Landslide Hazard and Risk Mapping Procedures: Case Study from Parts of Ravi Catchment, Himachal Pradesh

V.K.Sharma*

Abstract

Landslide Hazard and Risk Mapping (LHRM) is multivariate and complex problem in mountainous environment. Landslide Hazard mapping has been significantly developed over past decades but framework for risk mapping are rarely the end product. The process of landslide risk estimation integrates the hazard levels with specific element or set of elements at risk etc. The paper evolves a procedure of a qualitative hazard and risk mapping in mountainous environment.

Identification of potential hazard zones, nature of the hazard, projected velocity and run-out distance are the primary steps involved in the LHRM. The quantification of the hazard may be obtained by either numerical weightings or by calculation of posterior probability while the quantification of consequences associating with the degree of losses (life, property and infrastructure etc), though difficult, can be evaluated in general terms. Three set of elements of risks have been outlined for the purpose viz. Risk to life (Grade-1), Social (Grade-2) and Infrastructure (Grade-3). For each grade a numerical adjustment rating (1 to zero) has been assigned.

The risk levels are determined by expressing hazard frequencies(Numerical ratings or probability values) multiplied with an assigned value of elements of risk in order to qualitatively classify the area with varying categories of risk levels such as Very High, High, Moderate, Low and Very Low, depending on the range of values.

A case study of LHRM has been presented based on the evolved approach to classify the terrain into five risk levels due to the threat of landslides. The LHRM may be of immense use for making quantitative or alternative decisions for the management of the landslide hazard and infrastructural planning for sustainable growth.

Introduction

Landslides, like other natural hazards are often unpredictable and have potentially damaging consequences. In simple terms, landslide hazard can be depicted as potential process of earth material to produce damage because of its impact characteristics, magnitude and frequency with which it occur. Landslide presents threat to life and livelihood throughout the world ranging from minor disruption to catastrophe. A spatial and temporal analysis of the threat of landslide is difficult to determine accurately because of variable factors responsible for their occurrences and areas exposed for risk. Numerous approaches for spatial landslide susceptibility and hazard mapping are available in different parts of the world, however, identification of risk, risk estimation and risk mapping is an emerging trend of research. The present paper deals with a preliminary procedure to prepare a qualitative Landslide Hazard and Risk Map (LHRM) on macro-scale. The procedure is performed in two stages *viz.* hazard mapping and risk level identification depending upon the set or set of elements at risk in a specific terrain. The general principle of hazard and risk mapping are outlined along with a case study of the procedure in Himalayan geo-environment.

*Geological Survey of India, Northern Region, Project: Landslide Hazard Studies, Lucknow 226024
e-mail: vksharma_gsi@yahoo.co.in

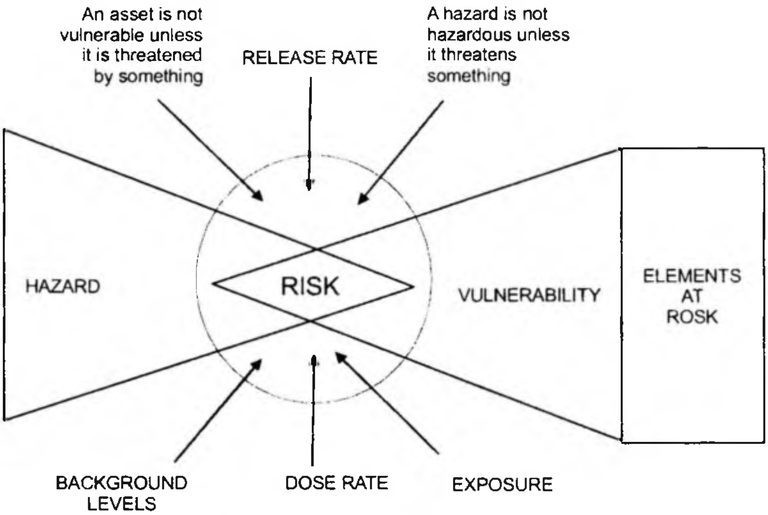

Fig. 1: Concept of risk analysis (Alexander, 2002)

Landslide hazard mapping framework

Landslide hazard as defined by Varnes (1984) mean the probability of occurrence within a specific period of time and within a given area of a potentially damaging phenomenon. Landslide susceptibility as used in many mapping procedures (Brabb et al., 1972) corresponds to hazard by equating spatial probabilities to temporal probabilities. Guzzetti et al. (1999) preferred the definition to include the magnitude of the event, i.e. the area, volume and velocity or momentum of the expected landslide. Landslide hazard mapping has been significantly developed over past few decades with number of different procedures, practices and models for identifying promising grounds for spatial prediction. Examples of the application of quantitative techniques to landslide hazard mapping were presented by Carrara (1989) in Italy where multivariate models were portrayed for predicting potential slope failures. Liener et al. (1996) proposed a rule based procedure to locate landslide prone areas.Mejia-Navarro and Garcia (1996) presented an Integrated Planning Decision Support system, for hazard based on Geographic Information System (GIS) platform and graphic user interface. In this approach, landslide hazard was computed as weighted summation of ratings assigned to natural physical factors. Clerici et al. (2002) proposed a procedure for landslide susceptibility zonation based on conditional probabilities. Leroi (1996) reviewed several landslide related maps production in France such as PER (Plans for Exposure to predictable natural Risk). Glade (2001) proposed an approach for a comprehensive natural risk assessment. In addition, number of different approaches to Landslide hazard evaluation reviewed by Soeters and Van Westen (1996), Disperati et al.(2002) preferred to use statistical approach proposed by Chung and Fabbri (1993). ZERMOS(Zones Exposed to Risk of Movements of the Surface) mapping procedure has been developed and applied since 1970 in France. These maps have always intended to cover all terrain instabilities including landslides. The maps are synthesizing and built upon a number of specific attributes like slope, lithology, structure etc. The defined hazard level, thus, are relative and only valid for particular map area. The maps of this type have also been created by Brabb et al. (1972), the concept has been applied and procedure has been extended by Nilson et al. (1979). The maps have been prepared through a combination of nature of ground, slope, climate, and

Table 1: Landslide hazard levels according to range of TEHD values.

Zone	TEHD VALUE	DESCRIPTION OF ZONE
i.	<3.5	Very Low Hazard Zone (VLHZ)
ii.	3.5-5.0	Low Hazard Zone (LHZ)
iii.	5.1-6.0	Moderate Hazard Zone (MHZ)
iv.	6.1-7.5	High Hazard Zone (HHZ)
v.	>7.5	Very High Hazard Zone (VHHZ)

inventory maps and a subjective assessment of various attributes.

Chung, et al., (1999) and Sharma, (1996) have used landslide inventory for probabilistic landslide hazard quantification. Guzzetti et al., (op.cit.), while assessing landslide hazard at basin scale, incorporated the magnitude of the event (i.e. landslide size) in the definition of hazard. Ideally, the Landslide hazard mapping incorporates the concepts of location, time and size. To complete a hazard assessment and mapping the following questions needs to be thrashed out-

- 'where' a landslide will occur *(probability of landslide susceptibility)*
- 'when' or how frequently it will occur, *(temporal probability)*
- 'How large' the landslide would be *(probability of a landslide of a particular size)*

In the present framework of Landslide hazard mapping, the hazard levels are described by a scale from VHHZ to VLHZ which combines the intensity of the danger and spatial proneness according to numerical rating of set of parameters (BIS: IS: 14496 (part-2); 1998) *viz.* lithology, structure, slope morphometry, relative relief, land use and land cover and hydro geological conditions. A detailed evaluation of Landslide Hazard Evaluation Factor (LHEF) rating scheme showing numerical weightings of sub-categories of all the causative factors has been made for each facet identified on topographical map of 1:50,000 scale. The total estimated hazard (TEHD) of an individual facet (Table1) has been obtained by adding the ratings of the individual causative factors.

Landslide risk assessment

The concept of risk

The most complete definition of risk is given by Varnes (1984) as "the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomenon (such as landslide) for a given area and reference period". This definition is relatively easy to put into practice when risk is evaluated for a single landslide in a given area and time. Difficulties arises when risk analysis is done for larger area, consisting of more than one hazard zones.It is, indeed, very difficult to locate exactly the element at risk versus the possible locations of the landslides (van Westen et al., 2006).

In general, risk is represented as a product of Hazard (expressed as probability of occurrence within a reference period), and Vulnerability of a particular type of element at risk and Element at risk. The methods used for risk analysis can be grouped into:

(i) *Qualitative methods,* where probability and losses expressed in qualitative terms;

(ii) *Semi-quantitative methods,* where indicative probability, qualitative terms, and

(iii) *Quantitative methods,* in which probability and losses are quantified

Risk, thus, is a measure of the probability and severity of loss to the elements at risk, usually expressed for a specific unit area, object or activity, over a specified period of time. Two basic parameters in risk assessment, therefore, are important *viz.,* the element at risk (E) and its vulnerability (V).

Vulnerability is defined as the degree of loss on specific element or group of element at risk due to natural phenomena (Such as landslide in present context) of a specific intensity. Vulnerability can be estimated for individual structures, for specific sectors or for selected geographic areas (e.g., areas with the greatest development potential or already developed areas in hazardous zones.) The vulnerability should be expressed by a scale starting from 0 (no body loss or 'Zero loss') to 1 (total loss or 100% loss) and is a function of intensity of the phenomena and typology of element at risk. Formally the vulnerability concept should be expressed in terms of dependent probability (Einstein, 1988). The assessment of vulnerability is somewhat subjective and largely based on historic records. The landslide risk is generally calculated separately for life and property.

Elements at risk and risk determination

Elements at risk refer to the population, buildings, civil engineering works, economic activities, public services, utilities and infrastructure, etc., which are at risk in a given area. Generally all valued attributes threatened by the landslide hazard are the elements at risk. Emphasis is mostly given to buildings, population and infrastructure. Data collection techniques for a rapid inventory of elements at risk generally use high-resolution images, topographical maps and result in the generation of multipurpose elements at risk databases. Each of the elements at risk has its own characteristics, which can be spatial or temporal. A correct and exhaustive exposure map should contain the inventory of all settlements, infrastructure elements, land use type and people exposed at risk. The value of element at risk can be expressed in terms of number or quantity of exposed element (i.e. number of persons, buildings) or in terms of exposed area or in monetary terms.

The next step in the analysis of risk is the quantification of the vulnerability of the elements at risk, which is achieved by making an assessment of the degree of damage that may result from the occurrence of a landslide of a given type and volume. The estimation of the possible degree of damage should be based on damage relations, also called vulnerability/fragility curves derived from historical damage inventories.

The quantification of the amount to be included for the elements at risk could be in terms of monetary values (although this is often not required) or in the number of buildings or persons affected. The integration of all specific risks for all landslide types and volumes and all elements at risk results theoretically in the total risk

In the proposed framework for LHRM procedure, the elements of risk are categorized into three grades depending upon the importance of elements at risk. Three set of elements of risks have been outlined for the purpose *viz.*

-Risk to life (Grade-1),

-Social (Grade-2) and

-Infrastructure (Grade-3).

The elements in Grade-I, people exposed to risk and the structures that directly affect the life are placed. The Grade II covers the elements that are associated with lifeline features such as connecting roads, schools, Offices, electric lines, critical bridges etc. The remaining elements such as infrastructure buildings, forest roads, land use with forest cover etc. are placed in Grade-III. For each grade a numerical adjustment rating (1 to zero) has been assigned. Thereafter, the elements or set of elements at risk have been assessed with reference to particular surface area subject to land sliding. This varies depending upon land use and slope morphological characters of the terrain.

Risk mapping

Landslide risk is fundamentally a product of hazard and vulnerability, these two phenomenons can be managed in mutually varying proportions (Fig.1). It is difficult to separate vulnerability from hazard and risk as these concepts are interwined in complex ways (Alexander, 2002). Hence, it is difficult to design a standard all-embracing method of assessing vulnerability to landslides based on asset recognition and estimating potential death toll and cost of damage.

Landslide risk assessment and management comprises the estimation of the level of risk, deciding whether or not it is acceptable and exercising appropriate control measures to reduce the risk when the risk level cannot be accepted (Ho et al., 2001). It requires the number of issues to be addressed such as (a) Probability of landslides (b) Run-out behavior of landslide debris (c) Vulnerability of property and people to landslide(d) Landslide risk to property and people and (e) Management strategies and decision-making (Dai et al., 2002).

The risk levels, in the present framework, are determined by expressing hazard frequencies(Numerical ratings or probability values) multiplied with an assigned value of elements of risk in order to qualitatively classify the area with varying categories of risk levels such as Very High, High, Moderate, Low and Very Low, depending on the range of values.

Landslide Hazard and Risk Mapping (LHRM) in parts of Ravi catchment

Landslide Hazard and Risk Mapping (LHRM) has been carried out on 1:50000 scale covering about 100sq km area encompassing the Baira-Siul dam project which is located on river Baira-Siul, a tributary of Ravi river, about 46km north of Chamba town on Chamba –Tisa road.The LHRM involves the spatial assessment of the terrain to delineate areas of potential landslide risk of varying magnitude depending on the elements of risks. The approaches for hazard assessment studies, in general, comprise either rating of relative degree of hazard or calculation of absolute level of hazard; however, in the present case, a numerical weightage scheme adopted by Bureau of Indian Standard that by and large use rating of several components has been used to prepare a hazard zonation map.

Geologically, the rocks of study area expose a wide assemblage of rock formations ranging in age from late Proterozoic to Triassic (Aggarwal and Kumar, 2004, Sharma,2008 etc). These are grouped into lower and upper sequences; the lower rest over the Bhalai Formation of Proterozoic age. The Bhalai Formation consisting state, phyllite, schistose quartzite and schist is conformably overlain by the Chamba Formation, Manjir Formation and Katarigali Formation. The Chamba Formation consists mainly of phyllites and schists, Manjir Formation consists of grey and purple slates that at places has pebbly horizon and Katarigali Formation is represented by slates, carbonaceous shales and bands of limestone. The upper sequence is represented by black shale/slate of Salooni Formation and Saho volcanics. The Salooni Formation is overlain by Kalhel Formation (Triassic) that forms the youngest formation in the area. The entire stratigraphic sequence is regionally folded into a major syncline referred as 'Chamba syncline' with NW-SE trending axial plane.

Landslide Hazard and Risk Mapping (LHRM) has been carried out in two stages:-

Stage-I (Hazard estimation)

The study involved preparation of different composite factorial maps on 1:50,000 scale such as slope facet map, lithological map, land use and land cover maps incorporating data on the contributory factors *viz.* slope parameters including their orientation and inclination, relative relief, structural conditions, rock outcrop and soil cover, hydrological conditions. Facet wise details of all these contributory factors have been prepared for assigning Land Hazard Evaluation Factor (LHEF) rating (Sharma,2008) for each factor as per BIS (op.cit). For the purpose of initially following

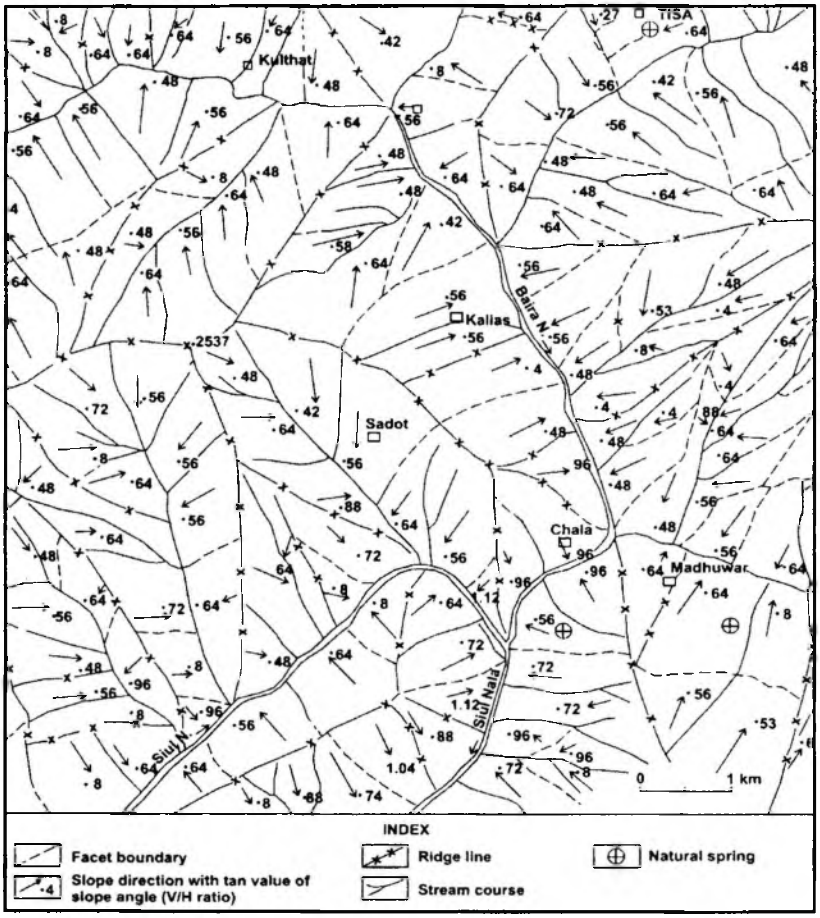

Fig. 2: Slope Morphometry map.

composite factorial maps on 1:50,000 scales were prepared.

(a) Slope morphometry map

The slope morphometry map is the base map for preparation of landslide zonation map of the area. The map defines various slope categories of the study area and has been prepared by demarcating slope facets on the Survey of India toposheets of 1:50000 scales (Fig.2) by dividing topographical sheet into smaller facet. The slope facets are generally delimited by ridges breaks in slope, streams and spurs etc. In all 132 slope facets are identified and for each the maximum slope angle and slope direction have been worked out. The distribution pattern of slopes indicate that 54% slopes are in the range of 26^0 to 35^0 inclination 24% in 16^0 to 25^0 inclination and 20% of slopes in 36^0 to 45^0 range and remaining 2% have slopes more than 45^0 inclination.

(b) Relative relief

The relative relief value of each facet was determined and corresponding LHEF rating has been assigned. The facets with more than 300m, 101m to 300m and less than 100m have been awarded corresponding ratings of1.0, 0.6 and 0.3 respectively. The area generally has high relative relief with majority of facets having relief of more than 300m.

(c) Lithological map

The response of lithology to the processes of weathering and erosion is the main criteria in awarding the rating of lithology. The important bedrock lithologies exposed in the area are slate, shale, phyllite and quartzite. The slates and phyllites of the Chamba Formation and Manjir Formation have been grouped as 'Type III'as per BIS norms and accordingly a rating of 1.2 has been awarded.The moderately weathered quartzite of the Chamba Formation has been given a value 0.6 after making correction for weathering .

The area is also occupied by overburden material which is generally Older debris deposits (Rating 1.2) with an estimated depths ranging from less than 5.0m, 6.0-10m, 11-15m and 16-20m with corresponding LEHF ratings as per BIS.

(d) Structure

The structural discontinuity in relation to the slope angle and direction has greater influence on overall stability condition of the area. The structural data have been superimposed on the lithological map and observed structural details are plotted on stereo net and preferred orientation and possible failure mode (planar or wedge) is obtained for the facets occupied by bedrock. The structural discontinuities evaluated for the purpose of facet wise projection strike in (i) N21°E-S21°W dipping vertically (ii) N29°E-S29°W dipping 78°NW (iii) N50°E-S50°W dipping39° NW (iv) N02°W-S02°E dipping 25°SW and (v) N43° E-S43°W dipping 46°NW. Three types of structural relations with slope parameters (maximum slope angle and direction) are studied and numerical ratings for each of the situations in either planar or wedge mode evaluated. The specific situations are (i) the extent of parallelism between directions of discontinuities and slope. (ii) Steepness of discontinuities and (iii) difference in dip of discontinuities to the inclination of slope.

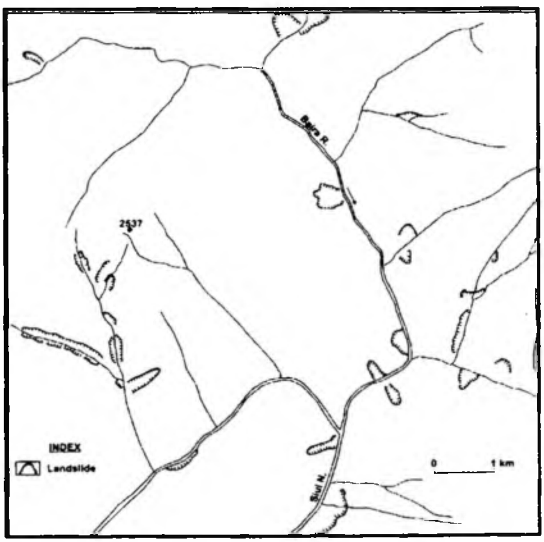

Fig. 3: Landslide Distribution map of the area.

(e) Hydro-geological conditions

The hydro-geological conditions of the area show that southeasterly portion of the area is generally wet as manifest by the presence of springs and perennial streams (wet and flowing conditions). The areas with old springs, zones prone to toe erosion close to streams has been considered as wet ground and areas of flowing springs assigned the highest rating of the category. Facet wise evaluation of the flowing, dripping, wet, damp, and dry condition is made with corresponding ratings 1.0,0.8,0.5,0.2 and 0.0 respectively. An overlay of a composite factorial map has been prepared for assigning the LHEF ratings of the causative factors.

(f) Land Use and Land Cover map

Land use pattern and land cover of a terrain is indirect indications of the stability of hill slopes as the roots of plants penetrates throughout the soil and increase their shear strength. A land use and land cover map was prepared and area divided into five categories viz. Agriculture land/populated flat land, thickly vegetated moderately vegetated, sparsely vegetated area and barren land with corresponding ratings as 0.6,0.8,1.2,1.5 and 2.0. In general, the land use pattern of the area suggests that northwest portion of the area is thickly vegetated with pockets of barren land. The agricultural land/populated area is confined mainly in eastern and northeastern zone. The southeastern part of the area is largely barren rocky zone with thick vegetation cover. The slope facet map is superimposed on Land use map to assign LHEF rating scheme to the individual facet.

A landslide incidences map (Fig.3) depicting all the major and minor landslide in the area have been prepared

A detailed evaluation of Landslide Hazard Evaluation Factor (LHEF) rating scheme showing numerical weightages of sub-categories of all the causative factors has been made for each facet identified on topographical map. The total estimated hazard (TEHD) of an individual facet has been obtained by adding the ratings of the individual causative factors obtained from the LHEF scheme. Facet wise distribution of the total estimated hazard values in the area facilitates spatial classification of the terrain into five zones *viz.* Very High hazard (VHH), High Hazard (HH), Moderate Hazard (MH), Low Hazard (LH), and Very low Hazard VLH) corresponding to the values more than 7.5, 7.5to 6.1, 6.0 to 5.1, 5.0 to 3.5 and less than 3.5 respectively (Fig. 4)

Stage-II (Risk mapping)

Risk estimation has been carried out in a qualitatively manner by considering hazard zones as deduced from the hazard Zonation mapping, elements at risk falling in the specific hazard zone and by synoptic evaluation of run out distance, possible

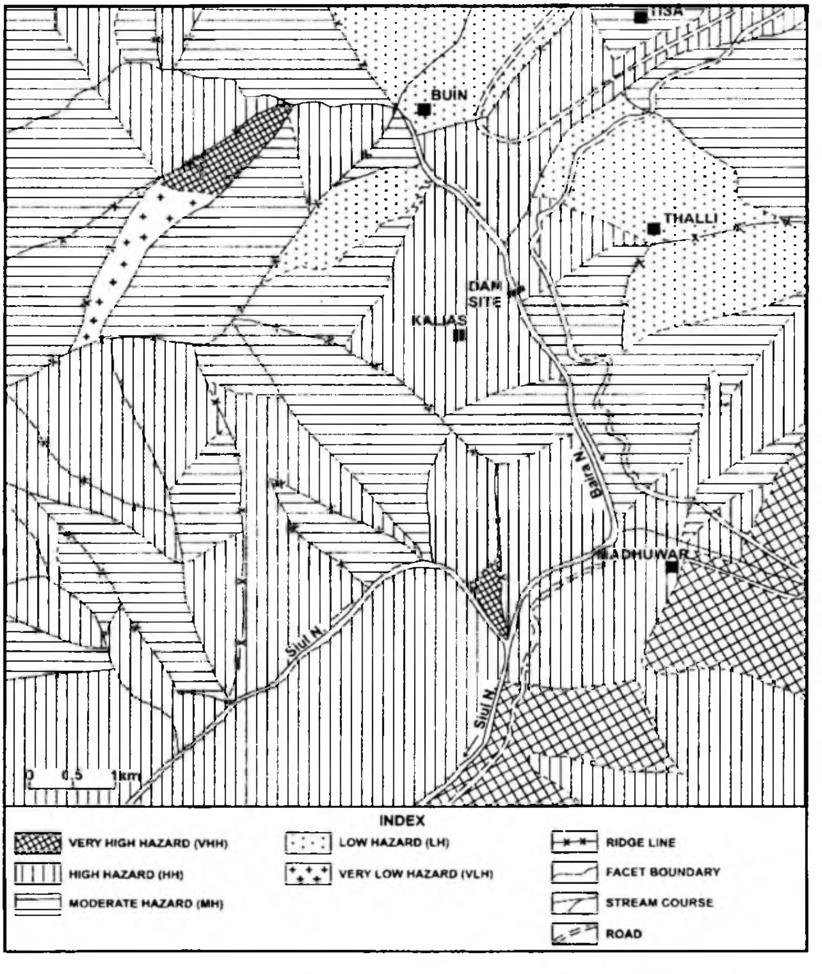

Fig.4: Landslide Hazard Zonation map of the area.

velocity and material type etc associated with landslide/s in the area. A full risk analysis, therefore, involves consideration of all landslide hazards zones (e.g. large, deep seated landslides, smaller slides, boulder falls, debris flows etc.) and all the elements at risk. Maps portraying different grades of elements at risk in specific slope facet have been prepared (Fig. 5).

Individual risk for the persons most at risk (elements of risk of Grade-I type) due to landslide phenomenon are qualitatively assessed facet wise by considering hazard categories values(weightings) and element or elements at risk. The elements at risks of grade-I,II and III have been assigned 1.0, 0.75 and 0.5 respectively depending upon the severity of the risk involved in a specific grade. T For example, In case of high hazard category with grade –I (Numerical weighting =1.00) element at risk, the risk level would also be high(risk value 7.6 to 10). A model calculation is given in Table 2 along with the general guidelines for the implication and definitions (Table 3).

The total risk (summing the individual risk of all the persons affected by the landslide hazards) for total risk (whether for property or for life) the risk for each hazard for element is summed up. Risk evaluation is, thus, the process of determining the significance of a risk to the individual, organization or community in a specific facet.

The ranges of values are categorized into five risk categories viz. very high, high, moderate, low and very low as per table 3 (Fig. 6).

Conclusions

The Hazard and Risk mapping evaluation are

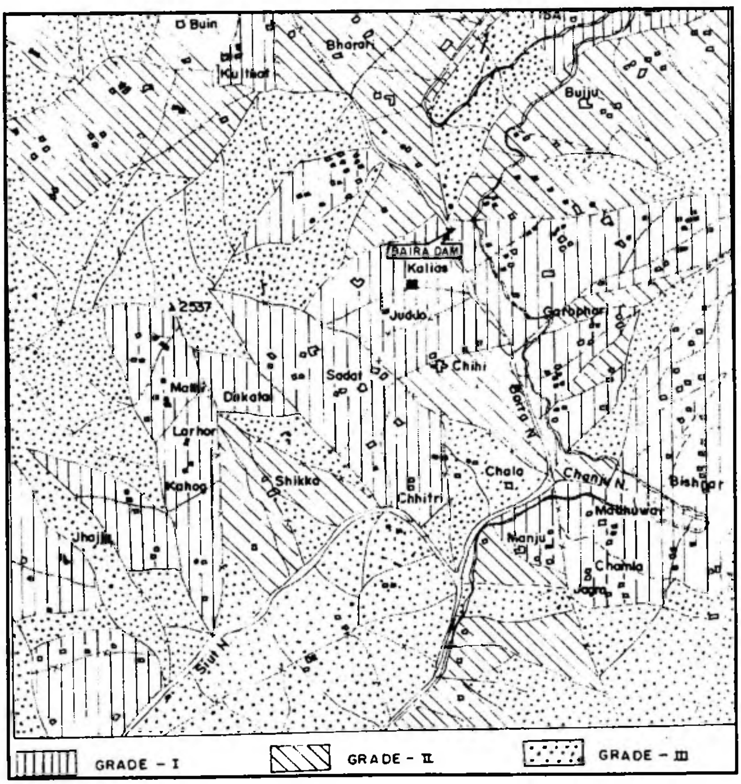

Fig. 5: Areas indicating different grades of Elements at Risk.

Table 2: Facet wise model calculation of hazard, elements at risk and risk levels.

Facet wise hazard category	Range of Weightings	Elements at risk with grade weightings			Risk values	Risk category
		Grade-I	Grade-II	Grade-III		
VHHZ	7.6-10.00	1			7.6-10	Very High Risk
			0.75		5.6-7.5	High to Moderate
				0.5	3.8-5.0	Low Risk
HHZ	6.1-7.5	1			6.1-75	High risk
			0.75		4.7-5.6	Moderate to Low
				0.5	1.83-2.25	Low Risk
MHZ	5.1-6.0	1			5.1-6.0	Moderate Risk
			0.75		3.8-4.5	Low Risk
				0.5	2.25-3	Low Risk

important to decide whether to accept or treat the risks levels and to set priorities for mitigation of the landslide hazard in a specific terrain. Mapping of levels of risk, thus, involves making judgments about the significance and acceptability of the estimated risk. Evaluation may involve comparison of the landslide risks with other risks or criteria related to financial, loss of life or other values. In a simple situation risk evaluation may be a simple judgment/ acceptable process of risk management.

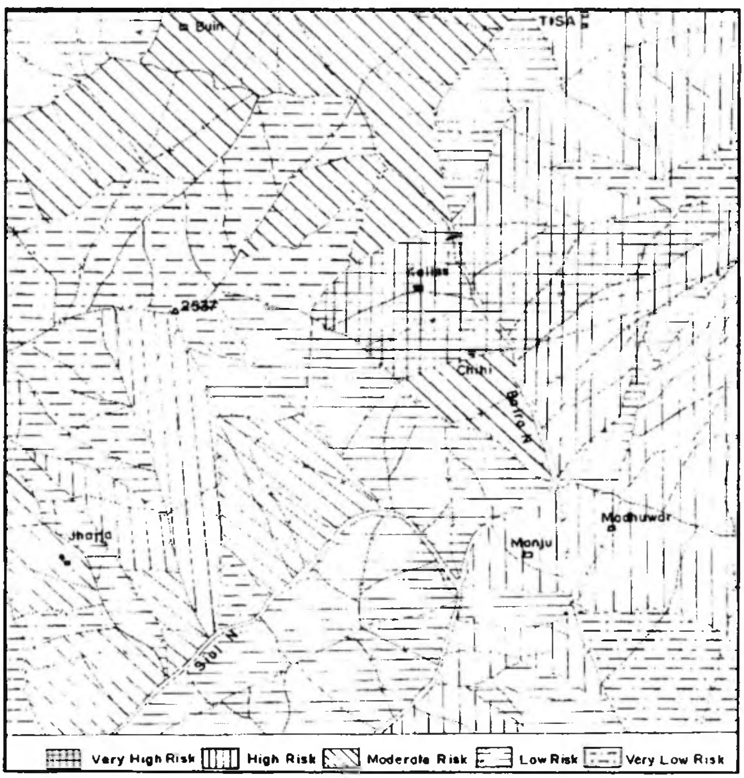

Fig. 6: Landslide Risk Zoning map of the area.

Table 3. Qualitative risk levels (modified AGS, 2000)

Risk values	Risk levels	General guide to implications
>7.5	Very High Risk	Extensive detailed investigations and research planning and implementation of treatment options essential to reduce risk to acceptable levels.
6.1-7.5	High Risk	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
5.1-6.0	Moderate Risk	Tolerable provided plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options.
3.5-5.0	Low Risk	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk.
<3.5	Very Low Risk	Acceptable, manage by normal slope maintenance procedures.

Landslide Hazard and Risk Map (LHRM) may be of use in preliminary assessment of levels of landslide risk associated with the exposed elements at risk. It is a derivative and dynamic map that may change according to the change in the grades of elements. Risk mapping alone has limited benefits and it is normal to carry the process to the next stages of risk evaluation and risk treatment by more specific studies.

Parts of Ravi basin have been divided into five zones, depending upon the hazard category and exposed elements at risk. The area encompassing Kalias landslide and Baira dam is Very High Risk zone whereas areas east of Siul River, though, have number of landslides have Low risk zone.

LHRM provides information on the potential economic impact associated with hazard-related risks in parts of Ravi basin. Such information is significant for prioritizing risk management programme for sustainable and fair growth.

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