

Application of remote sensing and GIS in landslide hazard zonation of Joshimath–Badrinath road corridor, Garhwal Himalaya, India

***Ghan Bahadur Shrestha¹ and P. K. Champati ray²**

¹*Mountain Risk Engineering Unit, Tribhuvan University,
Kirtipur, Kathmandu, Nepal*

²*Geoscience Division, Indian Institute of Remote Sensing,
Dehra Dun, India*

*(*Email: shresthars2000@hotmail.com)*

ABSTRACTS

In the Himalayan region, slope stability is a major concern for developmental activities. Generally, landslide hazard mapping is carried out to identify relatively stable areas for infrastructural development. In the present study, a statistical technique, called information value method, was used to characterise different geo-environmental parameters. These parameters were then integrated to produce a landslide hazard map in the Garhwal Himalaya, India. The landslide causative factors such as lithology, geomorphology, structure, land use, drainage, and anthropogenic activities were derived from high-resolution satellite images and topographic maps, and the information was integrated in a GIS. The terrain-related factors such as slope and aspect were extracted from a digital terrain model (DTM) derived from the stereo pair data of IRS-P5 Cartosat-1 acquired on 20 November 2005. The map shows that 5%, 51%, 39%, 4%, and 1% of the total study area falls in very low, low, moderate, high, and very high landslide hazard categories, respectively. The Joshimath town as well as A.T. Nala and Marwari villages are some of the most hazardous places in the study area. Similarly, Hanuman Chatti, Benakuh, Dam Site, Lambagar, Binaik Chatti, and Paturi as well as the Govindghat–Ghat and Vishnuprayag–Marwari road corridors fall in high and very high hazard zones.

INTRODUCTION

Every year, thousands of pilgrims visit the famous temple of Badrinath via the Joshimath–Badrinath road. During the monsoon period, many landslides damage the road and cause a severe loss of lives and property. In July 2004, a landslide dammed the Alaknanda River at Lambagar and washed away about 100 m long road stretch. The road was blocked for one month and thousands of pilgrims were rescued through a hydropower tunnel. Hence, present study was carried out to delineate the areas susceptible to such disasters. For this purpose, a landslide hazard map of the study area was prepared applying statistical methods. IRS satellite imageries were utilised to derive various parameters (such as landslides, lithology, and geomorphology) contributing to landslide hazard and they were integrated using a geographic information system (GIS).

The study area is situated in the Chamoli District of Uttaranchal State, India (Fig. 1). It lies between latitudes 30°30'53"N and 30°43'10"N, and longitudes 79°27'51"E and 79°37'07"E with a total area of about 164.53 km². The area has deep gorges and rugged mountains with the lowest altitude of about 1400 m at the Alaknanda–Vishnu Gad confluence and the height altitude of 6596 m at Peak Nilkanth. It lies in the Higher Crystalline Group of rocks in the Garhwal Himalaya

bounded by the Munsiri Thrust in the southwest and a thick sequence of Tethyan sedimentary rocks in the north. The Main Central Thrust (MCT) passes just above the Joshimath town (Gururajan and Choudhuri 1999). The study area is composed of north-dipping low- to high-grade metamorphic rocks, such as garnet-mica schists, augen gneisses, banded gneisses, quartzites, and amphibolites (Kumar 1976). Two local faults are observed near Vishnuprayag and some lineaments were interpreted from the imagery.

The Alaknanda River, one of the main tributaries to the Ganges, flows in the north–south direction and meets the Dhauliganga River at Vishnuprayag. The Rishiganga, Khiraoganga, Ghritganga, Nilganga, and Laxmanganga are the snow-fed tributaries of the Alaknanda River. Between Rarang Chatti and Vishnuprayag, there are a number of waterfalls. In the study area, all streams and rivers exhibit straight courses indicating a structural control.

Solifluction plays an important role in soil formation on slopes. River terraces are one of the most prominent landforms. Frequently the Joshimath–Badrinath road runs through high (about 50 m) terraces. Unpaired terraces on either side of the river indicate a tectonic control after the Late Glaciation time. The area experiences subtropical climate

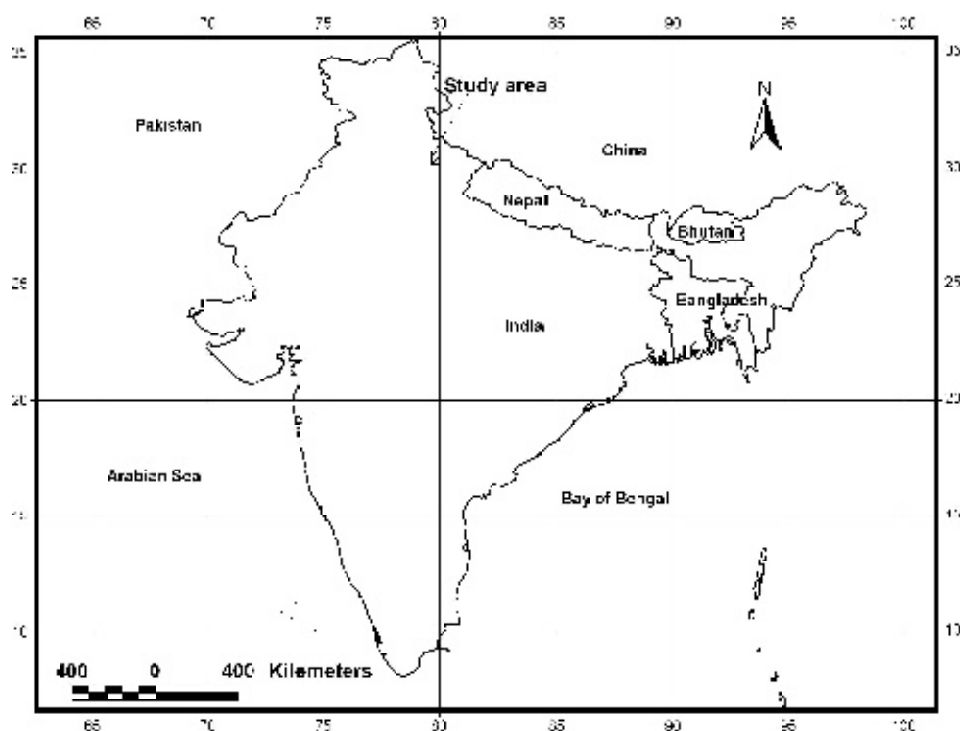


Fig. 1: Location map of the study area

with a hot and dry season in April–June, rainy season from July to September, and winter season from October to March. Snowfall from January to March is quite common in the area lying above an altitude of 2100 m. However, even at an altitude of 1300 m, snowfall can be observed during these months for a short interval of time. The road is disrupted frequently in winter due to heavy snowfalls, whereas it is blocked by landslides in the rainy season.

IRS Satellite image interpretation

For the purpose of landslide hazard mapping, satellite images (IRS-P5 Cartosat-1 acquired on 20 November 2005 of 2.5 m spatial resolution, IRS-P6 Resourcesat-1 acquired on 10 January 2005 of 5.6 m spatial resolution, and IRS-1C PAN acquired in 1998 of 5.8 m spatial resolution) were used to extract various thematic layers. For this purpose, Cartosat PAN ortho images and a digital terrain model (DTM) were obtained from the stereo pair of Cartosat-1. Six ground control points and other additional information was taken from the topographic maps (i.e. Sheets 53N/6 and 53N/10 on scale 1:50 000).

Mainly a visual interpretation of multi-spectral and PAN images was carried out to extract various thematic layers. For land use and land cover mapping, the IRS-P6 image gave better results. Landforms were interpreted from the IRS-P6 image. Lineaments were mapped on the IRS-P6 FCC image. Ridge offsets, sharp topographic breaks, and straight stream courses were used to identify the faults. The instabilities around Lambagar were mapped using the IRS 1C PAN and

IRS-P6 images. Drainage, contours (20 m interval), settlements, spot heights, and waterfalls were obtained from the topographic maps.

All the above thematic layers were finally transferred onto the large-scale (1:10,000) Cartosat PAN ortho image. In this process, necessary rectification and modification of the data were also carried out. The DTM was used to prepare a slope map and an aspect map as well as to delineate old and small landslide scars. All the above layers were further verified and corrected in the field in May 2005.

Spatial distribution of instabilities

Joshimath, A.T. Nala, Lambagar, and road corridors of the study area are severely affected by rockslides, rock falls, debris flows, and active gullies. The landslides in the study area occupy about 1.65 km². Some of the important ones are described below.

Subsidence at Joshimath

The Joshimath town is situated on an old, dormant rotational slide. Active and old scars are clearly outlined on the Cartosat PAN ortho image. Some old landslides and unclear scars were mapped using slope profiles (Shrestha 2006) and ground data (Fig. 2). The aspect of entire slope is essentially due north-east and it is smooth, straight to slightly convex. The slope generally consists of old colluvial soils of about 10 m depth.



Fig. 2a: Road sinking due to a large rotational slide at Oucha, view to W; Fig. 2b: A cracked house due to ground subsidence at Joshimath

A. T. Nala debris slides

Major problems at the A.T. Nala area are caused by intense gully erosion and rotational debris slides (Fig. 3). In the monsoon period, huge debris masses block the Joshimath–Tapowan road. The slope consists of sandy clayey gravel derived from moderately weathered gneisses. The slope gradient is about 15°, concave-shaped, and it is facing due NE. The middle part of the slide is still moving. Seeps and springs are also contributing to the slope movement. Below the road, a narrow and deep gully contains many large boulders, which are the remnants of a past debris flow. A few houses are still at a high risk of sliding. Many new as well as old scars are prominent on the Cartosat PAN ortho image.

Landslides at Lambagar

In this area, three large rockslides (Fig. 4) occurred in July 2004 and they coalesced to form a huge debris slide downstream. The debris slide blocked the Alaknanda River for 24 hours and about 100 m long road stretch was washed away. Failures were triggered by the porewater pressure developed in the jointed rock mass. A comparison of IRS 1C PAN (taken in 1998) and IRS P6 LISS VI (taken in 2005) temporal images revealed that the three rockslides are rapidly enlarging owing to their headward erosion (Fig. 5).

There is also a debris slide at a distance of about 25 km from Joshimath towards Badrinath. The slide is 405 m wide and 110 m long. It is composed of loose, ill-sorted, angular, and slightly weathered till with clasts reaching up to 7 m in size. The slopes are highly susceptible to sliding and the road is damaged every year, especially during the monsoon season.

LANDSLIDE HAZARD ZONATION

In the present study, spatial statistical prognostic modelling for landslide hazard zonation was used to prepare a landslide hazard map. Similar techniques have been applied successfully in China, Italy, and many other countries (IIRS 2005). For landslide hazard zonation, the information value (Yin and Yan 1988) of different themes was calculated applying the following equation.

$$I_{A,j \rightarrow T} = \log\left(\frac{S_j / N_j}{S / N}\right)$$

where $I_{A,j \rightarrow T}$ = information provided by feature A and state j for event T to happen, N = total number of grids in the study area, N_j = number of grids having variable j , S = total number of landslide-occurring grids in the entire study area, and S_j = number of landslide-occurring grids within the “ j ” variable grids.

The following nine overlays were selected for landslide hazard zonation:

- geology, geomorphology,
- lineament density,
- drainage density,
- slope,
- aspect,
- land use,
- cut slope failure, and
- fault zone.

For this purpose, vector files were converted into raster overlays with an individual cell size of 20 m. The information

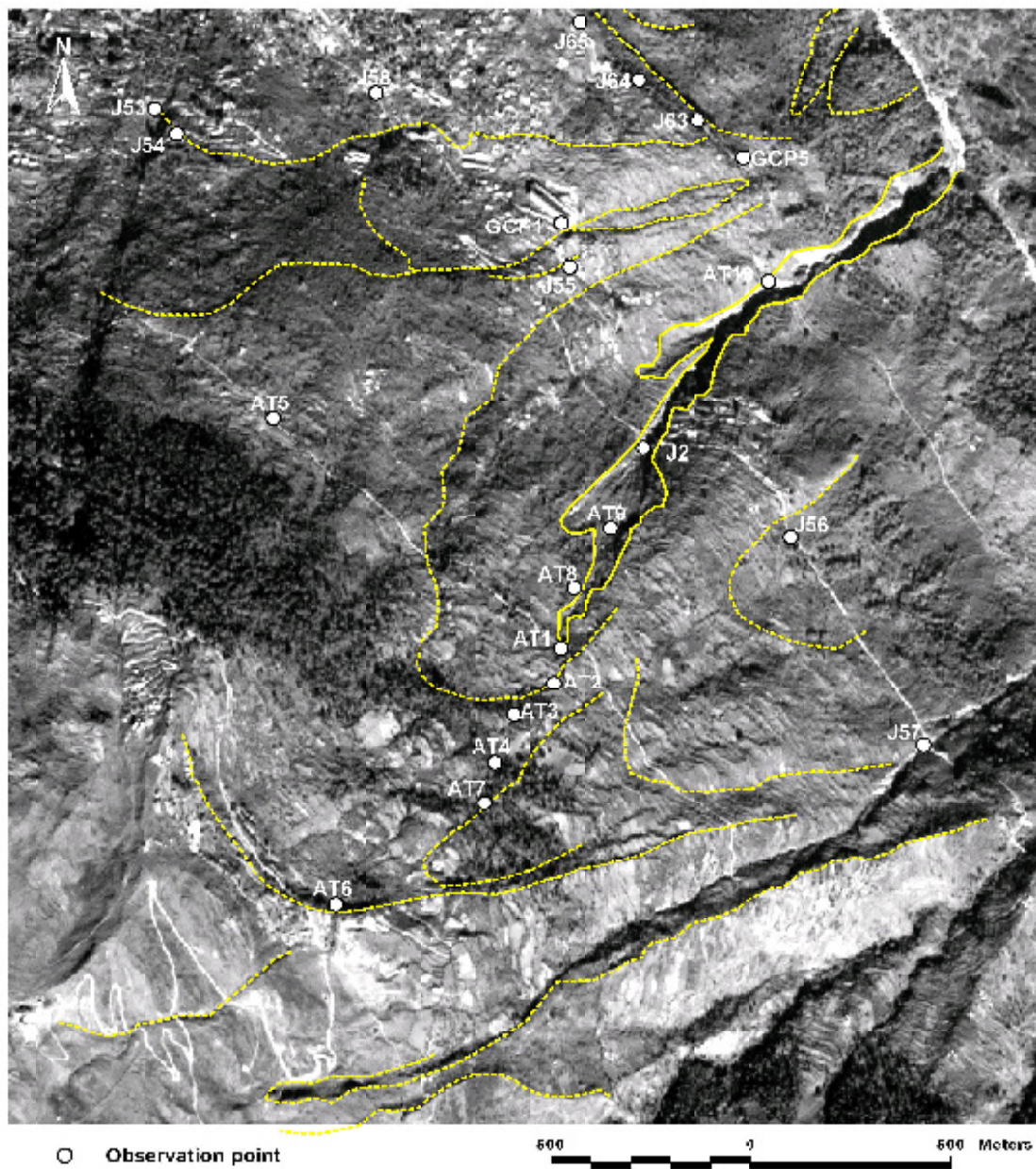


Fig. 3: Ortho image of A. T. Nala landslide. Dashed and solid lines show old and active scars respectively.

value of a thematic layer (Table 1) was calculated from the above equation and all the thematic values were then summed up to obtain a combined value map. The final landslide hazard map (Fig. 6) was prepared by reclassifying the map into five hazard categories (Table 2). The very low, low, moderate, high, and very high landslide hazard categories occupy respectively 5%, 51%, 39%, 4%, and 1% of the total study area. Similarly, 22%, 41%, 25%, 11%, and 1% of the landslide area falls in the very high, high, moderate, low, and very low hazard zones respectively. About 63% of the total landslide area in the Joshimath–Badrinath road corridor falls within 5% of the

high and very high hazard zones. About 90% of the landslide area around Joshimath and A. T. Nala falls within the very high and high hazard zones. Similarly, the landslides between Vishnuprayag and Marwari fall in high hazard zones, whereas at Lambagar, 70% of the landslide area falls in the high and very high hazard zones. Joshimath, A.T. Nala, and Marwari fall in high and very high hazard zones. Similarly, Hanuman Chatti, Benakuh, Dam Site, Lambagar, Binaik Chatti, and Paturi also belong to highly hazardous areas. The road corridor between Govindghat and Ghat as well as between Vishnuprayag and Marwari falls in very high and high hazard zones.

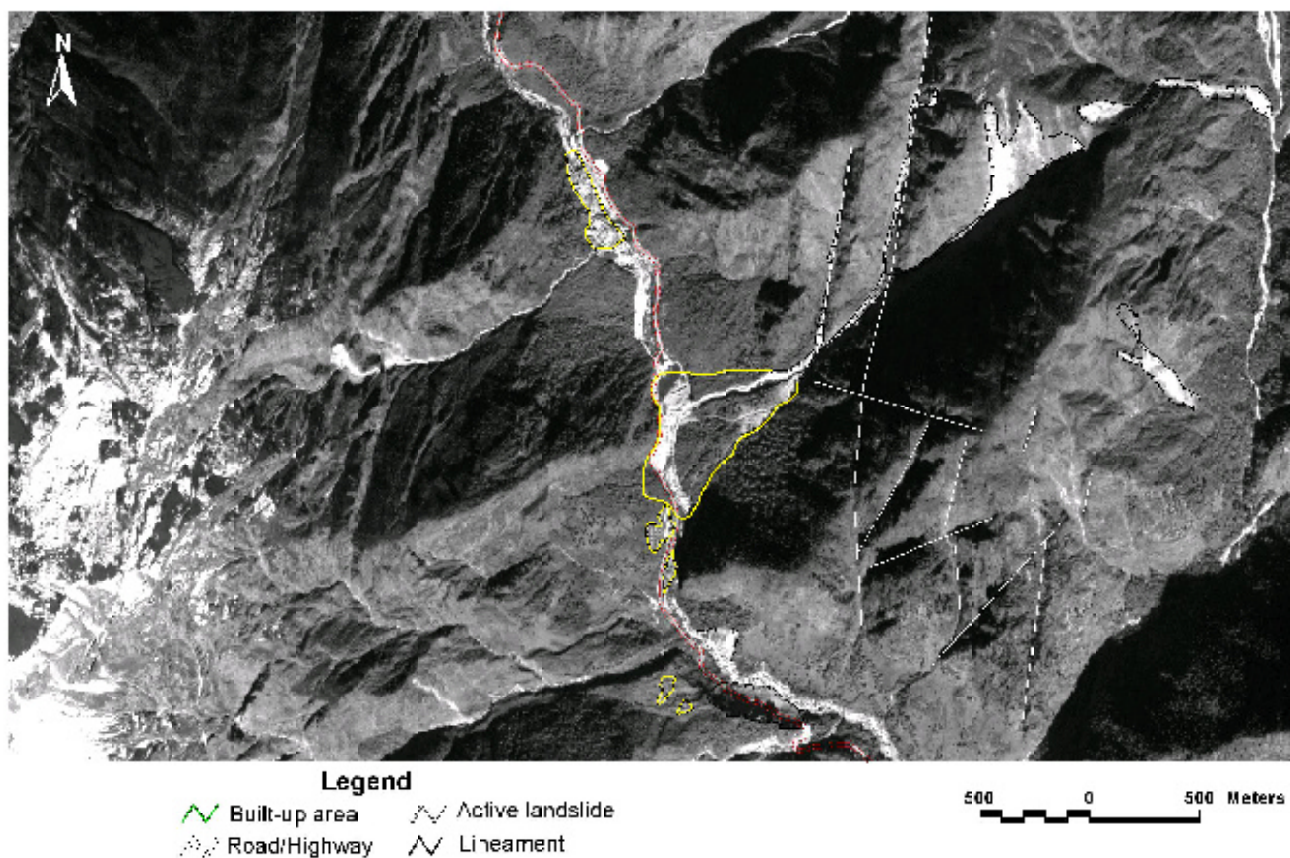


Fig. 4: A landslide damming the Alaknanda River at Lambagar (in the centre of image). Three rockslides form a cone-shaped debris fan downstream (Cartosat PAN Ortho image of 20 Nov. 2005)

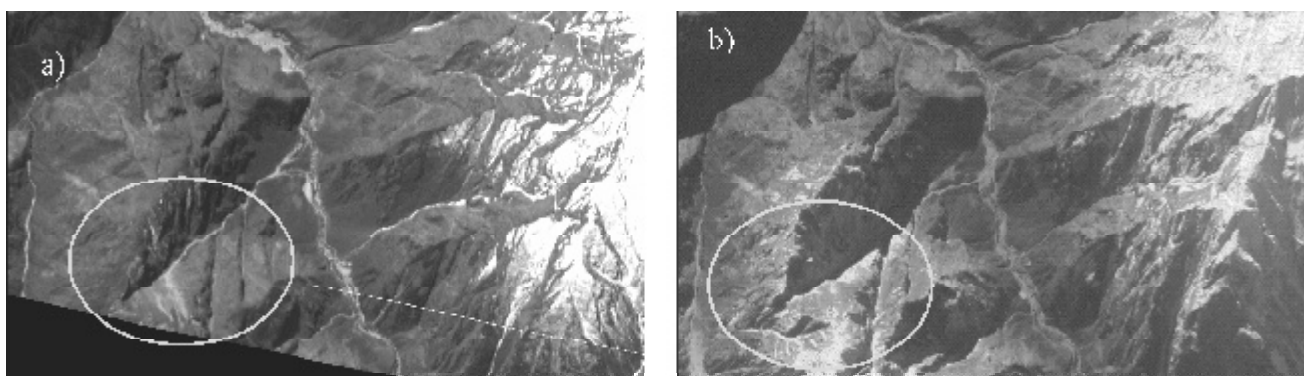


Fig. 5: Status of landslides at Lambagar. a) Landslide observed on IRS 1C PAN of 1998 and b) the same landslide observed on IRS P6 LISS VI of 2005.

Table 1: Information values obtained for different thematic layers

S. N.	Variables/attributes	Values	S. N.	Variables/attributes	Values	
1	<i>Geology</i>		5	<i>Faults/thrusts</i>		
	Granitic gneiss	-0.240		T1(100 m)	0.639	
	Quartzite	0.120		T2 (200 m)	0.535	
	Gneiss	-0.170		F1 (75 m)	0.017	
	Mica schist	0.310		F2 (150 m)	-0.405	
2	<i>Land use/land cover</i>		6	<i>Lineament density</i>		
	Snow	0.000		Very low	-0.293	
	Barren land	-0.094		Low	0.152	
	Grass land	-0.106		Moderate	-0.102	
	River bed	-0.335		High	-0.524	
	Moderate vegetation	-0.057	7	<i>Drainage density</i>		
	Dense vegetation	0.041		Very low	-0.093	
	Scrub/grass	0.331		Low	0.002	
	Agriculture	0.765		Moderate	0.078	
	Degraded vegetation	0.818			High	0.000
Built-up area	-0.816	8		<i>Aspect</i>		
3	<i>Geomorphology</i>			N (0-67)	0.133	
	Highly dissected denudational structural slope (HDDSS)		-0.717	NE (67-112)	0.111	
	Moderately dissected denudational structural slope (MDDSS)		0.124	E (112-157)	-0.126	
	Less dissected denudational structural slope (LDDSS)		-0.078		SE (157-202)	0.163
	Glacio-fluvial		-0.275		S (202-247)	0.040
	River bed		0.136		SW (247-292)	0.066
	Bank erosion		0.117		W (292-337)	-0.107
	Scree		0.435		NW (337-360)	-0.235
	River terrace		0.498		Flat	-0.771
	Till	1.055				
Debris fan	1.182					
Fan/scree	0.000					
4	<i>Slope classes⁰</i>					
	0-15	0.032				
	15-25	0.165				
	25-30	0.130				
	30-35	0.165				
	35-40	0.013				
	40-45	-0.126				
	45-60	-0.405				
	>60	-0.346				

Table 2: Area occupied by landslides and their hazard categories

Category	Landslide hazard		Landslide area	
	km ²	Per cent of total hazard area	km ²	Per cent of total landslide area
Very high hazard	1.6453	1	0.361966	22
High hazard	6.5812	4	0.674573	41
Moderate	64.1667	39	0.411325	25
Low	83.9103	51	0.180983	11
Very low	8.2265	5	0.016453	1
Total	164.5300	100	1.645300	100

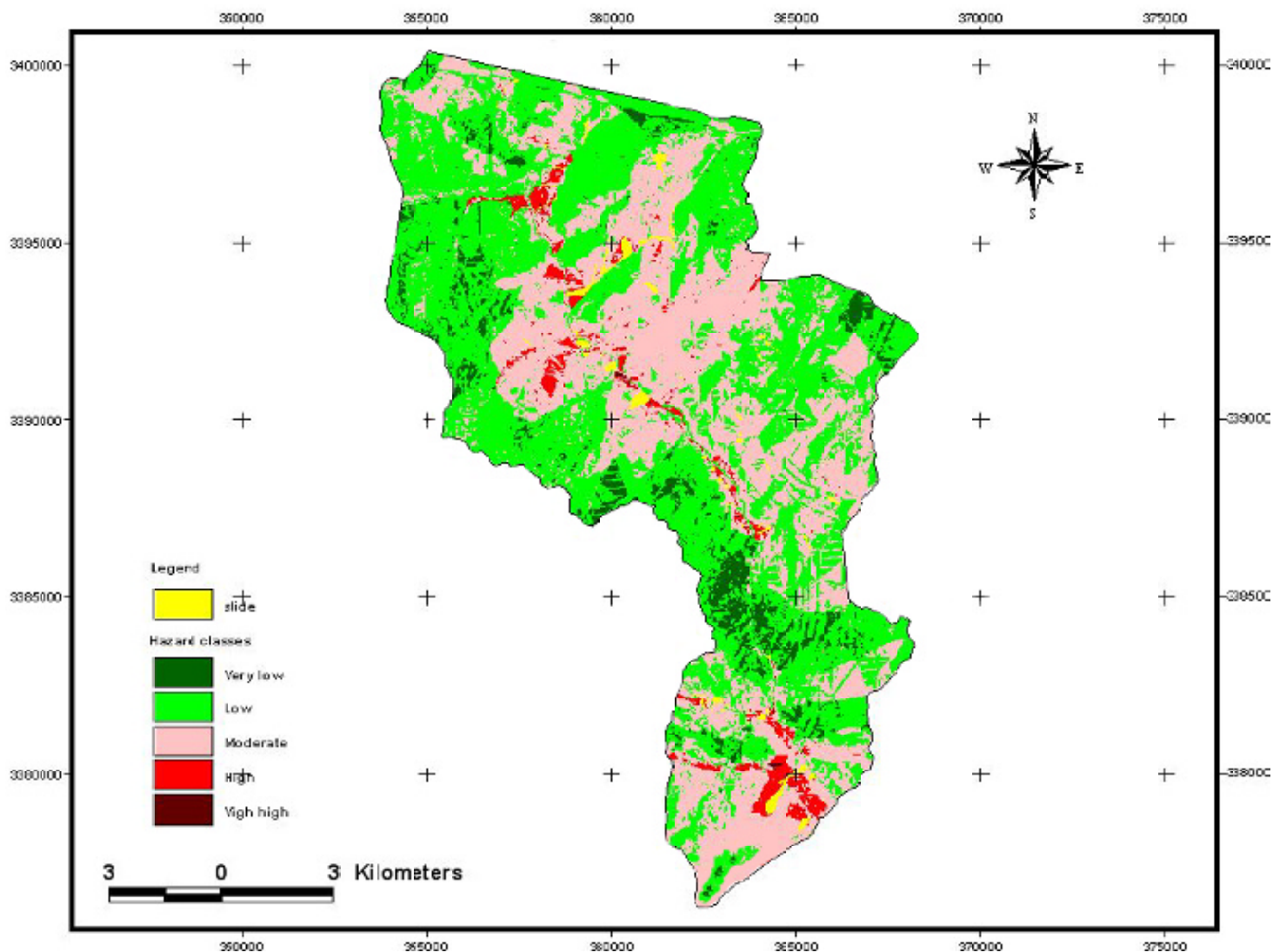


Fig. 6: Hazard map of the Joshimath–Badrinath road corridor

CONCLUSIONS

IRS-1C PAN, IRS-P6, IRS-P5 Cartosat PAN, and IRS-P6 FCC temporal images were useful for landslide hazard mapping in the Joshimath–Badrinath road corridor.

The information value method applied in this study is a simple and cost-effective tool to delineate hazardous areas in an inaccessible terrain like the Himalaya. The Joshimath town as well as A.T. Nala and Marwari villages are some of the most hazardous places in the study area. Similarly, Hanuman Chatti, Benakuh, Dam Site, Lambagar, Binaik Chatti, and Paturi as well as the Govindghat–Ghat and Vishnuprayag–Marwari road corridors also belong to high and very high hazard zones.

ACKNOWLEDGEMENTS

We are grateful to Dr. V. K. Dadhwal, Dean, IIRS, Dehra Dun, for providing computer facilities and field gear. We thank Professor R. C. Lakhera, Geosciences Division, IIRS, for his support and guidance as well as valuable suggestions during the study. Special thanks are due to Professor Ajay Kumar Naithani, Garhwal University; the staffs of Border Roads Organisation, Indian Army; and India–Tibet Border Police for providing accommodation during the fieldwork.

REFERENCES

Gururajan, N. S. and Choudhuri, 1999, Ductile thrusting, metamorphism and normal faulting in Dhauliganga Valley, Garhwal Himalaya, *Himalayan Geology*, v. 20(2), pp.19–29

IIRS, 2005, *Lectures note, RS and GIS applications in Geosciences*, Geosciences Division, Indian Institute of Remote sensing, Dehra Dun, India, 290p.

Kumar, G., 1976, Geology and Sulphide mineralisation in the Porkhari area, Chamoli District, Utter Pradesh, Geol. Surv. India, Misc. Pub. 16, pp. 92–98

Shrestha, G. B., 2006, Geotechnical characterisation and deterministic modelling of landslides along Joshimath to

Badrinath Area, thesis submitted to Centre for Space Science and Technology Education in Asia and the Pacific (affiliated to the United Nations), Indian Institute of Remote sensing, Dehra Dun, India, 40 p+.

Yin, K. L. and Yan, T. Z., 1988, Statistical Prediction Models for Slope Instability of Metamorphosed Rocks, Proc. 5th Int. Symp. On Landslides, Lausanne, v. 2, pp. 1269–1272