Landslide Zonation : An Overview of Emerging Techniques

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Abstract

A framework of multi-tier landslide zonation maps used in different natural slope conditions has been presented. The objective, however, is to develop procedures which allows one to make decisions on how to deal with a particular landslide situation. The article discusses with illustrative examples of each level of maps along with their strengths and weaknesses to facilitate decisions on choosing relevant level and technique for landslide mitigation strategy. A case study of terrain classification with a suggested land use in parts of northwest Himalaya is presented. A system of terrain classification with suggestive land use is of high societal value to cope up the menace of landslides.

Introduction

Landslide occurrences are common in Himalayan geo-environment and cumulative magnitude of annual damages on account of the hazard is always huge. The various reasons attributed for the hazard include geological set up, high relief with high seismic and rainfall intensity. With a view to keep the environmental degradation to be minimum, it is imperative to assess the hazard prone areas well in advance for sustainable development. There are two major strategies to mitigate the consequences of the landslide hazard *viz.* avoidance of hazardous areas and building structures to withstand the effects of the hazard. Implementing these strategies in a cost-effective and acceptable manner requires reliable information about where landslide hazards are likely to occur, and what their consequences might be.

Landslide zonation classifies the area into zones of different degree of susceptibility classes. The susceptibility evaluation generally comprises the rating of the relative degree of proneness to the slides and calculation of absolute level of hazard depending on the situation. The relative and the absolute determination can be divided into different approaches. The approach for Landslide zonation mapping, intended to contribute to landslide hazard mitigation strategy, has significantly evolved over the past couple of decades. Depending upon the parameters, scale, risk level and cost of the mapping number of techniques for landslide susceptibility evaluation are in vogues. The necessary prerequisite before any zonation work is to evolve a comprehensive modal on geology, topography, structure, hydro-meteorological and seismic factors, etc. A classification, based on the qualitative or quantitative categorization of terrain conditions of all the approaches available is presented in the following diagram (Fig.1).

Landslide Susceptibility Mapping

The landslide susceptibility mapping is typically depicted on maps that show spatial distribution of landslide prone zones. Development of these zones requires knowledge of the processes active in the area being analyses, and factors leading to the occurrences of landslides. The integration of all the factors and triggering agents is a difficult task for deriving spatial division of land into homogeneous areas or domains and their

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ranking according to degree of potential hazard caused by mass movement. The landslide susceptibility map (LSM) is useful for providing landslide information needed for planning and protection purposes. The maps are appropriate in all stages of building activities such as planning to maintenance. An ideal LSM should reflect information concerning at least one or more of the information on (i) Spatial probability (ii) Temporal probability (iii) Type of landslides (iv) magnitude and velocity of landslides and (v) Run out distance of landslides. The evaluation can be made from quite different levels of information based on the total risk (Rt) of an area that can be expressed (Varnes, 1984) by the equation-

$$Rt = (E)\ (Rs) = (E)\ (H * V)$$

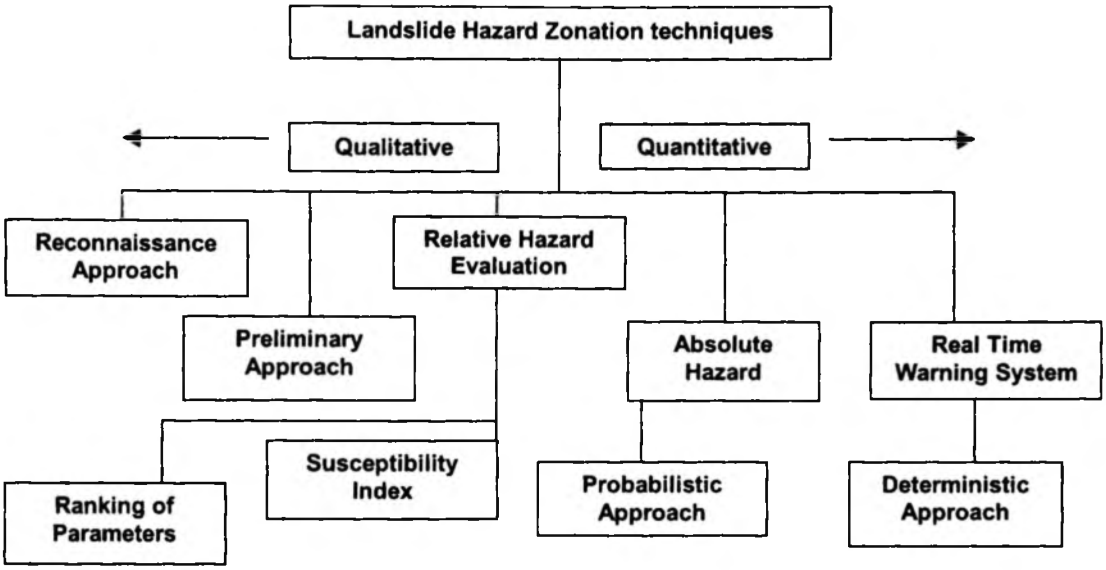
Where, E (*Element of risk*) - means population, properties, economic activities, including public services, etc., at risk in a given area. Rs (*Specific risk*) - means expected degree of loss due to particular natural phenomenon. It may also expressed by the product of H and V (*Vulnerability*) - means degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. H (*Natural Hazard*)- means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon. It is expressed from 0 (*No damage*) to 1 (*Total damage*). The hazard confined to expected occurrence of landslide, while the risk involve the expected damage consequences of landslides (lost lives, cost of damaged buildings, or fatalities, etc.). Spatial prediction is the forecasting of where within a given area and within a specified period of time landslides are likely to occur.

Different levels of LSM, their parametric inputs, capabilities and likely applications are described as below.

(a) Level-I (Reconnaissance stage) maps: The schemes for the first level of susceptibility mapping involve regional categorization of range of instability conditions on natural slopes. Basic information describing the state of nature of slope, geological and, hydrological conditions etc is collated on small scale with large area to provide an overview of the susceptibility of the terrain to land sliding. Such maps have been prepared for many countries like USSR (Churinov, 1968), Czechoslovakia (Matula, 1969), Italy (Carrara et al, 1976) and USA (Radbruch-Hall, D.H., 1977). In the overview map of the United States geological units were evaluated and classified based on the area occupied by landslides having high, medium and low incidences of landslides. Typical maps in Indian context include the landslide zonation map prepared by Building Material Technology Promotion Council, New Delhi (2005) and regional landslide zonation map (Mazumdar, 1981) of Northeastern part of the country.

(b) Level-II (Preliminary stage) maps: Such maps are prepared based on the integration of couple of parameters responsible for mass movements in a particular area and presented on 1:50,000 /1:25000 scale i.e. macro-scale. The basic conditions for slide initiation are determined by a complex integration of geo-environmental factors. The typical examples of the preliminary mapping include the landslide zonation carried out in Nilgiri hills (Sheshagiri et al, 1982), Sutlej catchment (Gupta, 1988). Chenab catchment (Sharan, 1992; Sharda,1994), Beas catchment (Chandra, 1992), Alaknanda catchment (Gairola, 1991), Ganga catchment (Bhatnagar et al, 1995, 96; Sharma, 1996) and Yamuna and Ravi basins. Various methods of zonation techniques were evolved using integration of thematic maps and their statistical analyses to prepare landslide susceptibility maps. Bureau of Indian Standards framed a scheme for macro - zonation of landslides,

Fig.1.Classification of different techniques for landslide zonation.



however not much of the terrain of the country is covered using the classic system hence the comparisons of the weightings in different terrain conditions is not yet validated. Remote sensing based GIS application has also been attempted for the zonation along some pilgrim routes in Himalaya and presented in the form of an atlas (NRSA, 2003). The preliminary levels of landslide susceptibility maps are of use for initial planning of developmental activities in hilly areas.

(c) Level-III (Detailed stage) maps: Detailed map, evolved by using relative evaluation of instability using measurable variables of various causal factors taking into account to classify the area. Such maps are generally of large scale (1:15,000 to 1:10,000) but have less coverage of area. Such relative susceptibility maps are of use in urban planning and other infrastructure development in an area with an objective of mitigating the landslide hazard. The application of the maps in and around prospective engineering projects site and reservoir area is recommended to highlight the hazard prone areas. Numbers of techniques for preparation of such maps are available. The numerical ratings of parameters like slope gradient, terrain component, terrain morphology, erosion and instability, hydrology and vegetation etc has been used by Brand et al (1988) in Hong Kong, to prepare engineering geological map and then an interpreted land use map to classify the area in different classes of geo-technical limitations. In case of rock slope conditions, numbers of schemes of numerical ranking (Barisone, and Bottino, 1990; Romana, 1988, Sharma et al, 1996) have been presented in different terrain conditions.

(d) Level-IV (Absolute hazard evaluation): The absolute hazard evaluation is covered in such types of maps either in terms of relative probability values or the deterministic model to provide inputs for design for supportive measures. The realistic risk analyses of the terrain is facilitated on the base map of such level wherein data on slope elements, joint pattern, rock-mass characterization and their inter-relation, rainfall etc. are documented for susceptibility mapping and slope protection work. The maps are generally on 1:10000 to 1:5000 scales and

the relative susceptibility is defined with an absolute spatial or temporal terms. The French maps (Leroi, 1996) on Plan for the Exposure to predictable natural Risk (PERs) generally drawn at 1:5000 to 10000 scale and Landslide zonation map of Nainital Township, Kumaon Himalaya (Sharma, 2006) are the typical for absolute susceptibility mapping.

(e) Level-V (Micro-level) maps: The maps for landslide monitoring and management are on micro-level scale (1:1000 or so) and have details to plan instrumentation to monitor the movements of slopes and classify the area in terms of rate of movement. Not much data on such objective mapping is available world-over.

A Model of Terrain Classification System

A typical case study of the multi-tier landslide susceptibility has been attempted (Fig.2) using Geotechnical Area study programme (GASP) and Geotechnical land use map (GLUM) models. The system was devised by Geotechnical Control office for use in Hong Kong's geo-environment conditions and differs substantially from any other system of terrain classification, but the broad framework is based on overall geotechnical assessment of land units, not only on the identification of hazard from a stability viewpoint. A case study of a regional framework (Table 1) following the terrain classification schedule for the GASP study is presented in parts of northwest Himalaya. The entire scheme is multi-tier from GASP to a derivative map-Geotechnical land use map which defines the natural slope constraints for land use management in a specific area.

The attribute information is presented on the map in alpha-numeric form(in the order of terrain component code, gradient and erosion and instability) which enables the efficient delineation of multi-attribute map units; it is also convenient for computerized storage and retrieval of the base information. This is a basically physical constraint map that represents major ground conditions controlling the development in the area.

The map is then further supplemented by an interpretive map-Geotechnical land use map (GLUM), which synthesizes the natural terrain constraints for land use management, planning and engineering purposes. The map represents a basic assessment of the geotechnical limitations associated with the terrain *viz.* zones of general instability, slopes steeper than 30°, disturbed terrain (extensive fill and cut), and zones of gully erosion, floodplains and colluviums. The GLUM is an interpretive map that classifies land units into *four* major classes (Table 2) on the basis of combination of attributes from terrain classification and other data collected. The classes indicate the general level of geotechnical limitations on a particular land unit. The system of classification, defined as:

(a) Class I: These are the areas that are characterized by a low level of geotechnical limitation and hence suitable for development. Only the normal geotechnical appreciation is required in such class.

(b) Class II: Such zones are characterized by moderate level of geotechnical limitation, and are of moderate suitability for development purposes, in spite of the complex terrain conditions than those of class-I.

(c) Class-III: These are areas of high geotechnical limitations and are of low suitability for development. Cost of site development, drainage works are high. Intensive investigations are necessary for the protection work.

Table1. Terrain classification schedule for regional GASP studies.

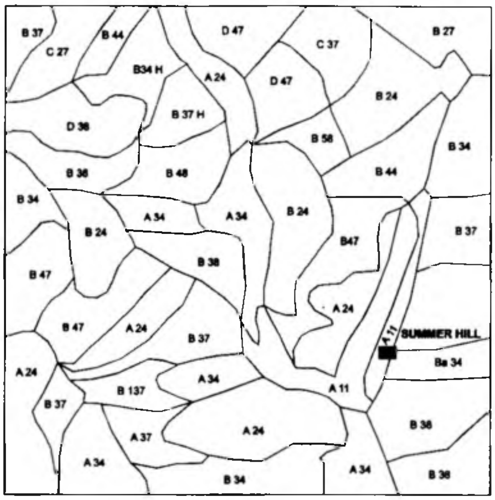
(a)Slope gradient	code	(b) Terrain component	code
0-5°	**1**	**Hillcrest or ridge**	**A**
5°-11°	**2**	**Side slope-straight**	**B**
15°-30°	**3**	**-Concave**	**C**
30°-40°	**4**	**-Convex**	**D**
40°-60°	**5**	**Foot slope-Straight**	**E**
>60°	**6**	**Colluviums-Concave**	**F**
		-Convex	**G**
(c)Erosion &Instability		**Drainage plain (colluviums)**	**H**
		Floodplain	**I**
No appreciable erosion		**Coastal plain**	**K**
Sheet erosion-minor	**1**	**Littoral zone**	**L**
-moderate	**2**	**Rock outcrop**	**M**
-severe	**3**	**Cut -straight**	**N**
Rill erosion -minor	**4**	**-Concave**	**O**
-moderate	**5**	**-Convex**	**P**
-severe	**6**	**Fill -straight**	**R**
Gully erosion-minor	**7**	**-Concave**	**S**
-moderate	**8**	**-Convex**	**T**
-severe	**9**	**General disturbed terrain**	**V**
		Alluvial plain	**X**
Well defined recent landslip,		**Reclamation**	**Z**
>1 ha in size	**a**	**Waterbodies:**	
General instability-relict	**n**	**-Natural stream**	**1**
-recent	**r**	**-Man-made channel**	**2**
coastal instability	**w**	**-Water storage**	**3**
		-Fish pond	**4**

Table 2. Classification of suggestive and use

GLUM characteristics	Class-I	Class-II	Class-III	Class-IV
Geotechnical limitations	**Low**	**Moderate**	**High**	**Extreme**
Suitability for development	**High**	**Moderate**	**Low**	**Probably unsuitable**
Engineering cost of development	**Low**	**Normal**	**High**	**Very High**
Intensity of site investigations required.	**Normal**	**Moderate**	**Intensive**	**Very intensive**

(d) Class IV: Such zones show the extreme geotechnical limitations and development on such sites should be normally avoided for sustainable growth. Intensive geotechnical investigations are necessary in such areas in case of some pressing need for development.

The phased study is intended only as a guide for planning purposes to the general level of geotechnical limitations of the ground and its resultant suitability for developmental activity. These maps are followed by another map- General Limitations Engineering Appraisal Map (GLEAM) which indicates features of engineering significance, such as the presence of instability conditions. The important information however, relates to the delineation of four development planning zones *viz.* (i) zones with good potential for development (ii) zones of local geotechnical constraints (iii) zones with major geotechnical constraints on development and (iv) zones of existing development



(a)

(b) Suggested categories of GLUM Class I, II, III and IV

Fig. 2 . Typical map of (a) Regional terrain classification using GASP scheme and (b) Geotechnical land use map.

Discussion on Choice of Zonation Maps

Geo-factors for the preparation of Landslide Susceptibility map are by and large similar in all levels; however the choices of methodology vary according to the details involved and elements at risk. The choice of method is primarily influenced by need and utility of the approach and overall risk areas covered for the mapping. Sometimes, numbers of assessment methods on different levels of maps are employed to achieve the desired objective of slope stability conditions in high-risk areas that have dense urban population.

For instance the slope management in Hong Kong follows a terrain evaluation approach (Brand, 1988) of the whole territory to provide a series of user friendly maps at regional (LevelI) and district map on 1:2500 scale through Geotechnical Area Study Programme and Geotechnical Land Use Map (GLUM) which classify land into four classes of stability conditions.

The multi-tier mapping framework entails, in order of ranked priority, a catalogue of geotechnical inputs for evolving engineering design for protection of slopes. Besides the GLUM model there are more than one approach for landslide evaluation depending upon the available details on geo-factors, cost and element of risk in a specific area. The structuring of such a complex topic as landslide susceptibility evaluation, though difficult task may be performed in several ways-each having its own limitations. A method of susceptibility classification with a suggested mode of land use plan is suggested in order to plan fair and sustainable development in the hilly terrain. The landslide susceptibility mapping, therefore, needs a holistic approach including in-depth analyses and instrumentation to mitigate the menace of landslides.

The lay out of the emerging methods are presented in the following table (Table3)

Table 3. Lay-out of the different types of landslide zonation maps

Level of maps	Parameters used	Main methods	Usage/application
Level-I	**Information on Regional tectonics,geology,Seismic blocks,Physiography,annual rainfall etc.**	**Superimposition and analyses of data on very small scale map (1:5million or so)**	**Regional overview of the hazard prone areas.**
Level-II	**Slope forming material, structural details, slope, relief, Inter-relation of slope and structural data, land use landslide inventories, hydro-geological conditions etc.**	**a) Mapping of susceptible classes.** **b)Numerical rating of causal factors.** **c)Statistical approach.**	**Preliminary planning of developmental activities.**
Level-III	**Slope parameters,lithology, structure, landuse and landcover,hydro-meteorological condition etc. including landslide inventory details.**	**a)Ranking of causal factors.** **b)Uni-variate or multi-variate analyses.**	**Project planning especially urban planning and other developmental activities.**
Level-IV	**Same plus geo-mechanical properties of the material involved.**	**Empirical** **(a) Deterministic** **b) Probabilistic**	**Design of slope cuts for open cast mines, reservoirs rim stability and other infrastructure planning purposes,**
Level-V	**Same as above,** **In-situ determination of geo-mechanical properties.**	**Slope monitoring using instruments, real time warning system etc.**	**Monitoring of high-risk areas for project planning and maintenance.**

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