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Evaluating Timber Volume Discrepancies in Teak Plantations of the Sagarnath Forest Development Project, Nepal: A Comparative Study

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Abstract
Accurate forest biomass estimation, productivity, yield regulation, and carbon stock rely on precise volume prediction at both the individual tree and stand levels. This study, titled "Comparison of Standing and After-Felled Volume of Timber in Teak Plantation in the Sagarnath Forest Development Project, Nepal," was conducted in the Sagarnath Forest Development Project (SFDP) in Sarlahi District. The primary objective of this research was to calculate the disparity in timber volume before and after harvesting in a teak forest. The 2D felling site provided 150 sample trees for data collection. Before felling, the diameter at breast height (DBH) of standing trees was measured using a diameter tape, tree height was measured with a range finder, and tree quality class was determined based on community forest inventory guidelines. After felling, the total length of the log, girth at the mid-length of the log, and the length and diameter of hollowness and the depth of the buttress were measured using a measuring tape. To compute timber volume before felling, the formula defined in the *Community Forest Resource Inventory Guideline, 2061* was utilized, while the quarter-girth formula was employed to calculate timber volume after felling. The findings indicated an overestimation of 696.80 cubic feet of timber before harvesting. A 95% confidence interval F-test demonstrated a significant difference in timber volume before and after felling. There was a loss of 14.58 cu. ft of timber volume due to hollowness in the tree, and 83.10 cu. ft of timber was lost due to buttresses. Likewise, a difference in volume was observed based on quality class due to inaccurate classification.

Keywords: Buttress, Felling, Hollowness, Standing trees, Timber volume.

1. Introduction
Teak (*Tectona grandis*), a highly valued tropical hardwood tree species native to South and Southeast Asia, thrives in its native range spanning India to Burma, Laos, and Thailand (Hansen et al., 2002). Teak plantations have been extensively established worldwide, both within and beyond their natural habitat. Indonesia, various tropical African countries such as Nigeria, Ghana, and Ivory Coast, and South and Central American countries including Panama, Costa Rica, and Brazil have witnessed the widespread planting of teak (Tewari & Mariswamy, 2013). Its versatility has led to applications in furniture, shipbuilding, carved-wood goods, and residential construction, due to its strength, durability, and ease of working without cracking. Forest inventory, a crucial data collection activity, plays a pivotal role in generating essential information on forest resources within a designated area. This process is instrumental in developing inventory-based forest management plans and enhancing forest productivity (Baral et al., 2018). Its primary goal is to determine the volume of timber growing in the forest, facilitating the regulation of forest yield (Chaturvedi & Khanna, 2000). By assessing timber volume, biomass, and carbon stock, forest inventory sets the groundwork for analysis, planning, and sustainable management (FAO, 2010).

In Nepal, teak plantation initiatives

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commenced in Chiliya, Rupandehi District, in 1960, followed by large-scale plantations in the Sagarnath Forestry Development Project (SFDP) in Sarlahi District and the Ratuwamai Project in Jhapa District. SFDP predominantly features teak as a major component of its plantations, and it has met nearly half of the nation's teak demand (Koirala et al., 2017). Within SFDP, a volume table for teak was prepared decades ago, guiding harvesting operations based on estimates of standing trees, considering factors such as diameter at breast height (DBH), total tree height, and tree quality (Baral et al., 2018). After felling, the actual volume of timber from each tree and plot is calculated. Discrepancies between estimated and actual volumes before and after harvesting may significantly impact forest management planning and decision-making (Basnyat et al., 2018).

Estimating the growing stock of harvestable and non-harvestable blocks is a critical aspect of determining yield, sustainable timber harvesting levels, growth status, and more (Bhattarai & Mandal, 2019). Timber volume can be measured either while standing or after felling, and the resulting data aids in calculations for forest biomass, carbon sequestration, yield regulation, site quality, and forest growth predictions (Das et al., 2020). Accurate calculations of actual total volume are essential for forest product valuation and estimating potential revenue generated from the forest (Jayasawal & Bishwokarma, 2016).

In SFDP, before felling, the volume of standing trees is determined using volume tables, and estimates are made for the quantity of timber to be harvested, guiding timber valuation. The tender for tree harvesting is based on this valuation, and the interested contractor pays the royalty selling price before commencing harvesting operations (Paudel et al., 2006). After felling, the actual total volume of timber and fuelwood is calculated. About 30% of value is estimated to be lost during tree harvesting (Boston & Dysart, 2000). These discrepancies arise due to differences in log quality, sawmill machinery, and target product specifications (Lock & Whittle, 2018). Discrepancies between estimated and after-felled timber volume before and after harvesting can lead to cost variations, necessitating the determination of these variations to guide cost estimates for timber harvesting and sales, and also to inform forest management planning and decision-making (Baral et al., 2018; Basnyat et al., 2018).

Various research studies have been conducted on volume estimation for different tree species, including teak in Nepal (Gautam & Thapa, 2007; Subedi, 2017; Subedi et al., 2021), and several studies have addressed growth performance, taper equations, and height-diameter relationships of teak in SFDP (Thapa & Gautam, 2005; Thapa & Gautam, 2007; Koirala et al., 2021; Koirala et al., 2017). However, no previous study has explored the variation in volume estimation before and after harvesting within SFDP; thus, a critical research gap exists in understanding the amount of volume discrepancies between before- and after-felling volume estimates. This research aims to quantify the amount of volume loss and also tries to delve into the factors contributing to this variation. The findings will provide a baseline for SFDP's resource managers and offer new insights to forestry professionals. Project researchers, district foresters, and private landowners can utilize these results to make informed decisions for better teak plantation management. The main objective is to conduct a comparison between predicted timber volume before harvesting and actual volume after felling in a teak plantation within the Sagarnath FDP. Specific objectives include estimating standing timber volume, calculating post-harvesting timber volume, and examining factors contributing to discrepancies between the two volumes.

2. Materials and Methods

2.1. Study Area

The Sagarnath Forest Development Project was selected as the study area, which lies in Madhesh Pradesh, Nepal (Figure 1). It was established in 2035 BS with the support of ADB and OPEC. SFDP lies in two districts, Mahottari and Sarlahi. The total project area is about 13,512 ha. The total plantation area is about 10,740 ha. The SFDP has divided the plantation units into Sagarnath, Bhaktipur, Laxminiya, Kushmari, Hatilet, and Murtiya. The SFDP has 79% alluvial soil, 14% undulating soil, and 7% of the area is covered by rivers, streams, sand, and gravel. The soil pH ranges from 5.1 to 6.4. SFDP is divided into three management units: Sagarnath, Hatilet, and Murtiya Forest Management Unit. The selected felling plot was 2D. Plot 2D is 25 ha, whereas the teak felling area was about 7.74 ha.

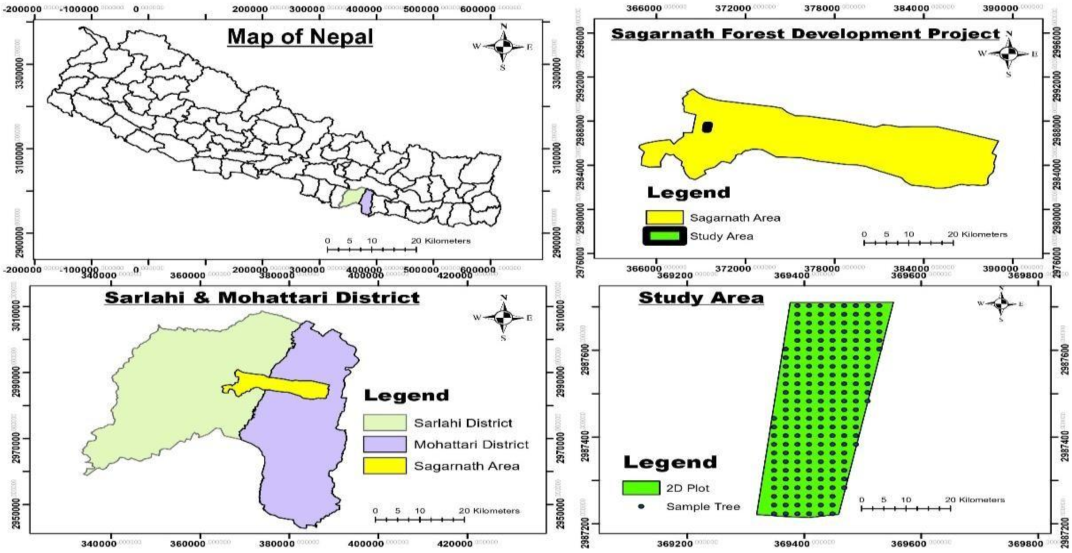

Figure 1. Map of study area

2.2. Sampling techniques

The data were collected from felling plot 2D, which is 25 ha. Out of the 25 ha, only 7.74 ha was felled, where 1,435 teak trees were marked. Systematic random sampling was done in the felling plot (Chaudhary & Pandey, 2016). Sample trees were selected at a distance of 20 × 20 m. The first tree was selected randomly.

2.3. Data collection

Quantitative data were collected during the field measurements. Forms were created to record information such as the tag number, stamp number, GPS (Global Positioning System) location, species name, total DBH of the tree, tree quality class before felling, and log length, girth, and hollowness size after felling.

2.3.1. Primary data collection

2.3.1.2. Reconnaissance survey

A reconnaissance survey was conducted to become acquainted with the general situation of the study area. During this survey, information about the felling area and the contractor chosen for tree felling was gathered. After the reconnaissance survey, a field form for recording information was created in collaboration with the field supervisor.

2.3.2. Measurement in the field

a) Before felling

The DBH of all marked trees was measured. The height of standing trees was measured with a rangefinder from a distance nearly equal to the trees' height. The quality class was evaluated using the criteria outlined in the *Community Forest Resource Inventory Guideline 2061* (MFSC, 2000):

Class I**:** Trees that are green, dead, or on the verge of death, standing or fallen, have a solid body and no scars of injury or visible diseases, and have the potential to yield more than three straight logs of at least six feet in length.

Class II: Trees that are green, dead, or on the verge of death, standing or fallen, with scars or other defects that make obtaining the full volume of the tree impossible. However, two straight logs of at least six feet in length are possible.

Class III: Trees have no potential for timber production and are only used for firewood.

b) After felling

The girth of the log at the middle and the total length of the log were measured with a measuring tape. In addition, the cross-sectional area and hollow length, if needed, were measured in the field with a measuring tape.

2.4. Key Informant Interview

Forest officers, foresters, rangers, and contractors were consulted based on their experience to determine the reasons for the difference in timber volume before and after harvesting. A total of 10 key informants were consulted purposively based on their years of experience in forest management activities and involvement in forest inventory and harvesting operations.

2.5. Secondary data collection

Previous study findings, maps, journals, publications, reports, published and unpublished materials, and other literature were examined in order to develop the methods and better understand, interpret, and analyze the research.

2.6. Data analysis

The collected data were analyzed using MS Excel. Before analyzing the data, they were cleaned. For further analysis, timber volume before and after felling was calculated. In this study, timber volume before felling is considered standing timber volume, whereas timber volume after felling is considered after-felled timber volume.

2.7. Volume calculation before and after felling

a) Volume calculation before harvesting

The volume of the standing tree was calculated using the cylindrical formula mentioned in the *Community Forest Resource Inventory Guideline, 2061* (MFSC, 2000) (Equation VI):

Total gross volume of standing tree (MFSC, 2000):

$$V_1 = \frac{\pi d^2}{4} \times h \times f.f \qquad \text{(Equation VI)}$$

where,

V = Total gross volume of standing tree in cubic feet (cu.ft.)d = diameter at breast height (DBH) in centimeter (cm)

h = height of tree in meter (m)

f.f = Form factor (0.5 recommended)

Standing timber volume: For I class tree: Net Volume = 2/3×Total Gross Volume

For II class tree: Net Volume= 1/2×Total Gross Volume.

b) Volume calculation after harvesting (MFSC, 2000)

The volume of logs after harvesting was calculated using the quarter-girth formula provided in the *Community Forest Resource Inventory Guideline, 2061* (MFSC, 2000) (Equation VII):

I. Total volume of log:

$$V_2 = \frac{g^2}{16} \times l \qquad \text{(Equation VII)}$$

where, V = Total volume of log in cu.ft.

g = girth of log measured at center in inchl = length of a log in ft.

II. In case of log with buttress:

Actual volume:

$$\frac{(g_b - d_b)^2}{16} \times h \qquad \text{(Equation VIII)}$$

Where, g_b = Girth of buttress log in inch.d_b = Depth of buttress in inch.

III. In case of hollow logs:

Hollowness volume (MFSC, 2000) = $l \times b \times h$ (Equation X)

Where, l = length of hollow defect b = breadth of hollow defecth = length of log

Actual volume = Total volume - Hollowness volume (Equation XI)

2.8. Difference in timber volume

The difference in timber volume (bias) before and after felling was calculated by subtracting after-felled timber volume from standing timber volume.

Bias = Standing timber volume – After-felled timber volume (Equation IX).

2.9. Test of Significance

An F-test was used to compare the variance of standing timber volume with the variance of after-felled timber volume. The F-test was conducted at a 95% confidence interval using MS Excel for statistical analysis.

3. Results

3.1. Timber volume before and after felling

Table 1 shows that timber volume before felling was higher in Class I. Similarly, timber volume after harvesting was also higher in Class I. Overall, the total volume before felling was higher than the timber volume after felling. Timber volume before felling per hectare (V_1/ha) for Classes I, II, and III was 347.76, 148.74, and 0 cu.ft., respectively. Likewise, the felled timber volume per hectare (V_2/ha) was 255.48, 135, and 15.99 cu.ft., respectively.

3.2. Difference in timber volume

Table 2 shows that timber volume before harvesting (3842.89 cu.ft.) was higher than timber volume after harvesting (3146.09 cu.ft.). Standing timber volume was 496.5 cu.ft. per hectare, whereas timber volume after felling was 406.47 cu.ft. per hectare. Standing timber volume for teak was overestimated by 18.13%.

Table 1. Timber Volume before (V1) and after (V2) felling

Class	Standing timbervolume (cu.ft.) (V1)	V1 per hectare	After felledtimber volume (cu.ft.) (V2)	V2 per hectare
I	2691.66	347.76	1977.43	255.48
II	1151.23	148.74	1044.89	135
III	0		123.77	15.99
Grand Total	3842.89	496.50	3146.09	406.47

Table 2. Difference in timber volume

Species	No. of sample	Standing timbervolume (cu. ft.)	After felled timber volume (cu. ft.)	Difference intimber volume (cu. ft.)
Teak	150	3842.89	3146.09	696.80

An F-test was conducted to test whether there was a significant difference between standing timber volume and felled timber volume. The results show that the variance of V1 is greater than the variance of V2, and the F value is greater than the one-tail critical F value; therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. Thus, the variance of standing timber volume before felling differed significantly from the variance of timber volume after felling at the 95% confidence level (Table 3).

3.3. Difference in timber volume due to hollowness and buttress (Defect)

The Table 4 that 83.10 cu.ft. was removed due to buttresses and 14.58 cu.ft. was removed due to hollowness. In total, 34 trees had buttresses and 25 trees were hollow out of 150 felled trees; that is, 23% had buttresses and 17% were hollow (Figure 2).

Table 3. Test of significant difference in timber volume

Parameters	Variable 1	Variable 2
Mean	25.62	20.97
Variance	471.85	246.89
Observations	150	150
Df	149	149
F	1.91	
P(F<=f) one-tail	4.56E-05	
F Critical one-tail	1.31	

Table 4. Difference in timber volume due to hollowness and **buttress**

Species	Total volume-a	Buttress volume-b	Hollow volume-c	Actual volume=(a-b-c)
Teak	3243.77 cu.ft.	83.10 cu.ft.	14.58 cu.ft.	3146.09 cu.ft.

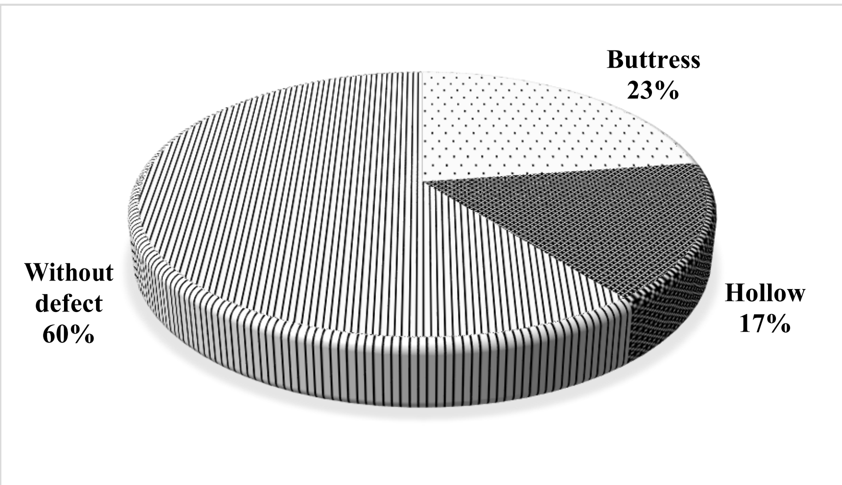

Figure 2. Percentage of defect in sample tree

3.4. Difference in timber volume based on tree class

Differences by tree class were evaluated to assess potential sources of error. Timber volume by class was tallied after log extraction, and the after-felling timber volume was compared with the estimated standing timber volume.

According to Table 5, after felling, Class I and Class II trees were overestimated by 714.23 cft and 106.34 cft, respectively. In Class III, timber volume from 17 trees was calculated after felling (123.77 cft), whereas the standing volume for this class had been underestimated as 0 cft (Figure 3).

Table 5. Difference in timber volume based on tree class

SN	Class	Observed no.trees	StandingTimber Volume_Cft	After felledTimber volume_Cft	Difference in Timber volume Class wise_Cft
1	I	70	2691.66	1977.43	714.23
2	II	63	1151.23	1044.89	106.34
3	III	17	0.00	123.77	123.77
	Total	150	3842.89	3146.09	696.80

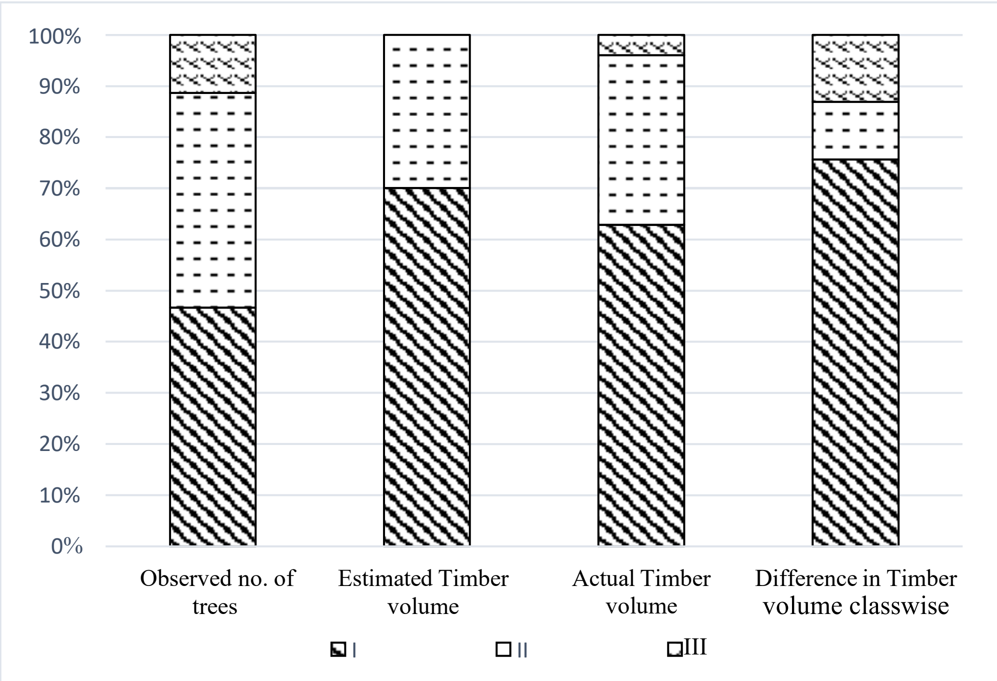

Figure 3. Difference in timber volume based on tree class

3.5. Sources of variation in timber volume before and after harvesting

Other sources of variation were analyzed based on key informant opinions. Ten different key informants were interviewed to identify the sources of error in timber volume calculation. Ninety percent of the key informants stated that losses occurred during conversion, and 60% identified observer error as a source of variation. Loss during conversion was attributed to the presence of defects in the timber. Standing volume was estimated by visually assessing tree quality class based on the physical features of trees, without using instruments. The resulting volume loss may also be due to the use of two different formulas for timber volume calculation before and after harvesting, as well as the technique used for timber conversion after felling. Chaudhari and Pandey (2016) stated that the quarter-girth formula underestimates actual volume by 22%. Likewise, 70% of respondents stated that the felling technique and precautions applied before felling were sources of variation. Similarly, 40% of respondents agreed that the handling and use of measurement instruments, as well as measurement error, were sources of variation (Figure 4).

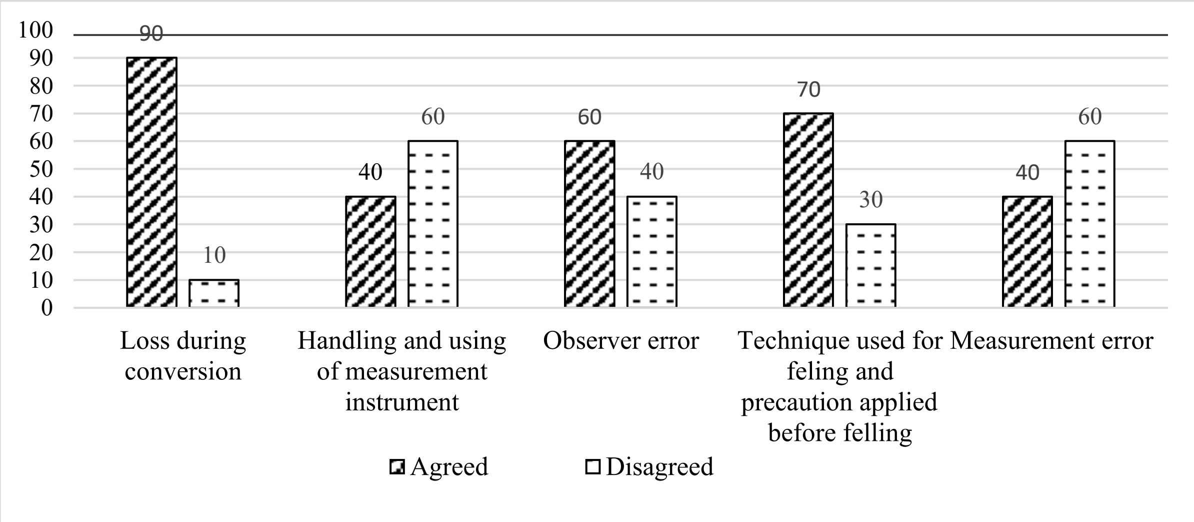

Figure 4. Source of timber volume variation based on key informant opinion

4. Discussion

The research demonstrated substantial differences between naturally growing teak (*Tectona grandis*) harvestable timber and extracted timber, with a total loss of 696.80 cu.ft., equivalent to approximately 18.13%. Such discrepancies are not unique. Research conducted in tropical and subtropical forests demonstrates that standing timber volume consistently surpasses actual values whenever visual assessment techniques are employed. According to Bhattarai and Mandal (2019), evaluation of partial tree defects in Nepalese community forests revealed comparable volume discrepancies in standing timber resources.

The difference in timber volume across tree classes—especially underestimation in Class III and overestimation in Classes I and II—highlights the influence of subjective tree classification. Standing volume measurements of Class III trees showed 0 cu.ft., but the felling procedure yielded 123.77 cu.ft. of timber. Our inability to accurately rate wood quality using visual observation agrees with Derikvand et al. (2018), who found that improper timber recognition occurs in inferior wood materials. Additional estimation errors may have occurred because instrument-based classification systems were not used. Proper training of observers through field activities under close supervision can significantly reduce observation errors, especially in situations requiring experienced observers (Paudel, 2015).

Defects such as hollowness and buttresses also played a role in volume reduction. We recorded losses of 83.10 cu.ft. due to buttresses and 14.58 cu.ft. due to hollowness, which, although lower in percentage terms (2.56% and 0.45%, respectively), corroborate findings by Adhikari (2019), who reported that hollowness accounted for 24.6% timber-volume loss in Sal forest. Although the percentage was small in the teak forest, this finding supports the notion that hollowness and buttresses are important variables in volume loss. Loss due to ocular estimation of hollowness can be reduced if instruments for detecting hollowness are used at the field level. If such instruments are adopted, more precise and accurate estimates of timber volume can be obtained.

Findings from key informant interviews identified various errors occurring at the operational level. Traditional processing methods resulted in 90% timber losses, according to respondents; the main production defects included sawing defects and non-commercial offcuts during log transformation. Aryal (2022) reported that the felling and sawing stages of *Shorea robusta* forests in Nepal experience 23%, 22%, and 31% timber losses due to inappropriate equipment use. Data from 70% of informants indicated that poor felling techniques and insufficient precautions were major contributing factors, consistent with Nikooy et al. (2010) regarding post-harvest reduction.

Another critical factor was inconsistency in measurement techniques before and after harvesting. Standing timber was estimated using the quarter-girth formula, while post-felling volume likely used Smalian's formula or sectional measurement methods. This variation is noteworthy, as Chaudhary & Pandey (2016) reported that the quarter-girth formula can underestimate true volume by up to 22%.

Observation and measurement errors also contributed to the variation. Our study used ocular estimation for classifying trees without instruments, a method prone to bias. According to Gertner (1984), measurement errors—especially those arising from faulty or absent equipment—can result in systematic over- or underestimation. The use of devices such as the Vertex, as recommended by Aryal (2019) and Pariyar & Mandal (2019), could significantly reduce such errors by improving height-measurement accuracy, especially when dealing with tall and defect-prone species such as teak.

Finally, untrained personnel and improper field recording contributed to inaccuracies. Paudel (2015) emphasized that observer training and field supervision are essential for reducing estimation errors in forest inventories. In our study, reliance on local manpower and the collection of felled wood by locals introduced further disturbances that may have affected volume measurement and classification.

Overall, our findings confirm that standing timber volume is frequently overestimated in forest inventories due to visual classification, tree defects, methodological inconsistencies, and operational inefficiencies. Adoption of standardized instruments, consistency in volume equations, and capacity-building for field observers are necessary to improve accuracy in timber-volume estimation and minimize post-harvest loss.

5. Conclusion

Standing timber volume before felling exceeded timber volume after felling by 18.13%. Among the three classes, Class I showed the highest timber volume. Factors contributing to variation in timber volume before and after harvesting included timber losses due to defects such as hollowness and buttresses, the use of different volume calculation equations, felling techniques, and precautionary measures during felling. Recommendations for concerned authorities include several essential points. First, wood defects should be assessed to prevent potential overestimation of timber volume; using advanced tools such as a tomograph for accurate assessment of internal wood decay in standing trees is highly advisable. Second, forest inventory measurements should be conducted without bias, using appropriate instruments and comprehensive training, while minimizing measurement variation to achieve precise estimates. Finally, employing skilled manpower during estimation and harvesting operations is strongly advised to ensure efficiency and accuracy.

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