GIS Based Landslide Hazard Mapping of Nallu Khola Watershed of Lalitpur District, A Case Study from Central Nepal

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Abstract:
Nepal frequently suffers from various types of water induced disasters like soil erosion, landslide, debris flow, flood etc. To mitigate the problem related to Landslides & Debris flow, Landslide Hazard zonation is important to quick and safe mitigation measures and make strategic planning for the future by identifying the most vulnerable areas and channelizing most of the protective measures and techniques to a more focused area.

This paper deals with landslide hazards analysis of Nalukhala watershed, Kathmandu, Nepal, using Geo-graphic Information System (GIS) and remote sensing data. Topographical/geological data and satellite image were collected and processed using GIS and image processing tools. The major factors used for the preparation of hazard zonation map were danger, slope aspect, relief, geology, internal relief and landuse. Data used to construct the landslide hazard maps were obtained form published works, topographical and geological maps, satellite images, and aerial photographs and other digital sources. Map compilation was accomplished using ARC View GIS 3.2, ILWIS 3.4 and SINMAP. Land slide susceptibility was analyzed using landslide-occurrence factors employing the probability frequency ratio model. The analysis of the map showed that the major landslide and debris flow causing factor were deforestation, road construction, unmanaged cultivation practice etc. This information could be used to estimate the risk to population, property and existing infrastructure like transportation network.

Key Words: *Landslide, Geographic information system, Frequency Ratio, Remote sensing, Debris Flow*

1. Introduction:

The Himalaya originated by the collision of two continental plates, the Tibetan and the Indian. This collision resulted in the formation of 2400 km long Himalayan belt, of which Nepal Himalaya occupies the central part of the belt with the length of 800Km. The Himalaya is seismically active and very fragile due to its inherently weak geological characteristics. Earthquake, landslides, floods, debris flow, and soil erosion has been significant phenomenon in loss of life and property in country like Nepal.

A hazard is defined as the probability of occurrence, within a specified period of time and within a given area, of a potentially damaging phenomenon (Varnes 1984 and UNDRO 1991). Most of such disasters are caused due to the natural and physiographical conditions of the country owing to its rugged topographically and weak geological formations, glacial lake outburst, flood, and concentrated heavy rainfall in monsoon and whereas several of theses are also attributed to human reasons such as excessive deforestation, poverty, unscientific land utilization etc. Initiation of many small and shallow landslide and debris flow scars during and after highly localized heavy precipitation events like in the Madi watershed in between 1948-1955 has also been reported from other areas of Nepal in recent years (Manandhar and Khanal 1988, Dhital et al. 1993, Upreti and Dhital 1983, Khanal 1998)

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2. Study Area:

The Nallu Khola watershed is situated at the northern face of the hills in Lalitpur district, about 17 Km south of the Kathamdu Valley. Its elevation ranges form 1510m to 2462m. The Nakhu Khola is being drained by the nallu Khola, the Lele Khola and Bhurunchuli Khola. The Nallu Khola is one of the tributaries of the Nakhu Khola. The The watershed area of the Nakhu Khola at Tikabhairab is 43 sq.km. The longitiudinal profiele of different streams in the watershed is shown in fig.1.The area of the Nallu Khola watershed is 23.4 sq.km.

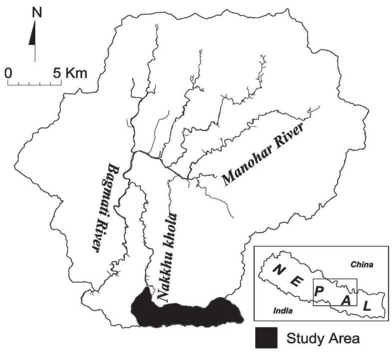

Fig 1: Map showing study area, Nallu Khola watershed

2.1 Historical Background of Disaster in the Study Area

On 30^{th} September 1981, heavy rainfall in the catchments area of Nakhu Khola caused debris flow in Nakhu Khola which swift away many person and caused heavy damages to houses, agricultural land, roads, irrigation canals(DWIDP).

As per the record obtained at that period from the Godawari station, the rainfall occurred for five consecutive days before the disaster (25 September 1981). The total depth of rainfall recorded at Godawari station by DHM (nearest station to watershed), was 266.7 mm which is 14% of the mean annual rainfall at Godawari. The peak flow of the flood contained not only water but also much sediment. When the sediment concentration reaches more than 50% in the flow then the power of the flood and debris become highly devastating. Due to the debris flow condition of Nallu Khola accompanied by high velocity, people did not have sufficient time to evacuate. Therefore, many people were swift away by debris flow. Field survey done after the event of 1981, indicated the Nallu Khola was the source of debris.

3. Methodology:

Data used to construct the landslide hazard maps were obtained form published works, topographical and geological maps, satellite images, and aerial photographs and other digital sources. Map compilation was accomplished using ARC View GIS 3.2, ILWIS 3.4 and SINMAP. Land slide susceptibility was analyzed using landslide-occurrence factors employing the probability frequency ratio model.

Frequency ratio model and relationship between landslides and landslide-related factors

In general, to predict landslides, it is necessary to assume that landslide occurrence is determined by landslide-related factors, and that future landslides will occur under the same conditions as past landslides **(Pradhan, A.M.S. (2003)**). Using this assumption, the relationship between landslides occurring in an area and the landslide-related factors can be distinguished from the relationship between landslides not occurring in an area and the landslide-related factors. We used the frequency ratio to represent the distinction quantitatively. The frequency ratio is the ratio of the area where landslides occurred to the total study area, and also, is the ratio of the probabilities of a landslide occurrence to a non-occurrence for a given factor's attribute. Therefore, the greater the ratio above unity, the stronger the relationship between landslide occurrence and the given factor's attribute, and the lower the ratio below unity, the lesser the relationship between landslide occurrence and the given factor's attribute (Saro Lee1 and Biswajeet Pradhan[2] (2006**))**. To calculate the frequency ratio, a table (table 2) was constructed for each landslide-related factor. Then, the ratio of landslide occurrence and non-occurrence was calculated for each range or type of factor, and the area ratio for each range or type of factor to the total area was calculated. Finally, the frequency ratio for each range or type of factor was calculated by dividing the landslide-occurrence ratio by the area ratio. The factors chosen such as slope, aspect, relief, internal relief, geology, landuse, precipitation, and vegetation index were evaluated using the frequency ratio model to determine the level of correlation between the location of the landslides in the study area and these factors. Probabilistic approaches are based on the observed relationship between each factor and the distribution of landslides.

4. Result and Discussion:

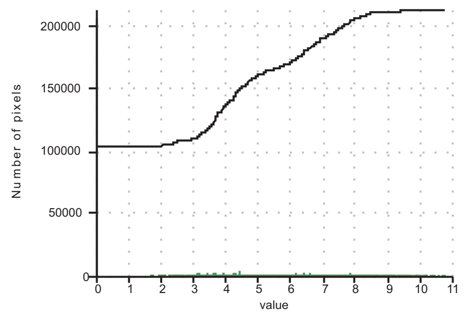

Fig. 2: Frequency Ratio curve

Table 1 : Range Allocated for the grouping of Hazard types.

Hazard type	Range
Low Hazard	<4.1
Moderate	4.1-8
High Hazard	>8

The relationship between landslide occurrence and slope (table 2) shows that cliff slopes have greater landslide probabilities. Below slopes of 35æ%, the frequency ratio were less than 2, which indicates a very low probability of landslide occurrence. For slopes above 35æ%, the ratio was >1, which indicates a high probability of landslide occurrence. As the slope angle increases, then the shear stress in the soil or other unconsolidated material generally increases. Gentle slopes are expected to have a low frequency of landslides because of the generally lower shear stresses associated with low gradients. Steep natural slopes resulting from outcropping bedrock, however, may not be susceptible to shallow landslides. In the case of the aspect (table 2), landslides were most abundant on south-facing, Southeast-facing and North-facing slopes. The frequency of landslides was lowest on east-facing, west-facing, and northwest-facing slopes, except in flat areas. The frequency ratio of land slide was highest in low relief. While high and moderate relief were lowest frequency ratio. In case of internal relief (table 2), landslide were most abundant in Very high-internal relief and High internal relief. The frequency ratio was lowest in low internal-relief slope. In the case of landuse, Freqency Ratio of cultivated land were hight and is greater than 1. The frequency ratio was lowest in case of bush and forested area. This might be due to unmanaged agriculture practice. The relationship between geology and landslide (table 2), the frequency ratio of Tistung formation and talus formation were highest. Where frequency ratio of Chandragiri formation and sopying formation were lowest.

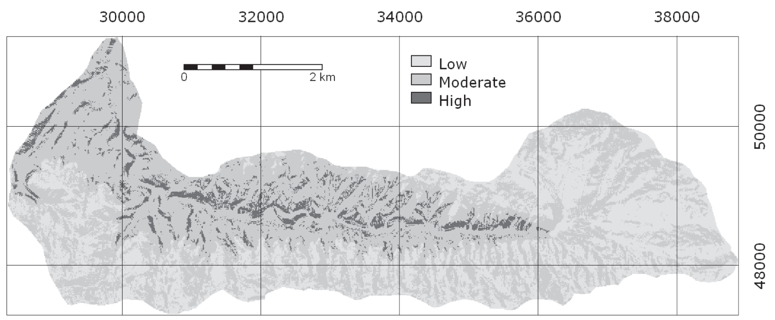

Fig 3. Landslide Hazard map of Nallu Khola Watershed.

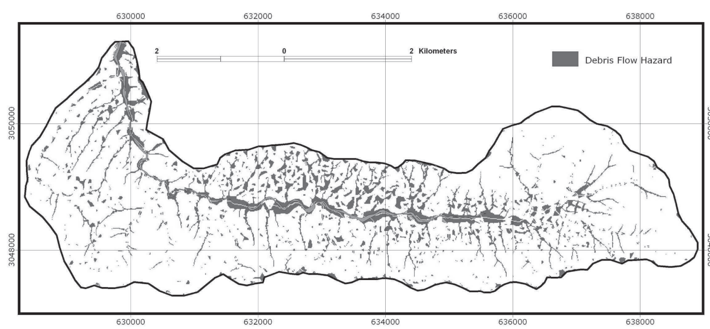

Fig 4: Debris Flow map of the Study Area.

Area occupied by different Hazard categories

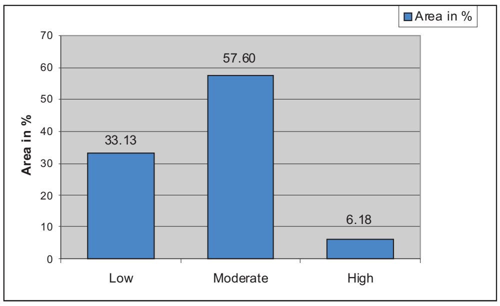

Fig. 5: Area occupied by different Hazard categories.

Table No.2 Calculation of frequency Ratio for each attributes class.

Attribute Map	Classes	Parameter		Landslide		Frequency Ratio
		Area	Area%	Area	Area%	
Slope	Gentle (<15)	3627600	15.970	11100	10.335	0.647
	Sloping (15-25)	4847200	21.339	20800	19.367	0.908
	Moderate(25-35)	7031100	30.953	29200	27.188	0.878
	High(35-45)	4214000	18.551	21800	20.298	1.094
	Cliff(>45)	2489500	10.960	24500	22.812	2.081
Aspect	N	1789300	7.877	11700	10.894	1.383
	NE	3068100	13.507	14600	13.594	1.006
	E	2305100	10.148	8800	8.194	0.807
	SE	2027900	8.927	16900	15.736	1.763
	S	2030100	8.937	22300	20.764	2.323
	SW	2595600	11.427	18800	17.505	1.532
	W	3008500	13.244	4800	4.469	0.337
	NW	3842800	16.917	4600	4.283	0.253
	N1	1513200	6.662	4900	4.562	0.685
Releif	Low(<1800m)	8319100	36.623	107400	100.000	2.731
	Moderate (1800-2100m)	10681200	47.022	0	0.000	0.000
	High relief(>2100m)	3706300	16.316	0	0.000	0.000
Internal Relief	Low(<15m)	3146500	13.852	11600	10.801	0.780
	Moderate(15-30)	9430100	41.514	35200	32.775	0.789
	High(30-45)	7431900	32.717	38300	35.661	1.090
	Very High(>45)	2008900	8.844	22300	20.764	2.348
Landuse	Bush	2317665	10.203	0	0.000	0.000
	Cultivation	9067125	39.916	54600	50.838	1.274
	Cutting	35594.05	0.157	0	0.000	0.000
	Forest	11084979	48.799	33800	0.093	0.002
	Sand	210064.4	0.925	100	0.093	0.101
Geology	Chandragiri Formation	3770700	16.600	0	0.000	0.000
	Sopying Formation	1022600	4.502	0	0.000	0.000
	Talus Deposit	1689500	7.438	14200	13.222	1.778
	Tistung Formation	16232100	71.458	93200	86.778	1.214

Hazard Zonation	Low	7525600	33.130	0	0.000	0.000
	Moderate	13083100	57.596	53200	49.534	0.860
	High	1404300	6.182	54200	50.466	8.163

5. Conclusion:

Almost 60 % of the study area lies in moderate to high hazard class of the hazard map prepared after detailed investigation of the factors that might be responsible for the onset of the landslides. This agrees with the fact that weak geological make of the slope forming mass of the lesser himalaya are greatly susceptible to landslide hazards.

The study also revealed that among slope classes, the moderate slope class(25-35^0) has the most control over the occurrence of landslide. It is due to the immediate slope classes such as moderate slope class (25-35^0) is less stable than both the high angled slopes and low angled slopes.

Though the study area is almost equally occupied by NW, W, N, NE, slopes, the high percent occurrence in the S ,SW and SE-facing slopes (Fig.13 , Fig.14) might be because of rain inducing wind in the area might enter the area form South, S western and South Eastern flank, increasing the load of the slopes, acting as lubricants and causing the slopes to fail.

The study area is characterized by the moderate relief(1800-2100m) and low relief(<1800m) category, landslide occurrence is only seen in the low relief(<1800m)category. The study area is almost equally occupied by high internal relief (30-45m) and moderate internal relief(15-30m). Landslide is found mainly in Tistung formation. Tistung formation consist greenish grey to brown fine grained phylites and slates interbedded with metasandstone and quartzites with thin bands of argillaceous limestone. Locally weather. Total thickness about 300m.

Large area is occupied by Forest and is followed by cultivation land. Large percentage of landslide occurred in cultivated land. It might be because of unmanaged agriculture practice. So appropriate methodology should adopt to reduce future impact. To reduce future impact, hazard mapping is suitable approach for planners, decision makers. Agriculture practice should be improved. The study focused mainly on the identification and classification of the hazardous zones as well as the identification of the causes debris flow, causes of slope instability that will help direct the preventive works to areas of high susceptibility indicated as high hazard regions on the hazard zonation map, so as to minimize the implications of such natural hazards by methods such as the bio-engineering techniques or immediate mechanical intrusion for eg, Gabion wall, Check dams etc. Before construction of road and any other physical infrastructure environmental component should be evaluated accurately weather the area is suitable for the construction or not, which may help in reducing the future loss.

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