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Landslide hazard mapping in Nepal: case studies from Lothar Khola (central Nepal) and Syangja district (western Nepal)

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ABSTRACT

The present paper attempts to evaluate the present status of hazard mapping in Nepal and describes the case studies of landslide hazard mapping of the Lothar Khola (central Nepal) and Syangja district (western Nepal) by two different methods: 1. The rating method proposed in the Mountain Risk Engineering (Deoja et al. 1991), and 2. Bivariate Statistical method developed by the Institute of Aerospace Survey and Earth Sciences (ITC), The Netherlands (Van Westen 1997). The first method is a manual one and used to make hazard map of the Lothar Khola watershed while the second one is GIS based and was utilized to produce hazard map of the Syangja district. Potentially unstable slopes were mainly found on the slopes ranging from 26-40°, residual soil cover, and in areas underlain by the slate and phyllite. Interestingly the slope movement is high in the areas covered by forest in comparison to the cultivated slopes.

INTRODUCTION

Nepal is located in the very heart of the Himalayan arc covering nearly one third of the 2,400 km long Himalayan mountain range. Nepal has roughly a rectangular outline with an area of about 147,181 km^2 and is bounded by the northern latitudes 26° 22' N and 30° 27' N and the eastern longitude 80° 04' E and 88° 12' E. Its length is about 885 km from east to west and the width varies from 130 km to 255 km. Nearly 83% of the country falls within the mountainous terrain and the remaining 17% in the south lies in the alluvial plains.

Many hill villages in Nepal are situated on or adjacent to unstable slopes and old landslides, which are reactivated from time to time. In recent years, cases of infrastructure damage by mass movements have increased steadily. The economy of the country is seriously strained because of the extensive rehabilitation work to be carried out every year. A significant reduction in landslide losses can be achieved by preventing or minimizing the exposure of facilities to landsliding by using hazard maps, which can be used to predict the relative degree of hazard in a given area.

Although the people of Nepal are suffering from the landslides at such a large scale, systematic study of landslides including hazard mapping and risk assessment has not begun yet. In Nepal, most of the landslide studies are confined either to the individual cases or the hazard-prone sectors of linear infrastructures. The landslide studies in Nepal are carried out by various professionals from the governmental departments, non-governmental and international organizations, and the academic institutions. The area of investigation, methodology applied, and the classification schemes followed by the investigators differ considerably.

This paper attempts to present the status of hazard mapping in Nepal and describe the two case studies of hazard mapping carried in the Lothar Khola watershed, central Nepal, and Syangja district, western Nepal. Manual method was applied to produce hazard map of the Lothar Khola watershed, whereas the Geographic Information System (GIS) was utilized for making hazard map of the Syangja district. Data for both the methods were collected from existing various maps and intensive fieldwork.

STUDY AREA

Lothar Khola watershed

The Lothar Khola watershed lies at the southern slopes of the Mahabharat Range in the Central Development Region of Nepal (Fig. 1). The watershed occupies about 169 km^2. The Lothar Khola is formed by nine small streams mainly flowing from north to south. The Lothar Khola flows along the north-south direction and passes through the Siwaliks before joining the East Rapti River. The river gradient of the streams that are higher at upper reaches of the watershed becomes gentle at the flat valley and flow into the ancient alluvial deposits.

Geologically, the Lothar Khola watershed consists of the rocks of the Upper Nawakot Group, Bhimphedi Group and Siwalik Group (Stöcklin 1980). The Upper Nawakot Group is composed of the Benighat Slate, Malekhu Limestone, Robang Phyllite and Metadiabase Amphibolite. The north-eastern part of the area is covered by the formations of the Bhimphedi Group whereas the southern part is covered by the rocks of the Siwalik Group (Fig. 2).

Syangja district

The Syangja district is situated in the Western Development Region about 200 km west from Kathmandu, the capital city of Nepal (Fig. 1). The study area is located at

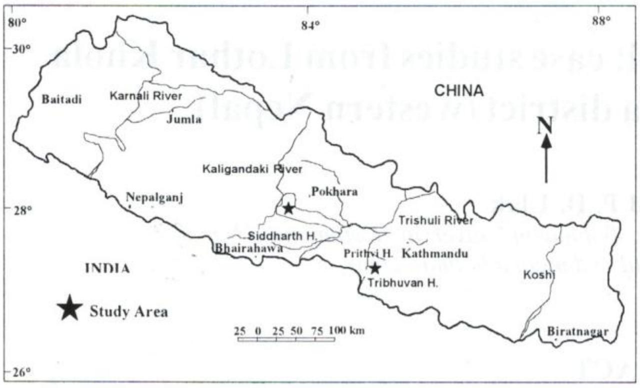

Fig. 1: Location map of the study area.

83° 25' 20" E to 83° 57' 45" E longitude and 27° 52' 20" N to 28° 12' 40" N latitude. It occupies 103,687 ha and divided into the sixty-two Village Development Committees.

Geologically, the Syangja district lies in the Lesser Himalaya. The rocks of the Syangja district are represented by quartzite, phyllite, metasandstone, slate, dolomite and limestone belonging to the Nawakot Complex (DMG 1999a, 1999b, 2000a, 2000b and 2000c), which comprises the low-grade metamorphic rocks. The main geological structures of the district are thrusts and faults. The thrusts are extending from north-west to south-east in direction whereas the faults are north-east to south-west in direction. The lineaments are directed towards north south.

PRESENT STATUS OF LANDSLIDE STUDIES AND HAZARD MAPPING IN NEPAL

Though landslides and related disasters frequently occur in the fragile and young Himalayan region of Nepal, there are only a few studies carried out by some institutions or individuals focusing on the extent, type, and causes of such disasters. Most of these investigations are of preliminary type. Very few attempts are made so far towards mitigating the hazards and preparing maps depicting the hazard and/or risk associated with these events. So far the works on landslide studies in Nepal are very widely scattered and the study is carried out by a large cross-sections of Government, Non-Government organizations and academic institutions.

Various methods of hazard assessment have been proposed and demonstrated in Nepal (e.g., Kienholz et al. 1983; Kienholz et al. 1984; Deoja et al. 1991; Dhital et al. 1991; Dangol et al. 1993; DPTC/TU 1994a and 1994b; Sikirikar et al. 1998; Dangol et al. 2002). Upreti and Dhital (1996) summarized various examples of landslide hazard mapping throughout Nepal.

Among several methods available for landslide hazard mapping, the method proposed by Deoja et al. (1991) has been widely applied in several landslide hazard mapping in Nepal, especially along the road corridors. For this mapping method requires the preparation of maps, which deal with natural states such as engineering geological conditions, slope and aspect as well as hydrological and land use conditions. Data are acquired by the study of aerial photos, topographical and geological maps, published and unpublished reports, and fieldwork. The landslide hazard map is finally prepared by superimposing all of the concerned maps and other relevant data.

Computer-aided landslide hazard mapping has been also used in Nepal. Based on the studies in Nepal, Wagner et al. (1990) developed the program "SHIVA" to make soil and rock hazard maps. This method takes into account the slope angle, lithology, rock structure, soil type, soil depth, hydrology, hydrogeology, and tectonics. The maps and data and produces the hazard maps. Hazard maps of a few area in Nepal were prepared using the software "SHIVA" (Dangol et al. 1993).

With the advent of Geographic Information Systems (GIS), their use for landslide hazard assessment has been increasing constantly in recent years (Carrara et al. 1991; Chacon et al. 1993; Akojima 1996; Van Westen 1997). GIS is a powerful tool for data storage, management, analysis, modelling and cartography. Many GIS softwares have also the capability of satellite image processing.

LANDSLIDE HAZARD MAPPING IN LOTHAR KHOLA WATERSHED

In the present study, the method proposed by Deoja et al. (1991) was largely followed. For this purpose, basic maps are prepared which include the slope map (Fig. 3), the engineering geological map (Fig. 4), the land use map (Fig. 5), the hydrogeological map, and the morpho-structural map for the individual river basin under study. It can show not only the hazard level (i.e. low, medium, high, very high) but also the major type of failure, extent, and direction of movement in case of failure. The landslide hazard map is prepared by superimposing all the above maps and other relevant data. In this method soil slope hazard map and rock slope hazard maps are separately prepared. The preparation of hazard maps is based on the calculation of the total hazard rating from each component in rock and soil. The hazards are categorized into low, medium and high hazards depending upon the total value of ratings. The main components considered in the hazard mapping are described below.

Hazard Components for Rock Slopes

Structural Component

It is defined by the geometrical relationship between the structural patterns of rocks with the inclination and direction of the natural slope. The structural component is rated on the basis of potentially unstable discontinuity planes and wedges. The structural relationship is found out by plotting the dip directions of rock discontinuities (bedding or foliation and joints) on the Schmidt net. The rating increases with the rise in the number of wedges and planes converging towards the direction of the natural slope (Table 1).

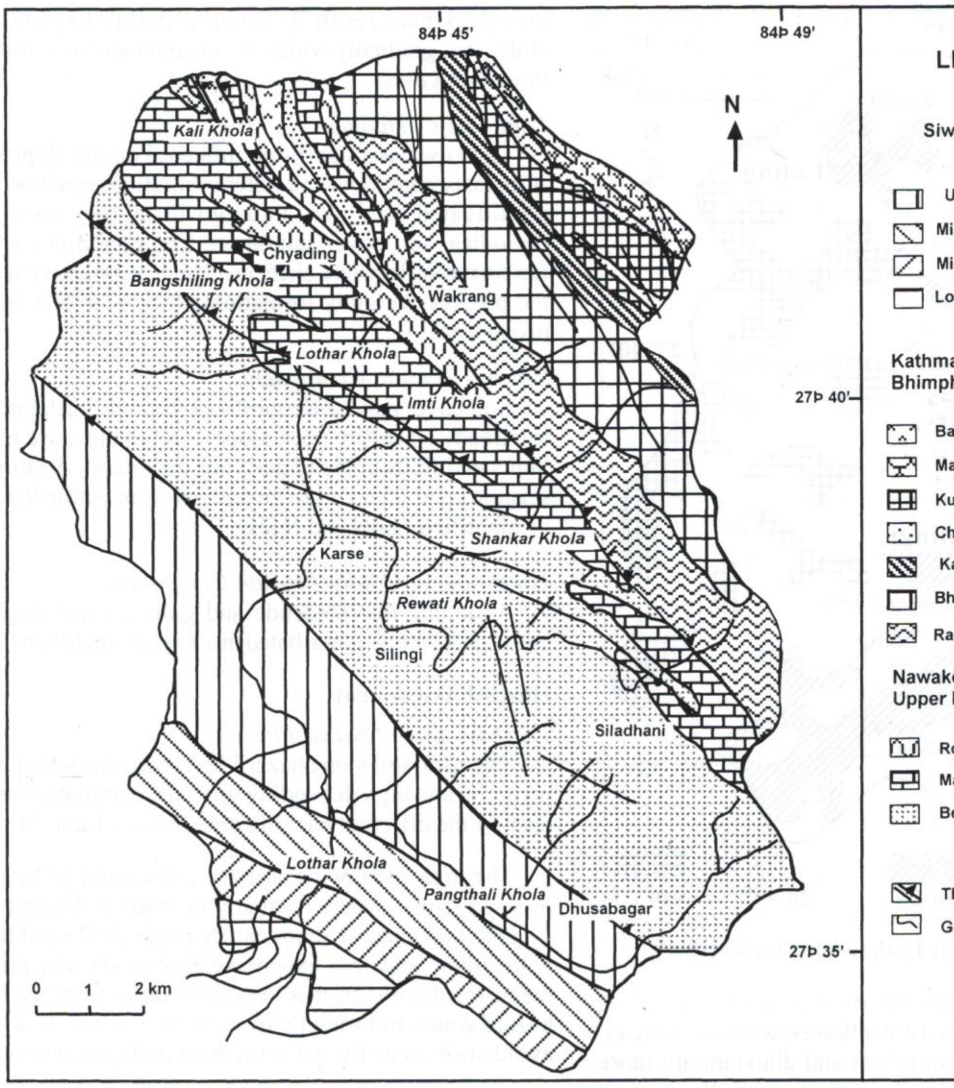

Fig. 2: Geological map of the Lothar Khola watershed.

Geo-mechanical (or Lithological) Component

This component includes the aperture, the persistency and the spacing of the discontinuities and weathering state of the rock. It also includes the friction angle of the rock corrected according to the waviness and the roughness of the discontinuities. This component is rated rock-wise according to the average rock mass strength (Table 1).

Hydrogeological Component

The hydrogeological component depends on the groundwater and the surface water. It also depends on the position of the groundwater table and surface water flow. The rock shear strength is decreased around springs and at both banks of the rivers, where the groundwater table is at a shallow depth.

Seismo-Tectonic Component

The component takes into account the interrelated effects of seismicity and tectonic elements (like faults and folds) because, they induce an open and radiating fractures of the rock mass.

Land Use Component

This component has little influence on the rock slope hazard but is nevertheless accounted for. Slopes with thin soil (<1 m) are considered as rocky. Forest increases the rock mass strength through the root reinforcement of the trees. So, no hazard rating is attributed to forest cover. Cultivated land, although rare on the rock slope may induce water seepage from the thin soil cover into the fractured rock mass. Rock slopes when barren ease surface water flow and lead to water seepage into the jointed rock mass.

Rockslide Component

Assuming that rockslide may reoccur and widen, a rating is attributed in a zone around them (Table 1).

Hazard Components For Soil Slopes

Soil Type versus Slope Component

The soil slope stability is primarily a function of the permeability, the friction angle, and the cohesion of the material. Cohesionless soils like colluvium or alluvium are

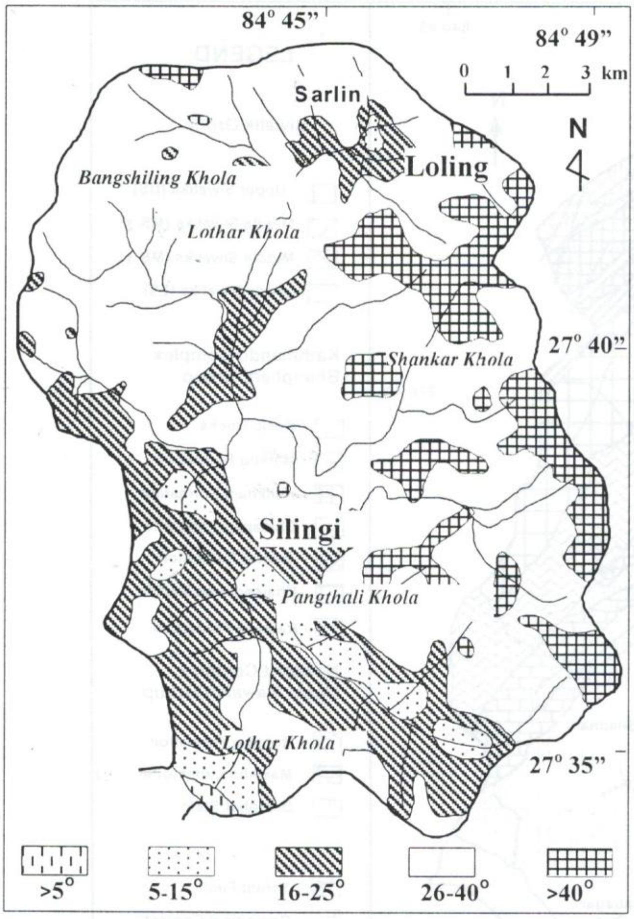

Fig. 3: Slope map of the Lothar Khola watershed.

pervious because the content of fines is generally low. They, therefore, allow an easy internal water flow between the particles. As a result, cohesionless colluvium and alluvium are more stable than cohesive residual soils that generally contain higher amounts of fines and generate more pore pressure.

Soil Depth Component

A thick soil cover can be regarded more stable because of the fact that in the thick soil the groundwater table is generally deep. In such a case the groundwater has less destabilizing influence in comparison with the thin soil cover that may be permanently saturated or groundwater may rise after heavy rains. The soil cover is subdivided as far as possible according to their thickness: very thick (> 6 m), medium (3 to 6 m) and shallow (1 to 3 m).

Hydrogeological Component

The water table is generally shallow close to a river, a stream, or a spring. Groundwater has a negative influence on the slope stability. The limit of its influence is fixed at both banks of a river or a stream or around a spring in accordance with their seasonality.

Hydrodynamic Component

Soil covers may undergo bank underscouring and thick soil beds may be undermined by streams and rivers. These processes may result in material destabilization through slides that gradually widen the channel and may block them in certain cases.

Land Use Component

Land use has a significant influence on soil slope stability. A forest is water flow and water infiltration regulator, whereas a cultivated land may undergo instability owing to the periodical soil cover saturation. The conditions are worse for barren soils where sheet erosion is very active leading to the progressive gully formations, followed later by sliding processes.

Seismo-Tectonic Component

Soil cover may be destabilized through earthquakes that, as already stated for rock slope components, are related to faults and folds in the underlying rock mass. A rating of the seismic component is attributed therefore within the inferred or identified faults and folds.

Landslide and Gully Erosion Component

Assuming that landslide and gully erosion might recur and widen a rating is attributed in a zone around them (Table 2).

Hazard Assessment

Classification of Hazard Level

The rock/soil slope hazard levels are classified into low, medium, and high depending upon the cumulative impact of each of the different hazard components (Table 3).

The areas of low hazard are considered to be more or less safe zones where normally no natural disaster occurs. The medium hazard zones can be made stable and harmless with minor and less expensive protection and mitigative measures. However, it is very difficult to stabilize the high hazard zones and sometimes even impossible. It is better to avoid such areas for the settlement and cultivation.

The high rockslide hazardous area lies at the upper catchment of the Lothar Khola around the Sarling, Wakrang villages, are associated with major thrust (Mahabharat Thrust, MT) and other local faults localized in slates, limestones and schists. The high soil hazardous area lies at the Wakrang, Wasbang and Silingi villages (Fig. 6).

LANDSLIDE HAZARD MAPPING OF SYANGJA DISTRICT

Landslides are the results of various causative factors affecting slope instability at a specific location. The first step generally is to map individual landslides and subsequently digitize them for the purpose of landslide inventory. The presumed causative factors are either mapped in the field or gathered information from other data sources and transferred into GIS data layers.

During the desk study the topographic maps were studied to understand the general situation of relief, drainage, structural patterns, landslides, and land use. The interpretation of aerial photographs (1:50,000 scale) was

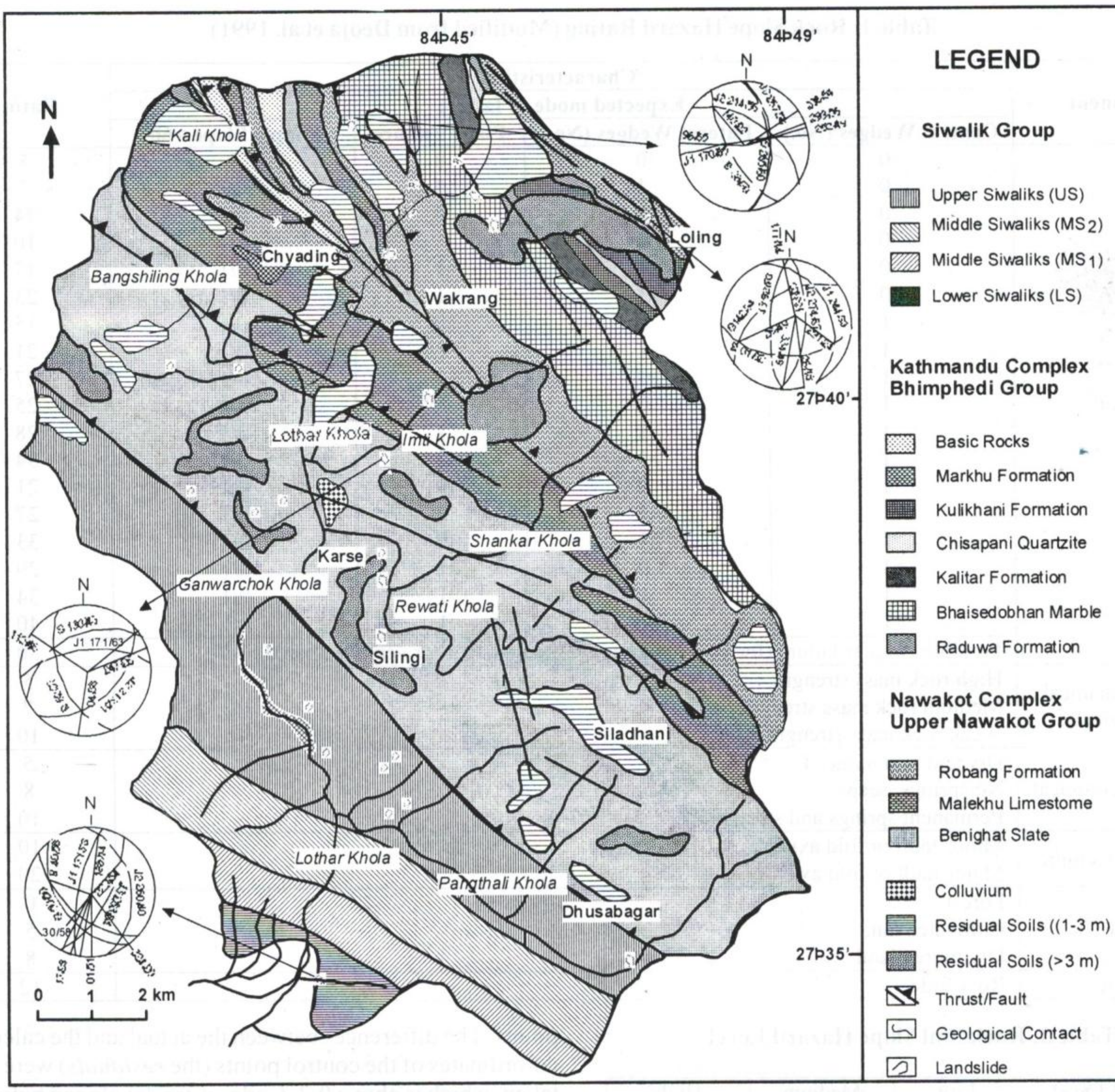

Fig. 4: Engineering geological map of the Lothar Khola watershed.

carried out to assess the rock soil coverage, to verify the land use pattern of the study area, to check the landslides and other instabilities, and to extrapolate the geological information. The land use pattern was checked randomly on the basis of tone and pattern. The aerial photographs and satellite data were very useful for the study of instabilities, since all the landslides were not shown on the topographic maps. Due to clear shape and pattern, old landslides now covered by forest were also depicted from the aerial photographs and satellite imageries. Similarly, on the basis of tone, pattern and structure, they were also used to delineate the soil and rock zones and also for extrapolation of geological maps. The aerial photographs and satellite data were also used to identify the hydrological, and the geomorphologic conditions, as well as the potentially hazardous zones for the detail fieldwork. The landslides and other instabilities were transferred on to the topographic maps for field verification and study. After the desk study, field survey was carried out which consisted of:

- General understanding of landslide sites,
- Detailed data collection of large and medium landslide sites,
- Investigation of unstable sites, deposits and gully, which may become the source of sediments,
- Verification of land use pattern, and
- Collection of other necessary data for hazard mapping.

Analysis and modeling in a GIS requires input of relevant data of two types: *spatial data* representing geographic features (points, lines and areas) and *attribute data* (descriptive information). For this purpose, topographic maps of 1: 25,000 were taken as the base map for contour lines, spot height, drainage, land use types, roads, trails, irrigation canals, VDC and DDC boundaries, and landslide. To digitize soil slopes and rock slopes, information from the aerial photographs was utilized. Similarly, aerial photographs were

Table 1: Rock Slope Hazard Rating (Modified from Deoja et al. 1991)

Component	Characteristics				Rating
	Expected mode of failure				
	Central Wedges (No.)	Lateral Wedges (No.)	Plane Failure	Topple Slope >60^0	
Structural	0	0	0	1	5
	0	1	0	0/1	7
	0	>1	0	0/1	14
	0	0	1	0/1	10
	0	1	1	0/1	17
	0	>1	1	0/1	23
	1	0	0	0/1	15
	1	1	0	0/1	21
	1	>1	0	0/1	27
	1	0	1	0/1	25
	1	1	1	0/1	28
	1	>1	1	0/1	34
	>1	0	0	0/1	21
	>1	1	0	0/1	27
	>1	>1	0	0/1	33
	>1	0	1	0/1	29
	>1	1	1	0/1	34
	>1	>1	1	0/1	40
	Possible circular failure (for very random orientation in soft or very weathered rock)				30
Geomechanical (Lithological)	High rock mass strength				5
	Medium rock mass strength				7
	Weak rock mass strength				10
Hydrogeological	Dry and rain induced				5
	No springs, seeps				8
	Permanent springs and streams				10
Seismo-tectonic	Minor fault or fold axis				10
	Major fault or fold axis				20
Land use	Forest				0
	Cultivated land				5
	Dry barren land				8
Rockslide	Rockslide				12

Table 3: Rock/Soil Slope Hazard Level

Hazard Level	Low	Medium	High
Total Rating	<40	41-65	>65

also used for extrapolation of geological information. Rainfall data were taken from Department of Hydrology and Meteorology (DHM 1970-1997).

Data input was done with utmost care, as the results of analyses heavily depend on the quality of the input data. For manual digitizing analogue (paper) maps, CalComp Drawing Board III was utilized and *Keyboard entry* was done for entering attribute data. The latitude and longitude of topomap were transformed to metric system. Then a co-ordinate system for the Syangja district was created using UTM projection with Everest (India, 1830) ellipsoid. A minimum of four *control points* and the corresponding *map coordinates*, were specified in order to calculate the transformations between digitizer and map coordinates. Since both coordinate systems were taken metric, an affine transformation was used. Using the affine transformation, new sets of co-ordinate pairs are calculated for the control points. The differences between the actual and the calculated co-ordinates of the control points (the *residuals*) were never taken, which is above 0.2. Codes were developed before the actual digitization for various types of segments.

All the 100-m contour lines were digitized and about 70% of the 20-m contour lines were digitized. All the spot heights given in the topomap were digitized. Similarly, drainages of the area were digitized. Land use patterns were reclassified into: forest, bush, grassland, cultivated area, barren land swampy zone, orchard/nursery, tea/coffee plantation and urban area. Roads include highway, feeder road and district road. In case of trails, only main trails were digitized, because they have only significant role for the hazard ratings. Instabilities are classified into landslides and gully erosion. Landslides encompass different categories of mass movement.

After the digitization of segments and connecting them by snapping, the segments were checked for self-overlapping, dead end, code consistency and intersection without node. After the maps are error-free, then point maps were created with appropriate domains and the segment maps were polygonized.

Table 2: Soil Slope Hazard Rating (Modified from Deoja et al. 1991)

Component	Characteristics		Rating
	Type of Soil	Slope (°)	
Soil type/slope	Alluvium	<25	8
		25-40	10
		>40	12
	Colluvium	<25	9
		25-40	11
		>40	13
	Residual	<25	11
		25-40	13
		>40	15
Depth	Thick (>6 m)		10
	Medium (3-6 m)		12
	Shallow (1-3 m)		15
Hydrogeological	Dry and rain induced		5
	No springs, rare seeps		7
	No springs, seeps		10
	Rare springs, seeps		12
	Springs and seeps		15
Hydro-dynamical	Low gradient		5
	Medium gradient		10
	High gradient		15
Land use	Forest		0
	Dry cultivated land		5
	Dry barren land		8
	Wet cultivated land		10
Seismo-tectonic	Minor fault of fold axis		8
	Major fault of fold axis		15
Landslide and Erosional Gully	Presence of landslides and erosional gullies		15

As the analyses in ILWIS are based on raster data, the vector maps (points, segments and polygons) are required to convert to raster format (rasterization). Before starting the rasterization of various maps, a georeference was created. The georeference contains the minimum and maximum X and Y co-ordinates of the raster map, the number of rows and columns and the pixel size. Then in order to convert maps from vector into raster format, a mesh with pre-defined cell size, is laid over the map. By interpolating the digitized contour lines a Digital Elevation Model (DEM) of the Syangja district (Fig. 7) has been created. Then a slope map and an aspect map have been created using the DEM.

In practice, there are several types of landslide zonation methods: landslide distribution, qualitative hazard, statistical hazard, deterministic hazard and landslide frequency analyses. Among them, the present study has prepared two types of hazard maps, viz. qualitative landslide hazard map and statistical landslide hazard map. The former was prepared by combining the geology, slope and land use and the latter was prepared using the following maps: geological, land use, DEM, slope, aspect, river distance, path distance, geological structure distance and rainfall.

To prepare statistical hazard map, various parameters of individual maps are classified by using the Slicing operations

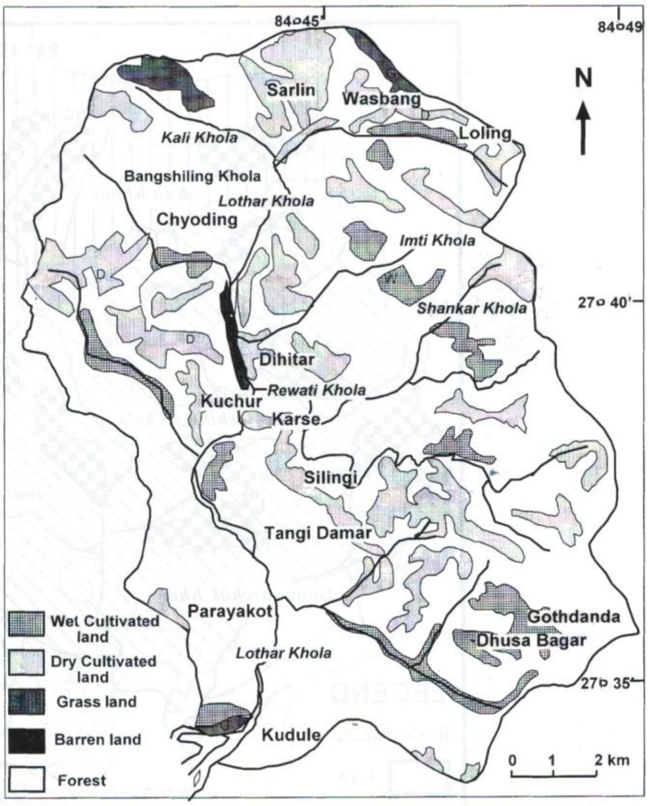

Fig. 5: Land use map of the Lothar Khola watershed.

derived those parameters. Then the factor maps were overlaid with landslide activity map and landslide density for each class and the overall landslide density for each class were calculated.

The first step in the statistical hazard analysis is to calculate a weight value for each parameter. Many different methods exist for the calculation of weight value. The method used for present study is called the *Landslide Index Method.* A weight value for a parameter class is defined as the natural logarithm of the landslide density in the class divided by the landslide density in the entire map.

The method is based on the following formula:

$$Ln\ Wi = \ln[Densclas/Densmap] = \ln[Npix(Si)/Npix(Ni)/\textstyle\sum Npix(Si)/\sum Npix(Ni)]$$

Where,

Wi = Weight given to a certain parameter class (e.g., rock type, or slope class)

Denclas=Landslide density within the parameter class

Densmap=Landslide density within the entire map

Npix(Si)=Number of Pixels, which contain landslide, in a certain parameter class

Npix(Ni)=Total number of Pixels in a certain parameter class.

This method is based on map crossing of a landslide map with a certain parameter map. The map crossing results

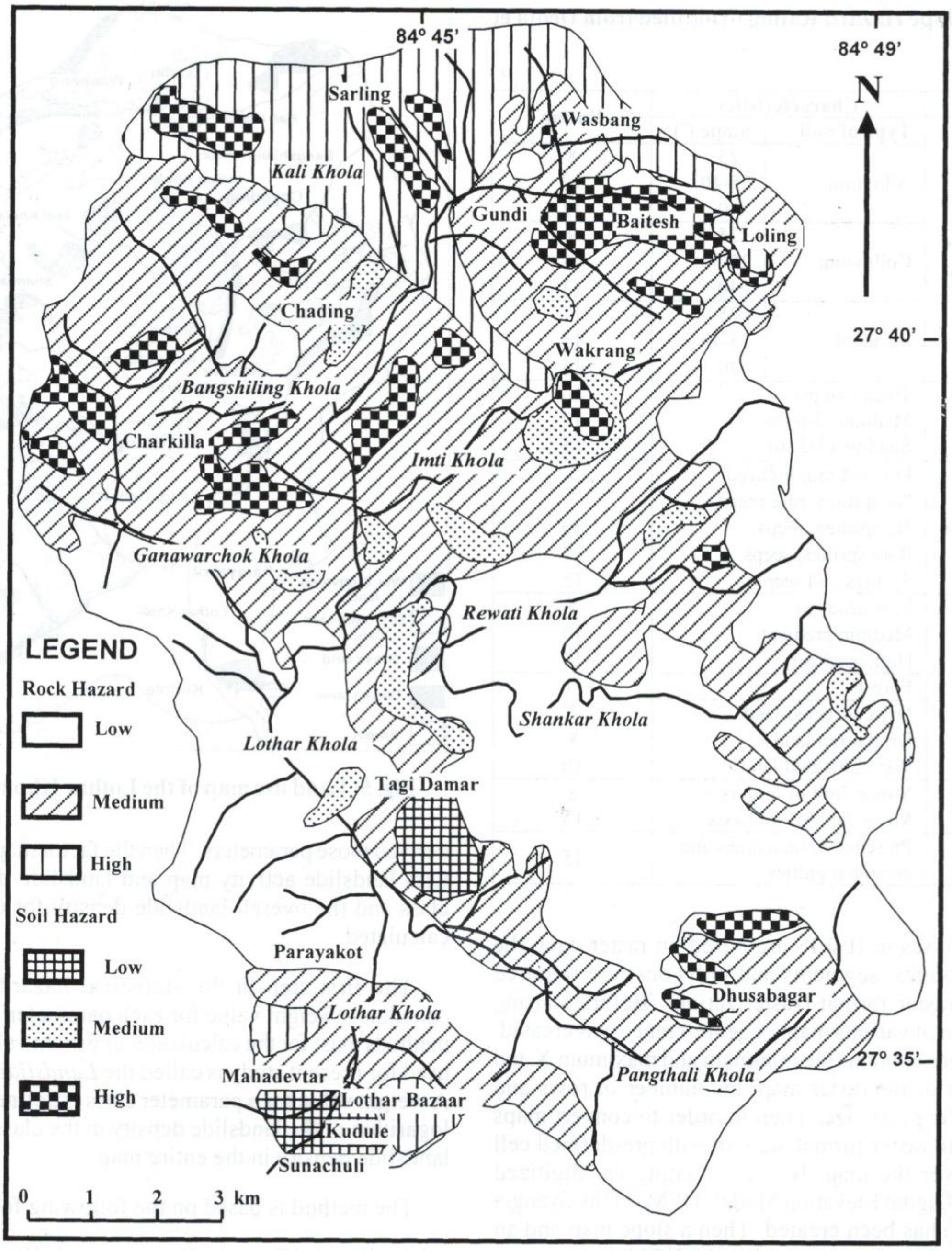

Fig. 6: Hazard map of the Lothar Khola watershed.

in a cross table, which can be used to calculate the density of the landslide per parameter class. A standardization of these density values can be obtained by relating them to the overall density in the entire area.

All these calculation have been carried out in cross table, by creating an attribute table with the respective domain. The above-mentioned procedure was repeated for all the parameters maps (Geology, Land use, Altitude (Demclas), Slope (Slopeclas) Slope Aspect (Aspclas) Distance from stream (Rivdist), Distance from geological structures (Strucdis) Distance from the paved road (Roaddist), Distance from the main trail (Pathdist) and Classified mean annual Rainfall (Rainclas).

All the weight maps were combined together into a single map using certain combination rules. $Weight = Wslope + Wgeol + Wland + Wdem + Wasp + Wriv + Wstru + Wroadp + Wpath + Wrain$

The resulted map was reclassified into three classes: low, medium and high hazards (Fig. 8). It shows that the low hazard zone is 1.72%, medium hazard 95.26%, and high hazard 3.02%.

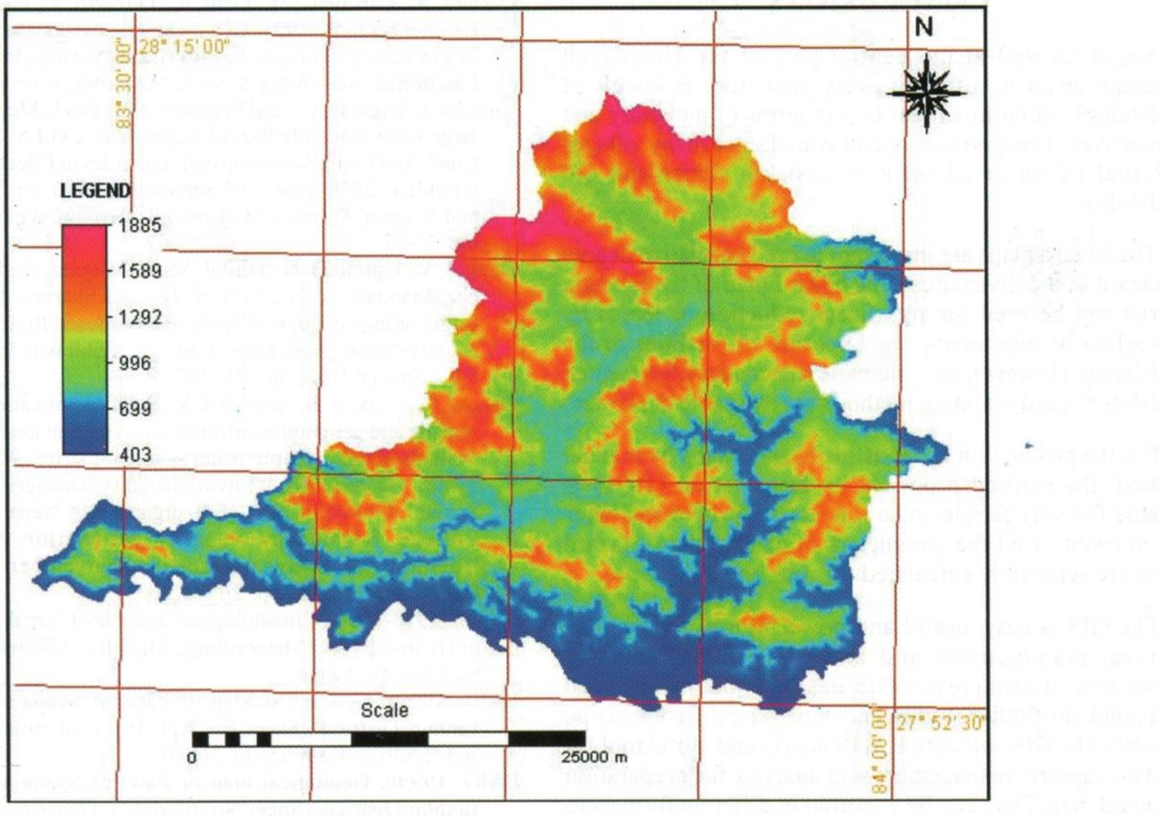

Fig. 7: Digital elevation map of the Syangja district.

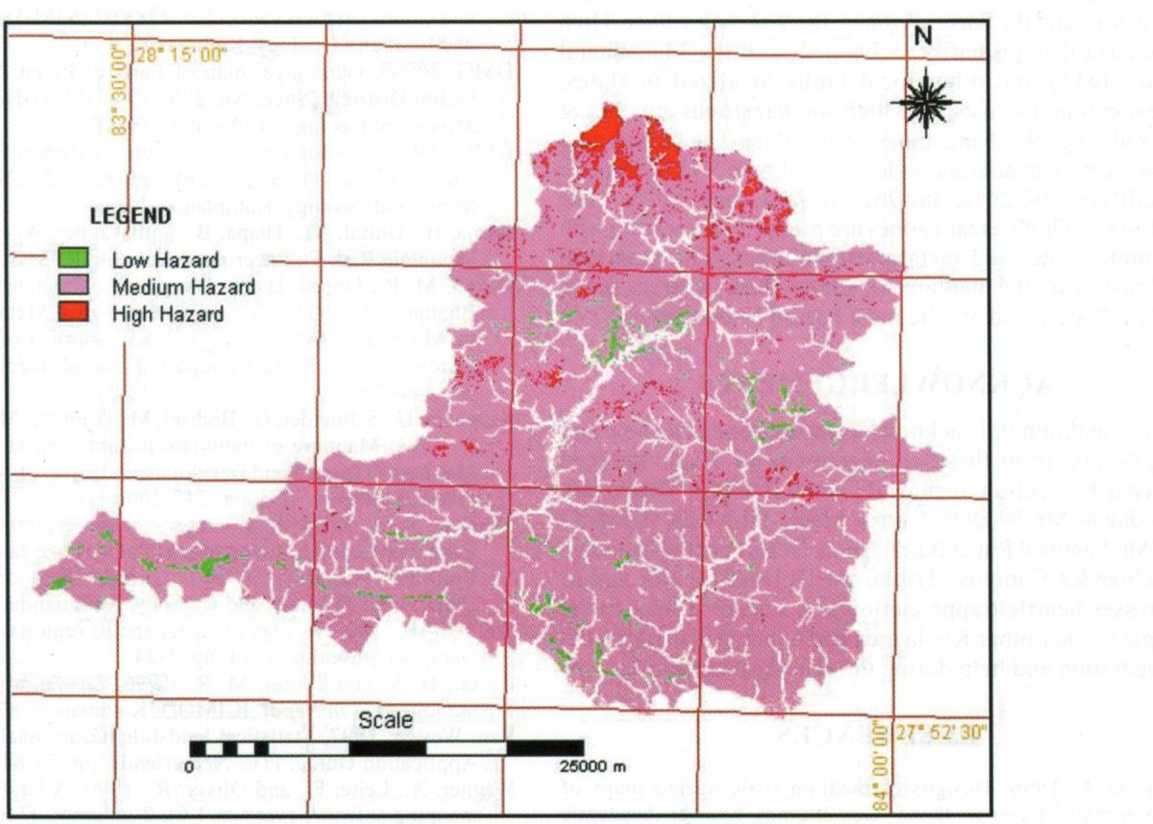

Fig. 8: Hazard map of the Syangja district.

CONCLUSIONS

Nepal located at the central part of the Himalayan mountain chain is suffering every year from problems of landslides leading to a great loss in terms of monetary and human lives. This problem is aggravated since many villages in Nepal lie on or adjacent to unstable slopes and old landslides.

The hazard maps are important to predict relative degree of hazard in the given area. The hazard map of the Syangja district can be used for significant reduction of losses by preventing or minimizing the exposure of facilities to the landsliding. However, no systematic and commonly accepted landslide hazard mapping methods are available at present.

For the production of landslide hazard maps by manual method, the method proposed by Deoja et al. (1991) is suitable for hilly terrain since it is not subjective and takes into account of all the parameters of natural state. Hazard levels are separately calculated for rock and soil slopes.

The GIS is easy, useful and powerful tool for the data capture, management and analysis for hazard map preparation. It also creates GIS database that can be used for a number of other studies encompassing different scope of works.The GIS software ILWIS is easy and useful tool for the data capture, management and analysis for preparation of hazard map. Data can be exported in different formats to be used by various GIS softwares. The most hazardous areas in the Lothar Khola catchment are located at the upper reaches around the Sarling village, the Wakrang village. High rock hazard is primarily associated with the Mahabharat Thrust (MT) and other local faults localized in slates, limestones and schists. The high soil hazardous area lies at the Wakrang, Wasbang and Silingi village.The hazard map of the Syangja district shows low hazard zone 1.72%, medium hazard zone 95.26%, and high hazard zone 3.02%. The medium and high hazard zones are primarily associated with dolomite, slate, and metasandstone areas. The grassland and bushes are the medium hazardous areas, whereas forest and cultivated land are the most hazard prone areas.

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