Role of vegetation in slope stability: Case studies of forested slopes in the Mahabharat Range, Nepal

Yajna Prasad Timilsina1,*Ram Prasad Sharma1 and Prakash Paudel2
1Institute of Forestry, Pokhara Campus, Tribhuvan University, Pokhara, Nepal
2Kabeli Energy Limited, Buddhanagar, Kathmandu
(*Email: ramskarmag@yahoo.com)

ABSTRACT

The study was aimed at identification of the role of vegetation and soil in slope instability in the Mahabharat Range of Nepal. The bio-physical informations were collected from the Laxmi Narayan, Lasti Berenata, Sambot and Jamune Dha Bama Community Forest of Mahabharat Range of western Nepal. The landslides are in pelite rocks such as phyllite, gritty phyllite and schist. The pelite rocks are highly weathered forming sandy loam texture. The studied landslides fall in Shorea robusta- and Schima wallichii-dominated forests with major tree species like Shorea robusta (Sal), Schima wallichii (Chilauna), Alnus nepalensis (Uttis), Pinus roxburghii (Loth Salla) and Lagerstroemia parviflora (Bojdhainaru). The dominant shrub species are Osbeckia nepalensis (Angeri small), Maesa chizia (Bilauna), Rosa brunonii (Bainselu) and Woodfordia fruticosa (Dhairo). Pogonatherum crinitum (Muse Khara), Chrysopogon sp. (Tipepati), Imperata cylindrica (Siru), Bidens pilosa (Karo), Anaphalis contorta (Bukkipal), Onychium uosonium (Chille uma), Eupatorium odoratum (Bannara) and Reinwardtia indica (Pyauli) are major herb/grasses species. The surplus load of vegetation (tree species) in the studied landslides with groundwater activities were found to have significant role in slope instability instead forested area. As the slip plane is deeper than 3.4 m, tree roots has no anchoring role for stabilization of the studied landslide.

Keywords: Slope stability, forested slopes, Mahabharat Range, Nepal

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INTRODUCTION

Landsliding is a very common natural phenomenon and one of the main natural hazards in Nepal. Many villages in hilly areas of Nepal are situated on or adjacent to unstable slopes and old landslides which have been reactivated from time to time during monsoon season. The Midland areas have been highly susceptible to landslide due to complex interaction of natural and man-made factors (Pradhana 2007). Precambrian to Cambrian Lesser Himalayan metasedimentary zone of western Nepal is one of the vulnerable zones among morpho-tectonic units of Nepal due to its rugged mountain topography, complex and fragile nature of the geological formations, active groundwater activities, soft soil cover, high intensity rainfall in the monsoon season, steep slope and surcharge loads of vegetation (Uperti 2001). Loss of income, livelihood opportunities and property, starvation including displacement of affected families were the major implications of these disasters (Achyut 2004).

The geological structures such as thrusts/faults, folds, bedding, foliation and joints in rocks are playing vital role in landslide triggering (Uperti and Dhital 1996). Weathering of rocks in slopes reduces the strength of rock and soil, and chemical alterations in clay are thought to have contributed to triggering of landslides (Zaruba and Mencel 1982). The geotechnical properties such as composition, depth, shear strength and organic matter of soils are the main factors contributing to soil slope failures. Debris slides are observed in coarse-grained soils with steeper (35-45 degrees) slopes and rotational slides are characteristics of fine-grained thick soils with gentler slopes (Uperti and Dhital 1996). The seepage proves the groundwater flow in landslides that exerts pressure on soil particles and flushes out fine particles in fine sand and silt that reduces the strength of the forested slope. Rainfall is one of the main factors controlling the frequency of landslides that depends upon climatic conditions, topography and geological characteristics of rocks and soils. It increases frequency of landslide during monsoon due to saturation of subsoil (Galay 1987). An increase in natural slope produces a change in the internal stress of the rocks or soil mass, and equilibrium conditions are disturbed by an increase in shear stress (Zaruba and Mencel 1982). Vegetation plays a vital role in slope stability (Howell 1999). Generally, the vegetation cover increases the shear strength of the soil with its root network and protects the slope from landslides. The roots of the trees maintain the stability of slopes through their mechanical and biological effects and help to dry the soil slopes by absorbing some groundwater. However, if the landslide is deeper than the penetration depth of the roots,
vegetation cannot stabilize the slope (Newpane 2005). In this context, depth of failure surface is the determinan
t factor. Most of the vegetation can be effective to stabilize
shallow landslides mainly by increasing the shear strength of
soil. Vegetation can modify slope stability by the factors as mechanically reinforcing slopes through plant
roots, modifying soil moisture distribution and pore water
pressures, adding slope surcharge from the weight of trees,
and levering and wedging soil by roots (Gray 1970). The
first two factors increase stability of slopes; the third may
increase, decrease, or have no influence on stability, and
the fourth decreases stability. Pore water pressure results
from groundwater and surface water activities in saturated
condition which can reduce shear strength. A large number of
different stability analyses have been developed in soil and
rock mechanics, most being more complex. The application
of such analyses to forested natural slopes is usually
problematic because of the heterogeneous conditions of soil,
vegetation and geology. On the other hand, vegetation adds
slope surcharge from the weight of trees and wedging in soil
and rocks by roots. The increased shear stress produced by
the weight of a mature forest on an unsaturated cohesionless
soil is balanced by an equal increase in soil shear strength by
the tree surcharge (Gray 1970). For most mature forests,
an additional surcharge load contributed by the trees will have
effect on slope stability (Swanson 1970). If the weight of
trees becomes a problem, it is usually in cohesive soil during
heavy rain when the weight of increased soil moisture
enhances shear stress. In addition to this, groundwater in
highly weathered rocks and fine-grained soils result in
landslides through increase in pore water pressure and made
slip surface by saturation of soils. The increase of shear
stress in land results instability.

STUDY AREA AND METHODS

Four landslides namely in Lasti Berenata and Laxmi
Narayan Community Forests (CF) of Parbat District and
Sambot CF of Baglung and Jamune Dhaha Community-
Managed Forest (CMF) of Kaski District were selected on
the basis of slope classes i.e. 0-20°, 20-45°, 45-65° and
greater than 65° slope to know the vulnerability of land
according to slope. These landslides were selected from the
record of District Soil Conservation Offices (DSCO) of the
respective districts with due considering the vulnerability of
the forested slope and their impact on life and properties
losses of rural people in the area.

The length, breadth, height and failure depth of the
landslides were measured for area and volume calculation
by using respective instruments. The soil samples were
taken from the 0-30 cm depth for the identification of soil
texture.

The vegetation data in Lasti Berenata, Laxmi Narayan
and Jamune Dhaha forests were measured within landslide
area by making plots of the size 25x20 sq.m. The data
from Sambot Landslide were taken just above the landslide
because all the vegetation were swept by the landslide.
Diameter at breast height (DBH) and height of tree species
were measured within 25x20 sq.m. plot from each landslide
by using diameter tape and Abney level. The seedling and
shrub species were counted within 5x5 sq.m. nested plot.
The seedling and shrub are categorized into three classes
namely short, medium and tall. The height of each class from
each class was measured by using measuring tape and rod
for average height determination. Specieswise herbs/
grasses were counted and measured their average height
within 1x1 sq.m. nested plot according to seedling and shrub
categorization method for the identification of frequency.
The weight of seedling, shrubs and herbs/grasses are not
included in addition of load for landslide activation.

From vegetation data, stem volume of trees was calculated
by using allometric equation (Sharma and Pukkala 1990),

\[
\ln V = a + b \ln (d) + c \ln (h)
\]

where,

- \(V\) = Total stem volume with bark in m³
- \(d\) = Diameter at breast height in cm
- \(h\) = height in m
- \(a\) = intercept in the equation

Table 1: Parameters a, b and c and \(R^2\) for major tree species (Source: Amaty and Shrestha 2002).

<table>
<thead>
<tr>
<th>S.N</th>
<th>Tree species</th>
<th>Parameters</th>
<th>Coeff.of determination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>1</td>
<td>Pinus roxburghii</td>
<td>-2.9770</td>
<td>1.9235</td>
</tr>
<tr>
<td>2</td>
<td>Shorea robusta</td>
<td>-2.4554</td>
<td>1.9026</td>
</tr>
<tr>
<td>3</td>
<td>Schima wallichii</td>
<td>-2.7385</td>
<td>1.8155</td>
</tr>
<tr>
<td>4</td>
<td>Alnus nepalensis</td>
<td>-2.7761</td>
<td>1.9006</td>
</tr>
<tr>
<td>5</td>
<td>Lagerstroemia parviflora</td>
<td>-2.3411</td>
<td>1.7246</td>
</tr>
<tr>
<td>6</td>
<td>Miscellaneous in Hills</td>
<td>-2.3204</td>
<td>1.8507</td>
</tr>
</tbody>
</table>
b and c are regression coefficients.

The intercept and regression coefficients values of different tree species are given in Table 1. The volume and wood density were multiplied to obtain the biomass of the stem. Branch, leaf and root biomass were estimated to be 45%, 11%, and 46% of the stem biomass, respectively.

The collected data were analyzed both qualitatively and quantitatively. The data collected during the fieldworks were categorized and variables were selected. The data were presented in descriptive manner in frequency tables, diagrams and graphs. Mainly Statistical Package for Social Sciences (SPSS) and Microsoft Excel were used to analyze the data information.

RESULTS AND DISCUSSION

Characteristics of landslide measurements

The measurement of slope, length, breadth and failed depth reveals that landslide area and volume is higher in Jamune Dhaba, Laxmi Narayan and Lasti Berenata sites compared to the Sambot landslide. (Table 2). The data obtained from landslide measurements shows that all the landslides fall in the category of deep-seated landslides. Tree roots play a great role in stabilization of slope up to 0.5 m, i.e., only in shallow landslides. They are not effective for deep-seated landslides or slope failures (Howell 1999). The depth of failure of studied landslides are greater than 3.5 m. Therefore, tree species in all landslides have no significant role on stability of slope. The biomass of the tree species add surplus load to the landslide. Landslides in Laxmi Narayan CF, Sambot CF and Lasti Berenata CF are located in steeper natural slope and the landslide in Jamune Dhaba CMF are located on gentler slope. The coarse-grained soil (sandy loam), steeper natural slope, surface water, surplus load of trees and groundwater are the causes of landslide in first category of landslide. The causes of landslide in Jamune Dhaba CMF are groundwater and toe cutting by river. The volume of landslides shows that large mass was washed out from the landslide. The slope of the Laxmi Narayan landslide is 36° and depth of failure is 7.5 m. Lasti Berenata landslide has the highest slope and middle depth of failure. Jamune Dhaba landslide has the lowest natural slope and middle depth of failure.

Fig. 1 shows that 49% of the area is covered by Lasti Berenata Landslide followed by Jamune Dhaba Landslide (26%), Laxmi Narayan Landslide (20%) and Sambot Landslide (5%). The scatter diagram in Fig. 2 illustrates that there is no direct relationship between natural slope and depth of failure of landslides in the studied area.

Soil texture in landslides

The data obtained from the laboratory analysis indicates that soils in all the landslides fall in sandy-loam texture with minor variation in sand, silt and clay proportion. Texture has great role in soil strength to stabilize forested slope. Sand is

<table>
<thead>
<tr>
<th>Landslides</th>
<th>Slope (Deg)</th>
<th>L(m)</th>
<th>Breadth (m)</th>
<th>H (m)</th>
<th>Area (m²)</th>
<th>Volume (m³)</th>
<th>F.D (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr.</td>
<td>M1</td>
<td>M2</td>
<td>Toe</td>
<td>Av. B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. Dhaba CMF</td>
<td>20</td>
<td>99</td>
<td>43</td>
<td>41</td>
<td>46</td>
<td>48</td>
<td>43.7</td>
</tr>
<tr>
<td>L. Narayan CF</td>
<td>36</td>
<td>100</td>
<td>45</td>
<td>50</td>
<td>30</td>
<td>10</td>
<td>33.75</td>
</tr>
<tr>
<td>Sambot CF</td>
<td>49</td>
<td>29</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>36</td>
<td>28.45</td>
</tr>
<tr>
<td>L. Berenata CF</td>
<td>72</td>
<td>250</td>
<td>30</td>
<td>36</td>
<td>50</td>
<td>30</td>
<td>33.85</td>
</tr>
</tbody>
</table>

Cr-crown, M1-Middle one, M2- middle two, Av. B- Average Breadth, L- Length, H- Height, F.D- Failed Depth
non-cohesive soil, whereas silt and clay are cohesive soils. Non-cohesive soil provides pore water pressure which can lowers the shear strength, but not significantly. The sufficient pore water in cohesive soils has the least strength (Johnson et al. 1988).

The Table 3 shows that the proportion of clay particles in the landslides of Laxmi Narayan and Lasti Berenata CF is higher than in other two landslides. The former two landslides contain significant percentage of sand particles with macro pore spaces that increase pore water pressure. The Laxmi Narayan CF contain relatively higher percentage of silt and clay. Higher groundwater activities due to unlined canal above that landslide and surface runoff water in monsoon saturates the soils and results in lowering of the shear strength of soils. Among the four landslides, the landslide in Laxmi Narayan CF is more vulnerable and has great chances to damage life and properties of Pharse village. Groudwater and surface water has significant roles in the landslide of Jamune Dhaba CMF. However, it is comparatively less vulnerable due to the high percentage of sand particles and gentler slope. The landslide in Sambot CF contains higher percentage of silt and clay without groundwater activities indicates it is least vulnerable.

**Vegetation analysis of landslides**

As indicated in Table 4, tree density is rich in the plot of Lasti Berenata landslide area of Naglibang-9 of Parbat District with dominant species *Shorea robusta* followed by Jamune Dhaba, Laxmi Narayan and Sambot landslide areas, respectively. Average DBH of tree species is the highest in the plot of Lasti Berenata landslide followed by Sambot, Laxmi Narayan and Jamune Dhaba landslides, respectively. Similarly, heights of tree species were almost same in the plots of four landslide areas. However, it was slightly higher in the landslides of Laxmi Narayan CF and Sambot CF. Total biomass of trees was highest (20229.96 kg) in the Lasti Berenata landslide of Parbat District with an area 8462.5 Sq.m followed by Laxmi Narayan (6843.75 kg with area 3375 Sq.m of Parbat), Sambot (1927.14 with area 813.67 Sq.m of Baglung) and Jamune Dhaba landslide, Kaski district with lowest value (1544.59 kg with area 4370 Sq.m) but, biomass of trees are distributed more uniformly (consistently) in the Jamune Dhaba area in contrast to more heterogeneity of Lasti Berenata area.

**Inferential analysis**

From parametric F-test based on one way analysis of variance (ANOVA) revealed that there was significant difference in the average biomass of trees in the four landslide areas, i.e., average biomass of at least one pair sites varies considerably out of six pair landslide areas as in Table 5 (p=0.099 <0.1). But, in multiple comparison, only the average biomass of the pair of the sites Jamune Dhaba and Lasti Berenata differ significantly from least significance difference test (LSD test) with value p=0.014<.10. Furthermore, 90% confidence intervals of these pairs excludes zero verified the significance as indicated in Table 6.

On the other hand, seedlings of the Jamune Dhaba landslide were dominated by *A. nepalenis* having average height 3.6 m followed by Laxmi Narayan, Sambot and Lasti Berenata landslide area. The study of shrubs on the sites showed that Jamune Dhaba was rich on shrub species with dominant species *Rosa brunonii* followed by Lasti Berenata, Laxmi Narayan and Sambot landslide. On the other hand, the landslide in Laxmi Narayan CF was rich on herbs/grasses.
Table 3: Particle size analysis for soil texture in four landslides.

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Selected landslides</th>
<th>Percentage</th>
<th>Soil textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jamune Dhaba CMF</td>
<td>74.5</td>
<td>18.5</td>
</tr>
<tr>
<td>2</td>
<td>Laxmi Narayan CF</td>
<td>54.5</td>
<td>28.5</td>
</tr>
<tr>
<td>3</td>
<td>Sambot CF</td>
<td>59.5</td>
<td>25.5</td>
</tr>
<tr>
<td>4</td>
<td>Lasti Benenata CF</td>
<td>64.5</td>
<td>18.5</td>
</tr>
</tbody>
</table>

Table 4: Vegetation analysis of four landslides.

<table>
<thead>
<tr>
<th>Vegetation Categories</th>
<th>Name of landslides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jamune Dhaba (4370 Sq.m)</td>
</tr>
<tr>
<td></td>
<td>131.1</td>
</tr>
<tr>
<td></td>
<td>12.53</td>
</tr>
<tr>
<td></td>
<td>10.81</td>
</tr>
<tr>
<td></td>
<td>1192.85</td>
</tr>
<tr>
<td></td>
<td>351.73</td>
</tr>
<tr>
<td>Trees</td>
<td>Total tree biomass (kg)</td>
</tr>
<tr>
<td></td>
<td>Average tree biomass (kg)</td>
</tr>
<tr>
<td></td>
<td>Standard deviation of biomass (kg)</td>
</tr>
<tr>
<td></td>
<td>Standard error of biomass (kg)</td>
</tr>
<tr>
<td></td>
<td>C.V. of biomass (%)</td>
</tr>
<tr>
<td></td>
<td>Dominant species</td>
</tr>
<tr>
<td></td>
<td>Density</td>
</tr>
<tr>
<td></td>
<td>Average height (m)</td>
</tr>
<tr>
<td>Seedlings</td>
<td>Dominant species</td>
</tr>
<tr>
<td></td>
<td>Density</td>
</tr>
<tr>
<td></td>
<td>Average height (m)</td>
</tr>
<tr>
<td></td>
<td>Dominant species</td>
</tr>
<tr>
<td>Shrubs</td>
<td>Density</td>
</tr>
<tr>
<td></td>
<td>Average height (m)</td>
</tr>
<tr>
<td></td>
<td>Dominant species</td>
</tr>
</tbody>
</table>

with dominant species *Pogonotherum crinitum* followed by Jamune Dhaba, Sambot and Lasti Benenata landslide area.

**Role of vegetation in studied landslides**

The role of vegetation in the studied landslides has not only significant role in slope instability. The uprooting of trees proves that there was not anchoring function in all the landslides due to deeper slip surface (>0.5 m) (Howell 1999). However, reinforcing function was more or less done by trees, seedlings, shrubs and herb/grass species. The comparison of landslide volume and total tree biomass with respect to studied sites is in Fig. 4. From that Jamune Dhaba landslide has a higher volume but the total fresh biomass is lowest. It shows that there is no significant role of tree species for surplus load for landslide. The Laxmi Narayan landslide has the highest materials washed out with addition of higher tree biomass. It shows the remarkable role of tree species in instability of forested slopes. The Sambot landslide shows...
Table 5: One way ANOVA of biomass.

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>Sum of Squares</th>
<th>Degree of freedom</th>
<th>Mean Square</th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between sites</td>
<td>40264.41</td>
<td>3</td>
<td>13421.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within sites</td>
<td>399793.31</td>
<td>65</td>
<td>6150.66</td>
<td>2.18</td>
<td>.099*</td>
</tr>
<tr>
<td>Total</td>
<td>440057.73</td>
<td>68</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significance at p<0.1.

Table 6: Least significance difference test (LSD) of biomass.

<table>
<thead>
<tr>
<th>Sites(I)</th>
<th>Sites(J)</th>
<th>Mean Diff.</th>
<th>Std. Error</th>
<th>P value</th>
<th>90% Confidence Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(I-J)</td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Jamune Dhaba</td>
<td>Laxmi Narayan</td>
<td>-44.54</td>
<td>27.41</td>
<td>.109</td>
<td>-90.29</td>
</tr>
<tr>
<td></td>
<td>Sambot</td>
<td>-42.046</td>
<td>26.26</td>
<td>.114</td>
<td>-85.86</td>
</tr>
<tr>
<td></td>
<td>Lasti Beranata</td>
<td>-73.59(*)</td>
<td>29.14</td>
<td>.014</td>
<td>-122.22</td>
</tr>
<tr>
<td>Laxmi Narayan</td>
<td>Sambot</td>
<td>2.49</td>
<td>24.92</td>
<td>.920</td>
<td>-39.09</td>
</tr>
<tr>
<td></td>
<td>Lasti Beranata</td>
<td>-29.04</td>
<td>27.94</td>
<td>.302</td>
<td>-75.68</td>
</tr>
<tr>
<td>Sambot</td>
<td>Lasti Beranata</td>
<td>-31.54</td>
<td>26.81</td>
<td>.244</td>
<td>-76.28</td>
</tr>
</tbody>
</table>

* The mean difference is significant at the 0.1 level.

Fig. 4: Proportion of landslide volume and total tree biomass.

Landslide in Jamune Dhaba CMF

The frequency shows that vegetation was not sufficient for stabilization of landslides due to 4.5 m failed depth, addition of 1544.59 kg fresh weight of tree species, not fulfilling anchoring function, higher groundwater activities, highly weathered rocks, surface runoff water in creeping zone and sandy loam texture.
Landslide in Laxmi Narayan CF

The frequency shows that vegetation was sufficient for slope stabilization. However, the landslide is more vulnerable due to 7.5 m failed depth, addition of 6843.75 kg fresh weight of tree species, higher groundwater activities, highly weathered rocks, surface runoff water in creeping zone and sandy loam texture. These causes were triggering factors for landslide because all causes lower the shear strength of rocks and soil masses. In this landslide, vegetation does not fulfill anchoring function for slope stability. So tree surplus load has role to landslide.

Landslide in Sambot CF

The landslide was contained only by pole-staged tree species (10 cm to 30 cm DBH). The frequency of vegetation was also sufficient for slope stabilization according to landslide area. The major cause of this landslide was toe cutting by rural road that result removal of support. When the toe was cut, the failed depth of 3.5 m was made below the anchoring function of tree roots. 1927.14 kg of fresh biomass has added extra load to the soil mass. So, the vulnerable land masses and tree biomass was fall down to the small village bazaar. The uprooting of trees proved that there is no role of vegetation to forested slope stabilization. The moderately weathered phyllite rocks with discontinuities showed that the landslide is still vulnerable.

Landslide in Lasti Berenata CF

The high coefficient of variance in Lasti Berenata CF shows that there were highly variations in trees size from smaller to larger. It provides anchoring and reinforcing engineering functions to the soil masses. The major causes of this landslide were highly weathering of rocks, higher groundwater activities, surface runoff water in creeping areas and tree surplus load. 20229.96 kg of fresh biomass with 4606.82 kg roots has added as a surplus load to the vulnerable soil masses. At this condition, the 5.5 m failed depth and uprooting of larger trees proved that there is not any role of vegetation to the slope stability means tree surplus load activate landslide.

CONCLUSIONS

The results from previous studies on the role of vegetation in sloppy land showed that vegetation mainly plays a positive role to stabilize forested-slope in shallow landslides due to fulfilling anchoring and reinforcing functions. However, in some cases they can play a negative role in slope stabilization due to addition of surplus load with respect to failed depth. All studied landslides of this research fall in deep seated landslide (greater than 3.4 m) category.

By analyzing soil texture, vegetation and socio-economic data of selected landslides, overall, vegetation has no significant role in forested slope stabilization. The role of vegetation in landslides of Laxmi Narayan CF, Lasti Berenata CF and Sambot CF was negligible. Among these three landslides, landslide in Laxmi Narayan CF is more complex and vulnerable to slope stabilization. Vegetation surplus load is not an alone triggering factor for land sliding. Groundwater activities and surface runoff water in landslides of Laxmi Narayan CF and Lasti Berenata CF were the major causes of slope instability. The major causes of the Sambot landslide were toe cutting by road construction, surface run-off water and surplus load of overlying two houses and tree species. The slip surface depth of this landslide increased when road was constructed. Water decreases shear strength of sandy loam textural soil. At this condition, total biomass of tree species in the form of surplus load to the vulnerable slope that activate movement of earth materials. The landslide in Jamune Dhaiba CMF was more vulnerable due to the causes of groundwater activities, surface run-off water and toe cutting by river.

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