sum_{n}^{i}(yi - y\hat{})} / (n - 1) \text{ ......(xi)}$$

$$\text{Prediction error} = (\sum \text{actual volume} - \sum \text{predicted volume}) / \sum \text{actual volume} * 100) \text{.........(xii)}$$

Results and discussion

Relationship between total volume and tree variables

The relation of volume with both the height and DBH was found to be strong and positive (Fig. 2). The Pearson Correlation between total volume and DBH was found to be 0.9897. Similarly, the correlation between volume and height was found to be 0.8610 whereas it was

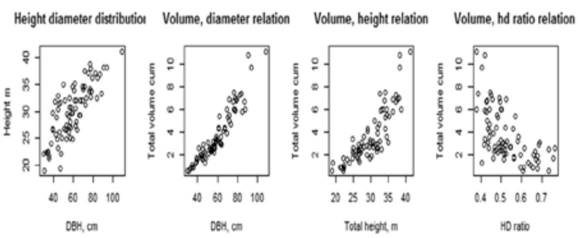

Fig 2: Relationship among different variables

0.8011 between DBH and total height. Since, the total height has strong and positive relation with DBH, the height adds very little effect on volume than that of the DBH alone.

Total stem volume model

Above mentioned models were fitted and checked both by graphically and numerically in order to identify the best predicted model. The fitted models were overlaid on the observed data (Fig. 3). In second graph, the observations are better distributed around the model throughout the DBH range. However, in all other figure, the models better capture the observation only in some part of the DBH range.

The seven different regression models as given above were fitted and checked both by graphically and numerically to test the best predicted model. The fitted models were overlaid on the observed data (Fig. 3).

Except the fifth and sixth models, the parameters of other five models are significant at 5% level of significance or even less. In general, all models fitted to the data well, as their good statistical fits in terms of R^2 explained greater than 80% of variability (Table 2). There were variations in standard error of estimate (SEE) in different models and equation 2 has the lowest SEE which is less than 0.2.

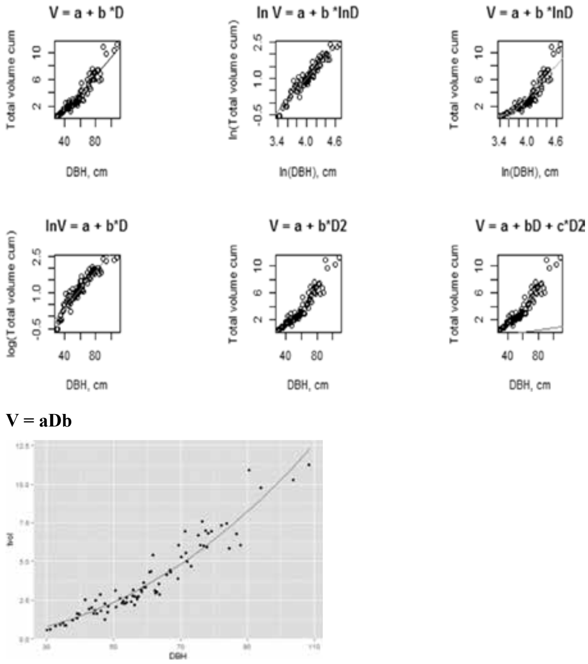

Fig. 3: Visualization of seven models

Table 2: Values of regression constants, std.error, R^2 with t and p-values of tested models

Mo del no.	Para meter	Estimate	Standard Error	t value	Pr(>|t|)	Sd. Error of Estimate	R^2	p-value
1	a	-4.3588	0.3291	-13.2500	<2e-16***	0.8053	0.8915	<2.2e-16
	b	0.1360	0.0053	25.6600	<2e-16 ***			
2	a	-8.0640	0.2930	-27.5300	<2e-16 ***	0.1859	0.9249	<2.2e-16
	b	2.2664	0.0722	31.4100	<2e-16 ***			
3	a	-27.2900	1.6610	-16.4300	<2e-16 ***	1.054	0.8142	<2.2e-16
	b	7.6680	0.4090	-18.7500	<2e-16 ***			
4	a	-1.1329	0.0937	-12.1000	<2e-16 ***	0.2292	0.8873	<2.2e-16
	b	0.0376	0.0015	24.9400	<2e-16 ***			
5	a	-0.3144	0.1626	-1.9330	0.568	0.724	0.9135	<2.2e-16
	b	0.0011	0.0000	28.8680	<2e-16 ***			
6	a	-0.7848	0.8744	-0.8970	0.372	0.7272	0.9137	<2.2e-16
	b	0.0154	0.0281	0.5480	0.586			
	c	0.0009	0.0002	4.3460	4.14e-05***			
7	a	0.0006	0.0002	2.9250	0.00449**	0.7306	0.8928	6.11e-06
	b	2.1144	0.0786	26.8970	<2e-16***			(converge nce tolerance)

Note: ** shows significant at 95% and *** shows significant at 99% confidence level

In the past, similar models were tested for different species (Hawkins, 1987; DFRS, 2006). Laamanen *et al.* (1995) developed a general volume model with R^2 of 97.1% and standard error of estimate of 0.13 for Adabhar, Bara district. The model developed for Sal by Sharma and Pukkala (1990) for producing general volume table has R^2 of 98.3% and standard error of estimate of 0.13 and it is widely used. In both cases, DBH and height were used as predictor variables but in this study only DBH was used as a predictor variable, which alone explained 92.5% variation of the observed tree volume. Lower R^2 value in this study may be due to the use of single predictor variable, DBH. SEE is greater in one explained variable than two variables (Pukkala *et al.* n.d.). Other similar models were also developed in the past but their statistics of fit was not mentioned (Acharya *et al.,* 2003).

The residuals of all models were analyzed. Due to the brevity of space, only graphs of the most suitable model (M2) were presented in figure 4. It is important to note that only model 2 showed homoscadascity and normality of residual distribution. The curve of the residuals was not seen sharply decrease or increase in the selected model. Similar trend was found for standardized residuals. Three outliers were found in which two outliers had underestimated and one outlier had overestimated values. The outlier samples were identified and analyzed. Though, removal of outliers improves the model reliability but they were not removed so as to represent the data from all parts of the study area.

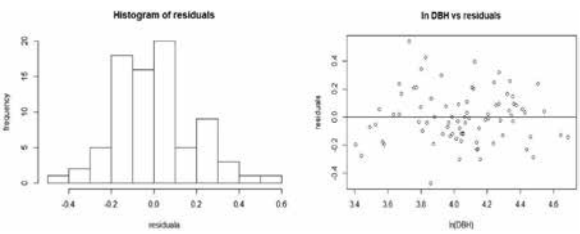

Fig. 4: Histogram of residuals and residuals versus Ln (DBH)

Over bark stem volume up to top 10 cm and top 20 cm top diameter

The distribution of ratios (M8 and M9) against its predictor variable clearly indicates that the data were distributed negative exponentially (Fig. 5). Hence the models with both side logarithms were used as in the past in similar cases (Sharma and Pukkala, 1990a; Laamanen *et al.*, 1995).

In this case, only logarithmic model was tested as used in similar past studies (Sharma and Pukkala, 1990a ; Laamanen *et al.,* 1995). All the parameters of both models were significant (Table 3).

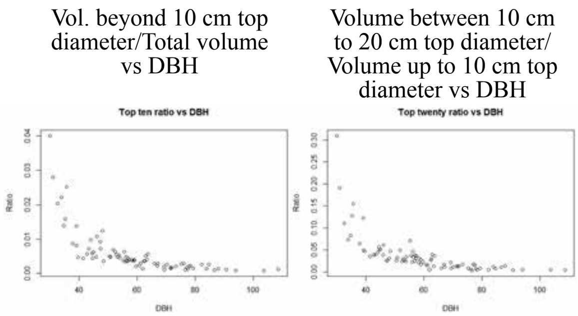

Fig. 5: Volume ratio of top 10 and 20 cm diameter vs. DBH

In comparison to total stem volume equation, the R^2 values of both equations were lower, while standard error of estimates was higher. It may be due to error accumulation from total volume model. Sharma and Pukkala (1990a) reported 78.9 and 74.1 R^2 values for the ratio of top 10 and

20 cm over bark diameter, respectively. Similarly their standard error of estimates was 0.51 for both the equations. These two models were better than Sharma and Pukkala (1990a) in terms of R^2 and SEE (Table 3). However, the fit statistics reported by Laamanen *et al*. (1995) was better than that of the study.

Table 3: Values of regression constants, R^2 and standard error of the models

Model no.	Model	a	b	R^2	SEE	n
8	$\ln(V_1/V) = a + b*\ln D$	5.0445	-2.6094	0.8241	0.3469	81
9	$\ln(V_2/Vt) = a + b*\ln D$	8.221	-2.954	0.7997	0.4253	81

Table 4: Prediction statistics of the models

Model	RMSE	Bias	Prediction error (%)
Total volume over bark	0.3958158	0.1836834	5.812
Volume up to 10 cm over bark	0.395469	0.1827535	5.809
Volume up to 20 cm over bark	0.4009819	0.1759837	5.769

The residuals of both models (M8 and M9) were found to be satisfactory and they were distributed evenly without any trend, so these models can be recommended. The residuals against DBH are shown in figure 6.

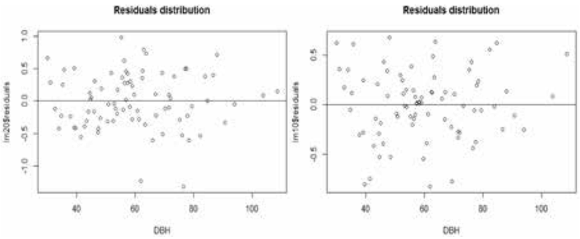

Fig. 6: Residuals *vs*. DBH in two models

Model validation

The definition and method of validation among the researchers were not found uniform (Kozak and Kozak, 2003; Bellocchi *et al*., 2010). Most of them considered components of fit statistics and graphical inspection for validation (Kozak and Kozak, 2003; Bellocchi *et al*., 2010). In addition to the analysis of fit statistics, Meehl *et al*. (2005) compared different models, which are used for similar purposes. Vanclay (1994) calculated the prediction statistics of independent data sets for model validation. Iles (2003) strongly recommended for checking few independent trees to measure accuracy of the volume table (cited by Ducey and Williams, 2011). Therefore, for validation of these equations, in addition to compare different equations, fit statistics and graphical inspection, the prediction statistics of 18 trees were analyzed.

The bias, RMSE and prediction error of models for total volume, and volume up to 10 and 20 cm diameter are almost similar (Table 4). The equation for total volume over bark was biased to 0.1 8 m^3 with RMSE of nearly 0.4 m^3, which is acceptable since validation data sets were fewer than modeled data, resulting losses of the information (Kozak and Kozak, 2003). Moreover, Hawkins (1987) recommended that the overall prediction error should be within 10 to 15 % of the actual value. In this study, the prediction errors of selected model was found to be within 6% and were lower than that of Acharya *et al.* (2003). But some statisticians argue that due to fewer validations data sets rather than modeled data validation losses the information (Kozak and Kozak, 2003).

The predicted values of all suggested models were plotted against the actual values of test data sets (Fig. 7). There is slightly underestimation of volume mainly in large-sized trees (Fig. 7).

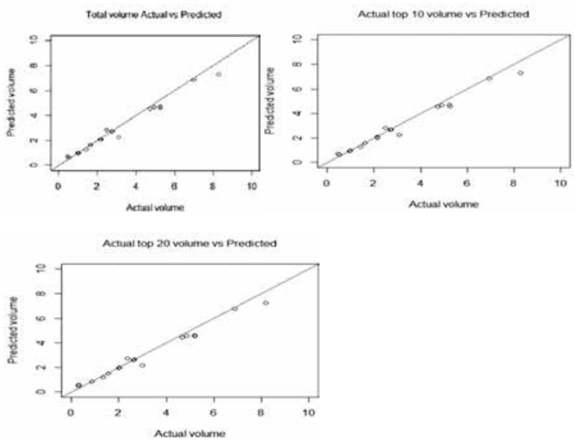

Fig. 7: Predicted versus actual volume

The individual error of test data set was evaluated by plotting against the diameter (Fig. 8). The overall prediction errors of all models were within limit but the error percentage of individual trees was a bit high in some cases. The models consistently underestimated volume of trees over the range of DBH (Fig. 8).

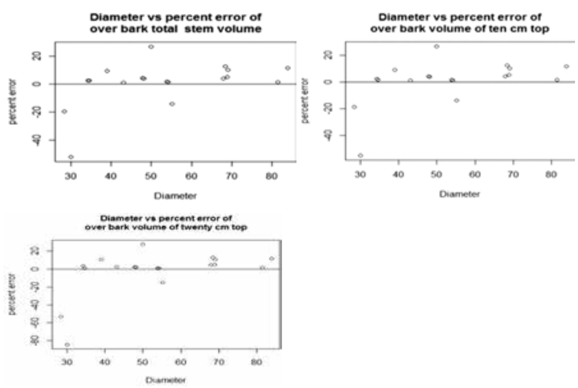

Fig. 8: Percent error vs. DBH of individual tested tree

Conclusion

Among the tested seven models, the recommended logarithmic model has the smallest RMSE and bias, and higher R^2. The model for total stem volume is ln V = 8.04674 + 2.26641 ln DBH. The models for ratio of volume beyond 10 cm top diameter to total stem volume is ln (V_1/V) = 5.0618 - 2.6094*ln DBH and ratio of volume between 10 cm and 20 cm diameter to volume up to 10 cm top diameter is ln (V_2/Vt) = 8.31144 - 2.954*ln (DBH). This study recommends for application of the equations within the range of sample data. Since, the samples are site specific, the models should be used cautiously in other places of Nepal after validating the models.

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