Economic interpretation of lost due to improper stump-height of trees in Nepal

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In recent years, import of timber and other wood products from different parts of the world have been increasing in Nepal. The Government of Nepal aims to be a self-sustain in timber production. In this context, the objective of this study was to estimate efficiency of harvesting practices in Nepal in relation to stump-height. We collected the data on the stump-heights and other biometric characteristics of the trees from different felling sites of Kailali, Kanchanpur, Jhapa and Morang districts of Nepal. The volumes of the individual trees as well as the proportions of the volumes of their stumps with different heights were calculated. Correlation and ANOVA were used to find the significance of the associated factors. The average stump-heights using the conventional felling method and the chain saw method were found to be 0.74±0.17m and 0.46±0.21m, respectively with wider range. The correlation between the stump-height and diameter at breast height (dbh) was found significant. Similarly, the harvesting method, skill and experience of the tree-fellers and tree species were also found to be significant with the stump-heights. On an average, 5% of the total timber production equivalent to one million cubic feet (cft) is lost in the Fiscal Year 2074/075 in Nepal while adopting the conventional method of harvesting because of the higher stump-height than the one prescribed by the Government. The estimated loss was NRs. 2 billion (roughly equivalent to US $ 20 million, @NRS 100 = 1 USD) to the national economy, and the Government had to bear loss of about NRs. 500 million (roughly equivalent to 5 million USD) from the royalty of timber. This amount of loss could be reduced to half by using power chain saw. Lack of skilled laborers, poor implementation of law, and weak knowledge of officials were major causes for losses in harvesting practices. Moreover, about 2% wood volume loss can be avoided, without any further investment, by setting minimum standard stump-height at 15 cm and providing training to the field staff and tree harvesters.

Keywords: Conventional method, correlation, harvesting, power chain saw, wood volume

In Nepal, forest covers 40.36% of the total land area of the country, which is almost 10.0% greater than the global average. On the other hand ,the forest area is lower than the average global per capita forest land available (FAO/UNEP, 2020; DoF 2017; DFRS, 2015). Within this forest area, the average number of stems greater than ten cm diameter is 430/ha (DFRS, 2015). Moreover, despite increasing efforts of the government and non-government actors, the mean stem volume per unit area of Nepal was decreased (DoF, 2017;DFRS, 2015).

The demand for timber is increasing in Nepal, particularly for post-earthquake reconstruction works. In the Fiscal Year (F.Y.) 2074/075 (2017/018), it was estimated that around 20.7 million cubic feet (cft) timber log was produced while nearly one million cft of sawn timber was imported (KC, 2019; MoFE, 2018). In the same F.Y., approximately NRs. 0.8 billion worth of plywood was imported through the Nepalgunj Custom Office alone. Further, steel and cement are increasingly used as substitutes of forest products (KC, 2019; MoFE, 2018).Thus, a large amount of foreign currency is going outside from the country every year due to lack of wood production.

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Despite higher potentials, wood production in the country is lower due to the lack of proper forest management tool and knowledge. It is estimated that 30% of value is lost during tree harvesting (Boston & Dysart, 2000). Small improvements in value recovery can lead to large improvements in the financial performance of forestry investments (Boston & Dysart, 2000). There have been several studies to compare and improve the productivity during the felling through different methods and tools throughout the world (Boston & Dysart, 2000; Hall & Han, 2006; Berch *et al*., 2012; Han & Renzie, 2005). These studies have indicated higher stump-height (the lower portion of tree bole left on the ground after felling trees) as one of the major causes of losses of timber volume. Therefore, since 1964 different techniques had been adopted to estimate the value of stumps left in normal harvesting (Boston & Dysart, 2000). However, there is a dearth of studies aimed at increasing wood productivity through improvement of harvesting technology in Nepal (Shrestha, 2017). Therefore, a suitable harvesting system is needed to enhance wood production (Akay *et al*., 2006).

In this context, this study aims to investigate the losses of timber volume and their monitory value during logging operations due to higher stumps. In this study, we assessed the average stump-height during the regular forest harvesting operations, evaluated the economic losses due to the prevailing harvesting systems, analyzed the causes of losses, searched the possible value gain during the felling operations, and recommend the attention for future operations. The findings of this study will be useful to develop guidelines for minimizing wood loss and maximizing benefits and improving productivity during timber harvesting operations.

Materials and methods

The sample trees were selected through purposive sampling covering the trees with all diameter range available in the felling area. Data were collected mainly for volume calculation (Table 1), and average stump height calculation (Table 2). In order to calculate the total volumes of trees and different sections of stumps of the felled trees, 42 samples of Sal (*Shorea robusta*) and 34 samples of Asna (*Terminalia alata*) were collected from the felling sites of the Ranijamara Irrigation Project, the Balchaur area of Kailali district and the felling site of the then Timber Corporation of Nepal (TCN), the Bani area of Kanchanpur district and the Manakamana, Hachumasa, Halluwagadh and Jukekhadi CFs of Jhapa district. Species name and diameter at breast height (dbh), diameter at 15 cm and 30 cm above ground level of all the sampled trees were recorded before felling. Then, the stump-heights and the over bark diameters along the tree-stem with 0.5 to 2 m interval up to the tip of the trees were measured using diameter tape after felling the trees (Subedi, 2017). The total volumes of the sampled trees and their stumps were calculated using the Smalian's Formula through the Sectional Method (Subedi, 2017) and stump volume (up to 15 cm) were calculated assuming the cylinder. Similarly, 15–30 cm above ground level, and above 30 cm to the tip of the individual stumps (left-over after felling) were calculated using the Smalian's Formula. The volume percentages of different sections of the stumps with respect to the total volume of the same trees were calculated. The details of the sampled trees measured in this way are presented in Table 1. In all these areas, harvesting operations were done in March to mid-June using saw and axe following the conventional method.

Table 1: Statistics of the sampled trees for volume calculation (first dataset)

Species	No. of samples (n)	dbh (cm)				Total tree height (m)				Harvesting method
		Av.	Std. dev.	Min.	Max.	Av.	Std. dev.	Min.	Max.	
Sal (*S. robusta*)	42	63.77	15.13	34.0	108.5	29.4	6.12	25.0	42.1	Conventional
Asna (*T. alata*)	34	71.83	20.24	37.9	116.3	35.7	4.0	8.0	41.2	Conventional
Total	**76**	**67.4**	**17.9**	**34.0**	**116.3**	**32.7**	**6.14**	**8.0**	**42.1**	

Secondly, in order to find out the stump-heights and the causes for their heights, the information on the tree species and the stump-heights of the felled trees using saw and axe were collected from the felling sites of Kailali and Kanchanpur districts while the same information on the felled trees using power chain saw were gathered from the Aahale, Ramite, Siddhartha, Sukuna, and Basanta Hariyali CFs and the Latijhoda Collaborative Forest (CFM) of Morang district (Table 2).

Table 2: Statistics of the sampled trees for stump-height measurement (second dataset)

Species	District	No. of samples (n)	Average dbh	Std. dev.	Min. dbh	Max. dbh	Harvesting method
Asna (*T. alata*)	Kailali	11	77.6	17.41	50.9	116.3	Conventional
	Kanchanpur	18	73.2	19.49	41.7	115.2	Conventional
	Morang	17	56.6	8.92	43.3	75.1	Chain saw
Karma (*A. cordifolia*)	Kailali	3	51.2	22.98	37.9	77.7	Conventional
	Kanchanpur	2	88.0	17.68	75.5	100.5	Conventional
	Morang	22	86.8	36.75	46.4	190.4	Chain saw
Tetrameles nudiflora	Morang	32	79.2	40.50	37.1	166.0	Chain saw
S. robusta	Kanchanpur	8	61.9	14.87	42.8	90.6	Conventional
	Morang	43	61.9	17.31	31.4	115.1	Chain saw
Others*	Morang	5	76.2	26.03	43.2	113.0	Chain saw
	Total/ Average	**161**	**71.1**	**28.07**	**31.4**	**190.4**	

* include *Albizia* spp, *L. coromandelica* and *T. bellirica*.

Out of the total 237 sample trees selected, 93 belonged to Sal (*S. robusta*), 80 belonged to Asna (*T. alata*), 32 belonged to Maina (*Tetrameles nudiflora*) and 27 belonged to Karma (*Adina cordifolia*). Similarly, 2 each belonged to Siris (*Albizia* spp) and Hallude (*Lannea coromandelica*) while 1 belonged to Barro (*Terminalia bellirica*). Among them, 118 trees were felled adopting the conventional method (Table 1 and Table 2) while 119 were harvested using chain saw (Table 2). The data were entered into the Excel Sheet, and analyzed in the R environment (R Core Team, 2018).

In addition to the measurements of tree characteristics, 15 groups of tree harvesters, at the aforementioned felling sites, were interviewed with regards to their years of experience and skill in felling trees, their knowledge about legal code on stump-height and physical challenges they used to face during tree felling. Similarly, the officials of the 10 community forest user groups were interviewed regarding their knowledge on tree harvesting technique and legal code.

The data were analyzed using the graphical visualization and statistical test. The Pearson's Product Moment Correlation Test was used for significant correlation with the dbh and stump-heights of the trees. ANOVA was used to test against the null hypothesis as there was no significant difference in the stump-heights with respect to the species and the laborers' performance at different locations. All the tests and analyses were performed separately for volume calculation data sets (Table 1) and stump-heights data sets (Table 2).

Results

Stump-height and dbh using conventional method

The average stump-height using the conventional method of felling was found to be 0.737±0.167 m (conventional method, of Table 1 and Table 2), but 0.697±0.16 m was noticed with the range of 0.25−1.2 m for the first data set, *i.e.* volume calculation dataset (Table 1). However as per the Government Guidelines (MoFSC, 2016), the stump height should not be higher than 30 cm. Figure 1 (a) indicates the positive linear relation of stump-height with the dbh (of volume calculation data set). The correlation between the stump-height and the dbh was found to be moderate (r=0.5822) but highly significant (df =74 and p-value =3.447e^{-08} at 95% confidence level). Around 80% of the interviewees (tree harvesters) reported that cutting trees at lower stump-height was more time consuming and more physically arduous, and therefore, they preferred to cut trees at higher stump-height. According to them, neither their supervisors nor any officials had provided any instruction regarding stump-height to them in course of tree felling. Though, the average stump-height was much higher, the minimum stump-height showed that there was possibility to cut trees at 25 cm above ground level using saw and axe. All most informants reported that they were unaware about the standard stump-height.

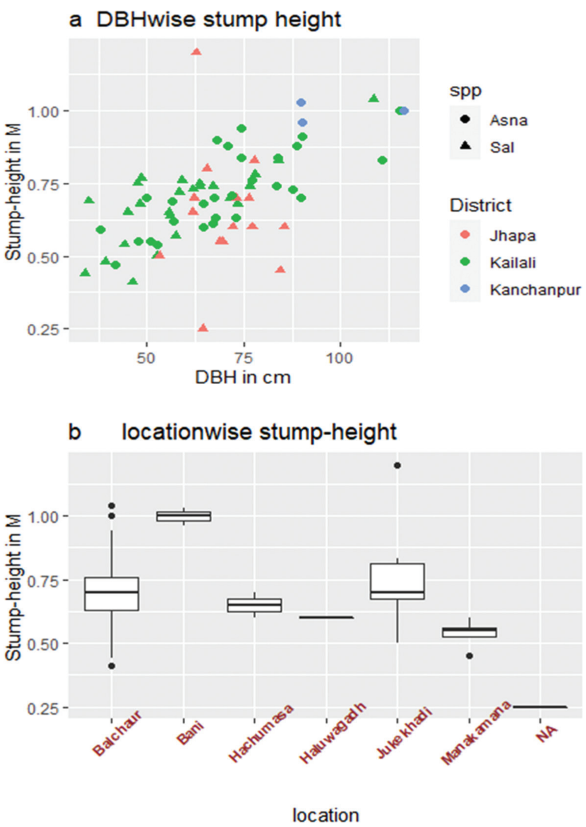

Fig. 1: In conventional method of felling-a) stump-height (m) vs. dbh (cm) with respect to different tree species and districts;and b) stump-height (m) vs. harvesters at different locations

Factors associated with stump-height adopting conventional method of felling

The stump-heights of both the species (*S. robusta* and *T. alata*) are not so distinguishable up to 75 cm dbh (Figure 1a); but, in the case of the trees with above 75 cm dbh, *T. alata* had higher stump-height, which might be either due to the perceived lower economic value of the species or difficulty in felling the trees with larger diameter at lower height. However, the difference in the stump-heights between the species was not found to be statistically significant (p-value =0.0571, df =74) when using conventional method of felling. No uniformity was noticed in the stump-heights even within the same district. Though, one stump-height was found to be highest in Jukekhadi CF of Jhapa district (Figure 1 b),the laborers of this district were found to be slightly more efficient (with lower mean stump height)than those of Kanchanpur and Kailali districts. It can be clearly noticed from Figure 1 b that the tree harvesters from the different places with almost similar terrain condition left over unequal stump-heights. The reason for this is that almost all the tree harvesters hired for the purpose were either inexperienced or not properly trained on tree harvesting.

Stump-height using chain saw

Figure 2a shows the clear difference in the stump-heights based on the felling methods. The stump-heights of the trees felled using the conventional method of felling were rarely lower than 60 cm above ground level (Figure 2a). The mean stump-height using chain saw was found to be 0.46±0.21 m above ground level with the range of 0.05−1.15 m (Table 3). However, Boston & Dysart (2000) found that the mean stump-height of the trees felled using chain saw was 20 cm above ground level which was a bit higher than that of the trees felled using other mechanical means. Han & Renzie (2005) found that chain saw felling left 19.8 cm stump-height. Similar type of study in British Columbia found the average stump-height to be 21.9 cm; the stump-height as per the Government's Guidelines being 30 cm (Hall & Han, 2006). In this regard, Pukkala *et al*. (undated) used the stump-height of 10 cm, Oderwald &

Johnson (2009) used 12 cm; Applegate *et al.* (1985) used 15 cm, and Eerikainen (2001) used 20 cm as standard stump-heights for total stem volume calculation of trees. They also found that the stump-height as low as 10 cm above ground level was attainable using chain saw. Fortunately in this study, we found 5 cm as the lowest stump-height; however, we noticed a wider range in the stump-heights which could be due to the variation in the capacity and experience of the harvesters using chain saw (Boston & Dysart, 2000).

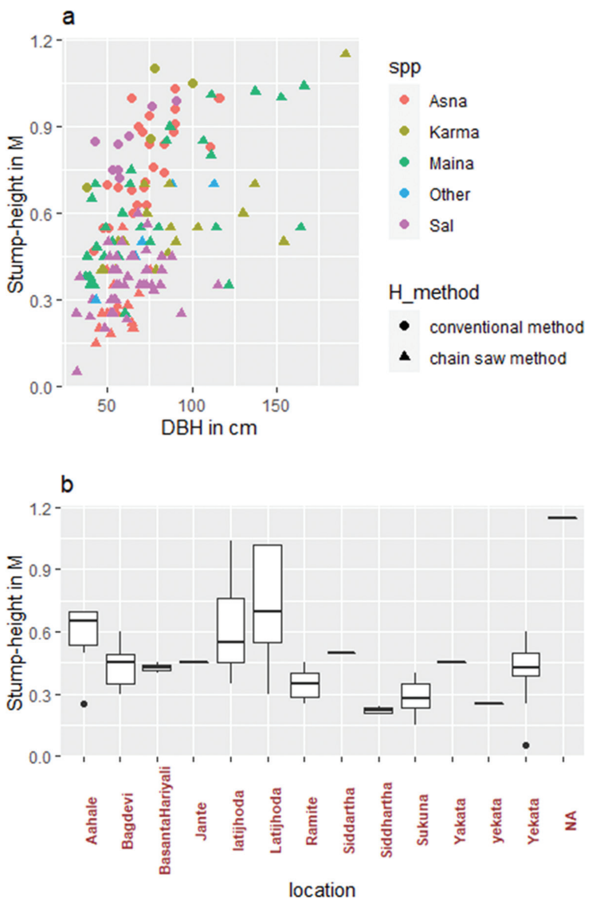

Figure 2: In chain saw method of felling-a) stump-height (m) vs. dbh (cm) with respect to different tree species and harvesting method; and b) stump-height (m) vs. harvesters from different places

When the felling was done using chain saw, the correlation between the stump-height and dbh was found to be higher (0.66) than that using the conventional method. The Pearson's correlation test also showed statistically significant (p-value=$2.67e^{-16}$ and df=117 at 95% confidence interval).Similarly, the stump-heights were also found significantly different among the species (p=$2.4e^{-11}$; df=114) when using the chain saw method. The detailed statistics of the stump-heights using chain saw among the species are presented in (Table 3). Han & Renzie (2005) also indicated that stump-height was significantly affected by the species, slope of the felling site, and average stump diameter; however, Keivan & Ghaffarzadeh (2018) found no significant difference between the different tree diameter classes and stump-heights when the trees were felled using chainsaw, but they found higher stump-height in the higher sloppy areas. Among the tree species, *T. nudiflora* had higher stump-height, mainly due to higher diameter range (>100 cm), larger swellings, buttresses and low economic value. The tree species having larger buttresses such as Karma also had similar stump-height (Figure 2a). Moreover, the tree harvesters were also found equally important factor for causing variations in the stump-heights. Figure 2b clearly shows variation in the stump heights in different locations due to different harvesters.

Table 3: Stump-height using chain saw method

Species	mean stump-ht.	Std. dev.	Min.	Max.
T.nudiflora	0.62	0.237	0.25	1.04
S. robusta	0.36	0.103	0.05	0.60
T. alata	0.28	0.100	0.15	0.55
A. cordifolia	0.53	0.178	0.25	1.15
Others	0.53	0.172	0.30	0.70
Av. stump-height	**0.46**	**0.208**	**0.05**	**1.15**

Most of the tree harvesters using chain saw were paid on the basis of the quantity of the harvested timber; therefore, they wanted to cut trees at lower stump-height if the trees were not twisted and devoid of buttress; the reason for higher stump-height, according to the tree-fellers, was that the trees to be felled were already stamped (locally known as "chhapan") at higher height, and they were instructed to cut the trees above the stamped portions so that the stamps were visible on the left-over stumps for the purpose of monitoring. Then, in course of our field observation, such stamp-marks were mostly noticed around 25 cm above ground level, which is against the Government's rule of stamping the trees to be felled within 15 cm above ground level (MOFSC, 2016). The harvesters described that cutting trees at higher heights were easy in the case of the trees with buttresses or twisted stems. A few experienced tree harvesters opined that it was feasible to cut trees as below as 10 cm above ground.

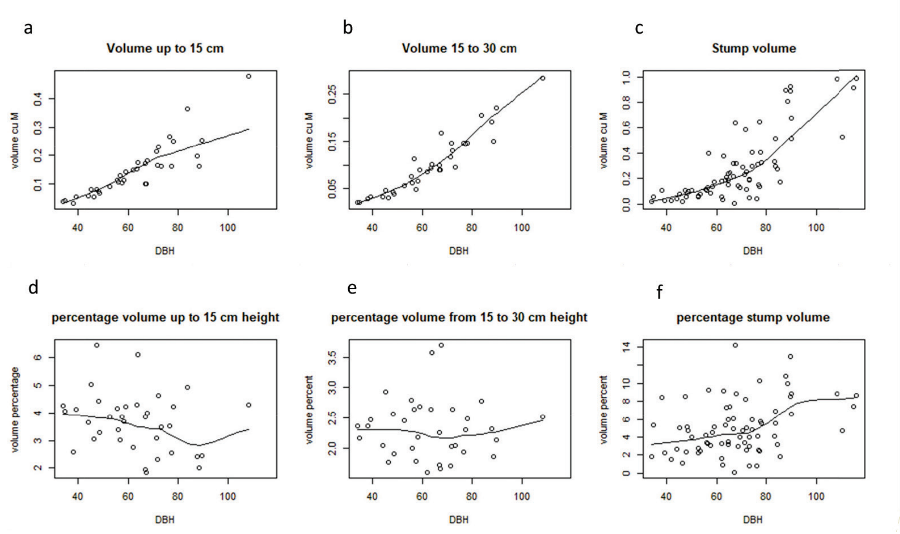

Fig. 3: Absolute volume of the stumps up to different heights (a, b, c), and their percentage as compared to the volumes of the whole trees (d, e, f)

During the interviews with the concerned CF officials, it was revealed that they were unaware about the loss of wood-volume owing to cutting of trees at higher heights. Only after convincing them the truth, they accepted that stamp-marks could be put at heights lower than 15 cm above ground even in the sloppy areas. However, Boston & Dysart (2000) argued that large range of stump-height is questionable to the skill and experience of the tree harvesters though in difficult situation, their safety should not be jeopardized for attaining lower stump-height.

Discussion

Stumps percentage of the total tree volume

We assumed that the stumps with the lowest height of 15 cm above ground level were not achievable; however, the absolute mean wood volume of the stumps up to 15 cm above ground level was found to be 0.1476 m^3 (Figure 3a) which was 3.65% of the total stem volume (Figure 3d). Similarly, the absolute mean wood volume of the stumps within the range of 15–30 cm height above ground level was 0.1007 m^3 (Figure 3b) which was 2.32% with the range of 1.60–3.70% of the total stem volume of the trees (Figure 3e).Based on the above discussion with the harvesters and the CF Officials, this proportion of wood can be achievable through efficient management and trained workers. Likewise, the mean wood volume of the stumps from 30 cm height above ground level to the tip of the stump (n=72) was 0.148m^3 (Figure 3c) equivalent to 5.07% with range of 0.04–14.20% of the total stem volume (Figure 3f). This is absolutely lost due to inefficient management and only partially obeys the rule. The absolute stump volume of the higher than 30 cm height above ground level were found to have gradually increased up to 80 cm dbh, and then increased more sharply in the cases of the trees with over 80 cm dbh (Figure 3c) which could be possibly due to the reason that the trees with larger dbh (above 80 cm) might have higher stump-height and might be butt-swelling (Figure 3a), especially in the cases of *T. alata*, *A. cardifilia* and *T. nudiflora*.

The study indicates that, on an average, 5.07% of the timber volume was lost through conventional method of felling due to the stump-height which was more than the prescribed by the Government (MoFSC, 2016). In the Fiscal Year 2074/075, about 20.7 million cft of timber wood were produced in Nepal (KC, 2019); thus, the amount of wood loss, owing to the felling of trees adopting the conventional method, was expected to be 1 million cft. Coincidently, about 1 million cft of sawn timber was imported from different countries in the same FY (KC, 2019). Assuming the rate of timber to be NRs. 2,000 per cft, there was a loss of NRs. 2 billion (roughly equivalent to 20 million USD @ of NRs. 100 = 1USD) to the national economy. On the other hand, the Government had to bear a loss of about NRs. 500 million from the royalty of timber if we assume the royalty rate of NRs 500 per cft or about NRs 300 million if we assume only 15% of the market price. This amount of loss could be reduced to half by using power chain saw since the average stump height (using chain saw) above the prescribed height is found more than half than the conventional method. About 2% of the further timber volume can be produced without any further investment through setting the standard stump height as 15 cm and strictly follow the government code and using power chain saw. In addition to this direct financial benefit, there was a loss of other ecological and climatic benefits, e.g. reduction of emission in the decaying process of stumps (Hall and Han, 2006). Lack of effective implementation of legal codes and hiring inexperienced laborers for felling of trees had resulted in the loss; however, it is to be noted that the Government's legal codes have clearly prohibited the hiring of untrained or inexperienced laborers for tree harvesting operations (MoFSC, 2016). Awareness raising and capacity building of the laborers and officials in operating power chain saw together with effective implementation of the legal codes will help to attain the national target for self-sustaining in timber production. However, as it is feasible to fell trees as below as 10 cm above ground level, felling trees within 15 cm above ground level is likely to increase timber production by 2.0% without any further investment.

Conclusion and recommendations

The harvesting method was found major determinant factor of higher stump heights. The average stump-height of the trees was found to be 0.74±0.17m and 0.46±0.21m through conventional harvesting method and power chain saw method, respectively. The stump-heights were found to be significantly correlated with the dbh of the trees in both the cases. However, the stump-heights were found to be affected by the species when the trees were felled by power chain saw. Though the absolute volumes of the stumps were directly related to the size of the trees, their percentage volumes were not affected by their sizes.

Nepal lost, on an average, 5% of the total timber volume per tree due to the higher stump-height than the one set by the Government, leading to the loss of one million cft wood through conventional harvesting in the FY 2074/075.The wood production throughout the nation can be improved by lowering the stump-height of the trees to be felled. This amount of loss could be reduced to more than half by using power chain saw. There is possibility of producing about 2% more timber volume by setting new standard and strictly following the government code. The major causes for higher stump-heights were the physical difficulties, weak knowledge and weak monitoring of the conventional felling method. In addition to this, stamping the felling-marks (on the trees) at higher heights, lack of experience and skill of tree harvesters and weak enforcement of the Government's Guidelines in the field are other major determinant factors for the same.The mean stump-height can be significantly reduced by setting new harvesting code in addition to strictly adhering to the Government's felling norms, adopting chain saw method of felling instead of the conventional method, providing necessary trainings to the concerned field technical staff and tree harvesters.

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