A Study of Soil Characteristics for Landslide Hazard Mapping of Nallu Khola Watershed, Nepal

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1. Introduction

Landslides are the most common natural hazards in Nepal. A systematic study of landslides, including hazard mapping and risk assessment on a larger scale, has not been undertaken in Nepal[2]. A study of landslide hazard mapping based on soil characteristics and slope analysis was carried out in Nallu Khola watershed, which is located in the middle mountain physiographic zone of central Nepal. Soil properties related to slope stability are analyzed and some geomorphological parameters considered as indicators of hazard prone areas are discussed in this paper.

2. Materials and Methods

A variety of topographic and soil characteristics exist in the Nallu Khola watershed (16.04km^2). The watershed was divided into 5 zones based on geology, soil color and topographic map of the area for soil sampling purpose (Fig. 1). Soil colors were distinguished by comparing with "Revised Standard Soil Color Charts"[1]. Four soil samples were collected from each zone. Particle size distribution was determined by the hydrometer method. Liquid limit tests were carried out by the classical Casagrande technique. Direct shear tests of air dry as well as saturated soil samples were carried out using a shear box. The rate of shearing displacement was fixed at 1mm/minute to allow full drainage of soil water. Cohesion c' (kgf/cm^2) and angle of internal friction ϕ' (degrees) were estimated for each soil in dry and saturated state. Then, the safety factor S_f of slopes were estimated by using the following equation:

$$S_f = \frac{c' + (\gamma - \gamma_w) D \cos^2\theta \tan\phi'}{\gamma D \sin\theta \cos\theta}$$

Where γ and γ_w are the densities of soil and water respectively in g/cm^3, D (cm) is the average depth of soil in each zone, and θ is the slope gradient in degrees. In the case of dry soil, γ_w is omitted. Based on S_f estimated for each zone with respect to D and different θ values, potentially unstable areas were identified. Then, the results were compared with landslide density estimated using the landslide distribution map of the study area, which was prepared by combining data taken from the field, aerial photographs and topographic map. These results were also compared with drainage densities in each zone, and average slope gradient, which were estimated from the 1:25000 topographic map.

3. Results and Discussion

The general and geomorphological characteristics of 5 zones of Nallu Khola watershed differ from each other indicating a difference in the stability of slope, as shown in Table 1. It was observed in the field that the soils are accumulated mainly by weathering of bedrock except stream sides. The relationship between slope gradient and soil depth of the sampling sites is shown in Fig. 2, which indicates that depth of soil decreases with increasing slope gradient. This relationship also indicates the development of soil by bedrock weathering, break down of balance between shear strength and shear stress due to increase in soil mass, and occurrence of landslides to attain again an equilibrium or steady state in a cyclic manner over time.

The results of all the tests are shown in Table 2. Only the soil of zone 1 is loam, the others being sandy loam. Cohesion of the soil in dry state is highest for zone 1 and lowest for zone 5 indicating that these soil have highest and lowest shear strength respectively. When these soils are saturated c' decrease drastically. In saturated state, value of ϕ' increased in case of zone 1 but ϕ' decreased to the lowest value in case of zone 5. Liquid limit is lowest for zone 4 and highest for zone 1. Values of c', ϕ' and liquid limit correspond to particle size distribution, with some exceptions. The relationship between S_f and θ for each zone, in dry and saturated states, is shown in Fig. 3. In the case of dry soil, S_f values are greater than 1 for slopes up to 40°. On the contrary, S_f values greatly decreased with respect to increase in θ for all the zones in saturated state. S_f for zone 1 and 5 drops down to the critical value 1 when θ is 26.9° and 10.2° respectively due to the difference in shear strength of the soil. This critical value of θ for zone 2, 3, and 4 lies between zone 1 and 5. At S_f = 1 in saturated state, the difference of S_f between dry and saturated state is lowest for zone 1 and highest for zone 5. This difference for zone 2, 3 and 4 is in between of zone 1 and 5. Based on these results, slope stability of each zone in decreasing order from the most stable to less stable is : Zone 1, Zone 3, Zone 2, Zone 4, and Zone 5.

The density of recent rapid-shallow landslide scars reaches maximum in zone 5, and minimum in zone 3 (Table 1). This density is slightly greater in zone 1 then in zone 3 but less than

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in all the other zones. Similarly, drainage density is maximum in zone 5 and minimum in 1. These results show almost same trend of stability order as the safety factor. Average slope gradient is highest in zone 2 and lowest in zone 3 indicating that the frequency of landslides which occurred in the past were highest and lowest in the respective zones. Based on these results, it can be inferred that future landslides will be more likely to occur similar circumstances to those of the past.

4. Conclusion

All the soils of Nallu Khola watershed are almost similar in texture except the soil of zone 1. But, mechanical properties like shear strength of the soil vary greatly in dry and saturated state from zone to zone. Consequently, the safety factor of slope also varies in the same way. Based on the safety factor, comparatively high and low landslide hazard zones are identified, which are further verified by comparing with landslide and drainage densities in each zone. Slope stability of each zone in decreasing order from the most stable to less stable is : Zone 1, Zone 3, Zone 2, Zone 4, and Zone 5. Hence, it can be concluded that a study of mechanical properties of soils provides a basis for soil slope instability or landslide hazard mapping of a watershed.

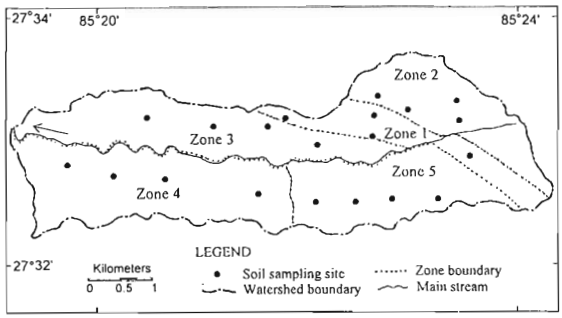

Figure 1. Map of the study area showing sampling sites in each zone.

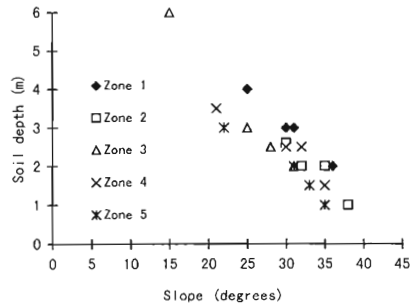

Figure 2. Relationship between slope gradient and soil depth in Nallu Khola watershed.

5. References

(1) Research Council for Agriculture, Forestry and Fisheries, Japan : Revised Standard Soil Color Charts, 1989

(2) Upreti, B. N. and Dhital M. R. : Landslide Studies and Management in Nepal. ICIMOD, Kathmandu, 1996

Table 1. General and geomorphological characteristics of five zones of Nallu Khola watershed.

Characteristics	Zones 1	2	3	4	5
Area(km²)	1.69	2.66	3.84	4.93	2.92
Soil color	10R 6/8	2.5YR 7/1	2.5YR 7/4	7.5YR 8/3	5YR 7/6
Rock type	A	B	C	D	E
Soil depth (m)	3.0±1.2	1.9±0.9	3.4±2.8	2.5±1.2	1.9±1.3
Average Elevation (m)	2080	2250	1840	1890	2010
Average slope (degrees)	30.73	37.77	24.82	30.21	28.09
Drainge density (km/km²)	5.14	7.47	6.98	8.23	10.99
Landslide density (No. /km²)					
Recent scars	4.73	7.89	3.39	8.72	14.38
Old scars	5.92	17.67	11.72	2.23	5.48
Total	10.65	25.56	15.10	10.95	19.86

10R6/8: Reddish orange, 2.5YR7/1: Light reddish gray, 2.5YR7/4: Pale reddish orange, 7.5YR8/3: Light yellow orange, 5YR7/6: Orange
A: Argillaceous and marly slate, thin limestone; B: Light, fine-crystalline limestone, partly siliceous; C: Sandstone, siltstone and sandy limestone; D: Siltstone, sandstone and phyllite; E: Phyllite, sandstone and silt stone

Table 2. Soils characteristics of Nallu Khola watershed.

Soil Characteristics	Zones 1	2	3	4	5
Textural class	Loam	SL	SL	SL	SL
Particle size distribution					
Sand (%)	52.90	60.90	56.90	52.90	58.90
Silt (%)	32.80	34.80	30.80	34.80	34.80
Clay (%)	14.30	4.30	12.30	12.30	6.30
Cohesion (kgf/cm²)					
Air dry	0.623	0.251	0.506	0.311	0.193
Saturated	0.084	0.001	0.066	0.003	0.010
ϕ' (degree)					
Air dry	28.19	35.75	33.62	32.62	25.55
Saturated	35.41	36.50	33.94	31.01	21.31
Liquid limit (%)	47.50	47.00	45.50	39.00	46.00
Bulk density (g/cm³)	1.22 ± 0.03	1.20 ± 0.05	1.23 ± 0.04	1.17 ± 0.04	1.10 ± 0.06

SL: Sandy loam

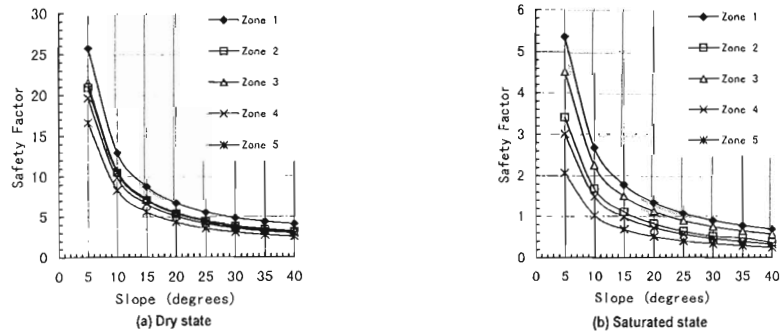

Figure 3. Relationship between safety factor and slope gradient in (a) dry and (b) saturated state.