Landslide hazard zonation using the relative effect method

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Abstract: A landslide hazard zonation map depicts division of the land surface into zones of varying degrees of stability based on estimated significance factors which are important in a slope area. Effective parameters for landslides are determined based on a quantitative approach by calculating the ratio of landslide percentage in a geological unit and the unit coverage percentage in the slope area. Then, the priority of each parameter is determined. There are different methods of landslide hazard zonation with some advantages and disadvantages. The authors suggest the Relative Effect Method (R.E.M), which is a statistical method using GIS software for landslide hazard zonation. This method determines the relative effect (RE) of each unit, such as surface geology, slope morphometry, climatic conditions, land use and land cover by calculating the ratio of the unit portion in coverage and landslide. The function that is used in this method is logarithmic. The advantages of the logarithmic function are in domain determination for output data and equality for plus and minus domains of calculated RE's.

The landslide potential and landslide hazard zonation in Bormahan basin were determined. The Bormahan basin, which has many landslides, is located in Binalood mountainous terrain in the northeast of Iran. Slope stability analysis was used to evaluate the landslide hazard zonation map in Bormahan basin.

Résumé: Une carte de zonation de risque d'éboulement dépeint la division de la surface de terre dans des zones des degrés variables de stabilité basés sur les facteurs estimés de signification qui sont importants dans un secteur de pente. Des paramètres efficaces pour des éboulements sont déterminés ont basé sur une approche quantitative en calculant le rapport du pourcentage d'éboulement dans une unité géologique et du pourcentage d'assurance d'unité dans le secteur de pente. Puis, la priorité de chaque paramètre est déterminée. Il y a différentes méthodes de zonation de risque d'éboulement avec quelques avantages et inconvénients. Les auteurs suggèrent la méthode relative d'effet (R.E.M), qui est une méthode statistique en utilisant le logiciel de GIs pour la zonation de risque d'éboulement. Cette méthode détermine l'effet relatif (RE) de chaque unité, telle que la géologie extérieure, les conditions morphometry et climatiques de pente, l'utilisation de la terre et la couverture de terre en calculant le rapport de la partie d'unité dans l'assurance et l'éboulement. La fonction qui est employée dans cette méthode est logarithmique. Les avantages de la fonction logarithmique sont dans la détermination de domaine pour des données de rendement et l'égalité pour positif et sans des domaines de calculé RE.

La zonation de potentiel d'éboulement et de risque d'éboulement en bassin de Bormahan ont été déterminées. Le bassin de Bormahan, qui a beaucoup d'éboulements, est situé dans le terrain montagneux de Binalood dans le nord-est de l'Iran. L'analyse de stabilité de pente a été employée pour évaluer la carte de zonation de risque d'éboulement en bassin de Bormahan.

Keywords: landslide, hazard zonation**,** relative effect method, bormahan basin, surface geology.

INTRODUCTION

Landslides are among the major natural hazards in the world. Mountainous terrains are characterized by steep slopes, fractured and folded and high relative relief weathered rocks. In hilly terrains of Iran, such as Bormahan catchment area in Binaloud mountains region, NE Iran, landslides are a major and widely spread natural hazards.

Determining the extent of landslide hazard requires identifying those areas which could be affected by a damaging landslide and assessing the probability of the landslide occurring within some time period. Landslide hazard zonation has been actively pursued for the last two decades and various methodologies are still being refined. Several attempts have been made to estimate the degree of landslide susceptibility and provided some procedures for landslide prediction modeling and quantitative hazard zonation (e.g., Carrara, 1983; Carrara et al., 1991; Chung and Leclerc, 1994; Djamaluddin, 1994; Chung et al. 1995; Chung and Fabbri, 1999; Guzzetti et al, 1999; Zaitchik and van Es, 2003). Some of these studies dealing in methodology only suggest the need to implement them in a GIS environment, but actual implementation has not been carried out (e.g., Gupta and Joshi, 1990; Anbalagan, 1992; Pachauri and Pant, 1992; Jade and Sarkar, 1993; Thigale and Khandge, 1995).

Data gathering and data access are two important aspects in the case of devising GIS based methodologies for landslide susceptibility mapping. Collection of data in digital format needs to be systematized to provide ease and speed in database development. Still there are unfortunate deficiencies in the existing prediction models. However, as in any predictions, the methods of prediction have no scientific significance without measuring the validity of the prediction results. In the present paper, the methodology used to prepare hazard maps is called a '**R**elative Effect' method which is described in detail in Section 4 of this paper.

PHYSICAL FEATURES

The Bormahan catchment area is located in the south side of the Binaloud mountainous region. The Binaloud mountainous region has northwest-southeast alignment and is a part of Alborz zone in the northeast of Iran. The Bormahan catchment is a small catchment which covers an area of about 20.96 km^2 from latitude 36º 33' to 36° 38' N and from longitude 58° 37' to 58° 40' E. In spite of the catchment size, there are great variations in the slopes. The mean annual precipitation according to the last 28 years statistical period is 365 mm which mostly falls as snow. A wet period in this catchment begins from middle of October to end of May. The mean annual temperature is about 5 degrees centigrade.

GEOLOGY OF THE STUDY AREA

It is recognized that the surface geology has a major control on the development of slope instability. The catchment area is underlain by Quaternary deposits and rock units of Jurassic age. More than 84% of the catchment area is covered by gray marl interbedded with light gray medium bedded limestone (Dalichay formation). A generalized geological map of the catchment site is shown in Figure1. This map shows the outcrops of the geological bedrock units and the various types of surficial deposits. They consist of the following stratigraphic formations.

Quaternary deposits

Quaternary deposits (Q) are mainly represented by alluvial (Qal) and debris flow materials. The alluvium is composed of clay, silt, and rounded to subrounded coarse grained materials, mixed with large angular rock blocks. Part of the area is covered by terrace deposits exposed at varying elevations. The debris flow deposits occupy some areas in the foothills of the mountain slopes. These deposits are represented by clay sandy and clay with gravel.

Dalichi formation

The Dalichi formation (Jdm) consists of light bluish grey to whitish grey weathered marl interbedded with light grey medium bedded limestone. This formation is moderately resistant to weathering and forms a distinct unit in the region with badland topography. In many parts of the area, especially in the middle and southern parts of the catchment, the ground surface is covered by overlying residual soil derived from the underlying marl (Figure 1).

Lar formation

The Lar formation (Jl) comprises mainly light grey to brown, thick to medium-bedded limestone. The upper part of the catchment area is characterized by the presence of carbonate walls (Jl) affected by a network of joints that commonly causes rock falls (Figure 1).

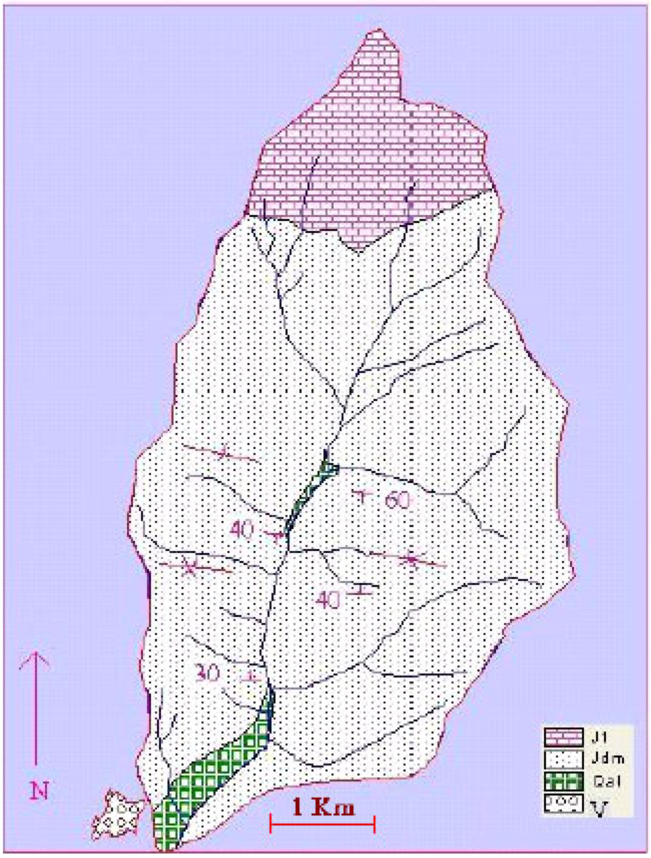

Figure 1. A generalized geological map of the Bormahan catchment (for an explanation of the key see the text)

GEOMORPHOLOGY

The region under study is mainly mountainous and is drained by the Bormahan River. The rock types described above, vary in strength from hard to soft rocks. Hard rocks consist of layered and massive limestone. Soft rocks are mainly marl and mudstone and siltstone. However, the occurrence of steep slopes in the hard rocks and gentle slopes in the soft rocks forms the morphology of the area (Figure 2). Figure 2 shows that the steep slopes are mostly seen in the north part of the area. Most of the area in the middle and south part of the catchment area has moderate slopes. The older terraces and the fan deposits generally have low to very low slopes. The morphological and structural setting of the area is determined by the superposition of the late alpine Orogeny. The morphology of the study area is strongly controlled by feature-forming Lar carbonate rocks. Usually the Dalichi formation is a slightly weathered, valley-forming rock unit with badland topography containing small ridges and hills.

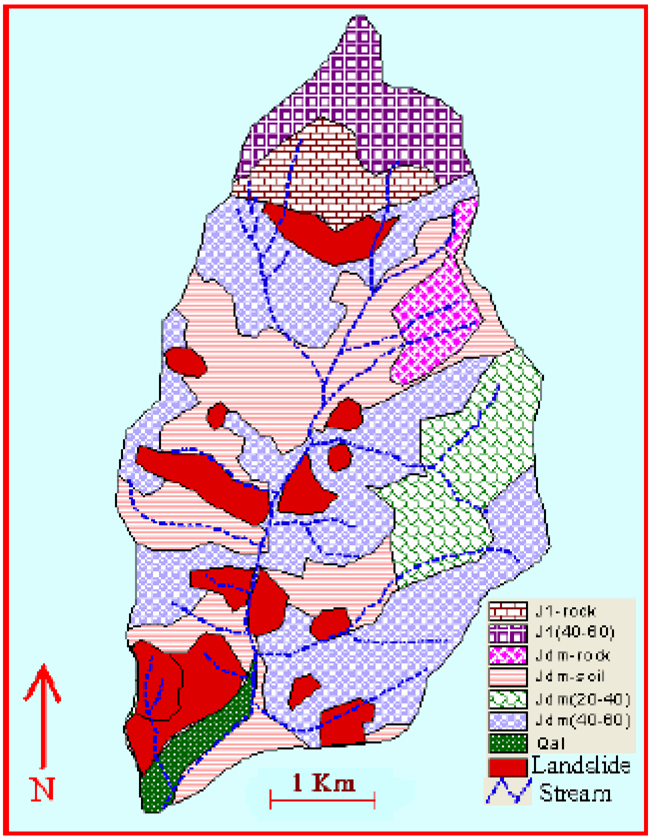

Figure 2. Slope steepness and geomorphological map of the Bormahan catchment area

METHODOLOGY

In this study, the relative effect of a parameter as a determining factor of slope instability is quantitatively determined by introducing a 'Relative Effect' function (RE). Given an area of study that contains a certain number of landslides, various thematic maps (geology, slope, soil thickness, soil texture, soil permeability, plant and forest) are prepared. Each map is covered individually by the landslide map. For every unit, the ratio of the unit area, *a*, to the total area of the study, *A*, and the ratio of the landslide area in the unit, *sld*, to the area of total landslide, *SLD*, are calculated;

$$AR = a/A \tag{1}$$

$$SR = sld/SLD \tag{2}$$

The relative effect function is then defined as:

$$RE = Log(\frac{SR}{AR} + \varepsilon), \tag{3}$$

where epsilon is a very small positive value near zero.

There are three cases for estimating a relative effect of each unit depending on its *RE*.

1- *RE* is less than zero when the share of a unit in landsliding is less than its share in area coverage. This means that it has an effect of decreasing landslide risk (negative effect).
2- *RE* is greater than zero when the share of a unit in landsliding is greater than its share in area coverage. This means that it has an effect of increasing landslide risk (positive effect).
3- *RE* is zero when the share of a unit in landsliding is equal to its share in area coverage. This means that it has no effect of decreasing or increasing landslide risk.

The advantage of using logarithmic function is that the positive effect and negative effect are quantitively equal.

Then using a GIS, all maps are integrated and an evaluation of landslide risk is determined by algebraic summation of *RE*s, multiplied by alpha,

$$\text{Slide risk} = (\Sigma RE \times \alpha), \tag{4}$$

Alpha is zero if there is no risk of landslide (e.g., slopes less than 5 degrees), otherwise the value of alpha is 1.

The higher positive values of slide risk indicate a higher risk of landslide and the higher minus values of slide risk indicate a lower risk of landslide.

We can also judge the effectiveness of an unit by simple summation of absolute values of *RE*s. Units with higher values of summation of absolute *RE*s, will be more effective and more important in landslide management and hazard mitigation than those with lower values.

LANDSLIDE HAZARD MAPPING

Interpretation of future landslide occurrence needs an understanding of conditions and processes controlling landslides in the study area. Three physical factors such as past history, slope steepness, and bedrock are the minimum components necessary to assess landslide hazard zonation. It is also useful to add a hydrologic factor to reflect the important role which ground water often plays in the occurrence of landslides. An indication of this factor is usually obtained indirectly by looking at vegetation, slope orientation, or precipitation zones. All of these factors are capable of being mapped. Specific combinations of these factors are associated with differing degrees of landslide hazards. The identification of the extension of these combinations over the area being assessed results in a landslide hazard map.

The scope of this study was to generate landslide hazard zonation maps that can be utilized to identify the potential landslide hazard in the mountainous area. A landslide zonation map was prepared based on *RE*s of the geological units, soil type, soil thickness, plant coverage, slope (Tables 1 to 5).

Table 1. Percentage of geological units coverage and related slide in the catchment area.

Type	% of coverage	% of slide	R.E
J1	12.17	0.65	-1.30
Jdm	85.22	98.89	0.06
Qal	2.61	0.46	-0.74
Sum(abs)	100.0	100.0	2.11

Table 2. Percentage of soil types coverage and related slide in the catchment area.

Type	% of coverage	% of slide	R.E
Clay	6.98	2.76	-0.40
Loam	29.32	35.86	0.09
Alluvial	2.64	0.84	-0.49
Non soil	15.56	2.89	-0.72
Silty Clay	42.70	37.48	-0.06
Sandy Loam	2.80	20.17	0.86
Sum(abs)	100.0	100.0	2.61

Table 3. Percentage of soil thickness coverage and related slide in the catchment area.

Type	% of coverage	% of slide	R.E
Non soil	15.39	2.99	-0.72
Alluvial	2.85	1.10	-0.41
<20cm	35.07	66.95	0.28
20-50cm	29.26	21.39	-0.14
50-90cm	17.43	7.57	-0.37
Sum(abs)	100.0	100.0	1.91

Table 4. Percentage of plant types coverage and related slide in the catchment area.

Type	% of coverage	% of slide	R.E
1:(Achinops - Anchusa)	10.57	35.76	0.53
2: (Cushinplant - Agropyron)	22.66	35.02	0.19
3: (Cushin plant - Artemisia)	2.16	1.71	-0.10
4: (Hulthemia - cushin plant)	8.03	1.97	-0.61
5: (Hulthemia - Artemisia)	2.95	1.29	-0.36
6: (Cushin plant)	53.64	24.25	-0.34
sum(abs)	100.0	100.0	2.13

Table 5. Percentage of slope classes and related slide in the catchment area.

Type	% of coverage	% of slide	R.E
1 (0-18)	32.22	20.21	-0.20
2 (18-33)	52.13	56.61	0.06
3 (33-56)	11.77	17.26	0.17
4 (56-78)	3.88	2.92	-0.12
sum(abs)	100.0	100.0	0.55

We evaluated the slide risk in hte Bormahan cachment area, and Figure 3 shows the landslide hazard zonation map. In this Figure, there are four classes for landslide risk where in Class 1 there is no risk, and the risk increases from Classes 2 to 4. Table 6 shows the percentage area of each class.

Table 6. Percentage area of risk classes in the catchment area

Class	Area (m^2)	Area percentage from Basin
1	16907333	82.67
2	1668957	8.16
3	1557380	7.61
4	315078.3	1.54
Sum	20448748	100.0

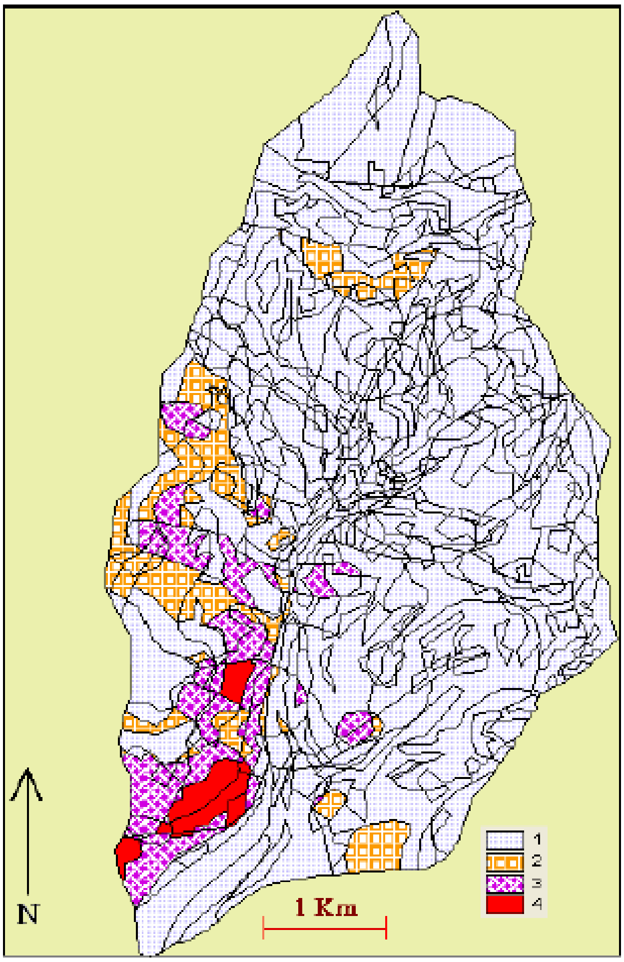

Figure 3. The landslide hazard zonation map. Class 1 has no risk, and the landslide risk is increased from class 2 to 4.

CONCLUSIONS

The the Bormahan catchment area is underlain by Quaternary deposits and rock units of Jurassic age. More than 84% of the catchment area is covered by gray marl interbedded with light gray medium bedded limeston. Twelve landslides have been occurred in the area. In this study, we used the relative effect of a parameter as a determining factor of slope instability that is quantitatively determined by introducing a relative effect function. A landslide zonation map with four classes of risk was prepared based on the relative effect of the geological units, soil type, soil thickness, plant coverage, and slope.

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