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Landslide Hazard Zonation Mapping and Comparative Analysis of Hazard Zonation Maps

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Abstract: Landslide hazard zonation mapping at regional level of a large area provides a broad trend of landslide potential zones. A macro level landslide hazard zonation for a small area may provide a better insight into the landslide hazards. The main objective of the present work was to carry out macro landslide hazard zonation mapping on 1:50,000 scale in an area where regional level zonation mapping was conducted earlier. In the previous work the regional landslide hazard zonation maps of Srinagar-Rudraprayag area of Garhwal Himalaya in the state of Uttarakhand were prepared using subjective and objective approaches. In the present work the landslide hazard zonation mapping at macro level was carried out in a small area using a Landslide Hazard Evaluation Factor rating scheme. The hazard zonation map produced by using this technique classifies the area into relative hazard classes in which the high hazard zones well correspond with high frequency of landslides. The results of this map when compared with the regional zonation maps prepared earlier show that application of the present technique identified more details of the hazard zones, which are broadly shown in the earlier zonation maps.

Keywords: Landslides; Hazard zonation; Garhwal Himalaya; Mapping

Introduction

Landslide hazard zonation refers to the division of land into homogeneous areas and ranking of these areas according to their degrees of actual or potential hazard caused by landslides and mass movements. In common practice landslide hazard zonation maps display the spatial distribution of hazard classes. Several landslide hazard zonation schemes involving different techniques are available in the literature. Some of them are made by Yin and Yan (1988), Carrara et al. (1991), Anbalagan (1992), Pachauri and Pant (1992), Juang et al. (1992), Jade & Sarkar (1993), Van Westen (1993), Chung and Fabbri (1999), Dhakal et al. (2000), Sarkar and Kanungo (2004), Sarkar and Gupta (2005), Kanungo et al. (2006) and Sarkar et al. (2008).

In general the techniques differ in selection of factors and their weight assignment. Basically there are three techniques for landslide hazard zonation mapping, and they are geomorphic analysis by direct hazard mapping in the field, factor overlay approach by weight assignment based on expert knowledge and statistical approach by correlating past and existing landslides with distribution of factors influencing landslide occurrence. Another aspect where the landslide hazard zonation techniques differ is the amount of hazard details required. In regional landslide hazard zonation, which is mostly carried out on 1:50,000 scale, an appraisal of landslide potential areas can be made over a large terrain. It is primarily based on the information derived from remote sensing

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data and the available maps of topography, geology, etc. Such studies, in general, do not call for intensive field study. In contrast to such schemes a more refined landslide susceptibility mapping based on considerable field studies can be meaningfully applied to a reasonably small area.

With this in view a macro landslide hazard zonation mapping was carried out in a part of the area where regional hazard zonation was previously carried out considering a larger area (Figure 1). The techniques used earlier by Sarkar and Gupta (2005) differ from the present methodology adopted using the landslide hazard evaluation factor rating technique of Anbalagan (1992). The technique used in this study is different in weight assignment to the factors and nature of factors for which more field studies were carried out. The result of the macro hazard zonation was compared with the previous regional zonation maps.

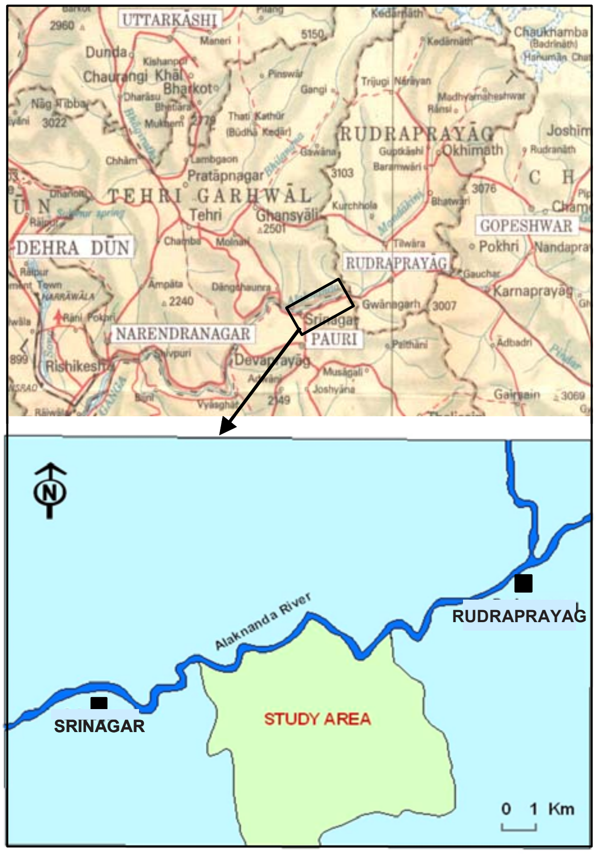

Figure 1 Study area

1 Previous Work

In the earlier study two regional zonation techniques were developed and applied to Srinagar-Rudraprayag area of Garhwal Himalaya. The zonation mapping was carried out on 1:50,000 scale with the help of aerial photo interpretation, field study and topographic maps. The details of these techniques and the results achieved are given in the paper by Sarkar and Gupta (2005). However, a brief summary of the earlier work is reported here.

The parameters considered for these techniques were slope, lithology, structure, land use, drainage density and relative relief. In one of the techniques named as Subjective Regional Zonation (SRZ) technique, initial weights called landslide susceptibility rating (LSR) were assigned to the parameters depending on their relative influence in slope instability as assessed from the field observations. The LSRs of these parameters were chosen in such a way that their sum equals 100. The maximum LSR was assigned to the slope followed by lithology, major fault, land use, relative relief and drainage density, respectively. The rating called landslide susceptibility index (LSI) for a class of a parameter was derived from the LSR and the normalised landslide density (NDLS), which is the ratio of landslide density of the class to the total landslide density of all the classes of the parameter.

$$LSI = NDLS \times LSR$$

For data integration the area was divided into 500 m × 500 m cells. Then, the integrated ratings, named as landslide potential scores, for each cell were determined by adding the LSIs of all the parameters. These landslide potential scores were contoured and the area was classified into five hazard classes at suitable class boundaries to produce the SRZ map of the area (Figure 2).

To reduce the subjectivity in the weight assignment, another technique named as Objective Regional Zonation (ORZ) technique was developed. In this technique no initial weights were assigned to the parameters, instead the ratings for the parameter classes called landslide susceptibility grade (LSG) were directly

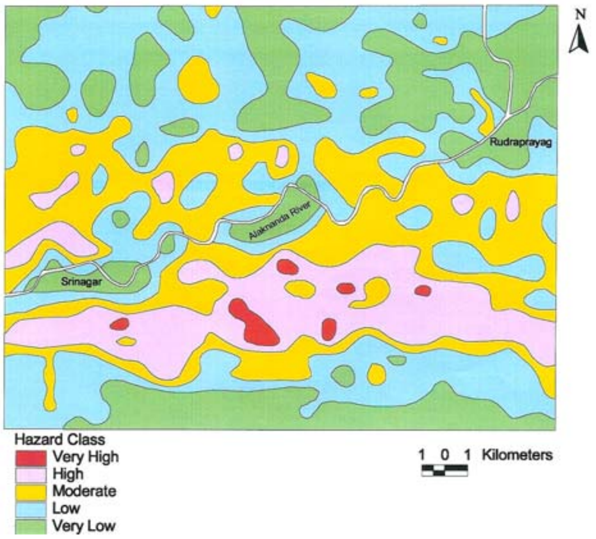

Figure 2 SRZ map using subjective rating technique

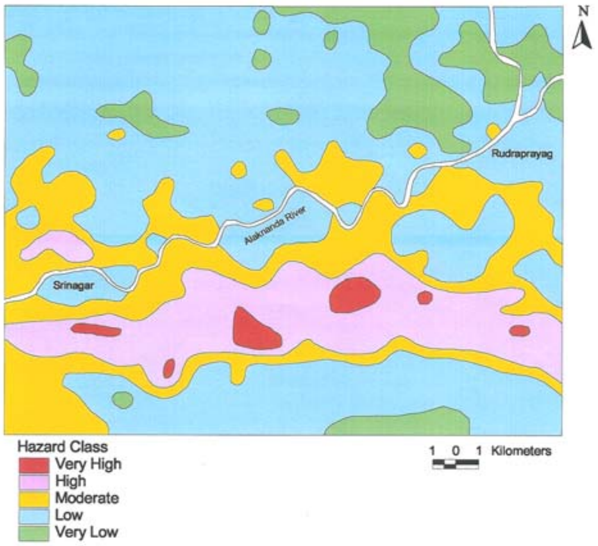

Figure 3 ORZ map using objective rating technique

derived from the frequency distribution of existing landslides in each parameter class. The LSG of class x belonging to parameter y is computed from the number of the cells of class x having landslides (NCL) and the total number of the cells with class x (NC).

$$LSG\ (x,y) = NCL(x,y)/NC\ (x,y)$$

The integrated landslide potential scores obtained for each cell were then classified into five classes of hazards by interpreting the frequency distribution of landslide potential scores. For this the scores were plotted against their frequency and the boundaries of the zonation class were selected in such a way that these coincide with significant change in gradient of the frequency curve. After contouring these scores the zonation map was prepared by classifying the contours at hazard class boundaries to generate the ORZ map of the area (Figure 3).

The results of these two techniques were validated on the basis of landslide density, which is the ratio of the number of landslides to the area of the hazard class (Table 1). For both the maps, landslide density increases as the hazard class increases. This validates the zonationa maps since the zones of higher hazard coincide with the areas of larger landslide concentration. Further, the separation between the classes as shown by the landslide density was quite significant particularly for ORZ map. Both the hazard zonation maps showed a similar zonation trend particularly for high hazard zones. However, there were some disagreements in low and very low hazard classes, which might be attributed to the differences in weight assignment and class boundaries.

Table 1 Landslide density of the hazard classes for SRZ and ORZ maps

Method	Hazard class	Area (km^2)	Number of landslides	Landslide density
SRZ	Very Low	129.25	17	0.13
	Low	131.50	20	0.15
	Moderate	111.75	47	0.42
	High	63.50	44	0.69
	Very High	8.50	11	1.29
ORZ	Very Low	54.25	4	0.07
	Low	233	43	0.18
	Moderate	87	33	0.38
	High	58	45	0.78
	Very High	11.75	14	1.19

2 Study Area

There is always a need for a more

refinement in landslide hazard zonation maps after the broad areas of landslide hazards are delineated. Such study should aim to assess the area with more field investigations so that more details of the parameter can be incorporated, which is difficult to obtain when a very large area is considered. Hence, from the two zonation maps prepared earlier, a small area of interest was selected to carry out macro landslide hazard zonation mapping (Figure 1). The area selected shows considerable variation in hazard classes and includes the high and very high hazard zones already identified by the previous methods. The area lies to the south of the Alaknanda River between 30° 10’ ~ 30° 16’ N and 78° 49' ~ 78° 57' E. The study covers an area of about 80 km^2.

3 Methodology

The technique used for macro zonation mapping is the Landslide Hazard Evaluation Factor (LHEF) rating scheme of Anbalagan (1992). This technique has been adopted as Indian Standard Code [IS 14496 (part 2): 1998]. The LHEF scheme uses the facet concept as the map unit for data collection. The facets, defined by the topographical boundaries and the major break in slope, facilitate easy identification of the slopes under consideration.

In this scheme, the factors considered are lithology, structure, slope, relative relief, land use and surface water condition. These factors are mostly similar to the factors considered in the previous methods. However, some of these differ in their nature and/or categories. In the lithology factor a correction factor, accounted for degree of weathering of rocks, has been incorporated. Also, the nature of soil, which has a considerable significance in inducing landslide, has been included in the lithology. The stability of a slope is greatly influenced by the disposition of the structural discontinuities, such as joints, beddings, foliation planes, in relation to slope. The chances of failure enhance as the discontinuity, or the line of intersection of two discontinuities, tends to be parallel to the slope. Where the dip of the discontinuity or plunge of the line of intersection of two discontinuities increases, the chances of failure increase, because the angle of friction for the discontinuity surface may be reached. Hence, in this technique, three types of relationships of structural discontinuities with slope are considered. In case of soil slope, the depth of soil cover is considered under the structural parameter. The evaluation of behaviour of hydrological condition on hill slope is not possible over large areas. However, the nature of surface indication of the behaviour of sub-surface water provides valuable information on the stability of hill slopes for hazard mapping purposes. Surface indication of water, such as flowing, dripping, wet, damp and dry is considered under this factor.

Ratings for different categories of factors in the above method are assigned on the basis of their estimated significance in causing instability. Then, the total estimated hazards are calculated facet wise, by adding the ratings of the categories of the factors present. The total estimated hazards indicate the degree of instability and are classified into five classes of range to define the landslide hazards. For the rating scheme and the details of the methodology the paper by Anbalagan (1992) may be referred.

4 Macro Landslide Hazard Zonation Using LHEF Rating Scheme

First of all, a facet map of the study area was prepared with natural topographic boundaries (Figure 4). The topographic boundaries are essentially the hill ridges, spurs, streams and major slope breaks. While preparing the facet map, the slope aspect was also considered. The area was divided into 121 facets and each facet was referred by a number. For all these facets, the data of each factor considered were collected.

4.1 Factor maps and data collection

The thematic maps prepared in the earlier study (Sarkar and Gupta 2005) were used along with the data from detailed field investigations for input data collection. The lithology, slope,

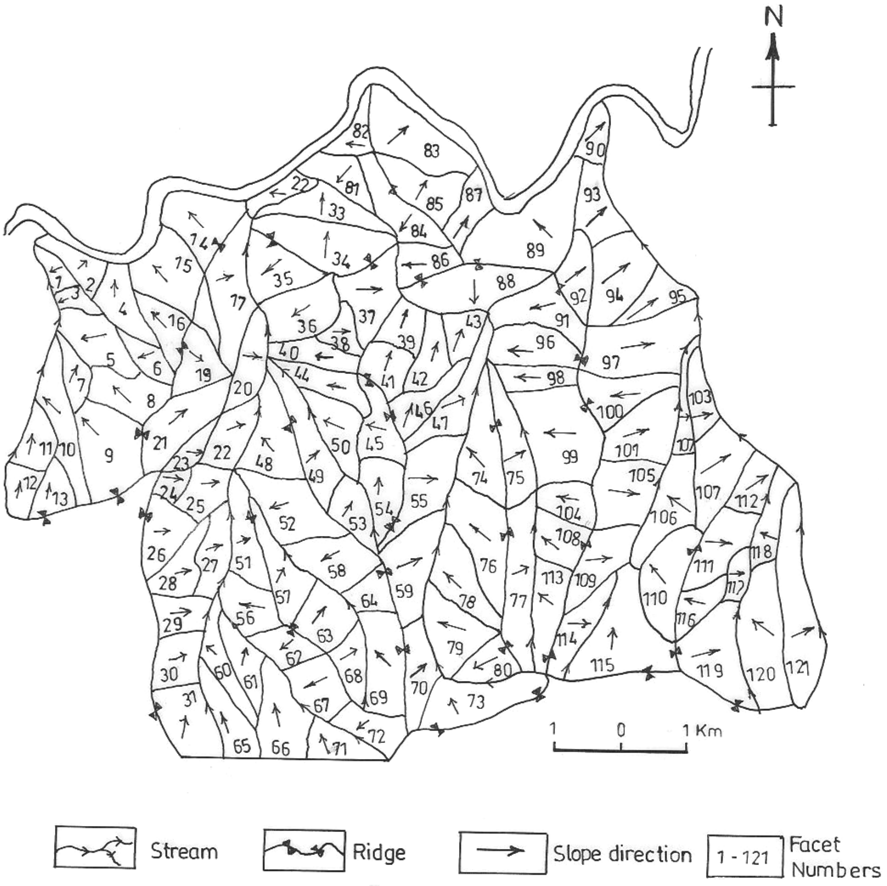

Figure 4 Facet map of the study area

relative relief and land use data for the present study area were generated from these maps. The degree of weathering was assessed from the field and was classified into high, moderate, low and nil. The structural data, i.e., the disposition of discontinuities on the slope and attitudes of beds and joints were determined in the field and the structural map was prepared which shows the prominent bedding and joint directions along with the dip amount in each facet. To establish the relation between slope face and discontinuity planes, these structural data were analysed with the slope data. The values of three types of discontinuity and slope relation as given in the methodology were thus determined. The surface indications of damp, wet, dripping and flowing conditions were judged in the field and data were accordingly collected.

4.2 Hazard zonation map

After collecting all these data, the numerical weights, following the rating scheme, were assigned to each facet according to the categories of the factors present in the facet. Finally the weights were added to obtain a total estimated hazards (TEHD) for each facet. It was found that the minimum TEHD is 3.4 for the facet number 60 while the maximum TEHD is 8.1 for the facet number 47. The landslide hazard zonation map was prepared by ranking the TEHD of each facet into five classes of hazards as given in the methodology (Anbalagan 1992). The zonation map is shown in the figure 5. It was found that out of 121 facets, 49 facets were in moderate hazard, 31 in high hazard, 24 in low hazard, 11 in very high hazard and 5 in very low hazard class. A percent area calculation of hazard zones revealed 13.36 % in very high, 25.36 % in high, 35.41 % in moderate, 20.05 % in low and 5.28 % in very low hazard class. A visual observation of this map reveals that the very high hazard zones comprising of few facets are in the central portion of the area. These zones are surrounded by high hazard zones. The extreme south of the map has facets of low and very low hazard classes. Overall, it indicates that the middle part is more susceptible to landslide activities than the southern and northern parts. This map is named as Macro Hazard Zonation (MHZ) map for further reference in the text.

4.3 Map validation

The MHZ map thus prepared has to be tested for its validity by means of presence of existing landslides. For this the landslide map for this area was prepared from the earlier landslide map where landslides were identified from aerial photo of 1:25,000 scale along with limited field checks. The landslide distribution map is shown by figure 6. Then landside density for each facet, which is the ratio of the number of landslides to area of the facet, was computed. The values of landslide density in each hazard class are given in table 2. From this table it can be observed that the landslide density for very high hazard class is 1.34 and that for the very low hazard is 0. It is also noted that not only the trend of landslide density values shows an increasing trend as the degree of hazard class increases, but also there exist reasonably good separations among the classes particularly very high and high hazard classes from the rest of the hazard classes. Thus, the zonation map is validated. When the landslide densities in each hazard class of the MHZ, SRZ and ORZ maps from table 1 and table 2 were compared, it can be seen that the prediction results of MHZ are marginally better than those of the other two maps.

Furthermore, success rate curve analysis was also carried out to strengthen the MHZ map validation. For this cumulative % landslide number and cumulative % hazard class was plotted (Figure 7). The curve shows that 20 % of the total area towards higher hazard class has 30 % landslides and 50 % of the total area towards higher hazard class explains 75 % landslides. Hence, the degree of predictability and the zonation map is validated also by the success rate curve.

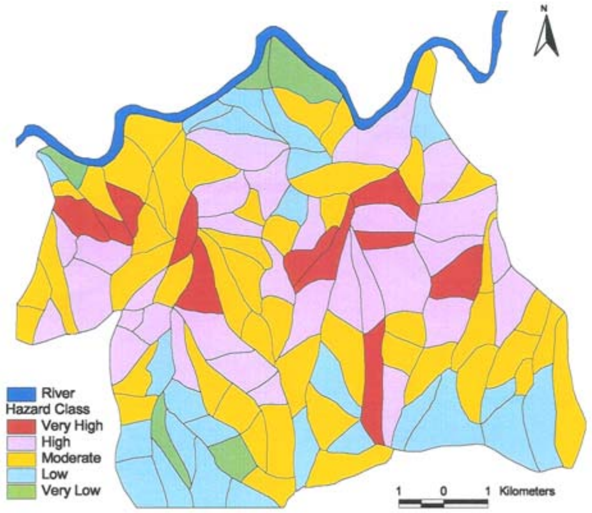

Figure 5 MHZ map using LHEF rating technique

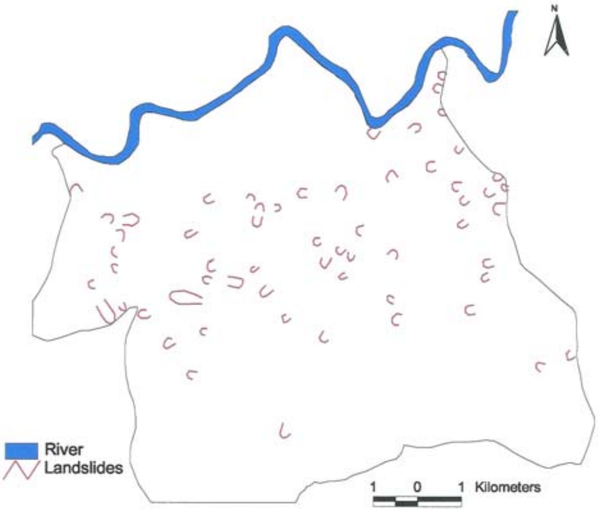

Figure 6 Landslide distribution map

Table 2 Landslide density of the hazard classes for MHZ map

Hazard class	Area (km^2)	Number of landslides	Landslide density
Very Low	4.54	0	0.00
Low	15.64	2	0.13
Moderate	27.62	20	0.72
High	19.78	23	1.16
Very High	10.42	14	1.34

5 Comparative Analysis of Landslide Hazard Zonation Maps

A comparative study on zonation maps, prepared by the earlier techniques and the present methodology, was carried out to estimate the degree of similarity in them. In order to compare the zonations in the SRZ and ORZ maps with that of the MHZ map, the area considered in the MHZ map was selected in other two maps and were enlarged to the same output scale as the MHZ map. These maps were named as SRZ1 (Figure 8) and ORZ1 (Figure 9) maps. Then, the TEHD values of the MHZ map were collected in a grid map with 500 × 500 m cell size. These values were contoured and classified using the hazard class boundaries of the same MHZ map to obtain a zonation map named as MHZ1 map (Figure 10). This is the same map as MHZ, only due to interpolation for contouring shapes of zones were changed a little. This exercise was done to bring all the maps in a same output mode. A glance at these three zonation maps reveals broadly similar trends for zonation. However, the MHZ1 map has more detailed zonation than the SRZ1 and ORZ1 maps.

A quantitative comparison of the maps can also be made as used by Sarkar & Gupta (2005). For this number of cell difference (NCD) value, which is the number of cells differing in hazard classes, was determined. It was obtained by determining the number of cells that are deviating by one or more hazard classes. Since there are five hazard classes the maximum hazard class difference for a cell is of four classes. For example for a particular cell, the hazard class difference of 1 means that if the cell lies in the moderate hazard class in one map then it will lie either in low or in high hazard class in the other map. It is to be noted that an NCD value of 1 should not be considered as significant difference between the maps because it is quite likely that the adjacent classes in two maps overlap.

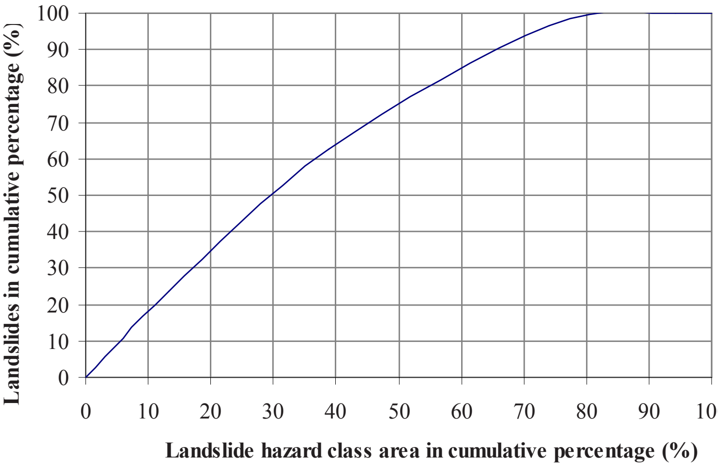

Figure 7 Success rate curve for the MHZ map

Table 3 Comparison of cells for the zonation maps

Hazard class difference	NCD for SRZ1 – ORZ1	NCD for ORZ1 – MHZ1	NCD for SRZ1 – MHZ1
1	142	155	166
2	20	35	37
3	1	3	3
4	0	0	1

The NCD values of the three pairs of maps, i.e., SRZ1 – ORZ1, SRZ1 – MHZ1 and ORZ1 – MHZ1 maps were determined, and they are given in table 3. The data for SRZ1 – ORZ1 maps show that out of 344 cells, 163 cells (47.38 %) differ in hazard classes. In this case it was observed that the majority of cells, i.e., 142 cells (41.28 %) are differing in one hazard class implying that good agreement exists between these maps. When ORZ1 – MHZ1 maps were compared it was found that out of the 193 differing cells (56.1 %), 155 cells (45.06 %) are differing in one hazard class. Hence, there exists a close agreement between these maps, but comparatively less than that in the previous pairs. The NCD values for SRZ1 – MHZ1 maps revealed that 207 cells (60.17 %) differ totally and out of these 166 cells (48.26 %) are differing in one class. In this case also the degree of agreement is quite reasonable but is lower than that in the previous two cases.

Since in all the cases, the majority of NCD values differ only in one hazard class, it can be said that all the maps show broadly a good agreement with each other. However, the results of ORZ1 – MHZ1 are slightly more comparable than those of the SRZ1 – MHZ1. Since the same set of factors and categories were used in both SRZ1 and ORZ1 maps, the disagreement between the two can be attributed to the different modes of defining the ratings and the class boundaries of hazard zones. The larger disagreement between SRZ1 and MHZ1 and between ORZ1 and MHZ1 is because of the additional difference in the choice of factors and their categories.

6 Conclusions

Landslide hazard zonation maps are of immense importance in hilly areas to assess the potentiality of landslide occurrence. This is one of the important aspects of the disaster management plan of any hill state. The methodology for landslide hazard zonation is not standardized so far, and different techniques vary in selection of parameters and their importance in inducing slope instability. With the help of available information about the geology and topography of the area and using remote sensing data, considerable estimation of

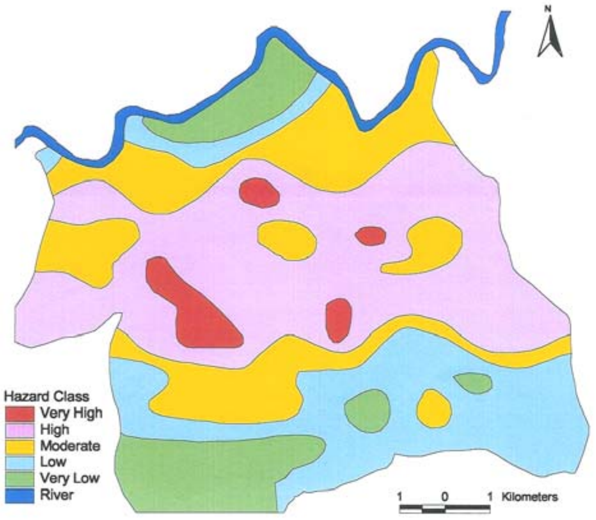

Figure 8 SRZ1 map of the area

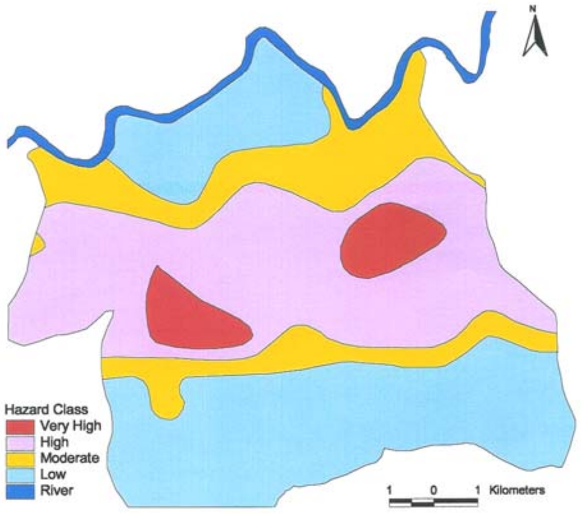

Figure 9 ORZ1 map of the area

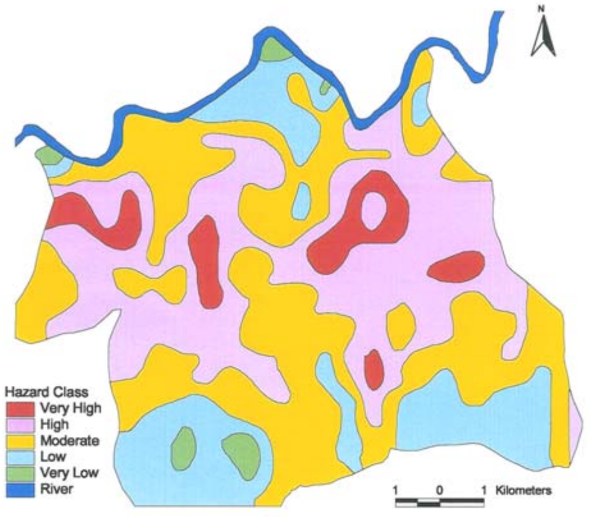

Figure 10 MHZ1 map of the area

landslide hazards can be obtained to identify the broad trends of hazard zonation. However, by considering more field based parameters a better assessment of landslide potential zones can be obtained. As in the present study the application of a macro hazard zonation technique has resulted in slightly more refined zonation of hazard classes. It should be noted here that the zones of very high and high hazard classes, which are without any landslides, indicate the potential zones of slope instability.

The comparative study between the previously prepared zonation maps with the present zonation map has shown that considerable amount of information about the hazard zones of macro hazard zonation (MHZ) map is available in the earlier regional zonation maps (SRZ and ORZ maps). However, using the LHEF rating technique for macro hazard zonation more refined zonation is obtained, albeit at the cost of detailed field study. It is also observed that in terms of landslide density MHZ map has predicted the landslide hazard little better than the other two techniques. This is obvious as the MHZ method takes into account more field parameters than the other two regional zonation techniques.

Presently there are many techniques available for landslide hazard zonation and susceptibility mapping. It may be concluded that the selection of method should be based on the scale of mapping, data availability and nature of hazard assessment.

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