Grid-Based Analytical Approach to Macro Landslide Hazard Zonation Mapping

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Abstract

In an attempt to simplify the quick appraisal or first level Landslide Hazard Zonation, i.e. Macro-level, a grid-based analytical approach is recommended. The Macro LHZ mapping for a five-fold classification of terrain is carried out using only three factors, viz. Lithology (or Ground Erodibility), Ruggedness Number (Relative Relief x Drainage Density), and Landuse/Land cover (or Vegetative Cover), that, in general, cover most of the causative factors used in BIS Guidelines. The methodology is based on an earlier concept of 'pS' (sediment generation potential), the values of which may range between 10 and 500 x 10^2.

It is pointed out that the selection and rating of causative factors in LHZ mapping continue to be arbitrary. An LHZ Guideline backed by well-documented statistical analysis of existing data would lend credit to the rating values and confidence in the methodology recommended.

Introduction

The landslide hazard zonation is based on rating scheme of causative factors termed Landslide Hazard Evaluation Factor (LHEF) in which numerical ratings for different categories are determined on the basis of their estimated significance in causing instability to slopes. The system has evolved over a long period after lots of international research and has emerged from the earlier probabilistic approaches. In India, the Bureau of Indian Standards (BIS) guidelines for Macro-zonation (Anon., 1998) consider six causative factors with accompanying LHEF Ratings for zoning landslide hazard (Table-1). The LHZ map is prepared based on Total Estimated Hazard (TEHD) calculated from LHEF Ratings on facet basis. The landslide susceptibility is classified into five categories ranging from very low to very high hazard zones (Table-2).

After intense work in differing physiographic domains all over the country, the Geological Survey of India has suggested some modifications to the BIS Guidelines that incorporate more elaborate rating scheme on the basis of ten causative

Table-1: BIS parameters for Landslide Hazard Zonation

S. No.	Causative Factor	Maximum LHEF
1	Lithology	2
2	Structure	2
3	Slope Morphometry	2
4	Relative Relief	1
5	Landuse and Land cover	2
6	Hydrological Condition	1

Table-2: Landslide Hazard Zones based on BIS Guidelines

Zone	TEHD Value	Description
1	< 3.5	Very Low Hazard Zone (VLHZ)
2	3.5-5.0	Low Hazard Zone (LHZ)
3	5.1-6.0	Moderate Hazard Zone (MHZ)
4	6.1-7.5	High Hazard Zone (HHZ)
5	> 7.5	Very High Hazard Zone (VHHZ)

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factors. Besides splitting Landuse and Land cover in to two separate factors; rainfall, landslide incidence and slope erosion have been added to the existing six parameters of the BIS. In the process, the maximum LHEF Rating has also gone up from 10 of BIS to 14 of GSI.

The LHZ is carried out in three different categories considering the requirements of information. While the Macro LHZ maps are on 1:50,000 or 1:25,000 scale, the Meso LHZ and Micro LHZ maps are on larger scales of 1:10,000 to 1:5,000, or more. The standard analytical approach is to collect and analyse data on facet basis, irrespective of the scale of mapping. Invariably, the existing 1:50,000 scale geological maps form the backbone of all data pertaining to important LHEF parameters on lithology and structure with some field inputs that face extreme inaccessibility constraints in the rugged terrains like in the Himalaya.

Analytical Constraints in LHZ

Apparently, the objective of the Macro LHZ mapping is altogether different from that of the Meso and Micro LHZ mapping. While the Macro LHZ maps should be for quick appraisal of terrains with respect to their vulnerability to slope failures, the Meso- and Micro-LHZ maps should provide detailed information required for site specific purposes like for reservoir areas, communication routes, major engineered structures, etc. For obvious reasons, while the Macro LHZ mapping would be covering large areas with accessibility constraints, the other two would be catering to much restricted areas of easy accessibility, and hence, better scope for data collection. Such differences in the objectives and the large variations in the area of coverage suggest that the approaches in the LHZ mapping could also be different for these two broad categories. Therefore, the overall approach to LHZ mapping needs to be reviewed in the light of data collection constraints.

Accurate data inputs in the facet-based analysis for LHZ mapping require very elaborate field data collection. This, however, is extremely difficult in the Macro-level studies, where data collection faces constraints, as large areas remain inaccessible, particularly in rugged terrain like the Himalaya. In such cases, the LHEF ratings have to be assumed leading to LHZ maps that tend to project a different picture than the actual one. It may, therefore, be prudent to avoid the elaborate and cumbersome facet-based approach and adopt a simpler technique based on lesser number of parameters that can be assessed from available data or through remote sensing techniques. For Meso- and Micro-LHZ mapping, the BIS or GSI Guidelines may be followed, as the accessibility of facet areas may be much better.

Grid-based Analytical Approach – The Concept

As an alternative to facet-based approach, a grid-based approach with simple and easily determinable parameters may serve the purpose of Macro LHZ mapping. Out of the six landslide hazard evaluation factors, *viz*. lithology, structure, slope morphometry, relative relief, landuse & land cover and hydrological condition, it is the structure that is difficult to determine for the facets or grids in inaccessible areas. The grid-based approach, therefore, may do away with this factor. Slope morphometry, relative relief and, to some extent, hydrological condition, are well represented by a single time tested geomorphic function – the Ruggedness Number - that is a function of relative relief and drainage density. Lithology may be simplified to represent the erodibility of the strata in general. The remaining factor of landuse and land cover may be used as such or may be replaced by vegetative cover.

The Macro LHZ mapping, therefore, may be carried out on the basis of only three factors, *viz*. Lithology (or Ground Erodibility), Ruggedness Number, and Landuse/Land cover (or Vegetative Cover). With the proposed modification in the factors to be used for LHZ mapping, the LHEF Rating may have to be modified appropriately. A 10 point Rating Scheme may be adopted with allocation of Ratings as 3 for Lithology, 4 for Ruggedness Number and 3 for Vegetative Cover. The resultant LHZ Map may be represented as a simple grid pattern map or a contour map.

The suggested technique has been derived from an old concept of grid-based estimation of Sediment Generation Potential 'pS' (Deva, 1990, 2001) that aims at classifying silt generating areas for catchment management plans in river valley development schemes, and, by corollary, may represent ground susceptibility to landslides. This quantitative methodology involves preparation of a sediment generation potential map of an area based on Ruggedness Number (Strahler, 1958), Ground Erodibility and Vegetative Cover. The work is carried out on 1:50,000 contour maps and digital satellite imageries. The area is divided into grids of 9 sq km area each and the sediment generation potential 'pS' is calculated using the formula:

pS = (Nr x Ge) / Vc
where, Nr=Ruggedness Number;
Ge=Ground Erodibility; Vc=Vegetative Cover

Ruggedness Number is the product of relative relief and drainage density. Ground Erodibility and Vegetative Cover are determined from five-fold classification Rating Table. While the lowest rating of 1 corresponds to low ground erodibility/ vegetative cover, the highest rating of 5 represents high ground erodibility/ vegetative cover. In general, the pS values would range from 0.1 to 5 @ 0.01 interval and, for convenience may be expressed in integers 10 to 500 x 10^{-2}. Higher or lower values are possible and may be found in extremely rugged or gently rolling terrains, respectively. As stated earlier, the 'pS' values themselves may be used for representing the landslide hazard, which has been divided into five classes of Very Low Hazard to Very High Hazard (Table 3).

Zone	"pS" Value (x 10^{-2})	Category
1	< 100	Very Low Hazard
2	100-200	Low Hazard
3	200-300	Moderate Hazard
4	300-400	High Hazard
5	> 400	Very High Hazard

Table 3: "pS" value based Landslide Hazard Zonation

A Case Study

The suggested methodology has been applied to the LHZ mapping of a part of Ravi Basin around Baira Dam in District Chamba of Himachal Pradesh (Fig.1, a). The area has been divide into 63 square grids of 9 sq km area each (6cm x 6cm). Relative Relief is found to vary between 123 and 1075 m; Drainage Density between 0.722 and 5.035 per km; and the resultant Ruggedness Number between 0.244 and 5.412. The assigned parameter rating values for Ground Erodibility "Ge" and Vegetative Cover "Vc" are found to vary between 2-3 and 1-4, respectively. The "pS" values range between 24 and 672 x 10^{-2}.

The suggested methodology is a much less time-consuming desktop procedure. The whole process of the analysis for the 670 sq km area has taken just a couple of days.

From the analysis, it is found that Very Low Hazard area occupies 29%, Low Hazard area 55%, Moderate and High

Hazard areas 6% each ; and Very High Hazard area 4%. In general, the higher hazard zones lie in the upper reaches of the Baira sub-basin. It is seen that the existing landslides are located in the lower hazard zones. Considering the BIS Guideline that 100-200 m strip on either side of major faults, thrusts and intra-thrust zone may be awarded an extra rating for accommodating higher landslide susceptibility depending upon intensity of fracturing, such an occurrence is attributed to the presence of the landslides in the vicinity of major tectonic lineaments, *viz*. antiformal axes.

Part of the mapped area has been analysed previously using Probabilistic and BIS approaches of Landslide Hazard Zonation (Fig1, b & c; Sharma, 2005, 2006). In general, the hazard zonation in the two maps does not correlate well. In the northwestern and southeastern part of the area, the high hazard zones of BIS methodology do not match with that of the Probabilistic approach. However, in the central part, there is correlation, but, to a limited extent only.

In the hazard zonation maps prepared using the three different methodologies, lots of variations are noted. This may be due to various factors including the possibility that the weight given to causative factors may be arbitrary.

Conclusion

In conclusion, it is reiterated that the Macro Landslide Hazard Zonation should be treated as a quick appraisal or 1st level map preparation exercise and may be carried out on grid base that is much easier compared to the cumbersome facet-based procedure and takes far too less time in data collection and computations.

Selection and rating of causative parameters is a different matter and continues to be arbitrary. This can be overcome by a statistical analysis of the existing database on individual landslides and landslide hazard zonation. It may also be added that an LHZ Guideline backed by well documented analysis of existing data would lend credit to the rating values and confidence in the methodology recommended.

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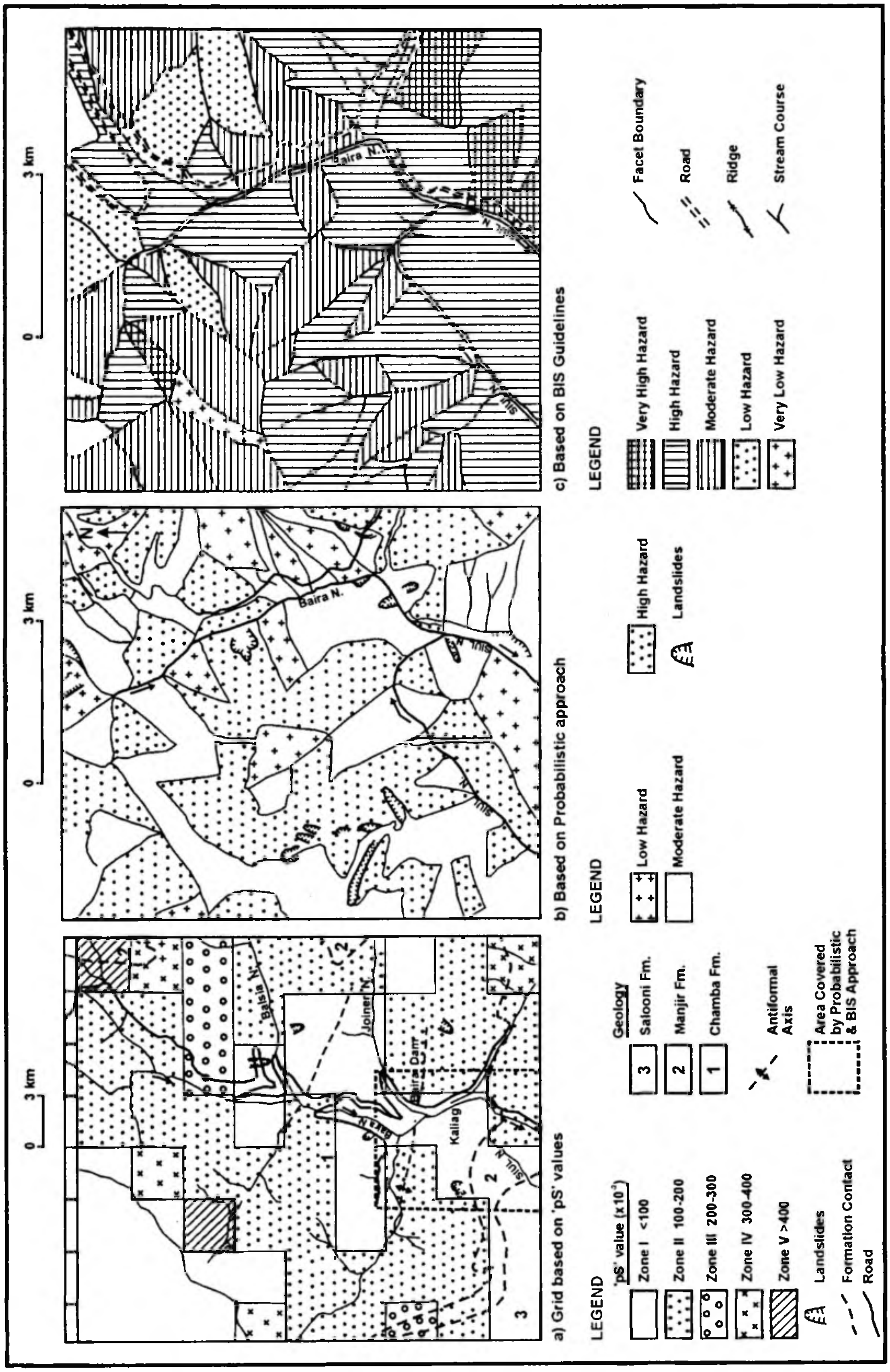
0 3 km
a) Grid based on 'pS' values
LEGEND
'pS' value (x10⁻³)
Zone I <100
Zone II 100-200
Zone III 200-300
Zone IV 300-400
Zone V >400
Landslides
Formation Contact
Road
Geology
3 Salooni Fm.
2 Manjir Fm.
1 Chamba Fm.
Antiformal Axis
Area Covered by Probabilistic & BIS Approach
Balsia N.
Joiner N.
Baira Dam
Baira N.
Kaliag
Siul N.
b) Based on Probabilistic approach
LEGEND
Low Hazard
Moderate Hazard
High Hazard
Landslides
Baira N.
Siul
c) Based on BIS Guidelines
LEGEND
Very High Hazard
High Hazard
Moderate Hazard
Low Hazard
Very Low Hazard
Facet Boundary
Road
Ridge
Stream Course
Baira N.
Siul N.