Tropical Agricultural Research Vol. 15: 316-326 (2003)

Remote Sensing and GIS based method for Landslide Susceptibility Mapping along Silchar-Shillong Highway, Northeast India

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ABSTRACT. *Landslides are one of the natural hazards, particularly in developing countries causing immense loss of human life and property. Remote Sensing and GIS based approach for identification of landslide susceptibility areas are known to provide vital spatial information support necessary for landslide hazard assessment. The present study has been carried out in parts of Shillong-Silchar Highway i.e. in the Cherupi-Lumshnong-Sonapur area of the Meghalaya and Assam States, India covering an area of 200 km^2. Various thematic layers such as lithology, geomorphology, structure, land use, slope amount, slope aspect, weathering, soil texture and soil depth, anthropogenic factors, dip-slope relationship, drainage and landslide incidence have been prepared by referring to IRS LISS-III and PAN merged satellite image, topographical map, literature and field observation. Spatial database organization and integration for landslide susceptibility analysis have been carried out by using information value method in ArcView GIS. The result showed a statistical relationship between of landslides with every class of thematic layer. The final integrated layers has been classified into five classes such as very low, low, moderate, high and very high showing relative landslide susceptibility in the region. The results when compared with existing landslides show good correlation. However, the study has highlighted the errors and uncertainties due to unavailability of adequate information.*

INTRODUCTION

Landslides are one of the prominent disasters in the Himalayas taking huge tolls of human lives and damaging property and vital infrastructure every year. Most of the steep slopes of the Himalaya are subject to slope failure due to various geological causes and triggered by events such as earthquake or extreme rainfall. In recent times, the frequency and magnitude of slope failures has increased due to human activities, such as road construction, deforestation and urban expansion. The problem of landslides becomes more aggravated, especially during the rainy season due to torrential rains on the vulnerable slopes. In the recent past a large number of human lives and property worth millions of rupees have been lost due to landsliding in the Himalayan region. In 1998, in a single event more than 200 people died near Malpa, Pithoragarh District, Garhwal Himalaya. Therefore, it is essential to understand the geo-environmental parameters particularly those affecting slope failures. Careful identification and categorizing of those parameters is very much essential, to predict future sliding areas. One of the steps in this direction is preparation of Landslide Hazard Zonation (LHZ) maps. Landslide Hazard Zonation refers to the division of a land surface into homogeneous areas or domains and their ranking according to degree of actual / potential hazard caused by mass movement (Varnes, 1984). Spectacular

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development in the application of space technology has made remote sensing a very powerful tool for assessment and monitoring of the landslides (NRSA LHZ Atlas, 2001). The development of GIS has greatly facilitated the preparation of Landslide Hazard Zonation maps in an integrated manner (Westen, 1993; Carrara, 1995; Champati ray, 1996). This study attempts to demonstrate these emerging technologies in preparation of landslide susceptibility maps in a semi-automated manner. Remotely sensed and auxiliary data can be digitally processed and integrated in Geographical Information Systems (GIS), which are having efficient tools for collecting, storing, retrieving, transforming, manipulating and displaying spatially distributed data (Bonham Carter, 1994). Basically a terrain is analyzed with respect to various geo-environmental factors that are integrated using a particular mathematical model to find out probability / susceptibility for landslides for each of the pixels in GIS domain. Terrain units showing a unique value for landslide probability / susceptibility of occurrence of similar phenomena in future are classified into several classes of probability / susceptibility *i.e.*, very high, high, moderate, low and very low. Hazard maps aim to predict where failures are most likely to occur without any clear indication of when they are likely to take place. However, these hazard maps can be used as a guide for future development of infrastructures, settlements and any other construction to avoid future disasters.

The main aim of the study is to prepare Landslide Susceptibility Maps on 1:25,000 scale along parts of Shillong-Silchar Highway corridor in the States of Meghalaya and Assam states using Remote Sensing and GIS techniques in conjunction with the ground surveys and existing collateral data. The specific objectives are: GIS based modeling for prepare Landslide Hazard Zonation Map (LHZ), ArcAvenue based software development for preparation of LHZ map in an automated manner, and assessment of accuracy between the output maps generated from integration techniques mentioned earlier.

METHODOLOGY

Study area

The study area consisted of 5 km width corridor along Silchar-Shillong highway, geographically bound by 25^0 0' 0" N to 25^0 15' 00" N latitudes, 92^0 20' 0" E to 92^0 30' 00" E longitudes (Figure 1). It covers approximately 200 km^2 along 50 km of national highway with 5 km corridor falling in parts of Jaintia Hills of Meghalaya as well as parts of Assam. The area is mostly covered by thick forest and experiences heavy monsoon rainfall during May to September causing landslides along the Highway, the most spectacular being the Sonapur landslide at the center of the study area.

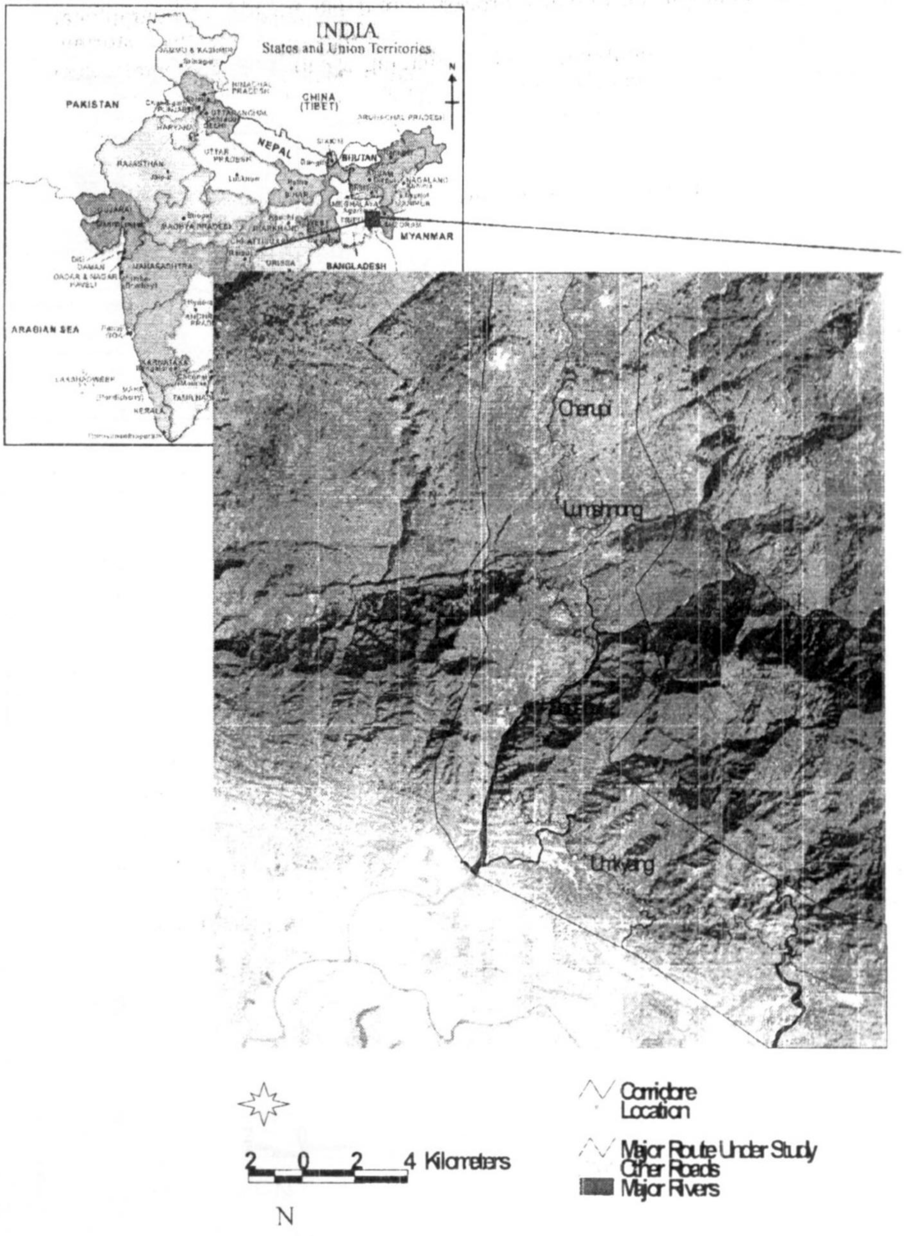

Fig. 1. Location map showing study area.

Geological set up of the region

The study area principally consists of three zones, which are characterized by distinct geology and physiographic set up. The southern areas up to the base of the Jaintia hills consist of mainly rocks of Surma Group and form undulating terrain and low lying hills. The areas north of this unit extending beyond Sonapur till Dauki Fault consist of mainly Barail Group of rocks forming high hills and steep ridges. The areas beyond Dauki fault consist of mainly plateau forming limestones and sandstones of Shella Formation belonging to Jaintia Group (Das *et al.*, 2001).

Data integration techniques for landslide hazard zonation

The main purpose of various data integration techniques or models is to combine spatial data from diverse sources together to describe and analyze interactions, to make prediction with models, and to provide support to decision makers. Many workers have developed and tested various integration techniques for landslide hazard zonation, each having its own advantages and limitations (Westen, 1993; Carrara *et al.*, 1995; Chung *et al.*, 1995; Champati ray, 1996). Broadly, Landslide Hazard Zonation maps can be prepared by using pure statistical techniques as well as a pure knowledge-based approach (Westen, 1993; Carara *et al.*, 1995, Champati ray, 1996; NRSA LHZ Atlas, 2001). The latter can be considered as a hybrid method when knowledge is derived from, or influenced by, the statistical analysis of data sets.

Information value based method

The statistical or probabilistic approach is based on the observed relationship between each factor and the past and present landslide distribution. Hence, landslide hazard evaluation using a statistical approach is highly objective and generates reproducible results. The strength of this functional approach is also directly dependent on the quality and quantity of data collected. Drawbacks derive from the fact that only few factors that are relevant for landslide assessment are mappable at reasonable cost. Errors in mapping past and present landslides will exert a large and not readily predictable influence on the model. Being data-driven, a model built up for one region cannot readily be extrapolated to the neighboring areas. Information value method is one of the statistical or probabilistic approach which can be readily applied in spatial domain. It implies the prior definition of terrain units and the selection of a set of instability factors. Each instability factor is crossed with the landslide distribution map, and weight values based on landslide densities are calculated for each parameter class.

In the present case, data driven approach i.e. information value method has been used to prepare Landslide Hazard Zonation of the study area. The methodology of the present study is briefly shown by the figure 2.

Data analysis

Data analysis was carried out in ArcView GIS grid format using the 'LHZ' extension. The spatial statistical relationship of different geo-environmental parameters and actual landslide occurrences of a region is the most important aspect to be analyzed for hazard zonation purposes. It underlies the principle that the conditions/parameters under which landslides have occurred in the past/present will also be responsible for future occurrences. Therefore, it is necessary to establish the statistical relationship of present landslides with parameters. This can be easily accomplished by calculating information value for each layer as explained earlier. According to information value method, the landslide density in a parameter class is divided by landslide density in the entire map. The natural logarithm of the value is used to give negative weights when the landslide density is lower than normal, and positive when higher than normal.

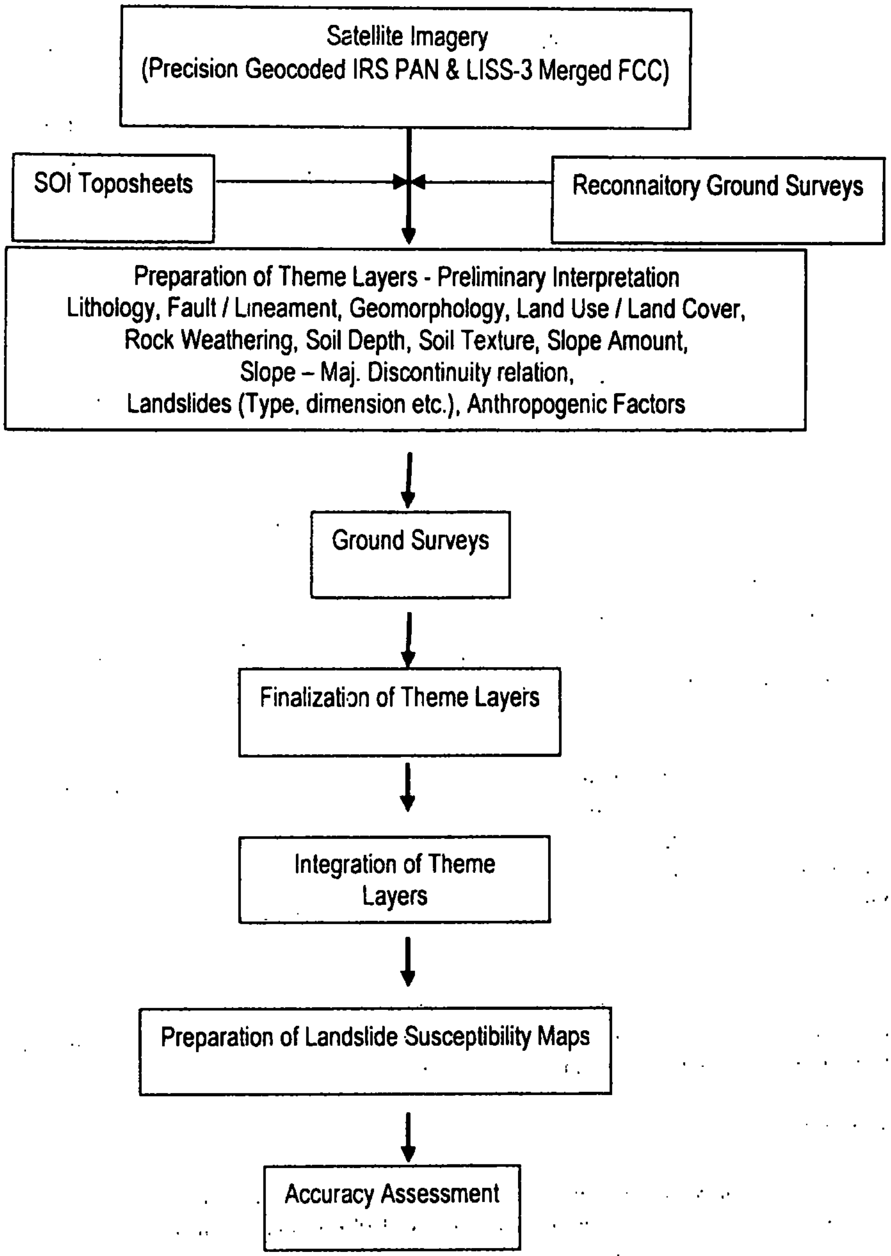

Fig. 2. Flow chart showing methodology.

RESULTS AND DISCUSSION

The rock mass strength is directly influenced by the rock types present in the terrain. Lithological units dominated by sandstone, siltstone, and sandstone with shale show positive information values indicating their positive influence on landslides. These are correlated with the Bhuban (siltstone), Jenam (argillaceous sandstone) and Laisong formations in the litho-stratigraphic succession (Figure 3). Laisong Formation (sandstone with shale) shows many active and dormant slides. However, information value for Jenam member does not correlate with the ground observations. This formation consisting of argillaceous sandstone shows many small slides along the road.

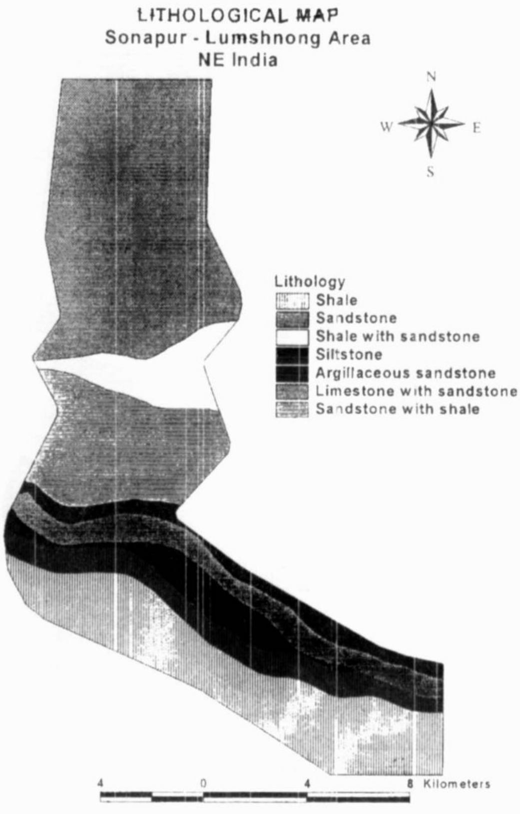

Fig. 3. Lithological map.

The areas underlain by Bokabil and Kopili shale formations show very few landslides as these areas have developed subdued topography due to weathering and denudation process. Lineament buffer zone shows positive relationship with landslides. The buffer zones were created up to a distance of 50 m from lineaments, 100 m from faults and 200 m from thrust. Geomorphologically, low and moderately dissected hill units show most of the mapped active and dormant landslides (Figure 4). Therefore, information values for these classes show positive numbers. Highly dissected hills show negative values. Therefore, it is concluded that dissection does not alone affect landsliding in this region. Most of the landslides occur due to wedge / planar failure caused by differential weathering of alternating weak and strong rocks (steeply dipping). The plateau region shows almost no landslides indicating negative values. Toe erosion affected areas show positiye information value and confirms high susceptibility for sliding. In rock weathering map, statistical analysis shows that low and moderate rock weathering classes having high information value for landslides than other classes. Highly weathered zones in the study area have developed subdued topography due to erosion and denudation, thereby showing less number of active slides.

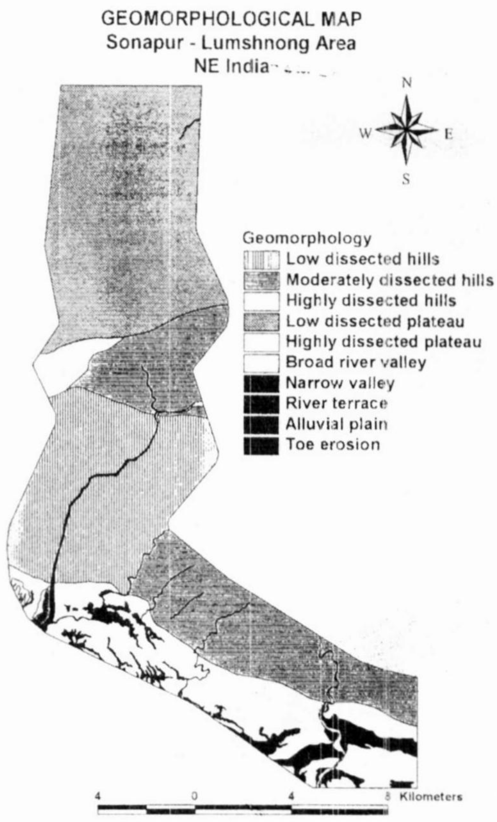

Fig. 4. Geomorphological map.

The anthropogenic factors map shows high information values for road cuttings as these areas are prone to landslides and many landslides are mapped along the road. The mining areas are mostly on the plateau, therefore, not contributing to slope instability in the region. The occurrence of slope failure depends greatly on the orientation of weak planes (bedding of rocks/joints) with respect to the topographic slope. Broadly, four conditions exist: (1) Dip and topographic slope in the same direction – mostly planar failure occurs, (2) Dip-slope in opposite direction- more stable situation, (3) Dip and slope at right angle – mostly wedge failure occurs, (4) Horizontal dipping areas-where such relationship does not contribute towards landslide assessment. Major landslides in the region including Sonapur slide have occurred due to wedge failure. Such areas mostly show perpendicular slope-dip relation, and therefore, show positive information value. Along the road, some landslides were observed in areas showing dip/slope in same direction.

In the soil texture map, the rock outcrops are highly correlated with the existing landslides, and therefore, show high information values. Additionally, hill slopes with loamy skeletal and sandy skeletal soils also show positive information values for their association with landslides in the region. Soil depth plays an important role for sliding, particularly slumping or circular failures in loose debris. However, in the present study, many landslides (rock slides, wedge failures) were found in areas, which have shallow soil depth. Due to high topographic relief, such areas don't develop thick soil profile. Thick soil profile is only seen in alluvial plains and low relief hills, having less probability for landslides. In land use/land cover map, barren rocky areas show very high positive information values, because most of the landslides are mapped as barren lands in the land-use map. Dense and medium vegetations also show negative information values. Degraded forest shows a very high positive value, confirming landslide potential in the class. Shifting cultivations show high negative values, as these areas normally occur in the plateau region and gentle slopes. As some of the forest blank areas are correlated with landslides, it shows positive information values. The slope gradient map shows very high information value for classes having slope 25-60 degree, beyond which it represents hard resistant rocks showing mostly stability except for occasional rock falls.

All the layers with modified attribute tables having the field of information values were integrated in *Map Calculator* and the final value which represents the cumulative landslide hazard susceptibility of a ground pixel are classified into one of the five classes: very low, low, moderate, high and very high (Figure 5). The histogram values in the raster map were transferred to an Excel worksheet in order to calculate cumulative histogram percentage. The relative hazard zones were determined as per the percentage cut-off values in the cumulative histogram. These cut-offs were selected on the basis of average density of landslides in the region following some guidelines given by Carrara *et al.* (1995).

Table 2. Percentage cut-offs for landslide susceptibility classes.

Relative Hazard/ Susceptibility Class	Percentage Cut-off
Very Low	0-40%
Low	40-65%
Moderate	65-90%
High	90-95%
Very High	95-100%

The success rate or validation of the spatial prediction capability of the susceptibility map can be evaluated once again by calculating the information values of the susceptibility class map with respect to the landslide map. In the present case, very high and high susceptibility classes show very high information values and cover almost 80% of actual landslides (Table 3). However, the actual validation is only possible if future landslides are taken into consideration and the weights of the hazard zonation map is calculated with respectt to such new landslides.

The resultant landslide susceptibility map shows low susceptibility in areas underlain by shale and topographically low lying and plateau regions. The areas,underlain by alternating sandstone/siltstone and shale show high susceptibility to landslides. Often these areas show steep slopes and due to differential weathering of alternating sequence of rocks, the soft underlying layer is removed, thereby reducing the support for the overlying hard resistant rock, which eventually slides due to the effect of gravity on steep slopes. Landslides in this region are triggered mostly by rainfall. High seismic activity also contributes in this regard.

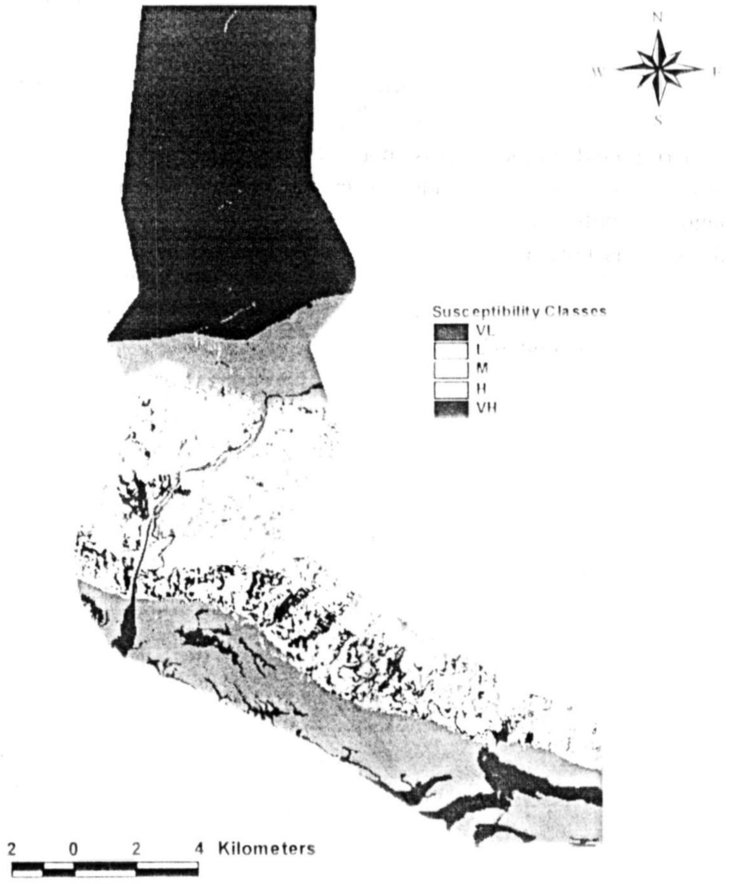

Fig. 5. **Landslide susceptibility map showing relative hazard classes.**

Table 3. **Calculation of statistical relationship of active and dormant landslides with hazard susceptibility classes.**

Class	Count	nclass	nslclass	inf value	Slide %
VL	765111	76511100	0	-9.490170	0
L	540682	54068200	32400	-1.059660	9.323741
M	389622	38962200	34700	-0.663342	9.985612
H	206689	20668900	52200	0.378885	15.02158
VH	115776	11577600	228200	2.433583	65.66906

nclass = no. of grids in each class of thematic layers
nslclass = no. of grids in each class having landslides

CONCLUSIONS

Overall the study has highlighted that remote sensing techniques greatly aid in the investigations of landslides. Although it does not replace fieldwork, it offers an additional tool from which a lot of information about landslide causes and occurrences can be extracted. Predictive models of landslide hazard constitute a major research field, which may well take advantage of the potentials of the new technological advancements. Since geographical electronic processing is becoming a fashionable, emerging discipline, GIS-driven data acquisition, manipulation and analysis will find an increasing number of supporters among institutions and individuals aimed at monitoring and forecasting natural disasters in general, and landslide hazards in particular. To predict landslides in any terrain a well-known geo-environmental parameter should be select carefully in order to simulate real terrain condition in GIS environment. Improper selection of the parameter will highly effect and add to error in the output map. The reliability and usefulness of hazard models are dependent on both the quality of the input factors, and the type of terrain-unit selected. More detail study of existing active, dormant and old landslides will definitely give reasonable information values and improve the output hazard map.

ACKNOWLEDGEMENTS

Authors are thankful to Dr. P.S. Roy, Dean/IIRS, Dehradun, India, Prof. Karl Harmsen, Director/CSSTE-AP, Dehradun, India, Prof. V.K. Jha, Head, Geosciences/IIRS, Prof. R.C. Lakhera, Senior Scientist/IIRS, Mr. Tilak Dharmaratne, Director/Gem and Jewellery Research and Training Institute, Sri Lanka and Dr. Ranjith Premalal de Silva, Senior Lecturer/Department of Agricultural Engineering, University of Peradeniya for their help and encouragement to carry out this study.

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