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Form Factors of an Economically Valuable Sal Tree (*Shorea robusta*) of Nepal

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Abstract: The accurate prediction of the volume of standing trees is a prerequisite for planning and decision making in sustainable forest management. In Nepal, limited information on form factor (i.e., the ratio of the volume of a tree to the product of its basal area and height) is available for economically important tree species. Thus, current management plans consider a simple approximation for all species irrespective of their height and diameter, which hampers the estimation of a sustainable harvest rate. Therefore, this study elaborates the form factor for Sal (*Shorea robusta*), an economically valuable tree of Nepal based on a random selection of 100 individual trees representing a wide range of diameters between 10 and 100 cm. Diameter and bark thickness were measured at every 1-meter interval of the length of the stem and branches until the diameter reached 10 cm. The analysis allowed for the estimation of an average form factor for Sal wood with 0.407 over bark and 0.336 under bark, while the form factor for the stem was 0.335 over bark and 0.281 under bark. The results indicate an increasing form factor until 70 cm diameter and a decreasing value for larger diameters, because of the large crowns of the mature Sal trees. We conclude that the default form factor of Sal (0.5) used in management planning results in an overestimation of standing tree volume. Using form factor according to diameter classes will allow a more accurate prediction of the standing volume.

Keywords: diameter; tree height; standing volume; allometry; taper; stem; wood; branches; bark; Terai

1. Introduction

Tropical forests are important for the rural livelihoods and economic development of a country like Nepal. The quantification of timber volume in forests is necessary to assess the economic potential of resources [1–3]. It requires timely, appropriate and effective quantification techniques which provide consistent and reliable timber volumes in forests [4–7]. For this, volume of individual trees in sample plots are estimated and aggregated to obtain tree volume on plot level. These data are scaled up to obtain total tree volume in forests. Hence, the estimation of stem volume of individual trees in a sample plot provides basic but important information on forest management planning. In addition, an accurate estimate of timber volume is important to understand their benefits from forest restoration and climate change impact mitigation, as the largest share of live tree carbon is stored in the stem [8].

The commonly used method to calculate tree volume is based on three factors: diameter at breast height (DBH), height (h) and the form factor (is also denotes by FF). The form factor is the reduction factor of the tree cylinder to the actual size of the tree [5]. Assessment of the form factor is important for volume estimation [5,9], as trees differ in shape due to aging and different forest management practices [10]. The accuracy of the volume predictions can be improved by deriving empirically measured form factors and the error associated in using the form factor to estimate volume will be minimized [3,11]. Moreover, the form factor has practical relevance for forest managers, as it allows for an easy estimation of standing volume by multiplying the basal area with the mean tree height and the predicted form factor. Especially for commercial tree species that are to be traded in the market, accurate planning of thinning regimes and harvesting time is important.

Shorea robusta (Sal in Nepali) is one of the major commercial species of Nepal, timber of which is primarily used for construction purposes. It is also the main source of income for rural communities and provides several employment opportunities [12]. Volume estimations of Sal tree forests are prominent in the Nepalese context since the government of Nepal is promoting the scientific forest management approach extensively. This approach is aimed at enhancing the productivity of forests and contribute to human well-being and national economic development [12,13]. In addition, the demand for timber has increased significantly in Nepal, a country where 0.83 million cubic meters of timber is imported annually [14–16]. Terai forests of Nepal—where *Shorea robusta* forests mainly occur—have the potential to fulfill this timber demand. In the current forest management plans for all tree species (including *Shorea robusta*), an approximation of the form factor, 0.5 is used irrespective of diameter and height [17]. Very few studies have focused on the development of volume equations for *Shorea robusta* [18–20], which cannot be easily computed in the field to estimate tree volume and required numeracy skills. Nevertheless, Thakur (2006) [21], attempted to estimate the form factor of *Shorea robusta* trees by climbing trees and measuring the diameter at every 3 m interval of the standing tree; however, this time-consuming and labour-intensive study did not provide a reliable data source for volume predictions. Similarly, Shrestha et al. (2018) [22], estimated the form factors of the *Shorea robusta* in the western part of the country based on observation of 52 felled trees. However, we could not find any studies that were carried out in the central part of the country. In addition, form factor varies by diameter and height of the tree; however, there has been no equation developed so far that supports deriving form factors by diameter. Hence, there is limited knowledge of accurate form factors using robust methods, especially targeting economically important species.

The Ministry of Forests and Environment is giving priority to scientific forest management for economic use of forest products, particularly timber. However, it lacks site-specific form factors or volume equations for calculating tree volume, resulting in risk of over- or under- estimation of annual harvest rates. In addition, the lack of accurate form factor questions the scientific forest management itself for being scientific. Therefore, this study aims to (1) estimate the form factors of *Shorea robusta* trees for the central Terai region of Nepal for different diameter classes and (2) to compare the results of the analysis with the tree volume estimated by taking form factor as 0.5, which will enable forest management to estimate stem volume and merchantable tree volume more accurately for this important tree species of Nepal.

2. Materials and Methods

2.1. Description of Study Site

The study was conducted in the Bara district in central Terai, located between the latitudes 26°51′ and 27°21′ N and the longitudes 84°51′ and 85°16′ E. (Figure 1), a tropical part of Nepal. The study site was selected considering the tree felling activities in preparation for a pipeline construction along the East-West Highway. The elevation of the area was 300 m above sea level. The average temperature was

24.0 °C, with a mean annual precipitation of 1830 mm [23]. The forests were dominated by *Shorea robusta*, along with other associated tree species such as *Semecarpus anacardium* L.f., *Holarrhena pubescens* Wall. ex G.Don 1837, *Terminalia alata* Heyne ex Roth and *Adina cardifolia*. However, *Shorea robusta* was the only species that is used for construction purposes, whereas other species are mostly used as firewood. According to Rautiainen (1999), the estimated age of the stand with average diameter above 48 cm is 120 years, with a mean annual increment of 5.87 m^3/ha [24]. Hence, the study assumed the age of the stand at around 120 years. In addition, the *Shorea robusta* tree has high dominance in the studied area (above 70%).

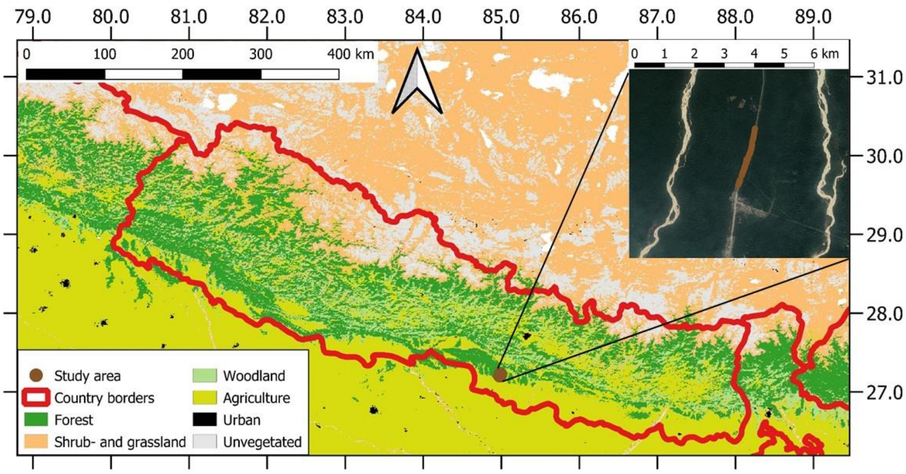

Figure 1. Location of the study area in Nepal and the main land cover types. The inserted image shows the location of the sampled trees using a Google Earth map as background.

Figure 1 shows the location of the study area within Nepal and aggregate satellite-based land cover, MOD12Q1 Version 5 [25]. This land cover map uses a supervised classification method with reflectance information from the MODIS sensor mounted on Terra and Aqua satellites of NASA (National Aeronautics and Space Administration). The spatial resolution is 0.5 arc minutes (~ 1 km at the equator). We aggregated the 14 original land cover types into six broad groups (forests, woodland and savannas, shrub- and grasslands, agriculture, urban and unvegetated).

The Timber Corporation of Nepal (TCN), a parastatal government organisation, was given responsibility for tree felling in the selected study site. They had divided the felling site into seven blocks, with 2 km length for each block. TCN had measured all trees above 10 cm diameter, including height, to estimate the volume of each harvested block. Since our interest was on *Shorea robusta*, we reviewed the inventory data and selected two blocks randomly, among the blocks which had high dominance and extensive representation of diameter classes between 10 cm and 100 cm.

2.2. Sampling Protocol

A total of 100 felled trees were measured, representing all diameter classes. We separated standing trees into eight diameter classes of 10 cm intervals, (10–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80 and above). We randomly selected at least 10 trees from each diameter class of good quality for the form factor measurement up to 80 cm diameter, whereas a few additional trees (4 in total) were selected for the replacement in later stages (if required) due to the quality of the trees or errors in measurement. Good quality trees include those trees which have high potential to produce timber. According to the Department of Forests, good quality tree includes trees with the straight bole having limited butt and attack of termites. We followed the grading of the TCN to select good quality trees, which was further verified by field observation. Of the total samples (100 trees) 12 percent were replaced by other trees, either because the quality of trees was poor, or because difficulties were encountered in tree measurement.

The height of the tree, crown length and crown width of the standing tree were measured before harvesting. Tree height and crown length were measured with the clinometer. The crown width is the average diameter of the maximum and minimum axes of the crown, which is measured before the tree is felled in both the axis manually. The horizonal distance of the crown spread was measured in the longest part of the tree and then in the perpendicular direction of the first measurement at the centre. The average was computed between the two measurements. The GPS coordinate and the neighbourhood tree species, including the distance from the selected tree and diameter, were also recorded. After the tree was felled, we measured the diameter over bark and bark thickness at stump height. The bark gauge was used for measuring the thickness of the barks. Two measurements of barks were carried out in opposite directions and the average was used to estimate barks.

2.3. Volume Estimation

In Nepal, only trees with a diameter above 30 cm is used for timber purpose. However, we measured down to 10 cm diameter for estimating the form factor as people use smaller *Shorea robusta* trees as poles and shafts for constructing cattle sheds and, small houses, and making furniture. Likewise, the diameter of the main branches and sub-branches were measured at every 1 m interval till it reached 10 cm. We also measured the bark thickness using a bark gauge. This allowed calculating volume: (a) including and (b) excluding bark. For this, we used the over bark measurements of diameter and segment lengths for estimating the volume following Equation (1).

$$V = \pi/12 \times L \times (Dob1^2 + Dob1 \cdot Dob2 + Dob2^2) \quad (1)$$

where V is the volume (m^3) of a tree's segment with measurements of length (L) in meter and two diameters over bark measurements at the base (Dob1) and the top (Dob2), both unit in m. For volume under bark, we calculated diameter under bark (Dub) by subtracting double bark thickness (BT) Equation (2). We then used Equation (1) to estimate volume under bark.

$$Dub = Dob - 2 \cdot BT \quad (2)$$

We calculated four different volume values for each tree, (1) volume of stem over bark, (2) volume stem under bark, (3) wood (>10 cm) volume over bark and (4) wood (>10cm) volume under the bark. "Wood" included both central stems and branches with larger than 10 cm diameters.

2.4. Form Factor Calculation

We calculated the form factor values for each tree for all four classes following Equation (3).

$$FFi = Vi/H/(DBH^2 \cdot \pi/4) \quad (3)$$

where, ("i" represents stem over bark, stem under bark, wood over bark or wood under bark), DBH the diameter at breast height (m), and H the tree height (m).

Only limited research has been carried out to estimate form factor for *Shorea robusta.* They were developed locally and lack the ability to explain the variation in form factors for the *Shorea robusta* trees growing in the region with higher site variabilities. In case of missing form factor, the default form factor (i.e., 0.5) is being used, specifically by the GoN [17]. In this study, we derived form factor using the volume functions from the literature [18,19] with the DBH and tree height measurements of our trees and using Equation (3). The derived form factors were compared with published and default form factors. This provided us with three reference form factors to compare with our new form factors. As Subedi (2017) and Sharma and Pukkala (1990) [18,19] do not provide volume functions for wood >10 cm, we had to first derive a consistent volume. We first applied the total volume with bark functions for *Shorea robusta* (including 0–10 cm stem tip and branches, Equation (4) [18] and Equation (5) [19].

$$V_{total} = \exp\,(-2.4554 + 1.9026\ LN(DBH) + 0.8352\ LN(H)) \quad (4)$$

$$V_{total} = \exp\,(-8.064 + 2.2664\ LN(DBH)) \quad (5)$$

Next we calculated the share of volume 0–10 cm to total volume with Equation (6) [18] and Equation (7) [19].

$$V_{0\text{-}10\ cm}\colon V_{total} = \exp\,(5.2026 - 2.4788\ LN(DBH)) \quad (6)$$

$$V_{0\text{-}10\ cm}\colon = \exp\,(5.0445 - 2.6094\ LN(DBH)) \quad (7)$$

Equations (4)–(7) use DBH in cm and height in meters, and are presented here as they appear in literature [18,19]. We then deducted the volume 0–10 cm (Equations (6) and (7)) from total volume to get the wood volume >10 cm for each tree, which is now comparable to the wood volume used in this study. We then calculated the corresponding form factor of volume estimated using models [18,19] using Equation (3).

2.5. Form Factor Models and Diameter-Height Function

We used form factor derived for 100 trees to develop simple models using DBH and tree height as input. We used second order polynomial functions ($y = a + bx + cx^2$) to test for non-linear relationships. We fitted models for form factor of stem and for form factor of wood (>10 cm) and including and excluding bark. This resulted in eight form factor models; four based on DBH and four on tree height. We calculated coefficient of determination R^2 and p value. We did not perform a validation of the models as we lacked an independent dataset and as splitting the dataset further would have reduced model accuracy.

We also calculated a diameter-height function using the Pettersen function to enable calculating tree height based on DBH.

3. Results

3.1. Overview of Measured Trees

The average DBH over bark of *Shorea robusta* trees was 48.7 cm ranging from 10.8 cm to 112.7 cm (Table 1). Likewise, the average height was 24.2 m with minimum and maximum height of 9.6 m and 36.5 m, respectively. The average crown length was 14.6 m varying between 3.0 m and 24.7 m, whereas average crown width was 8.4 m ranging from 2.0 m and 17.3 m.

Table 1. Characteristics of the sample trees.

Variable	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
DBH	10.8	34.2	48.7	48.7	61.8	112.7
Height	9.6	21.0	25.1	24.2	28.1	36.5
Crown length	3.0	11.8	15.1	14.6	17.5	24.7
Crown width	2.0	5.8	8.5	8.4	10.9	17.3

We also computed a diameter-height function using the observations of the 100 trees (Figure 2). After removing two outliers (indicated with circles in Figure 2), we fitted a Petterson function, where the height of the tree can be estimated using Equation (8):

$$\text{height} = 1.3 + (0.2371 + 2.02992/\text{DBH})^{-2.5} \quad (8)$$

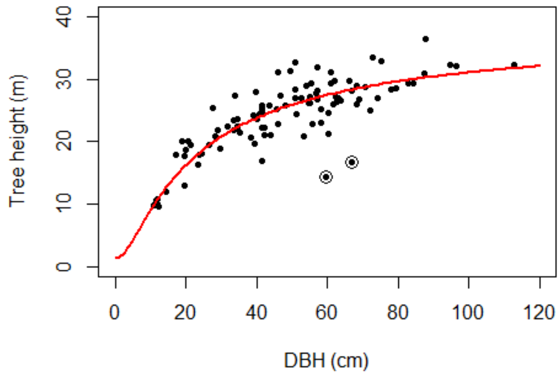

Figure 2. Diameter-Height relationship for the sample trees used for deriving form factor. Two circles indicate outliers not used for fitting the Diameter-Height function.

3.2. Form Factors for Stem and Wood with Diameter >10 cm, over and under Bark

The form factor was calculated for stem and wood measured over and under the bark. The estimated form factor ranged between 0.133 and 0.483 for stem (over bark), with an average of 0.336 while it was between 0.098 and 0.435, with an average of 0.271 for stem (under bark) (Table 2). Similarly, the estimated form factor was 0.407, ranging from 0.133 to 0.620 for wood (over bark). The form factor for wood (under bark) was 0.322, ranging between 0.098 and 0.475. It indicates that wood (over bark) has the highest form factors, and the stem (under bark) the lowest.

Table 2. Form factor over and under bark for the *Shorea robusta* trees.

Variables	Form Factor					
	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Stem over bark	0.133	0.307	0.342	0.336	0.380	0.483
Stem under bark	0.098	0.242	0.281	0.271	0.305	0.435
Wood over bark	0.133	0.372	0.409	0.407	0.453	0.620
Wood under bark	0.098	0.300	0.335	0.322	0.365	0.475

Note: Stem include main trunk of the wood, whereas the wood includes the main trunk and branches.

It was revealed that the under-bark form factors of wood and stem were always lower than the corresponding form factor over bark. The results indicated that the bark thickness was lower in younger woods and higher in older tress. It was also revealed that only 19% variation of bark thickness of woods can be explained by the diameter of trees.

3.3. Relationship of the Form Factors with DBH and Height of Tree

We estimated the form factor for four diameter classes to understand how the form factors change by the diameter classes. Table 3 reveals that the form factor of woods increases with diameter up to the 70 cm diameter class, and, thereafter, it decreases irrespective of the stem and wood over and under bark. Hence, the form factor changes substantially in a non-linear manner with increasing DBH irrespective of the stem and wood, when measured at over and under bark as well (see also Table 4).

As evident in Figure 3, the form factor of both stem and wood increased with an increase in DBH and/or height at the beginning, reached a peak (50–60 cm DBH and/or 20–30 m height) and then started decreasing with further increase in DBH and or height. The wood form factor was larger than the stem form factor in both under bark and over bark (Figure 3a,b). Over bark form factor was always higher than the under bark form factor for wood and stem (Figure 3a,b). The difference between the over bark and under bark form factor was highest during the middle sized (DBH/height) trees, and this difference became very small in mature or larger sized trees (Figure 3). It was found that the form factor of each case (stem and wood), irrespective of bark condition, was higher in wood and stem however, it was lower under bark in both cases. The form factor gradually decreased for trees higher than the diameter class (i.e., 70 cm and above).

Table 3. Form factor by diameter class for stem and wood (>10 cm) and over and under bark.

Form Factor	Diameter Class			
	10–30 cm DBH	**30–50 cm DBH**	**50–70 cm DBH**	**>70 cm DBH**
Stem over bark	0.312 ± 0.0785	0.354 ± 0.0415	0.350 ± 0.0550	0.299 ± 0.0468
Stem under bark	0.225 ± 0.0644	0.285 ± 0.0367	0.291 ± 0.0476	0.260 ± 0.0435
Wood over bark	0.332 ± 0.0975	0.430 ± 0.0666	0.436 ± 0.0527	0.394 ± 0.0655
Wood under bark	0.240 ± 0.0790	0.340 ± 0.0531	0.353 ± 0.0438	0.332 ± 0.0526
Number observations	n = 21	n = 30	n = 35	n = 14
Average tree height (m)	16.6	23.9	26.4	30.5

Table 4. Functions for estimating form factors using diameter and height.

Form Factor	Diameter at Breast Height (DBH) Function	R^2	p	Tree Height (H) Function	R^2	p
Stem over bark	$FF = 0.2302 + 4.927 \times 10^{-3}\ DBH - 4.753 \times 10^{-5}\ DBH^2$	0.230	<0.001	$FF = 0.03069 + 0.02806\ H - 0.000604\ H^2$	0.205	<0.001
Stem under bark	$FF = 0.1366 + 5.404 \times 10^{-3}\ DBH - 4.573 \times 10^{-5}\ DBH^2$	0.327	<0.001	$FF = -0.02295 + 0.02437\ H - 0.000479\ H^2$	0.250	<0.001
Wood over bark	$FF = 0.1818 + 8.999 \times 10^{-3}\ DBH - 7.579 \times 10^{-5}\ DBH^2$	0.416	<0.001	$FF = -0.0877 + 0.04166\ H - 0.000832\ H^2$	0.310	<0.001
Wood under bark	$FF = 0.1018 + 8.325 \times 10^{-3}\ DBH - 6.573 \times 10^{-5}\ DBH^2$	0.518	<0.001	$FF = -0.1058 + 0.03385\ H - 0.000633\ H^2$	0.357	<0.001

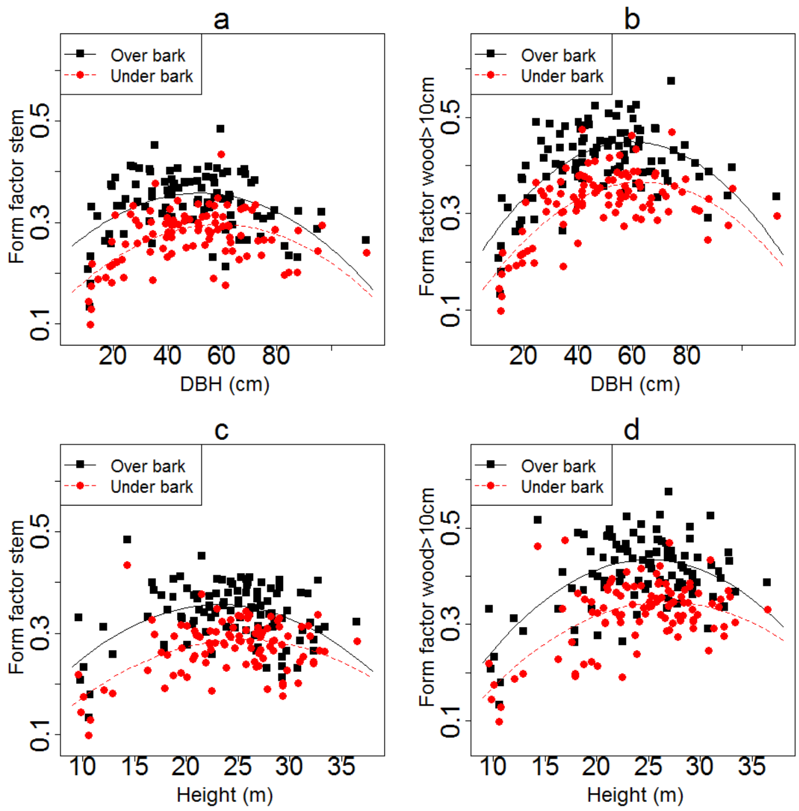

Figure 3. Over bark and under bark FF (form factor) of *Shorea robusta*, (**a**) FF of stem as a function of DBH, (**b**) FF of wood >10cm diameter as a function of DBH (**c**) FF of stem as a function of height, (**d**) FF of wood >10cm diameter as a function of height.

3.4. Form Factors Estimation

We provided 2-order polynomial functions, their coefficients of determination (R^2) and p values for estimation of the form factor using diameter and height (see Table 4). The following equations can now be used for estimation of the form factors of *Shorea robusta* according to the height and diameter classes.

3.5. Comparison of Form Factor

Figure 4 compares the form factor for wood >10 cm (stem and branches) of our 100 sample trees with three independent sources, (a) calculating the form factor using the published volume functions of [19], (b) calculating the form factor using the published volume functions of [18] and (c) assuming a form factor of 0.5 irrespective of DBH and tree height [17]. These three reference datasets require different input data (e.g., [19] only DBH, [18] both DBH and tree height), and we calculated the form factor as outlined in the Methods. In Figure 4 we added trend functions (dashed lines) for Sharma and Pukkala (1990) and Subedi (2017) [18,19] (p = 0.854; $p < 0.001$; respectively) and delineate the 1:1 relationship with a solid line.

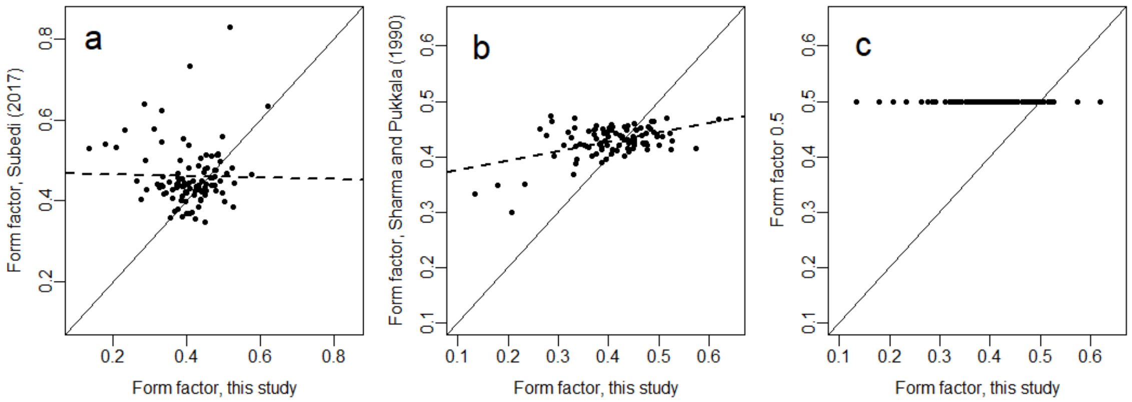

Figure 4. Evaluation of FFs derived by this study with other sources (**a**) FF based on volume functions by [19], (**b**) FF based on volume functions by [18] and (**c**) FF of 0.5.

Comparing our data with [19] (a) form factor indicates a mismatch between estimates and observations in several cases (points above 1:1 line in Figure 4a). A different pattern is evident when comparing the results with the form factor using the published volume functions in [18] (Figure 4b). The observations and predictions visually agree better, have the lowest bias of 0.0209 ± 0.0701 (mean ± standard deviation) and the p value of the trend function is statistically significant ($p < 0.001$) compared to p = 0.854 for [19] (bias 0.0532 ± 0.110). The simple assumption of a form factor equal to 0.5 overestimates our observations in most of the cases (see Figure 4c and also Figure 3). With 0.0927 ± 0.0791 also, the bias was largest when comparing our observations with the form factor of 0.5.

Figure 3 suggests non-linear changes in our form factor observations (i.e., low form factor for small and large trees, high form factor for middle-sized trees) and a good model should be able to capture this pattern. Thus, we plotted the error (prediction minus observations) between available form factor estimates and our observations by DBH (Figure 5). The form factor using the functions of 18 fits best to our observations but overestimates the volume predictions at low and high diameters (Figure 5b). The mismatch is even larger when comparing our form factor with [19] or a form factor of 0.5.

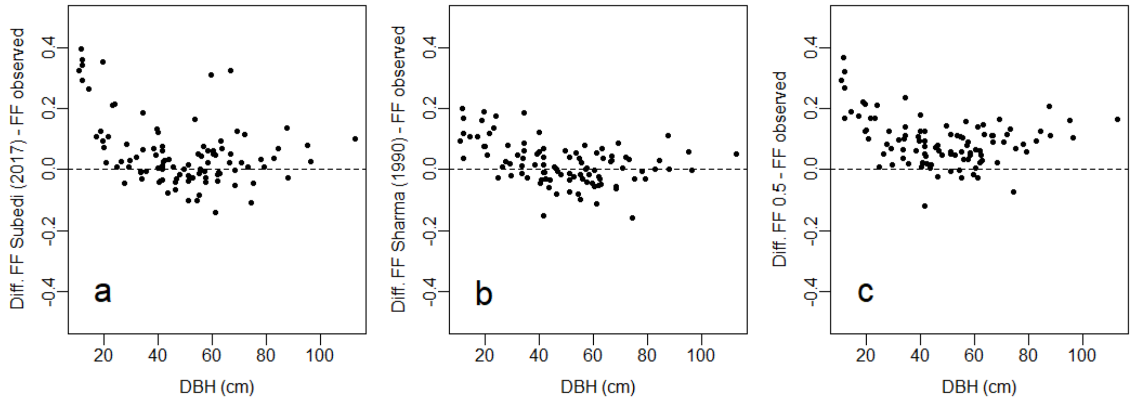

Figure 5. Error of three FF estimates compared with our observations (Difference = predicted FF − observed FF). From left to right we used (**a**) FF from volume functions by [19], (**b**) FF from volume functions by [18] and (**c**) FF of 0.5.

4. Discussion

In Nepal, there is no published form factor for *Shorea robusta*, and government officials of the district forest office use 0.5 as a default form factor for all species irrespective of diameter and height classes, including bark [17]. This study estimated the form factor of *Shorea robusta* for the stem and wood at 0.27 and 0.32 (DBH > 10 cm, excluding bark) respectively, based on the destructive sampling of 100 trees. Thus, the currently used method for estimating the standing volume of *Shorea robusta* using the form factor of 0.5 overestimates the actual tree volume. In other words, the actual harvest volume may be lower by 36% than the actual estimates. In discussions with government officials, it became evident that nobody was aware of how the form factor of 0.5 was derived and should be used in the Nepali context, which is also reflected Shrestha et al., (2018) and Baral et al., (2019) [22,26]. It is often justified that the use of the default form factors allows for maximum flexibility for volume prediction and estimation, and, hence, its use is still part of the forest planning for ecological and economic sustainability [1].

Our estimate of the form factor is quite low compared to that of other regional studies which estimate the form factor. Shrestha et al., (2018) [22] study in the central Terai of Nepal, estimates the form factor of the *Shorea robusta* trees up to 10 cm top diameter ranging from 0.51 to 0.65 in the western region of the country. Likewise, Thakur, (2006) [21], which is an analysis of the major tree species, such as *Shorea robusta*, *Schima wallichii*, *Castanopsis indica* and *Pinus species*, and miscellaneous species of Parbat district, estimates the form factor of 0.58 for the western hills of Nepal. The reasons for this deviation are manifold and may include (a) inconsistent definition of stem or wood between the two studies, and (b), methods used for quantifying the form factor are not the same.

Comparing the recalculated form factor (Equation (3)) using the estimated volume from the functions of the two previous studies allows for assessing the quality of the derived form factor of wood, including bark, of this study. This study provides form factors, with or without bark, stem, or tree (including stem). We used existing volume functions for studying the effects of using the newly developed factors. Subedi, (2017) and Sharma, & Pukkala, (1990) [18,19] provide functions for wood volume (including branches smaller than 10 cm). Our study excluded the stem tip and branches smaller than 10 cm since the study only focused on merchantable volume. [18] shows that the stem tip (smaller 10 cm) contains between 1% and 11% of total stem volume, and so excluding wood smaller than 10 cm may explain a deviation of up to 10%. We used diameter measurements every meter until the stems or branches were smaller than 10 cm and have on average 20 diameter measurements per tree, supporting a more accurate calculation of the stem taper. In comparison, Sharma and Pukkala, (1990) [18] had 10–15 measurements per tree, [19] did not specify the number of measurements per tree, but states that measurement intervals increased from 0.5 to 2 m from stump to tip. Thus, the data measured by [18,19] should have comparable accuracy to the data investigations in this study.

This, to our knowledge, is the first study that provides form factor for *Shorea robusta* in the central region of the country, which also allows us to examine the share of barks and branches in estimating standing volume. The form factor of wood over bark is about 0.407, which is 26% higher compared to the wood under the bark. Similarly, form factor of stem over bark is 0.336, where the share of the bark was about 24%. This reveals that bark influences nearly one-fourth of the form factor, which is similar to the results of [18]. The form factor of stem over bark (the central shoot until the first bifurcation) is 0.336 and thus about 83% of the wood larger 10cm is allocated into the stem. In turn, the branches contain a considerable share of merchantable wood volume in *Shorea robusta* and cannot be undermined. Branches, rather, have to be measured as accurately as possible. A shortcoming of our study is that we did not measure branches smaller than 10 cm. However, the number of branches in tropical species, like *Shorea robusta* makes measurement often unreliable [5,19]. While these small branches may not have immediate economic value, they may contain a substantial share of tree carbon and probably an even large amounts of the nutrient stored in tree biomass [13,27–29]. Further research is required to test the proposed models in other parts of the country, conduct validation using an independent dataset and expand the introduced methodology for tree volume or carbon.

5. Conclusions

We developed form factor functions for economically valuable species in Nepal to allow accurate and consistent volume predictions, which is essential for decision making for sustainable harvesting decisions. Our results show that form factor of *Shorea robusta* trees is far below the official estimate, thus resulting in over estimation of volume. There is a need to base the form factor on the diameter class to estimate tree volume accurately. Furthermore, we propose use of the form factor according to the diameter class for accurate assessment of volume. This kind of study needs to be carried out in the national context for other valuable species like *Shorea robusta* as well, and we suggest conducting a detailed analysis of the form factor in different regions of Nepal.

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References

1. Baral, S.; Gautam, A.P.; Harald, V.H. Ecological and economical sustainability assessment of community forest management in Nepal: A reality check. *J. Sustain. For.* **2018**, *37*, 820–841. [CrossRef]
2. Poudel, N.R.; Fuwa, N.; Otsuka, K. *The Impacts of a Community Forestry Program on Forest Conditions, Management Intensity and Revenue Generation in the Dang District of Nepal*; Discussion Paper: 13–24; National Graduate Institute for Policy Studies: Tokyo, Japan, 2014.
3. Adekunle, V.; Nair, K.; Srivastava, A.; Singh, N. Models and form factors for stand volume estimation in natural forest ecosystems: A case study of Katarniaghat Wildlife Sanctuary (KGWS), Bahraich District, India. *J. Res.* **2013**, *24*, 217–226. [CrossRef]
4. Cháidez, J.N. Allometric equations and expansion factors for tropical dry forest trees of Eastern Sinaloa, Mexico. *Trop. Subtrop. Agroecosyst.* **2009**, *10*, 45–52.
5. Tenzin, J.; Wangchuk, T.; Hasenauer, H. Form factor functions for nine commercial tree species in Bhutan. *Forestry* **2017**, *90*, 359–366. [CrossRef]

6. Hasenauer, H.; Petritsch, R.; Zhao, M.; Boisvenue, C.; Running, S.W. Reconciling satellite with ground data to estimate forest productivity at national scales. *Ecol. Manag.* **2012**, *276*, 196–208. [CrossRef]
7. Brooks, J.R.; Jiang, L.; Ozçelik, R. Compatible stem volume and taper equations for Brutian pine, Cedar of Lebanon, and Cilicica fir in Turkey. *For. Ecol. Manag.* **2008**, *256*, 147–151. [CrossRef]
8. Neumann, M.; Moreno, A.; Mues, V.; Härkönen, S.; Mura, M.; Bouriaud, O.; Lang, M.; Achten, W.M.; Thivolle-Cazat, A.; Bronisz, K.; et al. Comparison of carbon estimation methods for European forests. *For. Ecol. Manag.* **2016**, *361*, 397–420. [CrossRef]
9. Colgan, M.S.; Swemmer, T.; Asner, G.P. Structural relationships between form factor, wood density, and biomass in African savanna woodlands. *Trees* **2014**, *28*, 91–102. [CrossRef]
10. Ikonen, V.-P.; Kellomäki, S.; Väisänen, H.; Peltola, H. Modelling the distribution of diameter growth along the stem in Scots pine. *Trees* **2006**, *20*, 391–402. [CrossRef]
11. West, P.W. *Tree and Forest Measurement*; Springer: Berlin, Germany, 2009; pp. 1–190.
12. Basnyat, B. Commodifying the community forestry: A case from scientific forestry practices in Western Hills of Nepal. *J. For. Res.* **2020**, *25*, 69–75. [CrossRef]
13. Baral, S.; Khadka, C.; Vacik, H. Using MCA tools for evaluating community-managed forests from a green economy perspective: Lessons from Nepal. *Int. J. Sustain. Dev. World Ecol.* **2019**, *26*, 672–683. [CrossRef]
14. FenFIT. Federation of Forest-Based Industry and Trade, Nepal. 2015. Available online: https://www.fenfitnepal.org.np/en_US/ (accessed on 29 April 2020).
15. Poudel, M.; Kafle, G.; Khanal, K.; Dhungana, S.; Oli, B.N.; Dhakal, A.; Acharya, U. Linking land use and forestry transition with depopulation in rural Nepal. *Banko Janakari* **2018**, *27*, 130–143. [CrossRef]
16. Haack, B.N.; Rafter, A. Urban growth analysis and modeling in the Kathmandu Valley, Nepal. *Habitat Int.* **2006**, *30*, 1056–1065. [CrossRef]
17. Department of Forests (DoF). *Community Forest Inventory Guideline*; Ministry of Forests and Soil Conservation: Kathmandu, Nepal, 2004.
18. Sharma, E.R.; Pukkala, T. Volume Equations and Biomass Prediction of Forest trees of Nepal. *Surv. Stat. Div.* **1990**, *47*, 18.
19. Subedi, T. Volume models for Sal (Shorea robusta Gaertn.) in far-western Terai of Nepal. *Banko Janakari* **2017**, *27*, 3–11. [CrossRef]
20. Gautam, S.; Thapa, H. Volume equation for Populus deltoides plantation in western Terai of Nepal. *Banko Janakari* **2007**, *17*, 70–73. [CrossRef]
21. Thakur, R.B. *Determination of Form Factor of Major Tree Species of Parbat District (Sal, Chilaune, Katus, Salla & Miscellaneous Species)*; Livelihoods & Forestry Program: Parbat, Nepal, 2006.
22. Shrestha, H.L.; Kafle, M.R.; Khanal, K.; Mandal, R.A.; Khanal, K. Developing local volume tables for three important tree species in Nawalparasi and Kapilvastu districts. *Banko Janakari* **2018**, *27*, 84–91. [CrossRef]
23. Fick, S.E.; Hijmans, R.J. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *Int. J. Clim.* **2017**, *37*, 4302–4315. [CrossRef]
24. Rautiainen, O. Growth Dynamics and Management of Shorea Robusta Forests in Southern Nepal. Ph.D. Thesis, Faculty of Forestry, University of Joensuu, Joensuu, Finland, 1999; 42p.
25. Friedl, M.A.; Sulla-Menashe, D.; Tan, B.; Schneider, A.; Ramankutty, N.; Sibley, A.; Huang, X. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote Sens. Environ.* **2010**, *114*, 168–182. [CrossRef]
26. Baral, S.; Gaire, N.P.; Aryal, S.; Pandey, M.; Rayamajhi, S.; Vacik, H. Growth Ring Measurements of Shorea robusta Reveal Responses to Climatic Variation. *Forests* **2019**, *10*, 466. [CrossRef]
27. Bhattarai, K.P.; Mandal, T.N. Variation in carbon stock in litterfall, fine root and soil in Sal (Shorea robusta Gaertn.) forests of eastern Nepal. *Our Nat.* **2018**, *16*, 68–73. [CrossRef]

28. André, F.; Jonard, M.; Ponette, Q. Biomass and nutrient content of sessile oak (*Quercus petraea* (Matt.) Liebl.) and beech (*Fagus sylvatica* L.) stem and branches in a mixed stand in southern Belgium. *Sci. Total Environ.* **2010**, *408*, 2285–2294.
29. Turner, J.; Lambert, M.J. Nutrient cycling in age sequences of two Eucalyptus plantation species. *Ecol. Manag.* **2008**, *255*, 1701–1712. [CrossRef]