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

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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 Dhaba Community Forest of Mahabharat Range of western Nepal. The landslides are in pelitic rocks suchs as phyllite, gritty phyllite and schists. The pelitic rocks are highly weathered forming sandy loam texture. The studied landslides fall in *Shorea robusta-* and *Schima walichii*-dominated forests with major tree species like *Shorea robusta (Sal), Schima walichii (Chilaune), Alnus nepalensis (Uttis), Pinus roxburghii (Loth Salla) and Lagerstroemia parviflora (Botdhainro)*. The dominant shrub species are *Osbeckia nepalensis (Angeri small), Maesa chisia (Bilaune), Rosa brunonii (Bainselu) and Woodfordia fruticosa (Dhairo). Pogonotherum crinitum (Muse Kharu), Chrysopogon sp. (Titepati), Imperata cylindrical (Siru), Bidens pilosa (Kuro), Anaphisis controta (Bukiphul), Onychyium uoponium (Chille unyu), Eupatirium odoratum (Banmara)* 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 (Pradhan 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 (Upreti 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 (Upreti 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 Mencl 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 (Upreti 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 Mencl 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 determinant 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 (Swanston 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 Dhaba 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 Dhaba 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 breadth 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 species 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 m^3

d = Diameter at breadth 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: Amatya and Shrestha 2002).

S.N	Tree species	Parameters a	b	c	Coeff.of determination (R^2)
1	*Pinus roxburghii*	-2.9770	1.9235	1.0019	99.2
2	*Shorea robusta*	-2.4554	1.9026	0.8352	98.3
3	*Schima wallichii*	-2.7385	1.8155	1.0072	98.3
4	*Alnus nepalensis*	-2.7761	1.9006	0.9428	97.8
5	*Lagerstroemia parviflora*	-2.3411	1.7246	0.9702	97.5
6	*Miscellaneous in Hills*	-2.3204	1.8507	0.8223	97.7

b and c are regression coefficients

The intercept and regression coeficients 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 compaared 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 (Howell1 999). 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 36^0 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

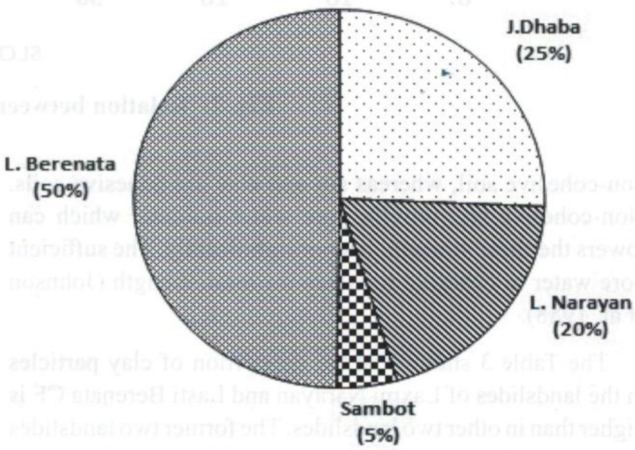

Fig. 1: Landslides area.

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 2: Landslide measurement in four sites.

Landslides	Slope (Deg)	L(m)	Breadth (m) Cr.	M1	M2	Toe	Av. B	H (m)	Area (m^2)	Volume (m^3)	F.D (m)
J. Dhaba CMF	20	99	43	41	46	48	43.7	3.0	4370	13110	4.5
L. Narayan CF	36	100	45	50	30	10	33.75	6.0	3375	20250	7.5
Sambot CF	49	29	25	26	27	36	28.45	2.7	814	2197	3.5
L. Berenata CF	72	250	30	36	50	20	33.85	2.3	8463	194634	5.5

Cr-crown, M1-Middle one, M2- middle two, Av. B- Average Breadth, L- Length, H- Height, F.D- Failed Depth

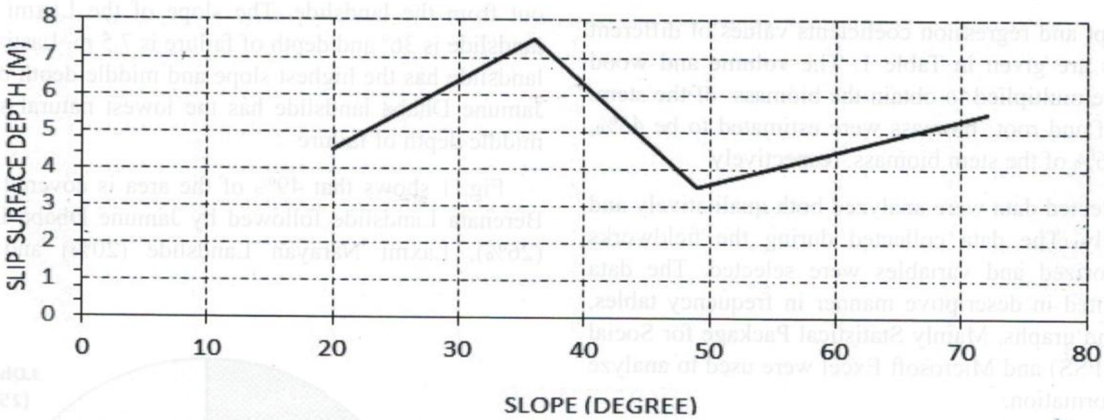

Fig. 2: Relation between slope and depth of faliure.

non-cohesive soil, whereas silt and clay are cohesive soils. Non-cohesive soil provids 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 Dhawa, 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 significannt 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 ($p=.099 <0.1$). 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 $p=.014<.10$. 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. nepalensis* 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.

S.N.	Selected landslides	Percentage			Soil textural class
		Sand	Silt	Clay	
1	Jamune Dhaba CMF	74.5	18.5	7	Sandy loam
2	Laxmi Narayan CF	54.5	28.5	17	Sandy loam
3	Sambot CF	59.5	25.5	15	Sandy loam
4	Lasti Berenata CF	64.5	18.5	17	Sandy loam

Table 4: Vegetation analysis of four landslides.

Vegetation Categories	Descriptions	Name of landslides			
		Jamune Dhaba (4370 Sq.m)	Laxmi Narayan (3375S q.m)	Sambot (813.67 Sq.m)	Lasti Berenata (8462.5 Sq.m)
Trees	Density	131.1	121.5	35.80	236.95
	Average DBH (cm)	12.53	19.88	20.40	22.42
	Average height (m)	10.81	11.94	11.61	10.95
	Above ground biomass (kg)	1192.85	5285.27	1488.28	15623.13
	Below ground biomass (kg)	351.73	1558.47	438.85	4606.82
	Total tree biomass (kg)	1544.59	6843.75	1927.14	20229.96
	Average tree biomass (kg)	11.78	56.32	53.82	85.37
	Standard deviation of biomass (kg)	5.00	76.29	26.31	148.30
	Standard error of biomass (kg)	1.29	17.98	5.61	39.63
	C.V. of biomass (%)	42.44	135.44	48.88	173.71
	Dominant species	A. nepalensis	S. wallichii	L. parviflora	S. robusta
Seedlings	Density	1398.4	1215	618.38	338.5
	Average height (m)	3.6	1.66	0.65	1.5
	Dominant species	A. nepalensis	S. robusta, A. pennata	L. parviflora	S. wallichii
Shrubs	Density	5768.4	3105	97.64	5416
	Average height (m)	1.62	1.006	0.5	0.706
	Dominant species	R.brunonii	S. cappa , I. atropurpurea	O. nepalensis	S. cappa
Herbs / Grasses	Density	961400	1019250	202034.39	431587.5
	Average height (m)	0.54	0.25	0.22	0.100
	Dominant species	E. odoratum	P. crinitum	P. crinitum	R.indica

with dominant species *Pogonotherum crinitum* followed by Jamune Dhaba, Sambot and Lasti Berenata 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.

Sources of variation	Sum of Squares	Degree of freedom	Mean Square	F value	P value
Between sites	40264.41	3	13421.47		
Within sites	399793.31	65	6150.66	2.18	.099*
Total	440057.73	68			

*Significanvr at p<0.1.

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

Sites(I)	Sites(J)	Mean Diff. (I-J)	Std. Error	P value	90% Confidence Intervals Lower	Upper
Jamune Dhaba	Laxmi Narayan	-44.54	27.41	.109	-90.29	1.20
	Sambot	-42.046	26.26	.114	-85.86	1.77
	Lasti Berenata	-73.59(*)	29.14	.014	-122.22	-24.96
Laxmi Narayan	Sambot	2.49	24.92	.920	-39.09	44.09
	Lasti Berenata	-29.04	27.94	.302	-75.68	17.58
Sambot	Lasti Berenata	-31.54	26.81	.244	-76.28	13.19

* The mean difference is significant at the 0 .1 level.

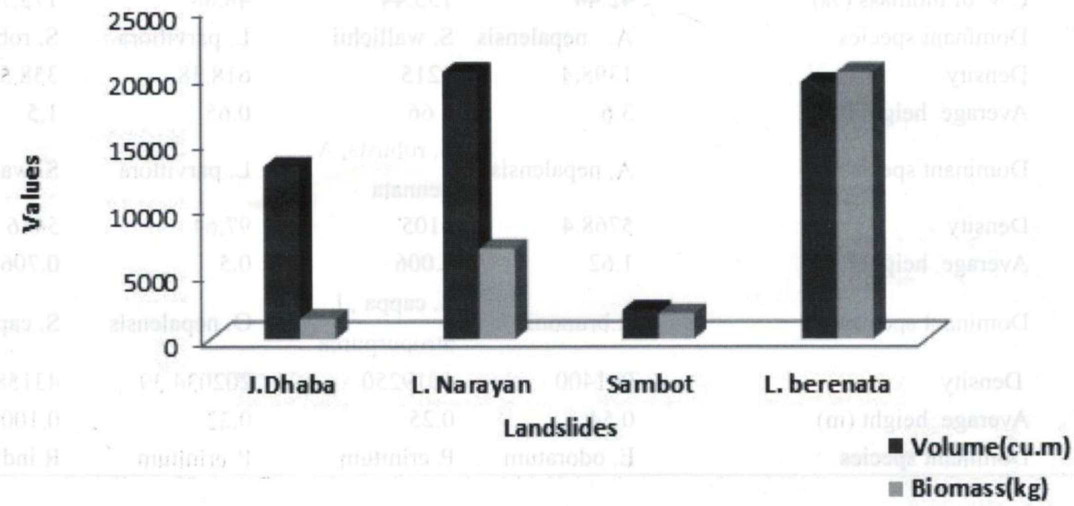

Fig. 4: Proportion of landslide volume and total tree biomass.

the smallest volume with the lowest additional tree load in comparison to the others. However, tree surplus load is a cause of landslide after rural road construction. The Lasti Berenata landslide has a higher volume with highest tree load. It indicates that the additional load of tree species could have great role in instability of forested slope with groundwater activities.

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, vegetations do 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 Dhaba CMF was more vulnerable due to the causes of groundwater activities, surface run-off water and toe cutting by river.

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