GIS Based Evaluation of Landslide Hazard along Shivpuri-Vyasghat Road Section, Garhwal Himalaya, India

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Abstract

Landslide is one of the major geological hazards, frequently occurring in Himalayas. Landslide Hazard Zonation (LHZ) maps, which divide the area into different categories of landslide hazard zones, help in systematic planning of developmental works in hilly terrains. In the present study, a part of National Highway (NH-58) in Garhwal Himalaya, India was selected for LHZ mapping. The inherent terrain factors of different slopes were studied using the data collected from topographic maps, aerial photographs, published literatures and field visits. For each of the factors, thematic maps were generated in GIS environment. The factors were assigned numerical ratings following Landslide Hazard Evaluation Factor (LHEF) rating scheme. The thematic data layers were integrated in GIS environment to arrive at LHZ map. Field landslide data were used to evaluate and validate the LHZ map.

Introduction

Among the various natural hazards, landslides are one of the most damaging hazards in hilly terrains. Landslide occurrences are very common in the Himalayan region. It causes losses to properties, man made structures, natural resources and sometimes, even human lives. As any other natural hazards, landslide also cannot be completely prevented, but with proper understanding of the characteristics of the hilly terrains, the intensity of its impact can be reduced. This can be achieved by identifying hazard prone hill slopes and thus by preparing Landslide Hazard Zonation (LHZ) maps. The LHZ maps show probability of occurrence of landslides by classifying the land into various classes of actual or potential landslide hazard. These maps are useful in identifying and delineating unstable slopes to take proper mitigative measures.

In the last few decades, several field based techniques for hazard zonation studies have been carried out in different parts of Himalayan region (Anbalagan, 1992; Pachauri & Pant, 1992; Sarkar et al., 1995). But these approaches support manual overlay of thematic maps, which is tedious job with poor data integration capability (Saha et al., 2002). Also, these techniques are time taking and often real time solution are not possible. In recent years, application of GIS has gained its popularity for thematic data layer preparation and their integration to arrive at the LHZ map (Gupta & Joshi, 1990; van Western, 1994; Nagarajan et al., 1998; Gupta et al., 1999; Dhakal et al., 2000; Saha et al., 2002; Carrasco et al., 2003; Lan et al., 2004; Sarkar & Kanungo, 2004; Süzen & Doyuran, 2004; Saha et al., 2005).

In the present study landslide hazard zonation (LHZ) mapping of Shivpuri - Vyasghat road section of Garhwal Himalaya was carried out following the Landslide Hazard Evaluation Factor (LHEF) method of Anbalagan, 1992. The preparation of thematic data layers and their integration were done in GIS environment.

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Study area and geology

The study was carried out in Shivpuri - Vyasghat road section (37 km.) on Rishikesh-Devprayag road (NH-58) in upper Ganga valley of Garhwal Himalaya (Figure 1). The area lies within latitude 30°12' to 30°03'N and longitude 78°24' to 78°35'E covering an area of about 47km^2. The area has been dissected by several high ridges, which are in the order of 986m, 1080m, 1076m, 1570m above mean sea level. The highest point on the road is Sakni Dhar (1014m above m.s.l.). The river Ganga is flowing downhill roughly following the road from Devprayag towards Rishikesh. There are several small streams present in the study area, which are flowing southward and ultimately joining the main river. Generally, the area receives less to moderate rainfall (about 100-125cm annually). The hill slopes in the area are in general moderately steep (25-35°) while very few escarpments or cliffs (>45°) are also present. Mostly the area is covered by moderate to thick forest, while some of the favorable hill slopes are used by the local people for agricultural purpose. Mostly the hill slopes are devoid of soil cover but at some places soil cover of <5m thick is present. Few slopes are having loose boulder conglomerate.

The study area is a part of Garhwal Synform with a normal stratigraphic sequence, which extend from the age of Precambrian through Paleozoic to Mesozoic (Kumar & Dhaundiyai, 1976). The major rock types of the area belong to five geological Formations. The Precambrian Lansdowne Formation composed of quartzite and phyllite forms the base. Over Lansdowne

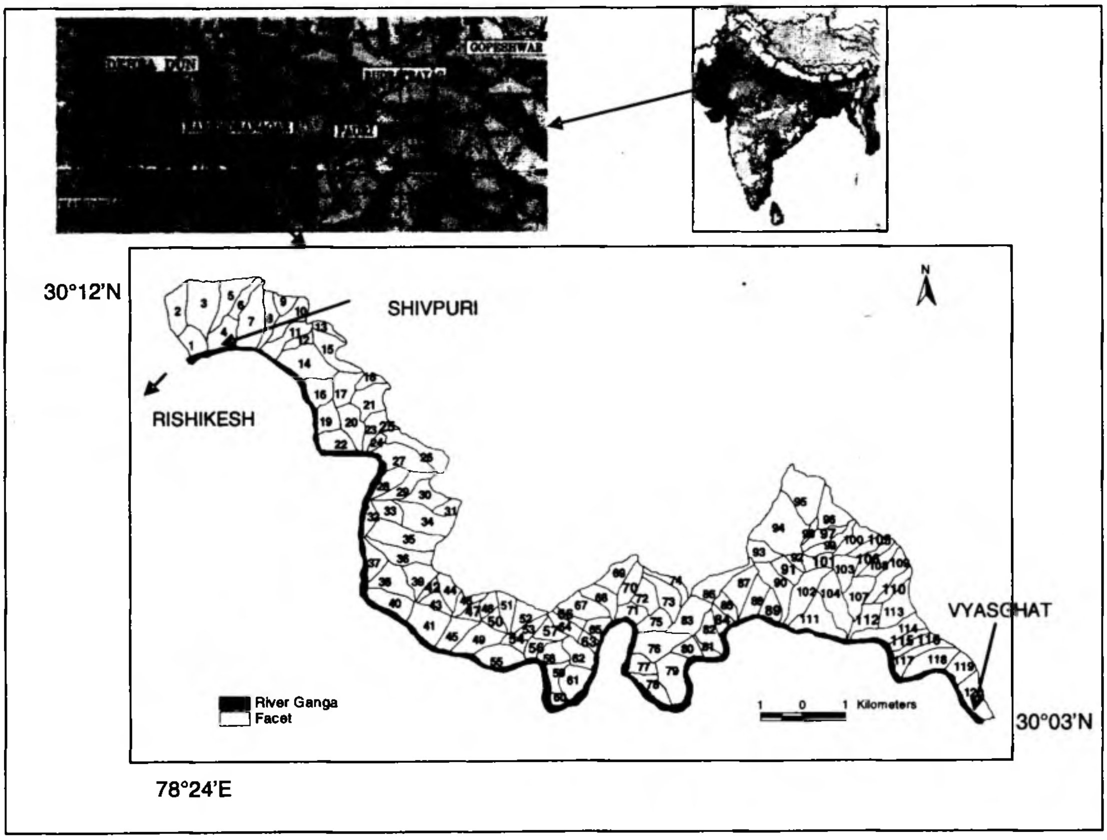

Figure 1: Location map of study area and facet map

Formation lies the Binj Formation (Lower Carboniferous) with an angular unconformity. The Blaini shale and limestone sequence (Middle to Upper Carboniferous), Krol shale (Permian to Triassic) and arenaceous sequence of Tal Formation (Jurassic to Cretaceous) were deposited successively (Kumar & Dhaundiyal, 1976). The area is not much structurally disturbed; however, by a few local faults.

Methodology

The present study employs a numerical rating scheme known as Landslide Hazard Evaluation Factor (LHEF) rating scheme of Anbalagan (1992), for landslide hazard zonation mapping. The scheme uses the basic causative factors responsible for landslides. Since the basic causative factors can be used in all types of terrains, the method has wider applicability. This technique has been already adopted as Indian Standard Code [IS 14496 (part 2): 1998]. This is an empirical rating scheme on 10-grade scale. The technique considers the slope facet as the mapping unit, which is the smallest unit field data collection. The facets represent a slope that is bounded by natural boundaries like valleys, ridges, spurs, etc. The slope properties within a facet are considered as homogeneous. Since the stability conditions remain constant within a slope facet, the data collection within the facet represents the true field condition. The facets can be mapped from topographic maps, aerial photographs and are easily identifiable in the field.

As the scheme deals with the inherent slope instability condition, it considers six slope factors such as geology (lithology and structure), slope morphometry, land cover, relative relief and hydrogeological conditions. These are the most commonly used factors for LHZ mapping (Gupta & Joshi, 1990; Gupta et al., 1999; Saha et al., 2002; Sarkar & Kanungo, 2004). The external factors like rainfall, earthquake and anthropogenic activity are not considered in this technique because the data are not always available. The numerical ratings for these six factors are assigned based on the expert opinion and field experience of the geoscientists. The ratings indicate the relative influence of the factors to cause landslide. Higher the rating more important is the factor. The several classes of the factors also have been assigned numerical ratings depending on their importance to landslide occurrence (Table 1).

In this rating scheme, very gentle slope class (0° -15°) has minimum rating where as very steep class (>45°), which is more prone to instability, has maximum rating. For rating assignment to lithology, the various litho types have the ratings according to their proneness towards landslide occurrence. The recent sediment under the soil types has maximum rating while quartzite being the strongest rock has the minimum rating. While assigning this rating the degree of weathering has been considered and for this, the correction factor for weathering is multiplied to obtain the respective litho-rating. To assign the rating for structures, the most vulnerable condition is considered and the possible highest rating is taken. In facets, where soil overburden is present, the rating of depth of soil layer is to be considered. The relative relief parameter has maximum rating of 1. Among the three relief classes, the highest relief class (>300m) has the maximum rating. In case of land cover classes, the barren land, which is supposed to be more potential to cause landslide, has maximum rating while relatively stable flat agricultural land has minimum rating. As the water influences slope instability, maximum rating has been assigned to the flowing water condition while minimum rating has been given to dry condition, under the factor hydrogeological condition.

As for any regional surmise for landslide hazard zoning, several factors need to be collectively considered; therefore a GIS approach is most suitable (Gupta & Joshi, 1990). Hence the

Table 1: Landslide Hazard Evaluation Factor (LHEF) rating scheme (Anbalagan, 1992)

Factor	Category		Rating
LITHOLOGY			(Maximum rating 2.0)
Rock type	Type-I		
	Quartzite and limestone		0.2
	Granite and Gabbro		0.3
	Gneiss		0.4
	Type-II		
	Well cemented terrigenous cemented rocks, dominantly sandstone with minor beds of clay stone		1.0
	Poorly cemented terrigenous sedimentary rocks, dominantly sandstone with minor clay shale		1.3
	Type-III		
	Slate and phyllite		1.2
	Schist		1.3
	Shale with interbedded claye and nonclayey rock		1.8
	Highly weathered shale, phyllite and schist		2.0
Soil type	Older well compacted fluvial material (alluvial)		0.8
	Clayey soil with naturally formed surface (eluvial)		1.0
	Sandy soil with naturally formed surface (alluvial)		1.4
	Debris comprising mostly rock pieces mixed with clayey/sandy soil (colluvial)		
	Older well compacted		1.2
	Younger loose material		2.0
STRUCTURE			(Maximum rating 2.0)
Relationship of structural discontinuity with slope			
i) Relationship of parallelism between slope and discontinuity Planar (α_j-α_s) Wedge (α_i-α_s)		>30°	0.20
		21°-30°	0.25
		11°-20°	0.30
		6°-10°	0.40
		<5°	0.50
ii) Relationship of dip of discontinuity and inclination of slope Planar (β_j-β_s) Wedge (β_i-β_s)		>10°	0.3
		0°-10°	0.5
		0°	0.7
		0°-(-10°)	0.8
		(-10°)	1.0
iii) Dip of discontinuity Planar - β_j Wedge - β_i		<15°	0.20
		16°-25°	0.25
		26°-35°	0.30
		36°-45°	0.40
		>45°	0.50

Depth of soil cover	<5m	0.65
	6-10m	0.85
	11-15m	1.30
	16-20m	2.0
	>20m	1.20
SLOPE MORPHOMETRY		(Maximum rating 2.0)
Escarpment/cliff	>45°	2.0
Steep slope	36°-45°	1.7
Moderately steep slope	26°-35°	1.2
Gentle slope	16°-25°	0.8
Very gentle slope	<15°	0.5
RELATIVE RELIEF		(Maximum rating 1.0)
Low	<100m	0.3
Medium	101-300m	0.6
High	>300m	1.0
LANDUSE AND LAND COVER		(Maximum rating 2.0)
Agricultural land		0.65
Thickly vegetated forest area		0.80
Moderately vegetated area		1.2
Sparsely vegetated area		1.5
Barren land		2.0
HYDROGEOLOGICAL CONDITIONS		(Maximum rating 1.0)
Flowing		1.0
Dripping		0.80
Wet		0.5
Damp		0.2
Dry		0.0

NOTE: The correction factor C_1 (highly weathered), C_2 (moderately weathered) and C_3 (slightly weathered) should be multiplied with the fresh rock to get the corrected rating.

For rock type-I, C_1 - 4, C_2 -3 & C_3 - 2

For rock type-II, C_1 - 1.5, C_2 - 1.25 & C_3 - 1

α_j - dip direction of joint, β_j - dip of joint, α_i - direction of line of intersection of two joints, β_i - plunge of line of intersection of two joint planes, α_s - direction of slope, β_s - inclination of slope thematic data layers for each factor were prepared in Arc view GIS and the classes were assigned the ratings following the LHEF rating scheme. The landslide hazard zonation map was prepared by integrating the data in GIS. The map was finally validated with the existing landslides of the area. The complete process of preparation of Landslide Hazard Zonation map is shown in the flow diagram (Figure 2).

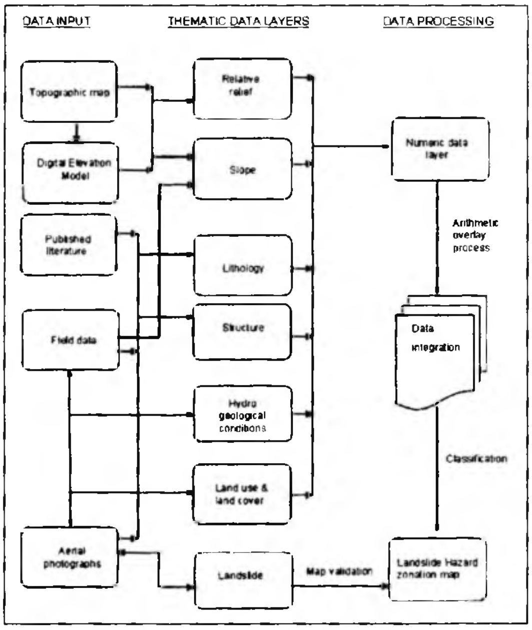

Figure 2: Flow diagram showing methodology

Thematic data layers

The thematic data layers for the six factors were generated in GIS using Survey of India toposheets (53J/12 & J/8, 1:50000 scale), aerial photographs (1:25000 scale), published literature and field data. These layers served as input data layers for LHZ mapping. The stereoscopic viewing of aerial photographs gives a synoptic view of the topography, which makes the slope facet identification easier. In the present study the facets were first identified in the aerial photographs and boundaries were digitized to generate the facet map on 1:25,000 scale (Figure 1). The facet map was used as the base map for field data collection. Preparation of all the thematic data layers is described below.

Digital elevation model & its derivatives

Digital Elevation Model (DEM) is the digital way of representing topographic surfaces. The model is not only used for representation purpose but also used to derive information on elevation, slope angle and slope aspect. The DEM was generated from the contours of SOI topo maps using the TIN (Triangulated irregular network) module of Arc View 3D Analyst (Figure 3). In this region the 500-800m elevation class occupies the maximum area.

From the DEM, a slope map was generated with 50m grid size. The slope values were classified into five classes with 10° intervals following the classification of earlier researchers (Anbalagan, 1992; Dhakal et al, 2000). The slope map represents the spatial distribution of slope classes (Figure 4). The map shows that the slope class of 25° - 35° covers nearly one-third portion of area, while the slope class of 35°-45° and >45° jointly covers about one-third area (Table 2).

Lithology map

The lithology map was initially prepared on 1:25,000 scale from the published geological map of Kumar and Dhaundiyal, (1976). After field visits necessary modifications were incorporated and the lithology map was prepared in GIS (Figure 5). The different rock types encountered in the study area and the area covered by them are listed in table 2.

To account for the degree of weathering in various rock types, facet wise weathering data were also collected in the field. The weathering data were classified into three weathering classes as high, moderate and slightly weathered, following the scheme. It was found that quartzites with phyllites showing moderate weathering is covering nearly half of the area.

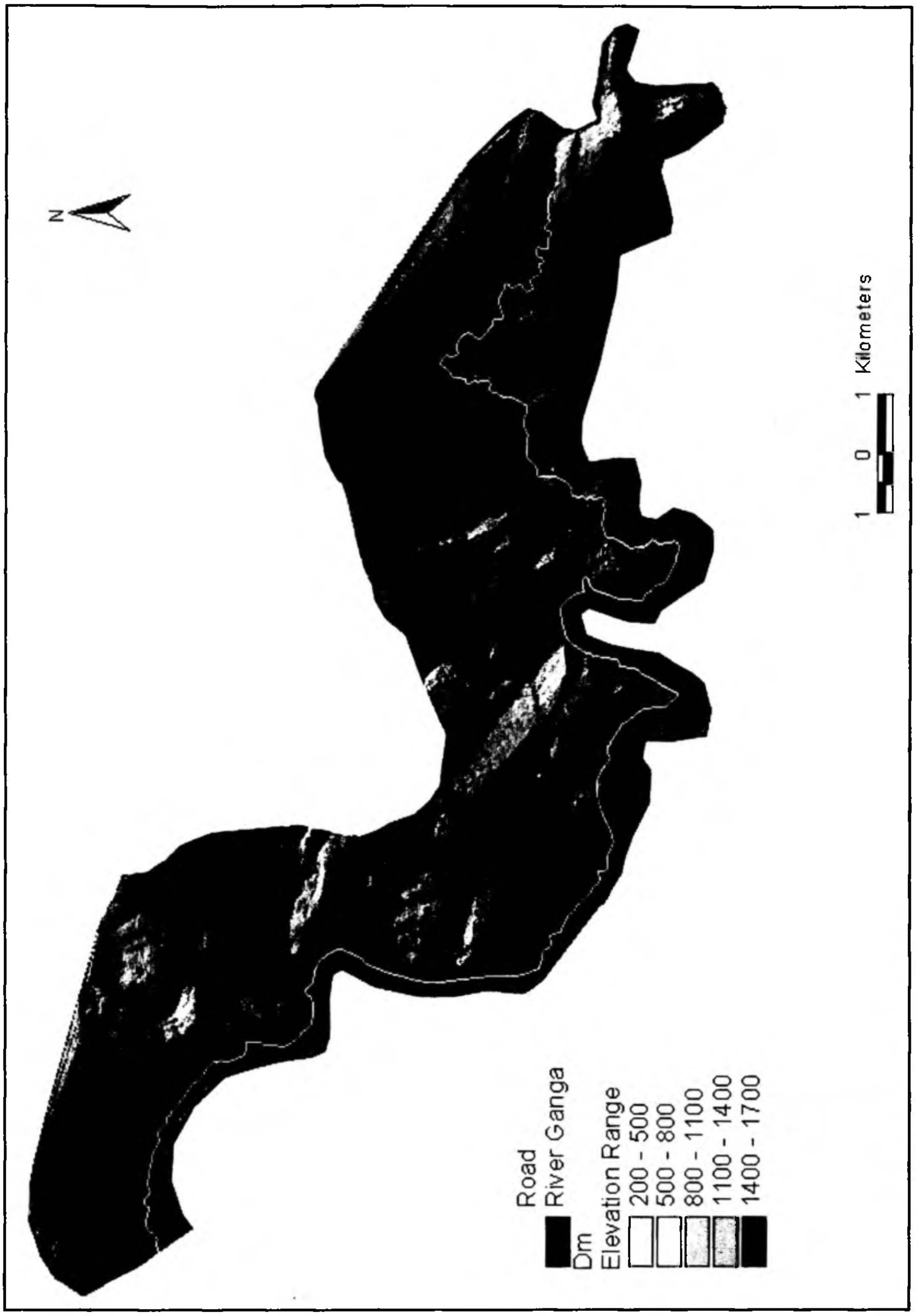

Figure 3: DEM of study area and its vicinity

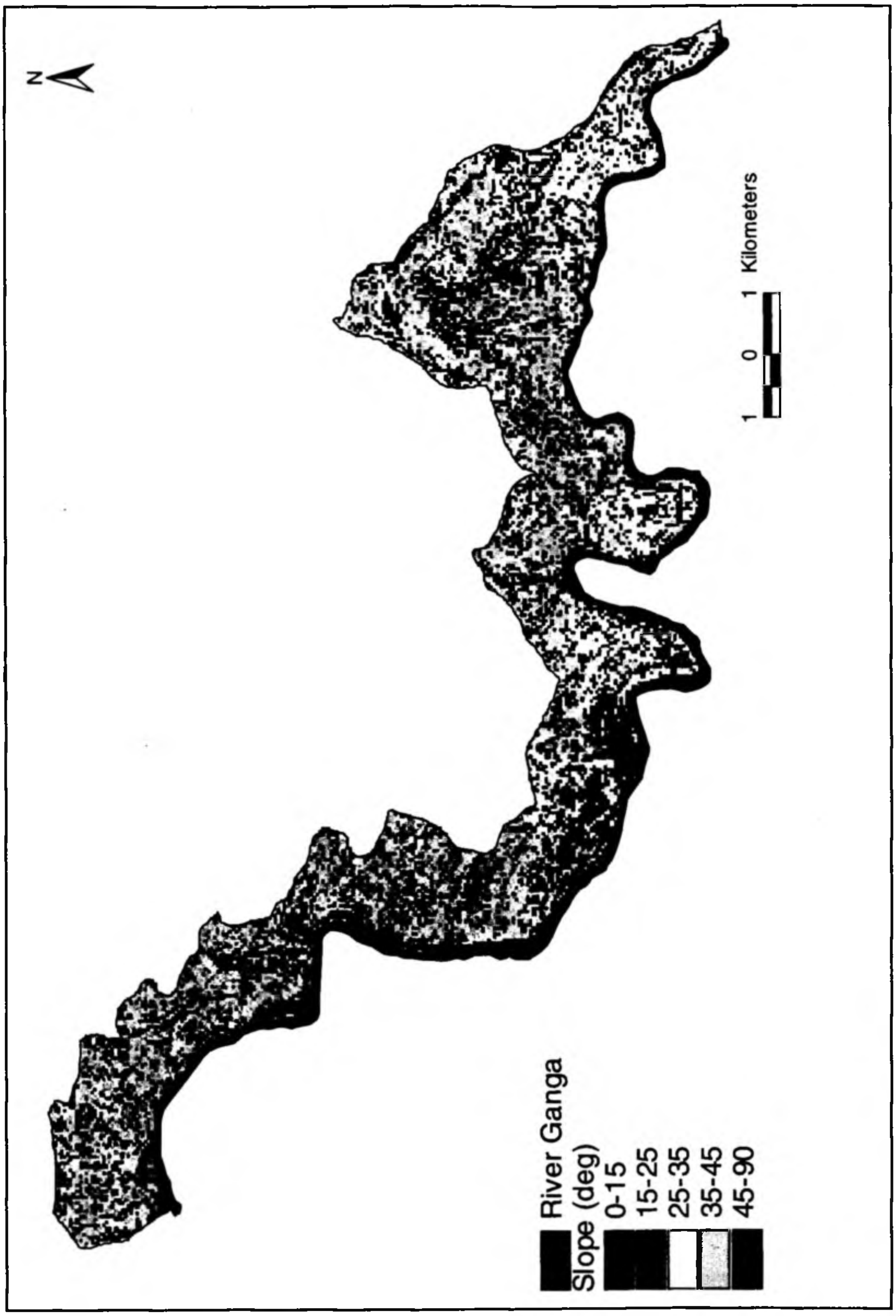

Figure 4. Slope map of the study area

Table-2 : Area covered by different classes of each factor

Number	Factor	Class	Area covered (km^2)	Percent area covered (%)
1.	Slope	0 - 15°	5.1575	11.0209
		15 - 25°	9.4475	20.1880
		25 - 35°	15.2250	32.5338
		35 – 45°	10.5000	22.4371
		> 45°	6.4675	13.8202
2.	Lithology	Shale	7.88	16.8300
		Limestone	3.75	8.0100
		Shale with limestone	2.29	4.8900
		Quartzite	5.39	11.5100
		Quartzite with phyllite	20.50	44.1000
		Dolomite	5.80	12.3900
		Boulder conglomerate	1.11	2.3700
3.	Relative relief	Low	0.1650	0.3525
		Medium	11.3425	24.2335
		High	35.2975	75.4140
4.	Land use	Agricultural land/flat land	4.7125	10.0646
		Thickly vegetated forest	6.7625	35.8000
		Moderately vegetated	18.3200	39.1265
		Sparsely vegetated	5.6225	12.0081
		Barren land	1.4050	3.0007

Structure map

In general the rocks of the study area are having 2-3 sets of joints. Strong rocks like dolomites and quartzites are having more than 2 sets of joints, while shales are having only one set of bedding joint. To study the structural relationship between slopes and discontinuities, structural data of all the discontinuities were collected for each facet. These data were plotted on stereo net to determine the possible failure modes. In most of the cases it was found that the hill slopes show either planar or wedge condition as possible failure modes. After analyzing the data, the most vulnerable joint sets were considered.

For facets, which contain soil overburden, the depth of the overburden was considered. In the study area the overburdens, which mainly comprise of loose and weathered boulder conglomerate horizons, have average thickness of <5m.

Relative relief map

Relative relief map shows the local relief of different facets. Facet-wise relative relief data were collected from the contours of Survey of India topo maps. These were classified into three classes and the map was prepared in GIS. It was found that the highest relative relief class of >300m is the most predominant class covering about two-third of the area (Table 2).

Land cover map

The land cover imposes a major effect on the stability of slopes by controlling the effect of

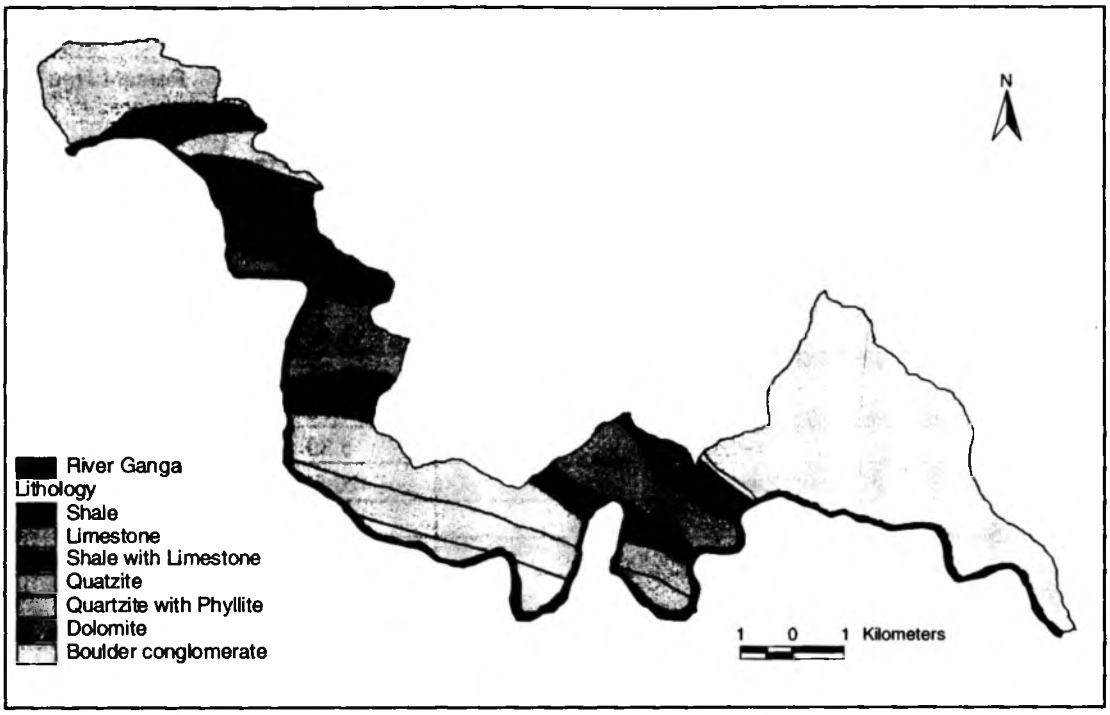

Figure 5: Lithology map of the study area (based on Kumar & Dhaundiyal, 1976)

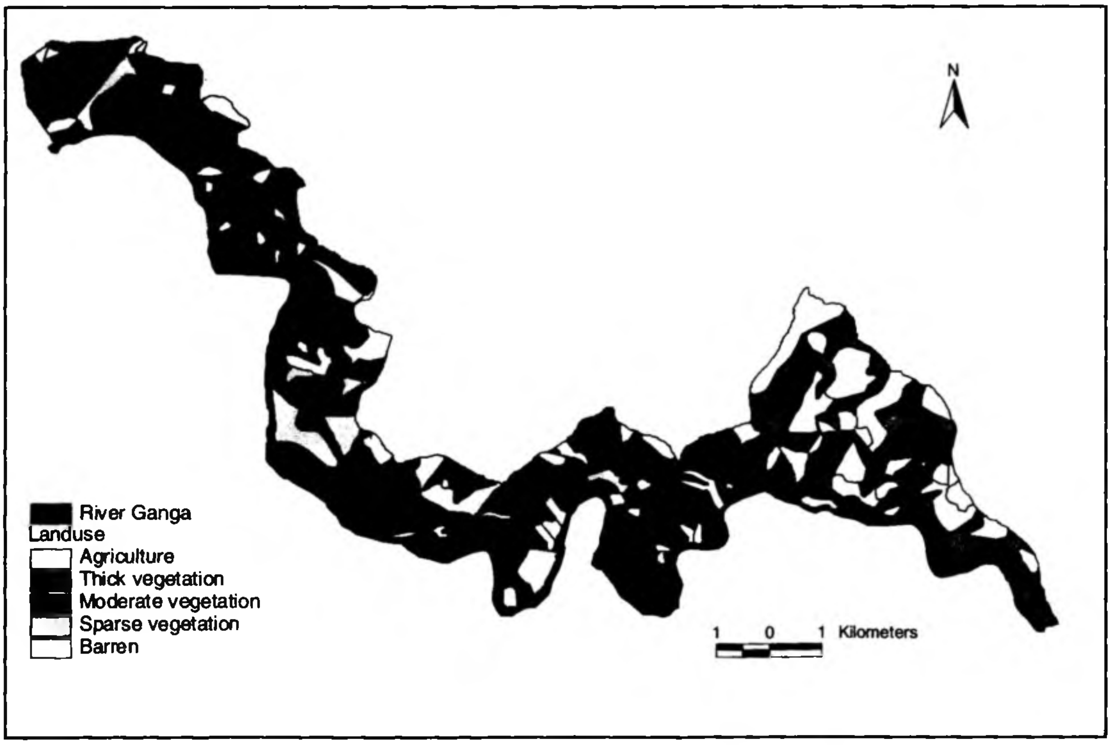

Figure 6: Land use and land cover map of the study area

geomorphologic actions like weathering and erosion. In LHEF rating scheme, five vegetation classes have been considered. The land cover map was initially prepared by aerial photo interpretation. The area was classified into agricultural land, thick vegetation, moderate vegetation, sparse vegetation and barren land. After field visits, some modifications were made to the pre-field map and final land cover map was generated in GIS (Figure 6). The area covered by different land use classes is tabulated in Table 2. It was found that moderate and thickly vegetated classes cover around two-third portion of the area while the barren land covers a very minor portion.

Hydrogeological map

The hydrogeological condition of a slope is an important parameter to assess the stability of the slopes as water reduces the shearing strength of the slope forming material causing instability. The hydrogeological data for each facet in the form of flowing, dripping, wet, damp and dry were collected from the field and a hydrogeological map was generated in GIS. One has to be cautious during field observation for this parameter, as it is dependent on seasonal changes. Hence, the field observations were carried out in pre and post monsoon for a judicious judgment of hydrogeological condition. The hydrogeological map shows only few facets of dripping and wet conditions.

Data integration for LHZ

To combine all the thematic data layers for LHZ mapping, the ratings of each factor classes were assigned following the LHEF rating scheme. This produce the numerical data layers for each factor and these ratings were stored as attribute information in GIS.

The spatial data integration of all the numerical data layers was carried out with 50m grid size using arithmetic overlay function of Spatial Analysis module of Arc View GIS. The addition operation of arithmetic overlay function was used, which simply adds the corresponding ratings of each causative factor for each cell of the study area. The resultant map shows the distribution of values of Total Estimated Hazard (TEHD). The TEHD indicates the net probability of instability. The higher TEHD value indicates more proneness to landslide. These TEHD values were then classified following classification scheme into five hazard classes as very low hazard, low hazard, moderate hazard, high hazard and very high hazard, to arrive at LHZ map of the area (Figure 7).

The different hazard classes with their TEHD values and the area covered by them are tabulated in the table 3. From the table it is evident that the low and moderate hazard classes are jointly covering around three-fourth portion of the area, while around one-fourth is having high hazard risk. Only 1.4% of the area shows very high hazard risk.

Table 3: Area covered by different Hazard classes

Hazard classes	TEHD values	Area covered (sq. km.)	Percent area covered (%)
Very low hazard	1.0–3.5	0.2850	0.6076
Low hazard	3.5–5.0	14.3775	30.6524
Moderate hazard	5.0–6.0	19.5975	41.7812
High hazard	6.0–7.5	11.9575	25.4930
Very high hazard	7.5–10	0.6875	1.4657

Map validation

The LHZ map so prepared needs to be validated to assess its accuracy. It is obvious that the accuracy of the hazard map will be higher if the high and very high hazard zones have more number of landslides than other hazard classes. For that purpose a landslide inventory map of the area was prepared using aerial photo interpretation and field checks. In aerial

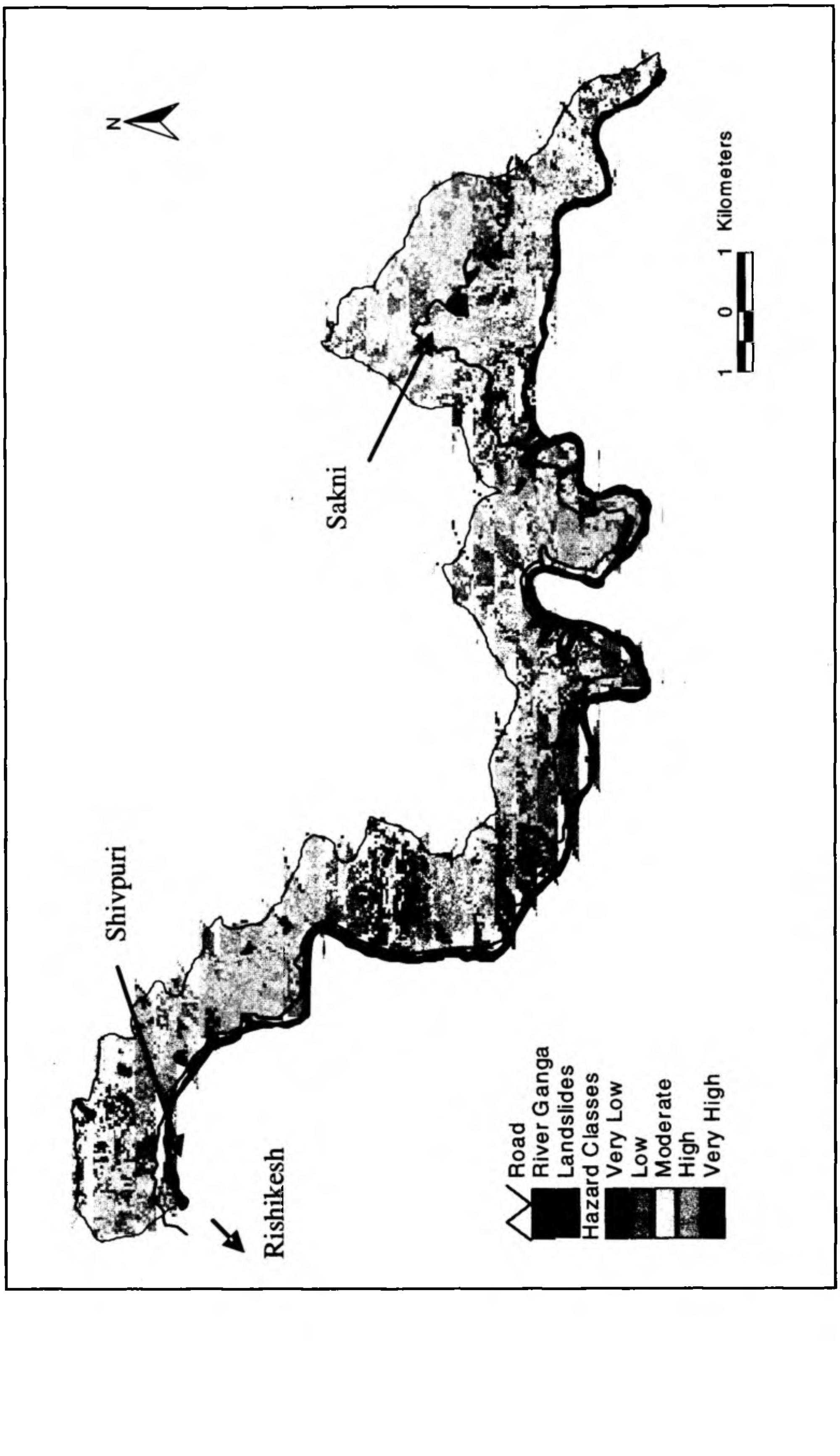

Figure 7: Landslides superimposed on LHZ map

photographs, the landslides are easily identifiable due to their tone, texture, pattern, shape, and association (Gupta & Joshi, 1990). They are mostly having circular to elliptical shape and show clear appearance of path of debris movement. The landslides were confirmed in the fields on the basis of morphological features, structural features, vegetation, presence of landslide scar etc. It was found that the recent and active landslides were easily detected in aerial photos while to identify the old landslides field observation were necessary as these were mostly covered by vegetation. Most of the landslides detected were found to be very close to the road (NH-58). So it can be inferred that road cutting may be one of the triggering factors for landslide occurrence in this area.

The landslide map when superimposed over the hazard zonation map (Figure 7), it was observed that the high and very high hazard zones contain most of the landslides in the area.

Further LHZ map also can be validated in a quantitative approach by computing the landslide frequency in each hazard class (Sarkar, 1996). Hence the density of landslide, which is the ratio of landslide area and area of that hazard class, were computed for each hazard class (Table 4). The table shows that though the very high hazard class is covering only 1.4% of the total area but the landslide density is very high (0.1054) as compared to other classes. Further, the landslide density in hazard classes is gradually increasing from very low hazard class (0.0088) to very high hazard class (0.1054). Hence, it can be inferred that the landslide hazard zonation map reflects the existing field instability conditions. However, the areas of high hazard zones, which are presently devoid of landslides, indicate high potentiality for slope instability. In future, the triggering factors such as heavy rainfall, earthquake or anthropogenic activities may trigger landslides in these predicted potentially unstable zones.

Table 4: Landslide densities in different Hazard classes

Hazard classes	Area (km^2)	Landslide area density (km^2)	Landslide
Very low hazard	0.285	0.0025	0.0088
Low hazard	14.3775	0.1775	0.0123
Moderate hazard	19.5975	0.4275	0.0218
High hazard	11.9575	0.4225	0.0353
Very high hazard	0.6875	0.0725	0.1054

Conclusions

In the present study landslide hazard zonation mapping was carried out employing the LHEF rating scheme in GIS environment. The LHZ map, having five different hazard classes, shows the spatial distribution of landslide potential zones. The map was found to be in good agreement with the existing slope instability conditions of the area. The areas of high hazard zones those are presently devoid of any landslides, show potential zones for landslide occurrence.

The LHEF rating scheme uses the basic causative factors responsible for landslides. Since the basic causative factors remain the same in all types of terrains, the method has wider applicability. The factors considered in this study are most commonly used for landslide hazard mapping in Indian terrain. Most of the input data can be easily collected from desk study including remote sensing data and field study. However the structural data needs detailed field input for judicial analysis, which sometimes is not easy to collect in difficult terrain. Further, the post monsoon data of hydrogeological condition may bring out realistic results.

The GIS was found to be very useful for spatial data management for landslide hazard zonation mapping. Application of GIS was mainly involved in preparation of thematic data layers and their integration to prepare the hazard zonation map. It was found that GIS is a powerful tool for data storage, retrieval, editing, updating, map preparation and performing overlaying operations. The best part is that data integration can be performed very quickly for any desired cell size.

The LHZ map helps in decision-making for site selection, before planning any developmental works. No constructional work should be done in high hazard zones. If it is required, the recognition of landslide potential area at the initial stages of planning may help to adopt proper control measures before implementation of construction activity starts.

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