Journal of Nepal Geological Society, 2000, Vol. 22, pp. 533–538

An overview of landslide hazard mapping and rating systems in Nepal

Megh Raj Dhital
Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal

ABSTRACT

The landslide hazard (LH) maps prepared by various agencies and individuals in Nepal can be classified into the following three types: (1) map of a region, (2) map of a corridor, and (3) map of a site. The regional LH maps include watersheds, sub-watersheds, or part of them. These maps are used mainly for watershed management, infrastructure planning, and estimating erosion and sedimentation. The LH maps of a corridor are prepared for the purpose of comparing them with other alternatives, delineating hazardous areas for further studies, and estimating risks in the construction or maintenance of the linear infrastructure in that strip. On the other hand, the LH maps of a specific site are prepared for the purpose of landslide (or slope) monitoring as well as for delineating areas requiring immediate, short-term, or long-term mitigation measures.

In Nepal, various rating systems are used for the preparation of LH maps. The number of attributes used for rating varies widely (from 5 to 20). Generally, there are from 3 to 5 subcategories in each attribute. The LH map is prepared by superimposing the rating attributes manually or by the help of a computer. This type of map contains from 3 to 4 hazard categories (i.e., low, medium, high, and very high). The rating system for a regional LH map is developed on the basis of landslide distribution pattern within the subcategory of an attribute. The LH map of a corridor is prepared by dividing it into soil and rock slopes based on the field data, topographical map, and/or aerial photo interpretation. The LH map of a site is prepared on 1:2,000 or larger-scale topographical maps or oblique photomosaic. Some examples of the above three types of LH maps are also given.

INTRODUCTION

Different organisations, countries, and researchers take the terms *hazard* and *risk* differently (e.g., see Brabb et al. 1972; Crescenti et al. 2000). In France and Switzerland, 'risk' is used instead of 'hazard' (e.g., Noverraz 1985). In many instances, hazards and risks are taken as synonymous due to the fact that risks are implicit and assumed proportional to the hazards, the relative levels are adequate for comparison purposes, and the quantification of the physical and monetary value is not considered necessary (Deoja 2000).

Hutton stated in 1785 that 'the present is the key to the past'. In case of landslide hazard mapping, the same principle of *actualism* is applied in a broader sense–'the present is the key to the past and future'. Generally, our predictions are based on the observations of the present conditions of the site. But, it is also equally necessary to include the *past conditions* of the area. The Mountain Risk Engineering (MRE) Handbook (Deoja et al. 1991) followed Einstein (1988) and proposed the following comprehensive procedure for landslide hazard mapping.

Maps containing different types of information are constructed in sequence. According to Einstein, *state-of-nature maps* are those that present data without interpretation. These include geological and topographical maps, precipitation data, and the like as well as the results of site investigation. *Danger maps* indicate the possible modes or failure mechanisms, such as debris flows, rock falls, and slumps. *Hazard maps* show the probability of failure for various failure modes shown on danger maps (Wu et al. 1996). For simple failure modes, the probability that such a failure could occur during a given time interval can be estimated on the basis of the probability distributions of the triggering mechanisms (rainfall, earthquake, etc.), soil or rock properties, slope geometry, and other controlling factors. The results can be shown on a map that delineates zones with different failure probabilities (Viberg 1984; Wu 1992). Alternatively, hazards are expressed qualitatively as high, medium, or low (Wu et al. 1996). Varnes (1984) defines risk in terms of specific risk and total risk. Specific risk is the expected degree of loss due to a particular natural phenomenon = hazard x vulnerability, where, vulnerability means the degree of loss to a given element or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude.

Any hazard map has its specific purpose, and therefore hazard mapping is guided by the following three principles: *avoidance*, *mitigation*, and *control*. Depending on the needs and the resources, we have to avoid, mitigate, or control a given danger. Consequently, the effort, cost, time, and rigour to prepare a hazard map must be justifiable within the framework of its use.

TYPES OF HAZARD MAP

The landslide hazard (LH) maps prepared by various agencies and individuals in Nepal can be classified into the following three categories: *map of a region*, *map of a corridor*, and *map of a site*.

The LH map is prepared by superimposing various rating attributes manually or by the help of a computer. This type of map generally contains from 3 to 4 hazard categories (viz. low, medium, high, and very high).

Regional hazard maps

The regional LH maps include watersheds, sub-watersheds, or part of them. These maps are used mainly for watershed management, infrastructure planning, and estimating erosion and sedimentation. In Nepal, most of the regional LH maps are prepared as follows.

- Preparing the danger map of an area;
- Finding out the area occupied by landslides in various state-of-nature types;
- Generating the ratings according to the distribution pattern of landslide in a given state- of-nature type;
- For manual LH mapping, dividing the area into homogeneous slope faces on aerial photographs, topographical maps, or in the field. For computer-aided LH mapping, it is done automatically;
- Adding all the ratings of each slope face or each pixel (Fig. 1);
- Dividing the area into high, medium, and low hazard levels based on the total rating; and
- As control, checking whether most of the landslides (more than 80%) lie on high hazard zones, a few (less than 20%) on medium hazard zones, and none on low hazard zones.

Ghimire (2000) made a hazard map of the Banganga Watershed (Fig. 2) using the GIS based bivariate statistical technique developed by International Institute of Aerospace Survey and Earth Sciences (ITC), the Netherlands. The overlays used for the preparation of hazard map are indicated in Table 1. It also gives the summery of the sources of spatial data, types of parameter derived, and the method of generating parameters for the regional hazard map (Ghimire 2000).

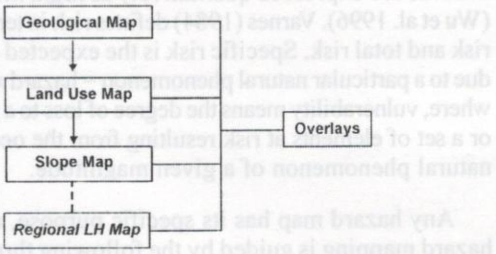

Fig. 1: Preparation of hazard map by adding various overlays

Hazard map of a corridor

The LH maps of a corridor are prepared for the purpose of comparing them with other alternatives, delineating hazardous areas for further studies, and estimating risks in the construction or maintenance of the linear infrastructure in that strip. The MRE Handbook recommends different procedures for different types of road as well as its different stages of assessment. In the prefeasibility study, a simple procedure is recommended whereas for the feasibility study a more elaborate procedure is proposed. At the prefeasibility stage, the main emphasis is placed on the selection of a few technically suitable alignments. It is done by comparing the hazard conditions in various alternative routes. At the feasibility stage, the hazard maps are prepared for delineation of potential dangers, so that they can be mitigated or controlled. At this stage, more detailed classification of danger types is made (Dhital et al. 1991).

During the detailed survey and design of the Gaighat–Diktel–Okhaldhunga road in eastern Nepal, the computer software SHIVA developed by Wagner et al. (1988) was used

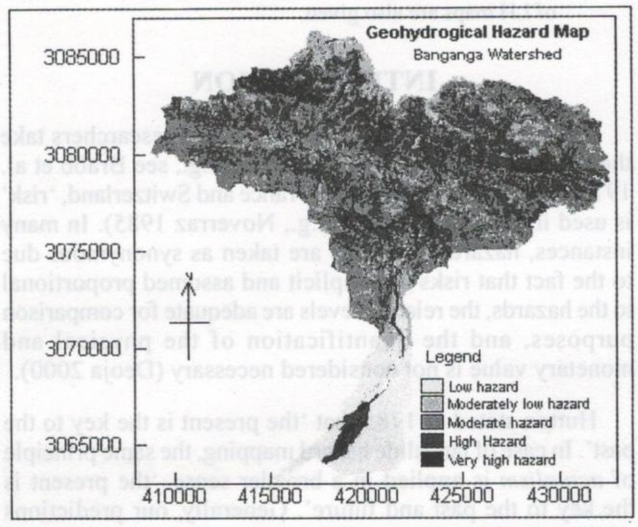

Fig. 2: Hazard map of the Banganga Watershed, western Nepal (Ghimire 2000)

Table 1: Data overlays and method of analysis (Ghimire 2000)

Data overlays	Database	Parameters	Method of generation
Geology	Geological map	Rock type	GIS
Structure	Geological map and LANDSAT (TM)	Lineaments, Dip slope relationship	VI*/FC** and GIS
Topography	Topographical map	Slope gradient and shape, Relief/relative relief	GIS based digital elevation model
Hydrology	Topographical map and aerial photographs	River and channel bed	VI*/FC** and GIS
Landform	Topographical map and aerial photographs	Landslide, gully erosion, channel shifting	VI*/FC** and GIS
Geomorphic units	Topographical map and aerial photographs	Geomorphic units	VI*/FC** and GIS
Vegetation density	LANDSAT (TM) 1998	Density class	Digital image processing
Land use/land cover	Aerial photographs and LANDSAT (TM) 1998	Use/cover Types	VI*/FC**, Digital image processing, and GIS
Settlement	Topographical map and aerial photographs	Location of houses/population density	VI*/FC** and GIS

*VI: Visual interpretation of aerial photographs/imagery; **FC: Field check to prepare rock and soil hazard maps of the entire road corridor. An example of soil hazard map of this area is given in Fig. 3 (Dangol et al. 1993). The overlays used were engineering geological map, soil type map, soil depth map, land use map, map of hydrological conditions, and hydrological map. In this stretch, most of the soil slopes belong to medium (moderate) hazard zone whereas there are a few critical areas with high hazard.

Hazard map of a site

The LH map of a specific site is prepared for the purpose of delineating areas requiring immediate, short-term, or long-term mitigation and monitoring measures. The LH map of a site is prepared on 1:2,000 or larger-scale topographical maps or oblique photomosaic. An example of this type of approach is the hazard mapping of the Jogimara Landslide (SWK 1994), where the entire landslide was divided into many zones depending on their probability of failure, and a sequence of failure mechanism was proposed.

The rockslide of Jogimara is situated on the Prithvi Highway, approximately 90 km west of Kathmandu. The rockslide (Fig. 4) is about 150 m long and 190 m high. The slide occurred on the Benighat Slates with the Jhiku limestone beds. It lies on the counter dip slope. The natural slope is steeper than 40 degrees and the failed slope is generally steeper than 45 degrees (Dhital et al. 1993).

For the purpose of hazard mapping, detailed engineering geological mapping of the landslide (Fig. 5), kinematic analysis of the discontinuities, and slope mass rating was carried out. The landslide was divided into four zones (Fig. 4). Zone I was the most hazardous one, whereas Zone IV was the least hazardous. However, during the next monsoon, Zone I failed, and together with it Zone IV also became unstable (as it lost the support) and failed. On the other hand, Zone II and Zone III are stable to date.

HAZARD RATING ATTRIBUTES

In Nepal, LH maps are based on various attributes studied in the field and laboratory. The number of attributes used for rating varies widely (from 5 to 20). Generally, there are from 3 to 5 subdivisions of an attribute. The main attributes for hazard map preparation are the following.

- Slope angle,
- Landform,
- Aspect,
- Relative relief,
- Drainage pattern,
- Hydrogeology,
- Rock type,
- Geological and engineering soil types,
- Engineering properties of rock,
- Engineering properties of soil,
- Soil depth,
- Rock structure,
- Land use, and
- Geometry of discontinuities.

Depending on the purpose of LH mapping, such factors as rainfall and earthquake are also used.

Rating attributes for LH map of a watershed

The LH map is made on the basis of quantitatively defined rating values. For developing the LH map of the Banganga Watershed (Ghimire 2000), the rating attributes were calculated by the Weight Value 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 mapped area. It is expressed by the following formula:

$$W_i = \log(DenseClass / DenseMap) = \frac{NPIX(Si) / NPIX(Ni)}{\sum NPIX(Si) / \sum NPIX(Ni)}$$

Where W_i = the weight given to a certain parameter class, *Dense Class* = landslide density within the parameter class,

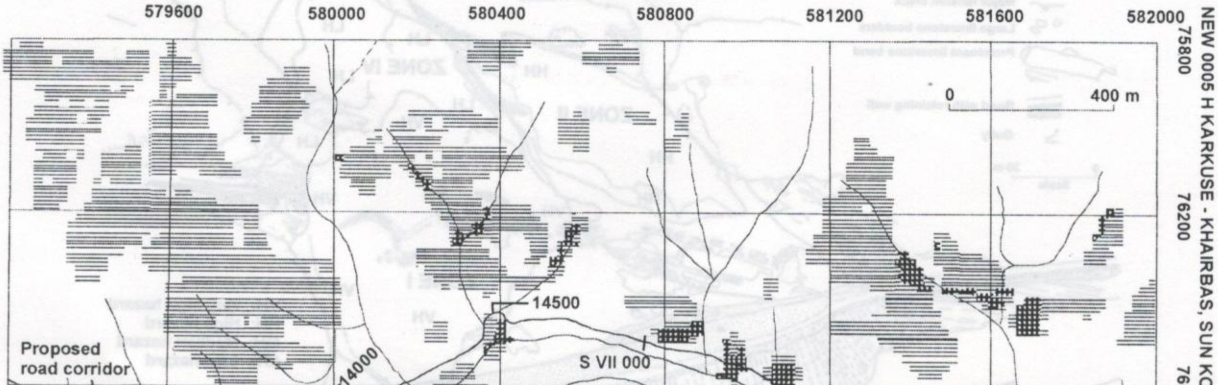

Fig. 3: Soil slope hazard map of part of the proposed Gaighat–Diktel–Okhaldhunga Road, eastern Nepal (Dangol et al. 1993)

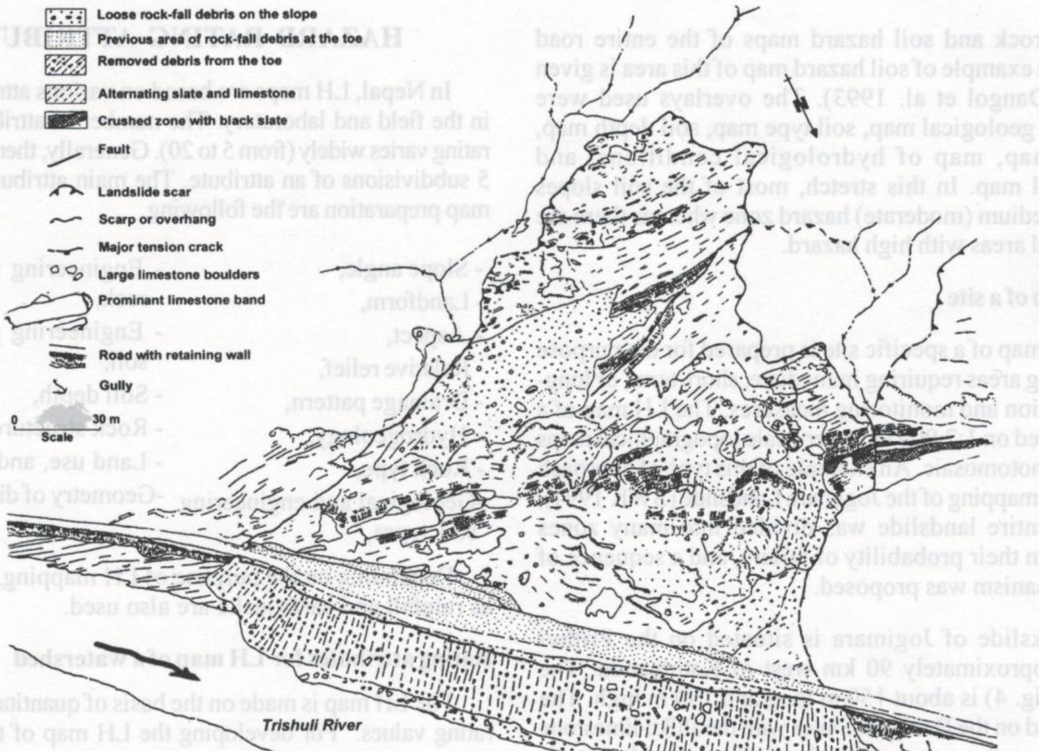

Fig. 4: Engineering geological map of the Jogimara Landslide (SWK 1994)

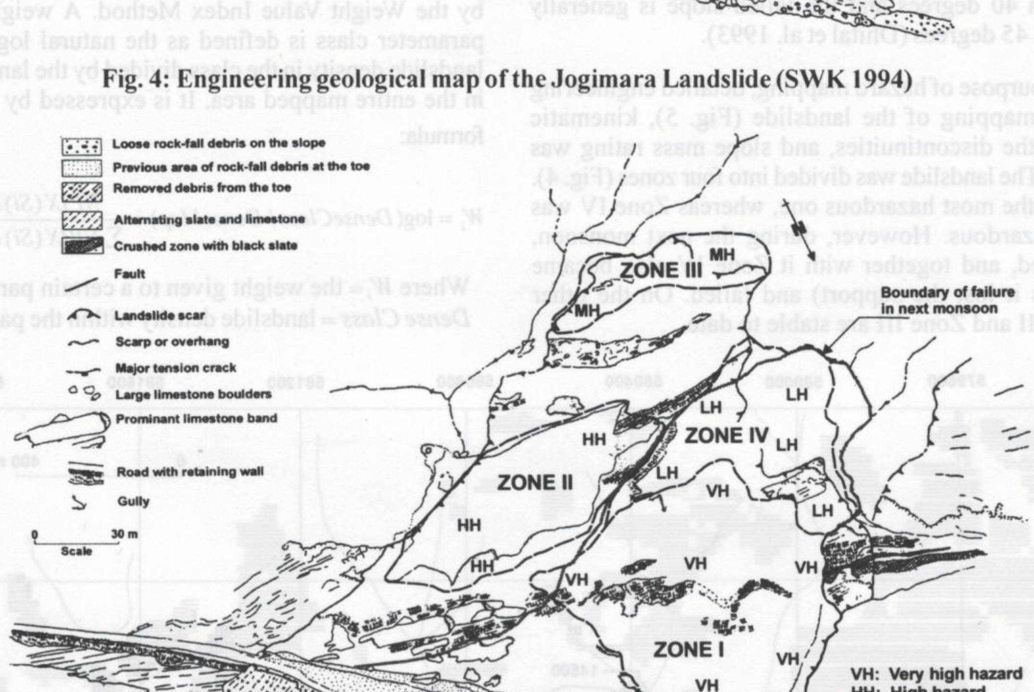

Fig. 5: Hazard map of the Jogimara Landslide (SWK 1994)

Dense Map = the landslide density within the entire map,

NPIX (Si) = number of pixels which contain landslide in a certain parameter class, and

NPIX (Ni) = total number of pixels in a certain parameter class.

To calculate the formula, a *cross table* is generally obtained by *map crossing* on ILWIS 2.1 GIS and Image Processing System developed by ITC. From the cross table, all input values for the formula are obtained. The natural logarithm is used to give negative weight when the landslide density is lower than normal, and positive when it is higher than normal. The LH map of the Banganga Watershed (Fig. 2) was created by combining the following overlays (Ghimire 2000): weight map of slope shape, weight map of relative relief, weight map of landform, weight map of vegetation density, weight map of slope gradient, weight map of geology, weight map of land use, weight map of dip slope, and weight map of lineament distance.

Rating attributes for LH map of a corridor

The MRE handbook gives the details of hazard mapping along a corridor. For this purpose, the corridor is divided into rock and soil areas, and each area is rated separately. Each rating attribute is carefully divided into various subcategories. Some empirical examples are given below.

Development of rating for slope angle

The distribution pattern of landslides in the area is as shown in Fig. 6.

Area of landslide in slope subcategory A = 14% (Rating = 1)

Area of landslide in slope subcategory B = 55% (Rating = 6)

Area of landslide in slope subcategory C= 31% (Rating = 3)

Development of rating for soil depth

The distribution pattern of landslides in the area is as shown in Fig. 7.

Area of landslide in subcategory A (soil depth less than 1 m) = 19% (Rating = 2)

Area of landslide in subcategory B (soil depth 1–3 m) = 55% (Rating = 5)

Area of landslide in subcategory C (soil depth > 3 m)= 26% (Rating = 3)

Development of rating for Hydrological conditions

The distribution pattern of landslides in the area is as shown in Fig. 8.

Area of landslide in subcategory A (within a distance of 50 m from a stream) = 75% (Rating = 8)

Area of landslide in subcategory B (between 50 and 100 m away from a stream) = 20% (Rating = 2)

Area of landslide in subcategory C (between 100 and 150 m away from a stream) = 5% (Rating = 0)

The subcategories are based on the *observed* or *expected* distribution of dangers within an attribute. In most of the cases, the observed distribution of dangers along a given corridor may not be statistically significant for developing a rating system out of it. In such a case, one has to assume an expected distribution pattern based on previous studies or experience.

Rating attributes for LH map of a site

For rating a specific site, the study area is generally classified into the rock slope or soil slope. For rock slope type, the following studies are carried out.

- Engineering classification of rock,
- Joint analysis,
- Kinematic analysis of rock slopes,
- Rock weathering grade,
- Rock slope rating,
- Laboratory tests for c and φ values, and
- Rock slope stability analysis.

For soil slopes, the following studies are carried out.

- Engineering properties of soil,
- Application of Unified Soil Classification system,
- Field and laboratory tests for c and φ values,
- Groundwater condition,
- Soil depth,
- Land use, and
- Soil slope stability analysis.

At this stage, the magnitude and recurrence period of landslide become more important for the preparation of the LH maps, and generally a deterministic approach is followed.

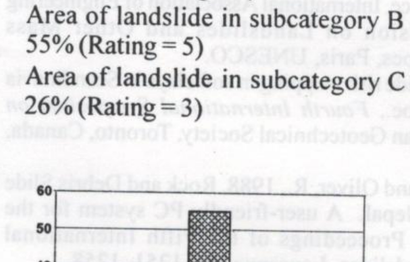

Fig. 6: Distribution of landslide area in various slope subcategories

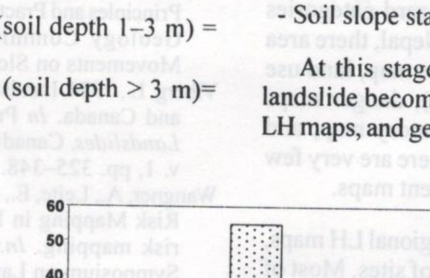

Fig. 7: Distribution of landslide area in various soil depth subcategories

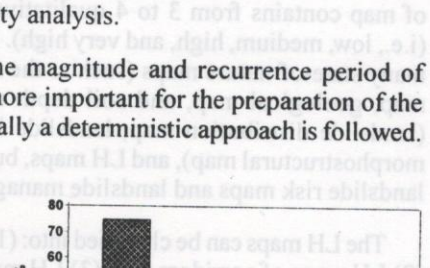

Fig. 8: Distribution of landslide area in various hydrology subcategories

UNCERTAINTIES IN HAZARD MAPPING

Every kind of hazard mapping is somehow a subjective and probabilistic approach. There are always some uncertainties. For example, there could be the following uncertainties while assessing the magnitude of a rockslide.

- Uncertainties in data acquisition (orientation of joint sets, their spacing, roughness, waviness, etc.);
- Complex interaction among various factors (rock weathering grade, depth of weathering, groundwater, land use, etc.);
- Uncertainties in assessing magnitude and frequency of some triggers (such as earthquake, river undercutting, and rainfall); and
- Dependency on the initiation position of failure (i.e., the magnitude of a rockslide may depend on the place where the failure initiates).

Similarly, if we want to deal with the frequency of failure, there may be the following uncertainties:

- Uncertainties in return period of triggers;
- Uncertainties in landform changes in the future;
- Uncertainties in future weathering conditions;
- Problem of toe cutting by a river, road, canal etc.; and
- Problem of human interference (such as construction of a new canal through the unstable area).

One of the important factors leading to slope failures is the presence of swelling clays (smectite, bentonite, etc.) in the soil and weathered rock mass. Hence, in Nepal there are not many instances of hazard maps showing the frequency and magnitude of landslide.

CONCLUSIONS

The LH maps produced in Nepal are similar in many ways to those produced in other countries. The number of attributes used for rating varies from 5 to 20, and generally there are from 3 to 5 subcategories of an attribute. This type of map contains from 3 to 4 qualitative hazard categories (i.e., low, medium, high, and very high). In Nepal, there area many state-of-nature maps (such as the slope map, land use map, geological map, and soil depth map), danger maps (landslide distribution map, landslide inventory map, and morphostructural map), and LH maps, but there are very few landslide risk maps and landslide management maps.

The LH maps can be classified into: (1) regional LH maps, (2) LH maps of corridors, and (3) LH maps of sites. Most of the maps are prepared for some specific purposes, such as road construction, watershed management, and forest management. The rating system for a regional LH map is based on the landslide distribution pattern within the subcategories of the attribute. The LH map of a corridor is prepared by dividing it into soil and rock slopes based on the field data, topographical map, and/or aerial photo interpretation. The LH map of a site is prepared on 1:2,000 or larger-scale topographical maps or oblique photomosaic.

REFERENCES

Brabb, E. E., Pampeyan, E. H., and Bonilla, M. G., 1972, Landslide Susceptibility in San Mateo County, California, U. S. Geol., Survey, Misc. Field Studies Map. MF–360.

Dangol, V., Upreti, B. N., Dhital, M. R., Wagner, A., Bhattarai, T. N., Bhandari, A. N., Pant, S. R. and Sharma, M. P.,1993, Engineering Geological Study of a Proposed Road Corridor in Eastern Nepal. Bull. Dept. Geology, Tribhuvan University, v. 3(1), Special Issue, pp. 91–107.

Crescenti, U., Rainone, M. L., and Sciarra, N., 2000, An example of landslide risk assessment in a historical site of Central Italy, Jour. Nepal Geol. Soci., v. 22 (Special Issue), pp.451–462.

Deoja, B. B., 2000, Mountain roads development in Nepal: engineering geological concerns, Jour. Nepal Geol. Soci., v. 22 (Special Issue), pp.167–178.

Deoja, B., Dhital, M., Thapa, B., and Wagner, A. (Principal Editors), 1991, Mountain Risk Engineering Handbook, ICIMOD, 875 p.

Dhital, M. R., Khanal, N. R. and Thapa K. B., 1993, *The role of extreme weather events, mass movements and land use change in increasing natural hazards: A report of the preliminary field assessment and workshop on causes and recent damage incurred in south central Nepal (July, 1993),* ICIMOD, Kathmandu, pp. 123 +

Dhital M. R., Upreti, B. N., Dangol, V., Bhandari A. N., and Bhattarai, A., 1991, Engineering geological methods applied in mountain road survey: an example from Baitadi-Darchula Road Project (Nepal). Jour. Nepal. Geol. Soc., v. 7, pp. 49–67

Einstein, H. H., 1988, Landslide Risk Assessment Procedure. *In* Proceedings of the Fifth International Symposium on Landslides, 10–15 July, 1988, Lausanne.

Ghimire, M. L., 2000, The study of geohydrological processes and their impact on the environment and socio-economy of Banganga Watershed (a case study of micro watershed of Western Development Region of Nepal). Report submitted to Centre for Space Science and Technology Education in Asia and Pacific, Indian Institute for Remote Sensing, Dehradun, India, 76+ p. (unpublished)

Noverraz, F, 1985, Project d'ecole ditection et utilisation des terrains instables, (DUTI).

SWK (Scott Wilson Kirkpatrick) Consulting Engineers, 1994, Report on Engineering-Geological Studies at Jogimara Rockslide, Prithvi Highway, Unpublished Report Prepared by Soil Test (P.) Ltd. Kathmandu, 7p.+

Varnes, D. J., 1984, Landslide Hazard Zonation. A Review of Principles and Practice. International Association of Engineering Geology Commission on Landslides and Other Mass Movements on Slopes, Paris, UNESCO.

Viberg, L., 1984, Landslide risk mapping in soft clays in Scandinavia and Canada. *In* Proc., *Fourth International Symposium on Landslides,* Canadian Geotechnical Society, Toronto, Canada, v. 1, pp. 325–348.

Wangner, A., Leite, E., and Oliver, R., 1988, Rock and Debris Slide Risk Mapping in Nepal. A user-friendly PC system for the risk mapping. *In:* Proceedings of the Fifth International Symposium on Landslides, Lausanne, pp. 1251–1258.

Wu, T. H., 1992, Prediction and mapping of landslide hazards. *In* Proc., *Second US-Asia Conference on Engineering for Mitigating Natural Hazards Damage,* Yogyakarta, Indonesia, pp. G 10–1 to G 10–08.

Wu, T. H., Tang, W. H., and Einstein, H. H., 1996, Landslide hazard and risk assessment. *In* Turner, A. K. and Schuster, R. L. (eds.) Special Report no. 247, *Landslides: Investigation and Mitigation,* Transportation Research Board, National Research Council, National Academy of Sciences, Washington D. C., pp. 106–118.