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Landslide Hazard Zonation of Sunkoshi -2 High Dam Project area using Quantitative Methods in Geographical Information Science

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Abstract—**Landslides are one of the critical geological processes, which causes not only enormous damage to civil engineering structures such as hydropower plant, road, bridges, dams and houses but also lead to loss of life. The construction of hydropower projects involve disturbance to the natural slop making them vulnerable to landslides. Therefore, there is a need for landslide hazard zonation so that hazardous area could be stabilized before it escalates major disaster. The present study attempts to develop a landslide model by using multi-criteria decision analysis using Geographical Information Science (GIS) and remote sensing techniques.**

The proposed Sunkoshi -2 High Dam Project area was selected for the model implementation. Digital topographical data, regional geological maps, remote sensing image and field data were used as inputs to the study. The data layers represent the elevation, drainage, soil type, geology (geological faults and existing landslide), slope, aspects and land use. A numerical rating scheme for the factors was developed for spatial data analysis in GIS. The resulting landslide hazard zonation map delineates the area into different zones of three relative classes: High, Medium and Low. The present study shows that the implementation of Sunkoshi – 2 High Dam Project would make the areas at the reservoir water level more vulnerable towards landside.

Keywords—Landslide hazard zonation, multi-criteria decision analysis, quantitative methods in GIS

I. Introduction

Landslides in mountainous terrain often occur during or after heavy rainfall, resulting in the loss of life and damage to the natural and /or built environment (Fuchu et al., 2002). Earthquakes, heavy rainfall and volcanic eruptions act as natural triggering mechanisms to initiate a landslide (Kessarkar et al. 2011). On the other hand, human activities such as disturbance to the natural slopes (slope cutting) and deforestation are the anthropogenic triggering mechanism. In a high dam reservoir type projects, the frequent fluctuation in the reservoir water level will make the adjoining slope vulnerable to landslide due to variation in pore water pressure. Though landslides and related disasters occur frequently in the fragile and young Himalayan region of Nepal, there are only few studies carried out focusing on the extend, type and cause of such disasters. Very few attempts have been made on hazard mitigation and to prepare maps depicting the hazard and/or risk associated with these events. So far, the work on landslide studies in Nepal is widely scattered.

II. Description of the study area

The proposed Sunkoshi – 2 High Dam Project (1,110 MW) was first identified in the Koshi Basin Master Plan Study (JICA 1985). The project plans to construct a 166 m high dam across the Sunkoshi River along with a dam-toe power station at the left bank of the river.

Geographically, the project area is located between longitudes 86° 10' 20" E to 85° 47' 30" E and latitude 27° 14' 00" N to 27° 29' 30" N between 400 m asl to 600 m asl. The entire project components and the inundation area will be located within Sindhuli (10 VDCs), Ramechhap (23 VDCs), Kavrepalanchowk (5 VDCs) and Dolakha (1 VDC) districts of Central Development Region of Nepal.

The scheme will impound about 80 km of the river stretch and its tributaries, creating a reservoir. The reservoir will have a surface area of approximately 70 km^2 at full supply level, a gross storage capacity of 4.37 billion m^3 and an effective storage of 3.04 billion m^3. The installed capacity of the scheme has been estimated to be 1,110 MW, with an annual energy generation capacity of 4,760 GWh (JICA 1985). The project area location map is shown in Figure 1.

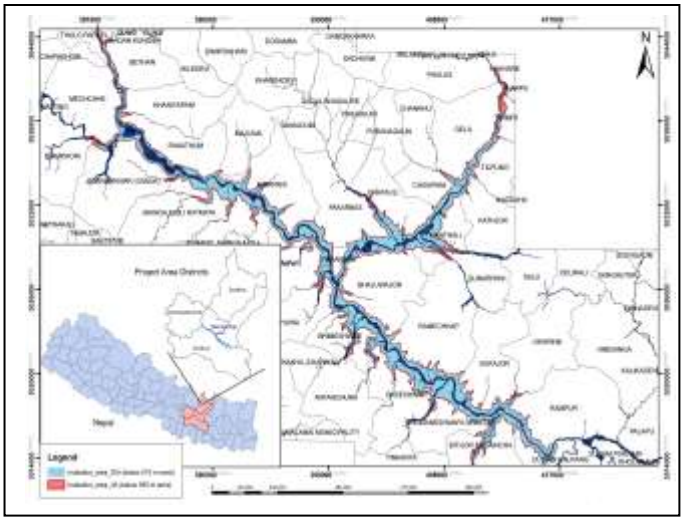

Figure 1: Project Area Location Map

III. Data Used and Methodology

Table 1: Different data layers / maps and sources

Data Layer	Sources
Remote Sensing Data	ASTER (DEM) (30 m)
Topographical map	Department of Survey (DoS), Government of Nepal (GoN) Topographical Map at 1: 25,000 scale
Land use / Land Cover Mapping (LULC)	Digital LULC map have been prepared by using Image Classification Tool in ArcGIS -9.3
Soil Map	Soil map of the area has been prepared as per the information from field investigation.
Geological map	Regional Geological Map of project area (Source: Modified after DMG, 1984)
Drainage density, Slope and aspect Map	Drainage network and drainage density have been created in GIS environment using DoS Map at 1:25,000 scales. Slope and aspect maps have been created using Spatial –Analyst Extension in ArcGIS-9.3 and Aster (DEM) data.
Existing Landslide and Location of Main Central Thrust Map	Existing landslides and location of MCT have been mapped through field investigation and referenced from regional geological map.

IV. Result and Discussion

Geomorphology: Sunkoshi River originates in Tibet and crosses the Himalayas from north to south, and then flows eastwards along the mid hills (Mahabharat) where many tributaries such as the Indrawati, Tama Koshi, Rosi Khola, Likhu Khola and Dudh Koshi join in. The total length of the Sun Koshi River is approximately 330 km, of which 280 km lies in the Nepalese territory. The gradient of the river is approximately 1/210 throughout the entire length of its course in Nepal and 1/450 between Tribeni and Dolalghat. Sun Koshi, Tamur and Arun rivers meet at Tribeni and the Indrawati River joins the Sun Koshi River at Dolalghat. The River is a combination of glacier fed and perennial rivers. Indrawati, Tamakoshi and Balephi are the major glacier fed tributaries upstream of the proposed dam site.

Elevation: The highest water level in the reservoir of the proposed project is 575 m, while the low water level is 516 m asl. This elevation range between 500 – 600 m asl will be vulnerable to landslide due to differential pore water pressure as a result of frequent fluctuation in the reservoir water level during the its operation. Moreover, the other factors such as slope, aspects and vegetation cover will also influence the sliding activities at this elevation range.

Drainage Density: Rivers and streams pass through weak geological formation indicating the area with higher possibilities for geological hazard such as landslide. Higher the drainage density greater is the possibilities for landslide. The drainage density map (number per square km) is shown in Figure 2.

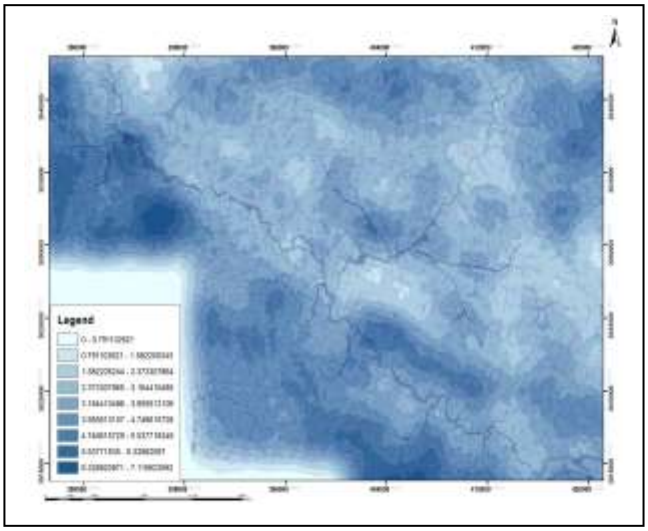

Figure 2: Drainage density map of the project area

Geological Structures: The major rock type of the project area are south dipping biotite schist, psammatic schist, quartzite and few carbonate bands which are intruded by injection gneisses. The Main Central Thrust (MCT) zone runs along the right bank of Sunkoshi River at the region upstream from the confluence of Sunkoshi River and Tamakoshi River.

The thrust crosses the river at the confluence and runs along the left bank passing the proposed dam and powerhouse area.

Some active landslides were observed in the project area along some stretch of MCT. Since, the MCT is sheared zone; the seismic waves generated due to tectonic activity triggers the landslide around this zone. Figure 3 shows the regional geology map of the project area.

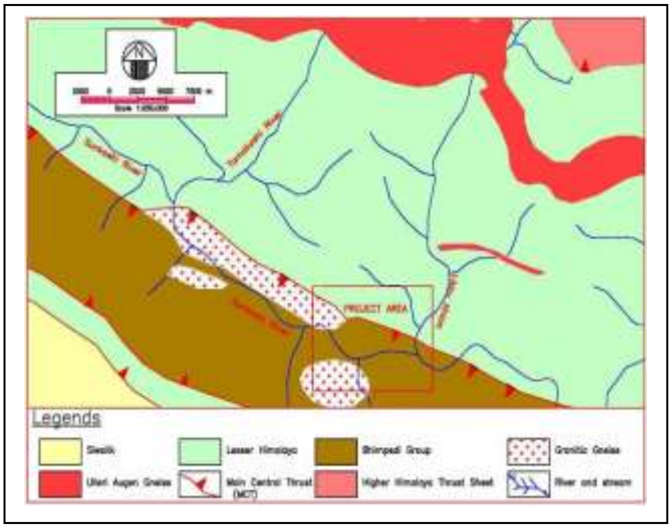

Figure 3: Regional Geological Map of project area (Source: Modified after DMG, 1984)

Slope gradient: Slope plays an important role in governing the stability of a terrain. As the slope increases, chances of slope failure also increase. However, variations in soil thickness and strength are two factors which vary over a wide range for both failure and non-failure sites (Borga, et al. 2002).

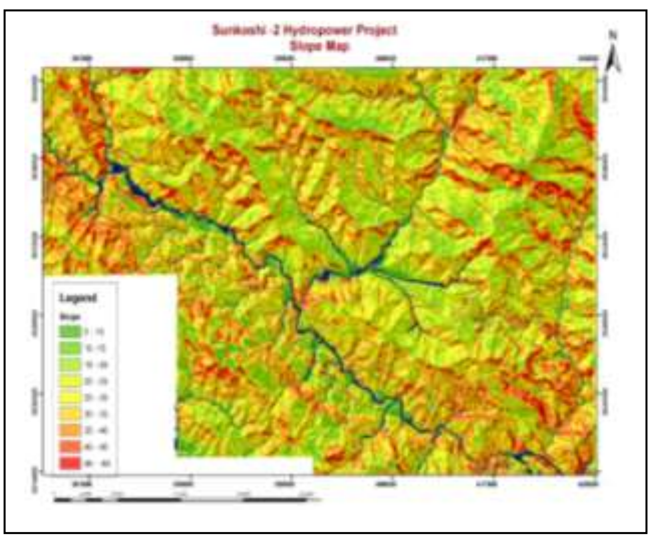

Figure 4: Slope Map of the project area

Aspect: The related parameters of aspect such as exposure to sunlight, drying winds, rainfall and discontinuities control the occurrence of landslides. Aspect degree are classified according to the aspect class as flat, north, east, south and west. The slope aspect map of the project area is shown in Figure 5.

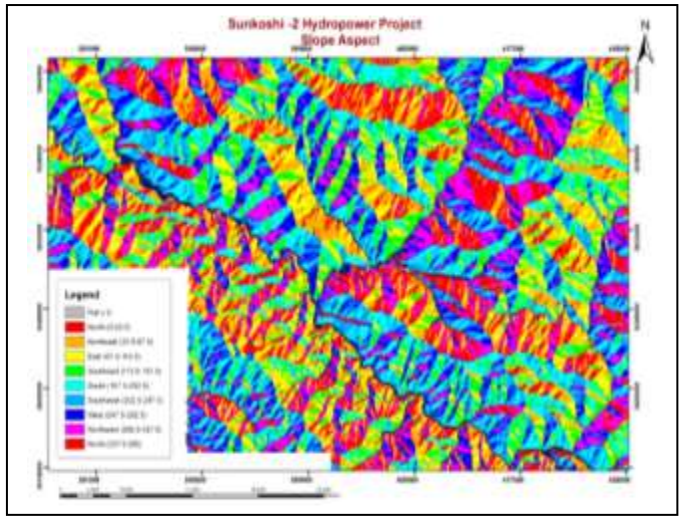

Figure 5: Slope Aspect Map of the project area

Land Use and Land Cover: Land use and land cover play an important role in instability of slope. Studies have shown that land-use or vegetation cover, especially of a woody type with strong and large root systems, help to improve stability of slopes (Dai et al. 2002).

Figure 6: Land use Map of the project area

Soil Type: The major soil types found in the project area are alluvial soil, residual soil and colluvial soil. Alluvial soil is present on either side of river terraces and consists of sand, gravel and boulder. Residual soil is present on the old terrace that consists of settlement and cropland. Colluvial soil is present along the gentle slope of the mountain and old landslide area. The soil cover of the project area is closely related with the land use pattern.

Landslide Hazard Zonation

The landslide hazard zonation map has been prepared by computing landslide potential index and classifying landslide potential index into several landslide susceptible zones such as low, medium and high. The landslide potential index is defined as:

Landslide Potential Index (LPI) = $\sum$n i = 1 (Ri * Wi)

Where Ri denotes the rank for factor i and Wi denotes the weight of class of factor i. In this study, the total number of factors (n) is eight.

Rank and weights of factors for landslide: The landslide hazard evaluation factor weights scheme is a numerical system that depends on the relevant factor. Ranks and weights of causative factors (parameters) need to be assigned in order to generate a landslide hazard zonation map. The relevant factor for landslide hazards zonation mapping shall include the major factors such as terrain slope, terrain height, drainage density, soil type, land use, aspect, presence of major geological faults and existing landslides. The stability of an area depends on the combined effects of the factors indicated above. The maximum landslide hazards evolution factor weights for different categories are determined based on their estimated significance in causing instability.

Table 2: Rank and weights of factors for landslide

Factor	Classes	Ranks (Ri), in %	Weights (Wi)	Remarks
Terrain Height (m asl)	370 – 400 400 – 500 500 – 600 600 – 700 700 – 800 >2000	13	8 9 10 8 6 1	The elevation range between 500 - 600 is vulnerable as it is the reservoir water fluctuation level.
Land use	Airport Rock exposure Cultivation Forest Grass land Bush land Degraded Forest River bank Barren land	12	1 1 5 2 7 7 8 8 9	Land use type such as barren land, degraded forest, bush land, grassland and agricultural land are highly susceptible to landslide.
Soil Type	Alluvial Colluvial Residual	11	5 9 7	Colluvial soil is the product of landslide, present on older landslide and sloppy area.
Aspect	Flat North Northeast East Southeast South Southwest West Northwest	10	Null 8 7 4 2 1 3 4 5	North facing slopes are susceptible to landslide due to lower vegetation and moist soil (low sunlight)
Terrain Slope (degree)	25 – 30 30 – 35 35 – 40 40 – 45 45 - 60	16	5 6 7 8 9	Steeper slopes (>40^0) are prone to landslide.
Drainage Density	High Medium Low	14	9 4 1	The area with higher drainage density has greater possibilities for landslide.
Existing Landslide (distance in meters from centre)	0 – 5 5 – 10 10 – 15 15 – 20 >40	15	9 8 7 6 1	The area of and adjoining to the existing landslides are susceptible to landslide
Presence of geological thrust, MCT (distance in km)	0 – 5 5 – 10 >40	9	9 6 1	Greater tectonic activities at MCT zone. However, the project itself will not cause to accelerate such activities.

The important factors responsible for the landslides were rated as percentage. Weights were assigned to the factors on 0 to 9 scales, where higher weight indicates a greater susceptibility to landslide occurrence. The details of ranks and weights for factors and their classes are presented in Table 2. After collecting pertinent data from the available sources described earlier, initial data maps were re-classified according to the weights given in Table 2.

Total Estimated Landslide Hazard Zonation (TELHZ) values: The landslide model is created and the ranks and weights are assigned to each category.

TELHZ Value = $T_H + L_U + S_T + S_A + T_S + D_D + E_L + G_T$

Where, TELHZ Value = Sum of Ratings of all causative Factors, T_H = Terrain Height, L_U = Land use, S_T = Soil Type, S_A = Slope Aspect, T_S = Terrain Slope, D_D = Drainage Density, E_L = Existing landslides and G_T = Major Geological Thrust

Based on TELHZ values three landslide hazard zones were categorized as shown in Figure 7.

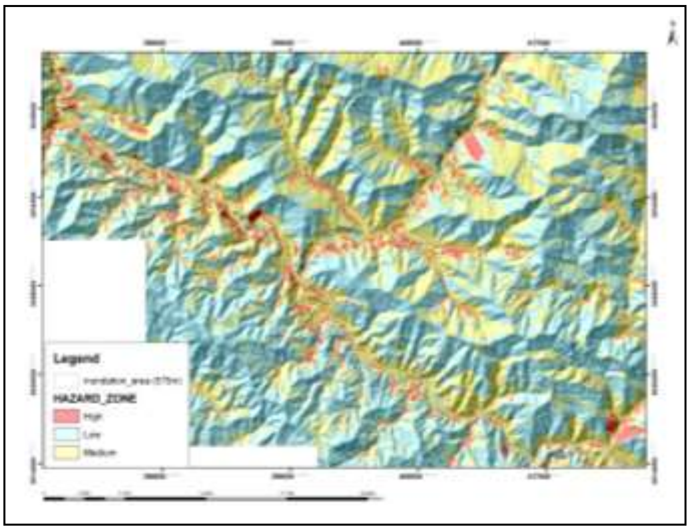

Figure 7: Landslide Hazard Map of the project area

V. Conclusion

The present study shows the application of GIS and remote sensing technique in landslide hazard mapping. The study identified the areas that will be prone to landslide during the project implementation. The area particularly the reservoir water level should be treated with greater care to minimize the landslide hazard during the reservoir operation. Further risk analysis (depending upon the households located on the high hazard zone) is recommended for planning the evacuation, resettlement and landslide protection measures.

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