CHAPTER 6

LANDSLIDE HAZARD ZONATION

6.1 INTRODUCTION

Preface to the study landslides, a wide variety of complex processes was employed that resulted in descending and outward movements under gravity, of diverse materials like mud, slush, rocks, etc. on unstable slopes. Its event is destructive, causing harsh damage to roads, bridges, houses and even loss of lives to those residing in mountainous terrains. The reasons accounted for are many; while some may be due to human actions others due to natural calamities. Landslides are usually prompted by earthquakes, heavy rainfall, road cutting, etc. so; such landslides cannot be completely prevented. But their concentration and severity can be minimized by effective counter measures and preparing for disaster awareness or management. Brabb (1993) accounted that at least 90% of landslides losses can be evaded if the problem is documented before any developmental activities or deforestation initiates. Hence, immense requirement is there for detection of unstable slopes, which can be fulfilled by following a systematic approach for spatial prediction of landslide prone slopes. This calls for a complete evaluation of landslide hazard and preparation of landslide hazard zonation maps.

LHZ mapping is an efficient tool used for detecting those areas that are, or could be, affected by landslides, and calculating the probability of such landslides happening within a specified period of time. It includes identification of zones on a mountainous terrain having varying degrees of proneness to landslides. LHZ maps are methodologically arranged to estimate landslide susceptible zones. Identifying the major sites and executing effective practical approaches for analyzing landslide hazard zonation have been developed.

The preparation of a LHZ map engages the study of the local geology and geomorphic setting, slope conditions including existing and potential instability, and land use datas. Land surfaces are divided into areas, and the relative status of these areas related to degrees of actual or potential hazard from landslides on slopes are traced.Such maps are important as they provide data regarding stability of areas and help in a significant way by minimizing loss to life and property while demarcating zones favourable for development. Scale is an important factor of LHZ mapping. Large scale maps on 1:10,000 or 1:5,000 are engaged for meticulous studies at the local level. In recent years, considerable attention has been done on landslide research in connection with hazard and risk assessment. It has moved ahead in both qualitative and quantitative methods. Qualitative approach needs more understanding on various factors which influence slope stability and using of judgement based on available information, observation and experience. A quantitative or semi-quantitative approach on the other hand needs analytical advancement based on appropriate geological/geotechnical models and/or detailed field observations and/or measurements. In both cases the summative result may be expressed as descriptive categories of hazard or susceptibility such as very high, high, medium, low and very low.

Landslide zonation mapping has been attempted in different parts of the world for about three decades. Blanc and Cleveland (1968) prepared Landslide Hazard Zonation maps of Southern California where the geological formations were classified into different lithologic groups and combined with slope categories, below and above the critical angle. Nilsen and Brabb (1973) did used maps presenting geological formations, slope ranges, and landslide debris to arrange a landslide zonation map of San Francisco Bay region. Varnes (1980) presented a landslide zonation map using slope, soil thickness, land use practice, and drainage as the vital factors. Takie (1982) took into account the type of rock fracturing, weathering characteristics, springs, vegetative cover, valley slopes, etc describing methods to make debris flow hazard maps. Two primary categories of landslide hazard mapping, to be exact direct and indirect mapping was examined elaborately by Hansen (1984). Employing valley density, elevation, slope angle, and formations Kawakami and Saito (1984) prepared a calculated landslide risk map. Wagner et al. (1987) presented preparation of rock and debris slide risk maps for road alignment principle using geological, structural, slope, and geomorphologic factors. ZERMOS the French method for mapping hazard did include factors like lithology, structure, slope morphology, and hydrology where the mapped area is divided into four zones of different levels of hazards with types of movement and direction, activity, and sites of erosion using different symbols.

Brabb et al. (1972) noted slopes of San Mateo County, California relating to percentage of outcrop area of a formation occupied by landslide debris with slope classes. Radbruch and Crowther (1973) studied the California area on the basis of lithology and the number of landslides recorded. In the United States, Radbruch et al. (1976) measured the frequency of slope failure in dissimilar groups of geologic units. An identical grouping of lithology and mass movements was used by Rodriguez et al. (1978) in southern Spain. The essential features used by Varnes (1980) to prepare landslide susceptibility maps were slope, soil thickness, land use practice, and drainage. Koirala and Watkins (1988) explained slope ranking system by adopting preventive measures in the course of excavation. Fugita (1994) submitted the relationship of landslides with the geomorphologic and geological features of SW Japan.

India being a landslide prone country, many experts have attempted mapping of landslide susceptibility taking into consideration the factors and the nature of the terrain. Relying on the frequency of landslides Seshagiri and Badrinarayan (1982) presented hazard zonation of the Nilgiri hills using numerical ratings of slope, land use, soil cover, and drainage. Later Central Road Research Institute (1989) took up zonation mapping considering nature and characteristics of rock and soil materials, the overall stability of slope constituting formations, slope angle, condition of slope surface, hydrological features, and toe erosion which were measured quantitatively. Thus overall ratings of slope stability were divided into three categories as very good, good, and fair. Regarding slope, lithology, structure, and earthquake epicentres Choubey and Litoria (1990) presented a LHZ map of the Garhwal Himalaya. Gupta and Joshi (1990) studied the Himalayas by means of a GIS approach giving index values to aspects like land use, lithology, major tectonic features, and azimuth of landslides. Mehrotra et al. (1992) assembled a landslide susceptibility index considering factors such as lithology, slope angle, distance from major thrusts and faults, land use pattern, and drainage density related to frequency of existing landslides. Anbalagan (1992) carried out mapping on factors such as slope, lithology, structure, relative relief, land use and land cover, and groundwater conditions of Kathgodam- Nainital area in the Kumaon Himalaya where the LHEF rating scheme was planned. It represents demarcation of facets, preparation of thematic maps, estimation of LHEF ratings, calculation of TEHD values and construction of a LHZ map of the area even with lack of data on topography, climate, geology, hydrogeology, seismicity and anthropogenic activity and their components or variables. However, Thigale et al. (1998) clarifies that a lot of complications prevail in preparing LHZ maps.

Instability of land area in Kohima town was studied by Walling (2005) where he presented a LHZ map using RS and GIS. Aier (2005) compiled a number of mitigation measures in the course of preparing a LHZ map along the NH 29 between Chumukedima and Kohima. Hiese (2005) projected a risk map of Kohima town and its surrounding. A grid-based method for organizing the terrain into five categories was suggested by Deva and Srivastava (2006). It utilized three factors including lithology, ruggedness number, and land use / land cover. An effort on risk zonation of the area in Garhwal Himalaya was performed by Pachauri et al. (2006) and conclusively added that rock fall velocity modeling can be used in landslide risk zonation. Related to the study in Chamoli area of Uttarakhand on LHZ mapping, Pachauri (2007), relates that facet-based LHZ is a very efficient tool for landslide mapping, and is cost effective in high relief areas of the Himalayan region.

Landslide susceptibility mapping is a way to logical and uniform identification and risk assessment of areas vulnerable to landslides; however, such work has not been earnestly attempted till date. Some of the earliest works in GIS environment was done by Carrara et al. (1991), Kingsbury et al.(1992), van Westen (1994), Nagarajanet al.(1998), Gupta et al.(1999) and Dhakal et al.(2000). With time this gap is being filled today with the present diffusion of hardware and software tools allowing earth science data to be efficiently and cost-effectively processed. At the present, various commercial systems are offered in the market; they vary in terms of hardware requirements, potential of spatial functions, efficiency of the database, and internal data structure like vector or raster models. RS and GIS technologies have gained prominence and contributed noteworthy product for spatial data analyses. They have confirmed to be very helpful and important tools for landslide studies. (Carrara, 1983; Carrara et al., 1991; Soeters et al., 1991) have rightly said that researchers have exploited RS and GIS technologies to develop and investigate data that are significant in evaluation of natural hazards. In recent times using of RS data and techniques for land surface change detection has achieved a lot of attention. For identifying landslides

Cheng et al. (2003) used RS techniques utilizing multi-temporal satellite imagery. To evaluate landslide hazard Ohlmacher and Davis (2003) opted multiple logistic regression and GIS technology. Utilizing vector and raster data it gives a great impact on the functionality of each system performing different classes of operations (Burrough, 1986; Aronoff, 1989; Laurini and Thompson, 1992). Its growth has led to rapid development of landslide hazard assessment methods (Aleotti and Chowdhury, 1999). In the present scenario, RS and GIS, with the help of computer software have achieved greater heights. GIS is a unique tool to store large amounts of data, including features of upgrading and analyses. Hence, landslide hazard is studied basing on statistical analyses, a physical approach or deterministic approach.

Statistical approach

Statistical approach connects all aspect on the foundation of investigational relations with past and present landslide events. Variation of factors that led to landslides in the past are resolved statistically where quantitative predictions for areas presently free of landslides but on conditions where similarities exist. In bivariate numerical studies, individual factor map is incorporated with the landslide map where weighing values based on landslide densities are calculated for every class. Similar such method is engaged in the Information Value Method (Yin and Yan, 1988; Sridevi and Sarkar, 1993). Another method is the multivariate statistical approach where each factor maps are modeled either on a grid basis or in morphometric part. Then on each sampling sections, the presence or absence of landslides is determined. The output can then be analysed using discriminant analysis, or multiple regression analysis (Carrara, 1983). A multivariate statistical model for assessing landslide hazards was then viewed by Chung et al. (1995). Other numerical technique regarding use of information models and fuzzy set theory were studied in this perspective (Yin and Yan, 1988; Juang et al., 1992; Jade and Sarkar, 1993). Later on Raj et al. (2011) estimated LHZ by means of the relative effect (RE) scheme in the south-eastern Nilgiris. This technique determined the RE of each unit using surface geology; slope morphometry, climatic conditions, and land use and land cover whereby calculating the ratio of the unit portion in coverage and landslide.

Heuristic approach

According to this method, landslide manipulating factors such as lithology, structure, slope morphometry, land use and land cover, drainage density, etc. are scored according to their assumed or expected importance in causing mass movements. This study employs prior knowledge accessible to experts on various causes of landslides in the area of investigation and knowledge is dependent on the experience of the expert. Abella and van Westen (2008) analyzed the heuristic model by examining the diverse landforms and the causative factors for landslides. The technique involves weights allocated by expert judgment and also components which includes slope angle, internal relief, slope shape, geological formation, active faults, distance to drainage, and distance to springs, geomorphological subunits, and existing landslide zones. Gahgah et al. (2009) examined GIS based LHZ using the heuristic method deliberating on factors related to landslide occurrence with factors such as lineaments, soil map, lithology, roads, drainage pattern, and rainfall together with slope angle and elevation from DEM. All these inputs were considered important for landslide hazard assessment and were then integrated into GIS for data processing.

Deterministic approach

The benefit of this method is its validity using geotechnical analyses to integrate landslide geometry, geotechnical properties of sliding material, and groundwater parameters and allowing the calculation of quantitative values of stability in terms of factor of safety (Jelínek and Wagner, 2007). It is summarized that the technique can be applied in huge scale for an individual landslide. It is particularly worked on problematic sites where the geomorphological and geological conditions are practically homogeneous. Nevertheless, complete knowledge of the area has to be inculcated keeping in mind that the key role to the successful analysis of any related study is the input data and parameterization of the primary geotechnical model. This method is helpful in reasonably recognizing unstable areas within the studied area and also to forecast potential slope instability if the mechanism of landslide is correctly defined.

Mapping of the targeted area is deliberated following Anbalagan (1992) and the approbation of the Department of Science and Technology (1994) and Bureau of Indian Standards (1998). The present study of LHZ mapping takes into consideration of the slope morphometry, relative relief, lithology, relationship of structural discontinuities with slope, groundwater condition, and land use and land cover. Thematic maps are created for slope, relative relief, lithology, structure, groundwater condition, and land use and land cover. For the contributory factor LHEF is allocated. The rating scheme of Anbalagan is a numerical system managed by the major causative factors of slope instability that aids in determining landslide vulnerability of a slope. The thematic maps created are then superimposed on the thematic layers in a GIS platform thus providing the required data for the LHZ map. And on the basis of the distribution of the TEHD values a LHZ map is generated. Thus landslide hazard map plays an important role to avoid unstable areas and also in minimizing loss of life and property. It also helps us to adopt appropriate mitigation or remedial measures. All in all, it gears us up for development and for safety.

6.2 LANDSLIDE HAZARD ZONATION MAPPING

The LHZ map demarcates the area of study into four different classes comprising low, moderate, high and very high hazard zones (Fig. 6.1a). Low hazard zones occupy an area of 0.5sq km. This represents 2.76% of the total area of study. Moderate hazard areas cover 2.54sq km, which is 14.03%. High hazard areas occupy 51% covering 9.23sq km, while very high hazard areas occupy 5.83sq km, which is 32.21% of the total area. Ratings for the various hazard zones are generated (Table 5.1). Table 6.1 shows the frequency of landslides on the various hazard classes. The pie charts depict the distribution of hazard zones and the frequency of landslide incidences on hazard zones (Figs. 6.1b).

Table 6.1 Frequency of landslide incidences on hazard zones

Category	**Area**		**Landslides**		**Frequency**
	km^2	**%**	**No**	**%**	**No/km^2**
Low hazard	0.50	2.76	-	-	-
Moderate hazard	2.54	14.03	-	-	-
High hazard	9.23	51.00	7	31.82	0.76
Very high hazard	5.83	32.21	15	68.18	2.57

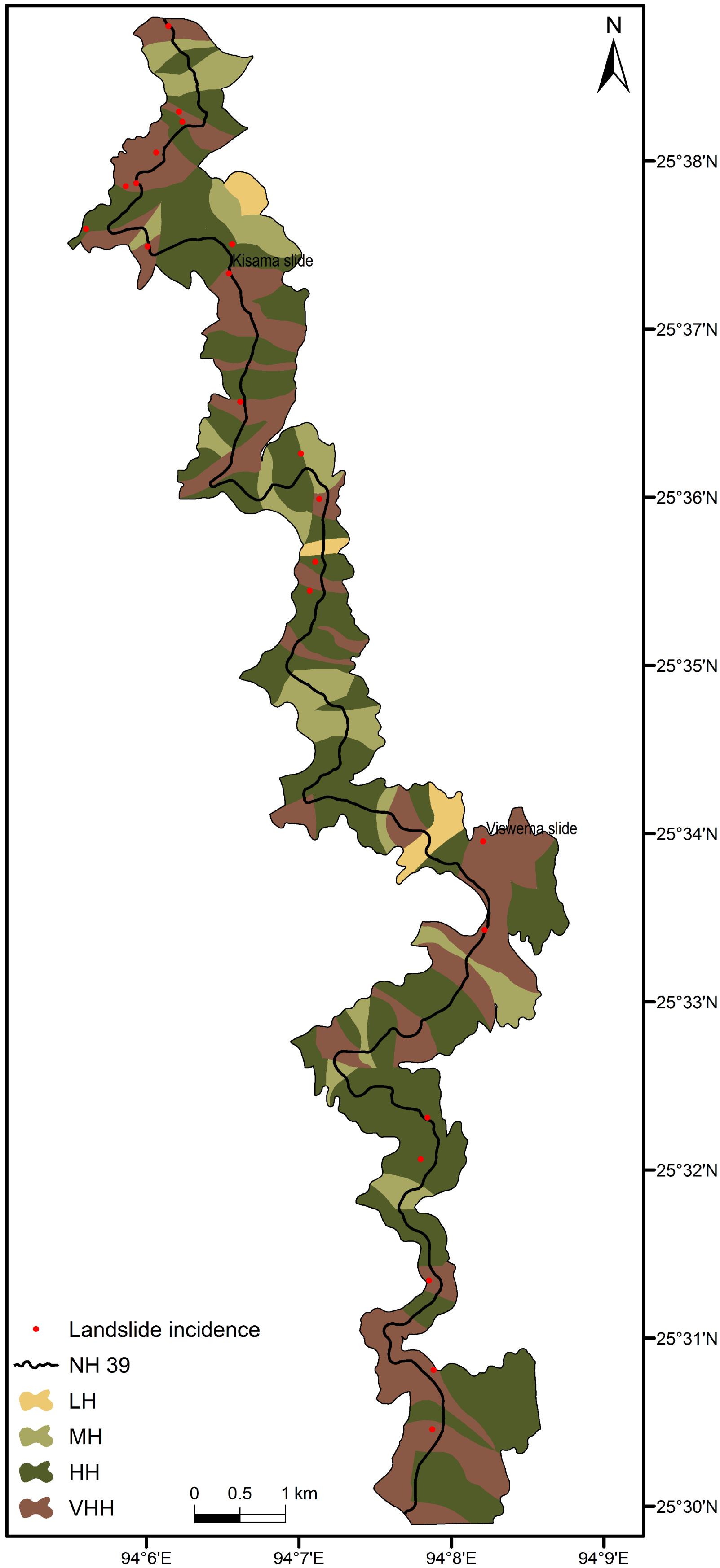

Fig.6.1a Landslide hazard zonation map

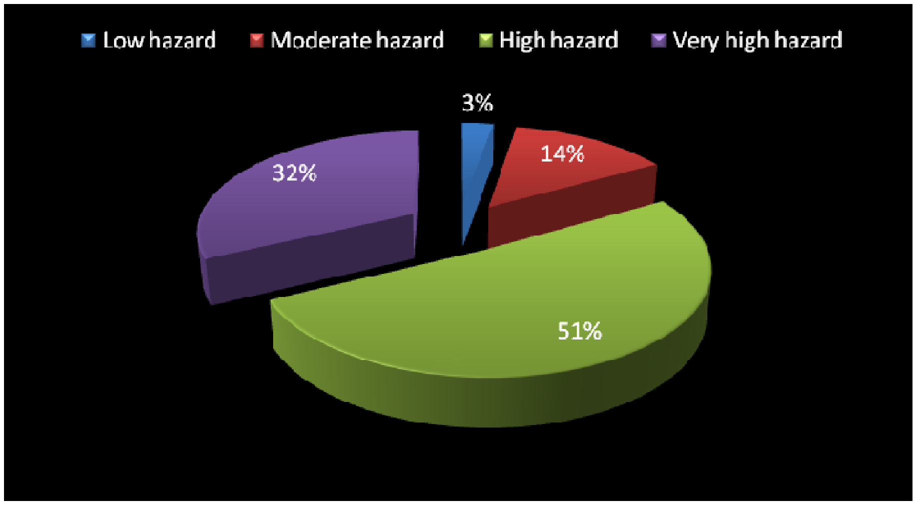

Fig. 6.1b Distribution of hazard zones

Plate 2.1 Spheroidal weathering

Plate 7.1.a Creeping indicated in man made structure