International Conference on Geotechnical Engineering for Disaster Mitigation & Rehabilitation
Chu, Phoon & Yong (eds) © 2005 World Scientific Publishing Company ISBN 981-256-469-1

LANDSLIDE HAZARD ZONATION IN INDIA: A REVIEW

S. SARKAR
Central Building Research Institute
Roorkee – 247667, India

D. P. KANUNGO
Central Building Research Institute
Roorkee – 247667, India

The assessment of landslide hazard and preparation of landslide hazard zonation map is an imperative task in the area of disaster management. There are many methods used by several workers in different parts of the globe. In most of the techniques though input parameters are mostly the same, they differ in ranking the factors. In general the methods are either based on the qualitative approach which dictates the weight assignment to the factors based on the experience and expert knowledge or the statistical approach which involve relationship between existing landslides and the factors. In India several hazard zonation mapping have been carried out in different parts of Himalaya. The paper presents few of the techniques used by the authors.

INTRODUCTION

In recent years, a number of major disasters have made the global community aware of the immense losses of human lives and properties. Although an individual slope failure is, in general, not so spectacular or devastating as an earthquake, a volcanic eruption or a flood, yet, being much more frequent and wide spread over the years, landslides have caused considerable loss of property and life. In many countries, economic losses due to landslides are great and apparently are growing as development expands into unstable hill areas under the pressure of expanding populations.

The landslide hazards, in general cannot be completely prevented, however, the intensity and severity of their impacts can be minimized if the problem is recognized before the development activity or deforestation begins. Hence, there is a dire need for identification of unstable slopes, which can be fulfilled by landslide hazard zonation mapping. The landslide hazard zonation (LHZ) of an area aims at identifying the landslide potential zones and ranking them in order of the degree of hazard from landslides. Several workers using different methodologies have carried out landslide hazard zonation mapping in different parts of the Himalaya. It is not possible to describe all these works; however, a brief outlines of commonly used methods are reported here.

LANDSLIDE PROBLEMS IN HIMALAYA

The occurrence of landslides is a common phenomenon in the Himalaya. In the recent past there were few landslide disasters in Uttaranchal Himalaya. The landslide disaster at

Malpa in the Kali valley occurred on 18th August 1998, which completely destroyed the habitation and wiped out temporary shelters of pilgrims going to Kailash-Mansarovar causing a death toll of more than 200 peoples. The Mandakini Valley of Rudraprayag district has been struck by several landslides as a result of heavy precipitation in the 3rd week of July, 2001. The important among them are Phata and Byung Gad landslides which killed 20 lives along with several injured. The landslide occurred in Uttarkashi on 24th September, 2003 has deposited a huge quantity of debris at the foot hill which caused a huge loss of property (Fig.1). It was fortunate to have no casualties as the district administration and scientific organizations took prompt action to evacuate the families as soon as the landslide was triggered.

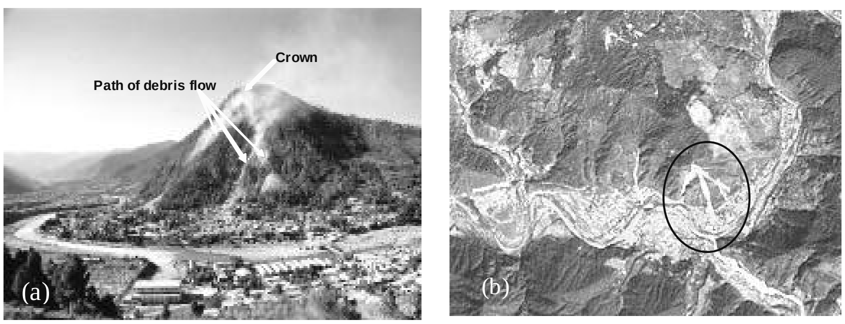

Figure 1. Uttarkashi landslide (a) Panoramic view, (b) Landslide seen in satellite image

FACTORS AND THEMATIC DATA LAYERS

Landslide can be triggered by both natural and man induced changes in the environment. The most common factors considered for landslide hazard zonation in India are lithology, soil, geomorphology, slope, drainage, lineaments, proximity to fault and landuse which are essentially the preparatory factors. The adverse nature of any of these factors affects the existing equilibrium of stability. These factors can be judiciously studied and the pertinent data can be collected from the existing field conditions. Over the past few years there has been a significant contribution of remote sensing and Geographic Information System (GIS) for preparation of thematic data layers representing the causative factors used for landslide hazard zonation mapping. In India remote sensing and GIS are now become an essential tools for landslide hazard zonation mapping (Gupta *et al*., 1999; Saha *et al*., 2005; Sarkar and Kanungo, 2004; NRSA, 2001; Nagarajan *et al*., 1998).

LANDSLIDE HAZARD ZONATION IN HIMALAYA, INDIA

Landslide hazard zonation mapping in various parts of Himalaya has been attempted by several workers by applying different techniques. The techniques such as qualitative map combination, statistical, fuzzy and ANN based methods are most commonly used. The selection of appropriate method depends on nature of data, expertise and mapping scale. In India most commonly used scale for LHZ mapping is 1:50,000 to 1:25,000. Efforts are being made for preparation of the Indian Standard code for landslide hazard zonation mapping for macro (1:50,000 to 1:25,000), meso (1:25,000 to 1:15,000) and micro (1:15,000 to 1:5000) level scales.

Qualitative Map Overlay Approach

In qualitative map combination method the Land Hazard Evaluation Factor (LHEF) rating scheme of Anbalagan (1992) uses the facet concept for data collection. In this scheme, ratings of the classes of factors are based on personal judgment of their relative contribution to landslide occurrence. The total estimated hazard (TEHD) which is cumulative ratings of the factor classes are suitably classified into different hazard classes. Gupta *et al*., (1999) applied the ordinal weighting and rating system based on the relative importance of factors derived from field knowledge. The landslide hazard indices for grids are obtained by multiplying ratings of the classes with the corresponding weight of the factor and then classified into various landslide hazard classes. The weights and ratings for factors and their classes respectively can be also computed based on their pair-wise comparison using Analytical Hierarchy Process (AHP). National Remote Sensing Agency, Hyderabad has developed an Atlas on Landslide Hazard Zonation for parts of Uttaranchal and Himachal Himalayas using the concept of AHP (NRSA, 2001).

Sarkar and Kanungo (2004) developed a rating scheme for factors and their classes based on the associated causative factors for landslides surveyed in parts of Darjeeling Himalaya. In this scheme, the factors were assigned numerical ranking on a 1-9 scale in order of importance. Weights were also assigned to the classes of the factors on 0-9 ordinal scale where higher weight indicates more influence towards landslide occurrence. Undertaking several iterations using different combinations of weights suitably modified the scheme. The integration of numerical data layers in GIS produced the landslide susceptibility map of the area (Fig.2).

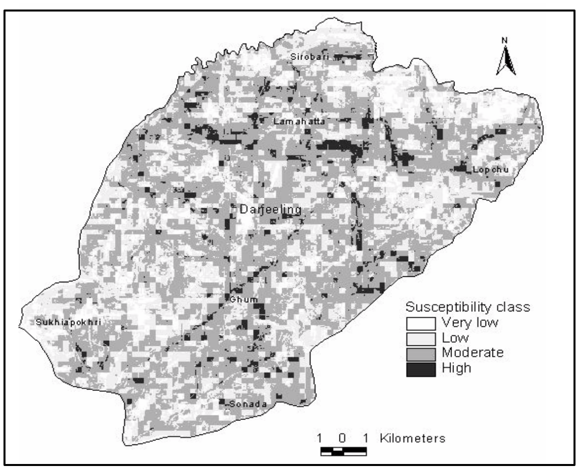

Figure 2. Landslide susceptibility map of parts of Darjeeling Himalaya
(Sarkar & Kanungo, 2004)

Statistical Approach

In statistical methods the existing landslides are correlated with the causative factors to predict the landslide potential zones. Gupta and Joshi (1990) adopted an empirical approach wherein statistical relationships of the factors with landslide occurrences are converted to landslide nominal risk factor (LNRF) based on the ratio of landslide incidence in a particular category to the average landslide incidence in various categories of that factor. These LNRF values were integrated to provide cumulative risk factor based on which landslide hazard zonation map was prepared.

The numerical weights of the factor categories derived from the frequency distribution of landslides, termed as Landslide Susceptibility Grades (LSG) was defined by Sarkar and Gupta (2005) for landslide hazard zonation mapping of Srinagar-Rudraprayag area of Garhwal Himalaya. The LSG of a category belonging to a factor is the ratio of number of grids of that category having landslides and the total number of grids with the category. This LSG was considered as the contribution of a particular category in promoting landslides. The landslide potential score for each individual grid was computed by adding the LSGs of different factor categories lying in each grid. These scores were then contoured to produce the landslide hazard zonation map (Fig.3).

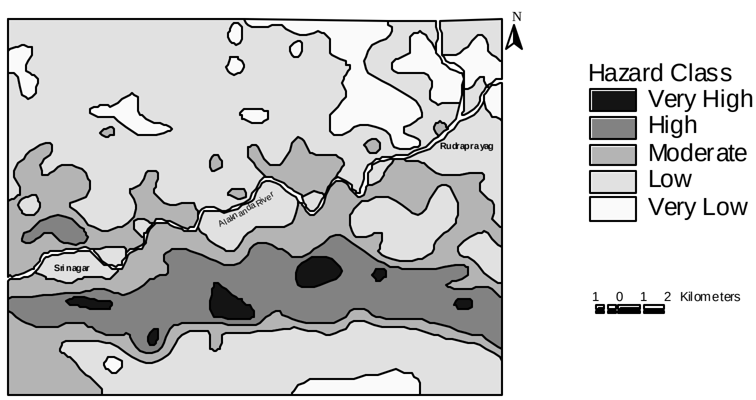

Figure 3. Landslide hazard zonation map of Srinagar-Rudraprayag area, Garhwal Himalaya (Sarkar and Gupta, 2005)

A very popular statistical technique is the Information Model which was first used for landslide susceptibility mapping by Yin and Yan (1988). Information model was used in different parts of Himalaya by Jade and Sarkar, (1993); Saha *et al.*, (2005). In this method the information value, which is the weightage for the category (variable) of a factor, supplied to landslide by variable i is expressed as:

$$I_i \; ? \; \log \frac{S_i / N_i}{S/N} \tag{1}$$

where, N = total number of grids, S = number of grids with landslide, S_i = number of grids with landslide having variable i, N_i = number of grids having variable i.

Total information value in grids then can be obtained by integrating the information value layers.

The statistical relationship between factors and landslides can also be achieved by the Certainty Factor (CF) model and can thus be used for hazard zonation mapping (Lan *et al*., 2004). The CF, defined as a function of probability is:

$$\text{CF} = \frac{pp_a ? pp_s}{pp_a ?1 ? pp_s ?} \quad if\, pp_a = pp_s \quad \text{OR} \quad \frac{pp_a ? pp_s}{pp_s ?1 ? pp_a ?} \quad if\ pp_a < pp_s \qquad (2)$$

where pp_a is the conditional probability of having a number of landslide event occurring in class a and pp_s is the prior probability of having the total number of landslide events in the area.

Fuzzy Model and ANN Approach

Recently approaches based on fuzzy logic and Artificial Neural Network (ANN) is getting popular for landslide hazard mapping. In fuzzy model, factors are assigned membership grade according to their contribution to landslide occurrences. ANN, a useful technique for regression and classification problems, has several advantages for LHZ mapping, as these have the capability to analyse complex data patterns. Also, ANN can process data at varied measurement scales such as continuous, near-continuous and categorical data, which are often encountered in LHZ mapping. An ANN involves training and testing processes. Based on training and testing accuracies of different neural network architectures, the most suitable network is selected and evaluated for LHZ mapping. ANN technique has been used by Arora *et al*., (2004) for LHZ mapping of parts of Bhagirathi valley in Garhwal Himalya. A combined application of ANN and fuzzy logic has been used by Kanungo *et a*l., (2005) to calculate the weights and ratings of the factors and the categories respectively.

MAP VALIDATION

The hazard zonation maps prepared should be evaluated for its validity with reference to the existing slope instability conditions of the area. The direct method to check the quality of a map is by field verification of signs of instability present in hazard zones. Another way to evaluate the map is by some statistical means in which the frequency of existing landslide in each hazard class is determined. The map having maximum landslide frequency in high hazard class and minimum in low hazard class can be considered as well representative of existing field condition. Further, statistical significance test such as chi-square test can also be performed to see the effectiveness of the hazard zonation map. Such validation has been attempted by Sarkar and Kanungo (2004) and Sarkar and Gupta (2005).

CONCLUSIONS

Spatial prediction of landslide potential slopes through landslide hazard zonation mapping is an important issue for disaster management. The different methods have their own merits and demerits. Since the landslide contributing factors vary from region to region, uniform rating criteria can not be applied to different geo-environmental condition. The statistical methods or approaches based on ANN and fuzzy logic seems to be more reasonable due to the objectivity in determining approach.

REFERENCES

Anbalagan, R., (1992). "Landslide hazard evaluation and zonation mapping in mountainous terrain", *Engineering Geology*, Vol.32, 269-277.

Arora, M.K., Das Gupta, A.S., Gupta, R.P. (2004). "An Artificial Neural Network Approach for Landslide Hazard Zonation in the Bhagirathi (Ganga) Valley, Himalayas", *International Journal of Remote Sensing*, Vol. 25 (3), 559-572.

Gupta, R.P. and Joshi, B.C. (1990). "Landslide hazard zonation using the GIS approach – A cases study from the Ramganga catchment, Himalayas", *Engineering Geology*, Vol. 28, 119-131.

Gupta, R.P., Saha, A.K., Arora, M.K. and Kumar, A. (1999). "Landslide hazard zonation in a part of Bhagirathi Valley, Garhwal Himalayas, using integrated remote sensing – GIS", *Journal of Himalayan Geology*, Vol. 20 (2), 71-85.

Jade, S. and Sarkar, S. (1993). "Statistical models for slope stability classification", *Engineering Geology*, Vol.36, 91-98.

Kanungo, D.P., Arora, M.K., Sarkar, S. and Gupta, R.P. (2005). " GIS based landslide hazard zonation using neuro-fuzzy weighting", *India International Conference on Artificial Intelligence*", Pune, India (in press).

Nagarajan, R., Mukherjee, R.A., Roy, A. and Khire, M.V. (1998). "Temporal remote sensing data and GIS application in landslide hazard zonation of part of Western ghat, India", *International Journal of Remote Sensing*, Vol. 19, 573-585.

NRSA. (2001). "Atlas on Landslide Hazard Zonation mapping in the Himalayas of Uttaranchal and Himachal Pradesh States using remote sensing and GIS" National Remote Sensing Agency, Hyderabad, India.

Sarkar,S. and Kanungo, D.P. (2004). "An integrated approach for landslide susceptibility mapping using remote sensing and GIS", *Photogrammetric Engineering & Remote Sensing*, Vol. 70, 617-625.

Sarkar, S. and Gupta, P.K. (2005). "Techniques for landslide hazard zonation – Application to Srinagar-Rudraprayag area of Garhwal Himalaya", *Geological Society of India*, Vol.65, 217-230.

Saha, A.K., Gupta, R.P., Sarkar, I., Arora, M.K., and Csaplovics, E. (2005). "An approach for GIS-based Statistical Landslide Susceptibility Zonation – with a case Study in the Himalayas", *Landslides*, Vol. 2, 61-69.

Lan, H.X., Zhou, C.H., Wang, L.J., Zhang, Li, R.H. (2004). "Landslide hazard spatial analysis and prediction using GIS in the Xiaojiang watershed, Yunnan, China", *Engineering Geology*, Vol.76, 109-128.

Yin, K.L. and Yan, T.Z. (1988). "Statistical prediction models for slope instability of metamorphosed rocks", *5th International Symposium on Landslides*, Lausanne, Switzerland.