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Landslide hazard zonation of Khorshrostam area, Iran

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Abstract: Landslide hazard zonation is a method to evaluate the risk where the potential hazard present. The causes of such hazards in an area can usually be identified and predicted. The results of such investigation are normally illustrated as a landslide hazard zonation map where zones of similar potential to landslide can be shown.

Khorshrostam is one of the area most prone to landslide in Iran where more than 13% of its surface area is affected by landslide activity. The landslide damages in the region include the disruption of many villages, farmlands, roads and also the erosion of land surface and consequently increases the rate of sedimentation in the flowing water into the reservoir of the Manjil-dam.

The method for landslide zonation used in this area consists of simple grid unit which includes a combination of factors indicating lithology, slope, tectonic, land use and ground water. The rate of landslide distribution for each factor regarding the grid unit is identified in the form of surface percentage index, SPI, and according to these values the weighing of the involved factors is arranged. A computer program is written on the bases of fuzzy set to calculate the hazard potential index, HPI, for each unit. The combination for units with similar HPI indicates the hazard susceptibility of that unit which is shown as LHZ map.

INTRODUCTION

Iran is a developing country with complex geology, active seismicity and seasonal rainfall. These factors have great influence on the development of natural hazards such as landslide and other types of ground mass movements. The occurrence of these hazards results in the lost of life and damage to economy. Preparation of landslide hazard zonation map is the first step to assess the degree of hazard and to evaluate it's potential.

Khorshrostam is an area with 1,268 km^2 which is situated to the southern part of Ardebil province in the north west of Iran (see Fig. 1). The area is located between 48°00' to 48°40' east and 37°00' to 37°40' north. The temperature variation is between –9°C to 18°C for winter and summer respectively. The mean annual rainfall is 450 mm and the maximum season of precipitation is between November to May which is coincide with the landslide activity of the area.

The area drains into the Qezel Owzan river system which ends up to the reservoir of Manjil-dam. It has been estimated that more than 14 million tons of sediments and suspended materials are carried from the studied area by the running water into the dam's reservoir annually (Mahdavifar, 1996).

The aim of this paper is to locate and to zone the area prone to landslide and to evaluate the risk of hazards. It is also intended to recognize the most important factors of instabilities in order to delimit or to reduce their effect.

GROUND SLOPES

Ground slope is the main factor in controlling landslide development in an area. It is known that as the slope angle increases the weight and consequently the volume of the effected slope per unit area will increase too. This may finally cause the increment of the driving forces. The slope type of each area has close dependency to the type of the ground and the geological condition of that region (Varnes, 1984).

The slope map of the area is shown on Figure 2. According to the rate of slope angle, three types of slopes are identified. Table 1 indicates distribution percentage of the slopes in the area. It

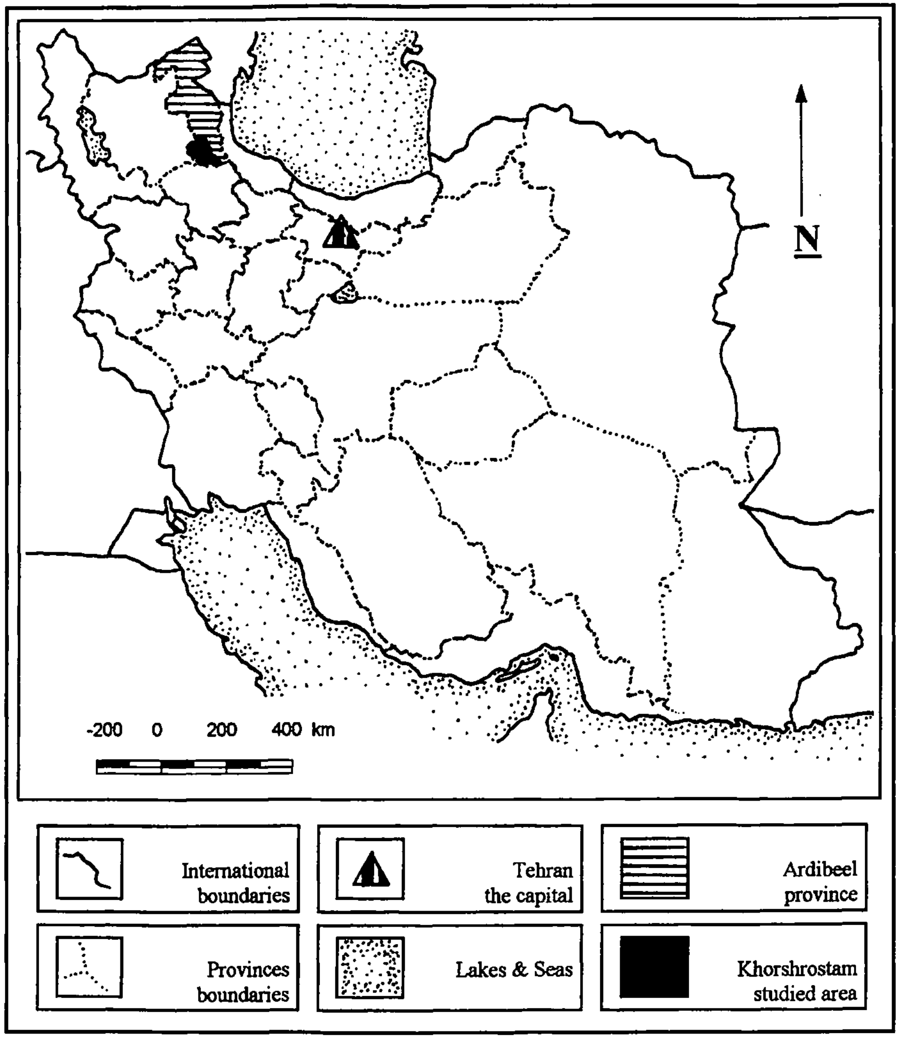

Figure 1. Geographical location map of the Khorshrostam area.

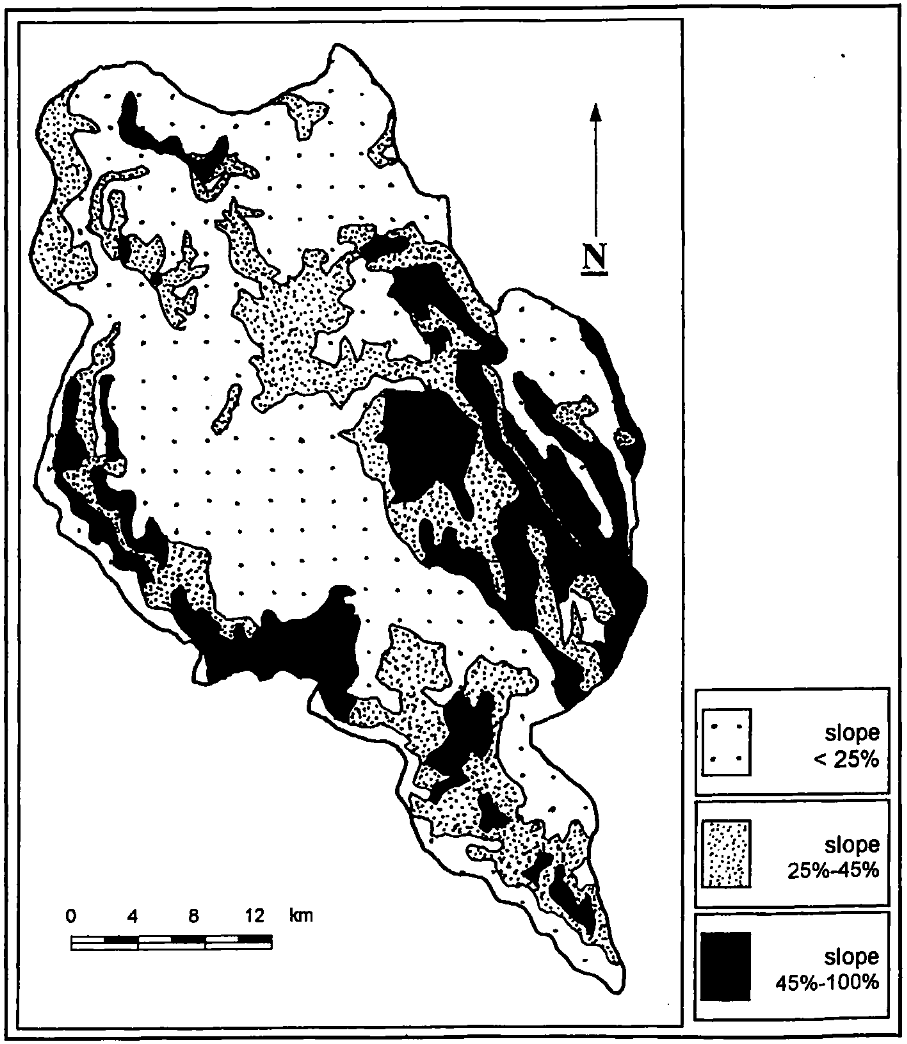

Figure 2. Land-slope map of the Khorshrostam area.

can be noted that most of the area has a slope range of less than 25% and almost one fifth of the area has a slope range of over 45%.

GEOLOGICAL SETTING

The general geological setting of the area is shown on Figure 3. The studied area is located to the west part of Bandar-e-Anzali quadrangle map of the northwest of Alborz mountain. According to Davies (1975), the oldest rock units are limestone, volcanic rocks and sandstone of Carboniferous to Permian which have very limited distribution. The sandstone, shale and conglomerate of Lower Jurassic with a surface distribution of only 2% and limestone of Upper Jurassic with a surface distribution of about 1%. But most of the area is covered by Tertiary rock units with different types of lithology. These units have surface distribution of about 94% and consist of mainly volcanic tuff and lava of Eocene age and marlstone and sandstone of Neogene age. The geological description of the area is summarized in Table 2.

As indicated in the above table about 65% of the area is covered by volcanic rocks mostly of andesitic to rhyolitic tuff and lava, and 21% is covered by red-beds rocks, mainly marlstone and conglomerate. These units are very sensitive to landslide and other types of ground mass movement.

Table 1. Slope range and their distribution in Khorshrostam area.

Slope Range	Slope Angle	Surface Area (km^2)	Distribution %
< 25%	< 14°	672	53%
25%–45%	14°–24°	355	28%
> 45%	> 24°	241	19%

TECTONIC

An overview of tectonic map is illustrated on Figure 4. The figure shows that the area consists of three structural zones which are defines as:

Mountain Uplift: This zone includes the north eastern part of the area and it is a part of Alborz mountains range. The zone consists a number of faults and folds and is elevated by the pre-Alpian orogenic activity. Different types of lithology from Carboniferous to Neogene can be found in this zone.

Elevated Plateau: This zones consists of Paleogene rocks mainly the volcanic lava and tuffs of Eocene. Most of the rocks are altered by the late intrusion of hydrothermal solutions.

Depressions: This zone mainly consists of Neogene Red-beds of marlstone, sandstone and conglomerate which are very susceptible to weathering and erosion.

A number of major and minor faults and folds in the form of synclines and anticlines, are recognized in the area. The longest fault is named Hero-Abad Fault with a length of 150 km. The fault is a strike-slip type and it has a trend of N330°W. Since the beginning of Quaternary no activity has been recorded from any fault in the area.

LANDSLIDE RECORDS

The studied area has a long experience with many types of ground movement. More than 213 cases of landslides are recognized and mapped. According to their size and land involved the ground movements of the area are classified into three categories; single landslide, concentrated landslides, and zoned landslide. Figure 5 shows the distribution of the landslide in the area. About 13% of the land surface is involved with ground movement which indicate that the area is very prone to landslide occurrence.

Table 2. Description of geological units in Khorshrostam area.

Unit	Geological Age	Formation's Names	Lithology	Surface Area %
A	Lower Jurassic	Shemshak F.	slate, shale, & detritic rocks	2 %
B	Upper Jurassic	Lar F.	massive and reef limestone	1 %
C	Paleocene	Fajan F.	conglomerate, sandstone & marlstone.	2 %
D	Late Paleocene	Ziarat F	silty and sandy limestone	6 %
E	Eocene	Karaj F	andesitic tuff, lava and agglomerate	55 %
F	Late Eocene	Post Karaj F	acidic volcanic rocks (rhyolite & trachyte)	10 %
G	Neogene	Red Beds F.	red sandstone, marlstone & conglomerate	21 %
H	Quaternary	Recent Deposit	alluvium and colluvium deposits	1 %

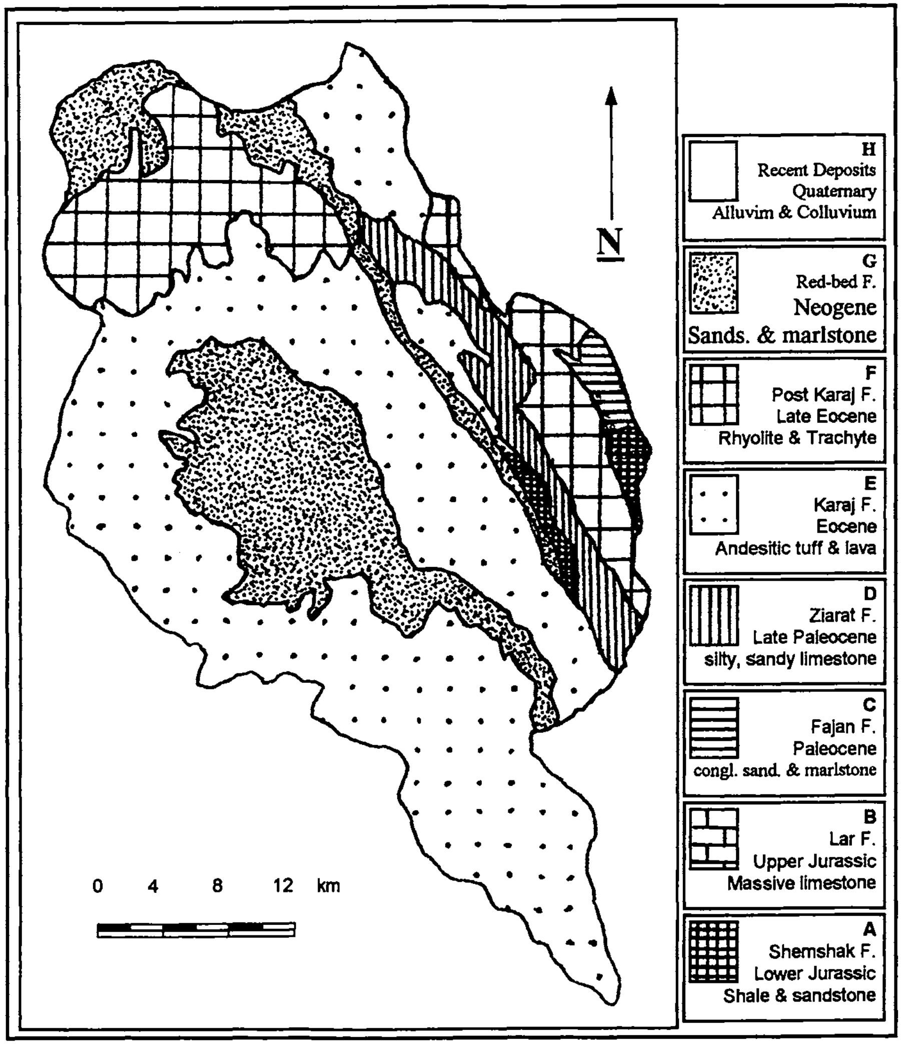

Figure 3. Geological set of the Khorshrostam area. Units B and H are not shown on the map because of their limited distribution.

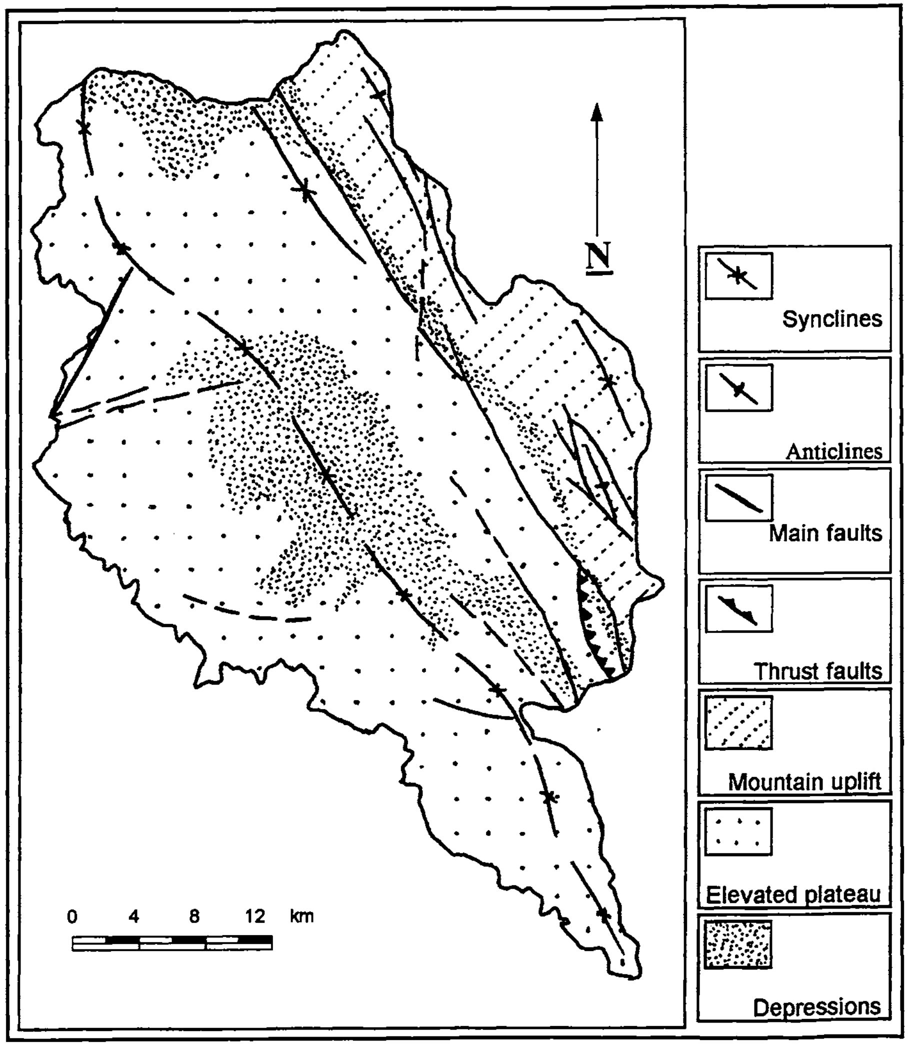

Figure 4. Structural geological map of the Khorshrostam area.

The location of landslides mapped on topography maps (scale 1:50,000) using aerial photographs (scale 1:20,000). Site visits then conducted to confirm and to complete the information obtained from aerial photograph studies, and to identify the exact location of the landslides on the ground surface.

DISTRIBUTION ANALYSIS OF LANDSLIDES

Many factors influence on the occurrence of landslides in the area. These factors are accounted as lithology, tectonics, slope, and land use and rainfall. Because the rate of precipitation is almost equal for the whole region and hence the rainfall effect is similar, therefore its effect was neglected in this consideration. The distribution of landslides in relation to the effecting factors is discussed in this section. To evaluate the rate of landslide distribution with regard to each factor, Surface Percentage Index, SPI, is identified. The surface percentage index can be investigated and calculated for each individual effecting factors separately and the susceptibility of the factor can be defined.

The SPI definition can be written as follows:

$$SPI = \frac{\text{surface area affected by landslide for a defined factor}}{\text{total area of that factor}} \times 100$$

The method used for landslide zonation is a simple grid units in which the whole area was divided into 5071 square units each with a length side of 500 m. Many effecting factors include lithology, tectonic, slope, land use and precipitation are combined to investigate the potential of

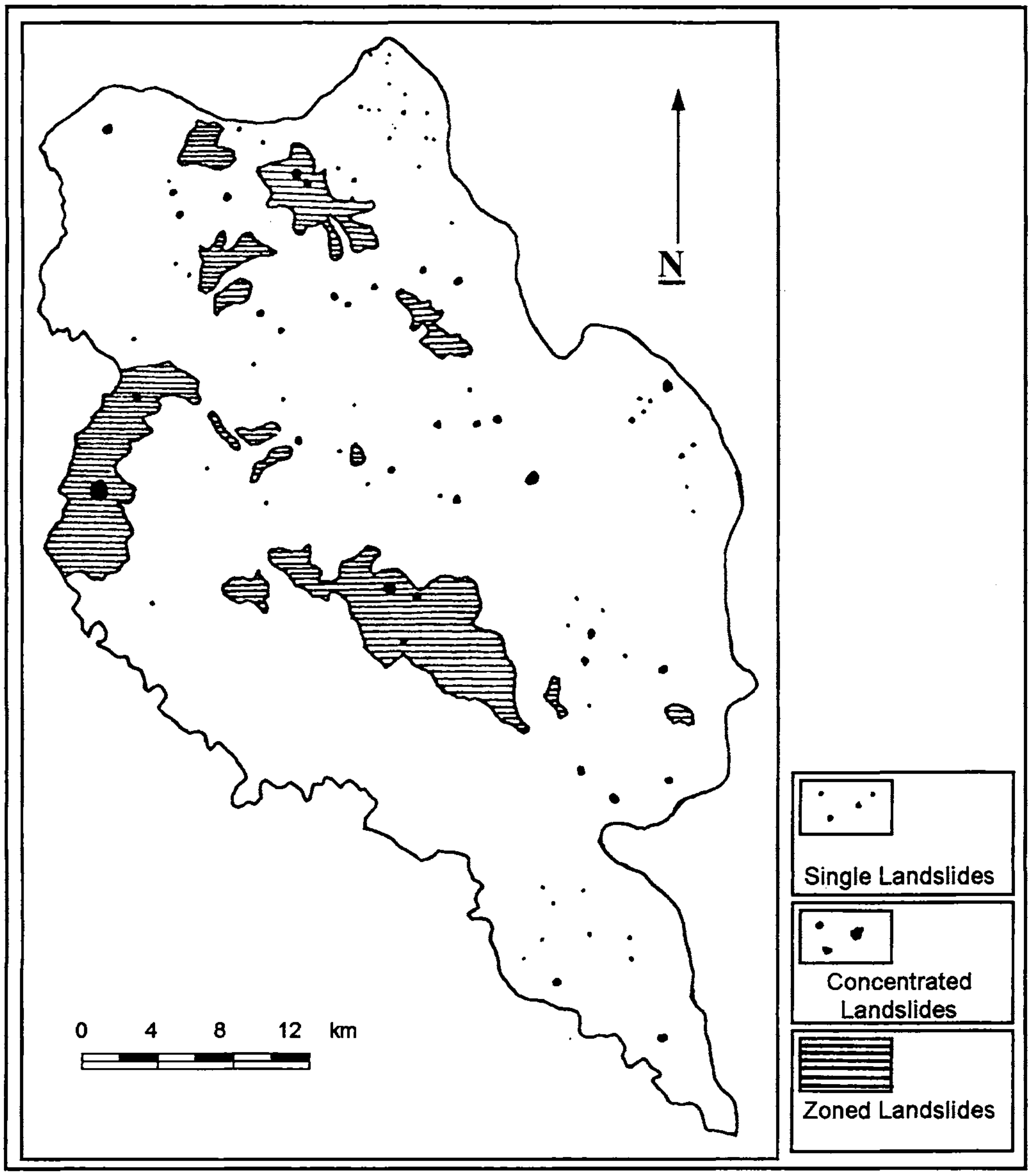

Figure 5. Landslide distribution in the Khorshrostam area.

instability of the area. The effect of sliding factors are summarized as follows:

Lithology: Geology of the area is controlled by two main factors; the lithology and their stratification. Different lithology has different reaction against the weathering and erosion agents which result in various type of products. Therefore different types of slope failure could be resulted. The rock units stratification which indicates the unit age is also a factor for differentiate the type of instabilities. Table 3 illustrate the effect of geology on the development of slope failure in the area.

It can be noted that Quaternary deposits are most prone to slope failure with of 45% of its surface are affected by landslide processes, but because they have very limited surface distribution (only 21 km^2), they show no great influence on the rate of hazard in the area. The acidic volcanic rocks (rhyolite and trachyte) of Late Eocene with SPI of 37% and the Red-beds of Neogene with SPI of 25%, reflect great sensitivity to landslide. These two units cover 31% of the surface area. The volcanic tuff and lava of Eocene which cover about 55% of the area, shows a SPI of only 9.5%.

Tectonic: Tectonic activity of the area which are recognized by main faults is another factor for controlling the development of slope instability of the area. The distribution of landslide in relation to the distance from the main fault, Hero-Abad Fault, is shown on Table 4.

It can be noted that as the distance from the faults increase the number of the recorded landslides increase as well, therefore it can be concluded that the distance from the faults has a reverse effect on the distribution of the landslides.

Slope Category: It has been noted that most of the landslides were occurred in areas with slope of less than 25%. These areas mainly consist of red-beds units and acidic volcanic rocks which are less resistance to weathering and erosion agents. The effect of slope on the distribution of landslides is presented in Table 5. It can be concluded that the slope factor has a reverse effect on the development of landslide in the area.

Land Use: Two types of land use is common in the area; dry farming lands and pasture lands. The landslide distribution in relation to the types of land use is shown on Table 6. There is no great difference between the number of landslide occurrence in either types of land use. The effect of the land use on the development of slope failure should be considered further and detailed studies need to be carried out in the area.

Ground Water: The ground water is mainly affected by the rate of precipitation in the area. The precipitation usually falls in the form of snow or rainfall and its rate of falling is same around the whole region throughout all seasons. The ground water effect on the engineering geological behavior of the soils and rocks which results in the formation of various types of landslide and ground movement. Because the area faces a similar amount of precipitation, the effect of the ground water was not accounted in this analysis.

HAZARD ZONATION ANALYSIS

For evaluation the rate of slope failure potential, the weight of each factor was considered with reference their surface distribution percent (SPI) in the area. A value of Hazard Potential Index, HPI, for each defined factors was calculated on the bases of fuzzy sets computation using the Monte Carlo simulation technique (Juang, 1992). The method was modified for calculation of slope failure potential in this area, and a computer program was written for this purpose to accelerate the procedure of calculation (Mahdavifar and Fatemi-Agda, 1996).

Table 7 summarizes the final results of the calculations. It can be noted that the minimum and maximum values of the HPI varies between 0.55 to 0.7 respectively. Five level of hazard potential is then classified regarding the HPI values (columns 1, 2, and 3, Table 7). By considering the number of units for each level (column 4, Table 7), and the number of units affected by landslide (column 5, Table 7), the surface percentage index (SPI) for each hazard potential value could be identified (column 6, Table 7).

According to the final results of the calculated HPI and their responded SPI values, the landslide hazard zonation map for the Khorshrostam area prepared (see Fig. 6). To evaluate the accuracy of the prepared map, the SPI values (column 6 of Table 7), of each defined factor were compared to the related values of HPI group (column 3 of Table 7). It can be seen that 24% of the areas with very high hazard potential (HPI > 0.7), is affected by landslides, in contrast only 5% of the area of very low hazard potential (HPI < 0.55), has involved in landslide processes. The map shows close correlation between the defined high hazard potential zones and the actual recorded landslides in the area.

Table 8 represents the detailed rate of weighing of the main sliding factors, for example, geology, slope, and distance from faults. It can be concluded that the geological units; F, G, and H, slope range of less than 25%, and distance from fault at 7 to 10 kilometers show high degree of slope failure potential.

Table 3. Surface distribution of landslides in relation to lithology.

Geological Units	Total Area (km²)	Affected Area (km²)	SPI
A	30	0.9	3.0
B	24	0.2	0.8
C	25	1.7	6.8
D	76	2.0	2.6
E	697	66.0	9.5
F	126	46.6	37.0
G	266	67.0	25.0
H	21	9.5	45.0

Table 4. Distribution of landslide in relation to distance from faults.

Distance from Fault (km)	Total Area (km²)	Affected Area (km²)	SPI
0–2	338	27	8
2–4	109	9	8
4–7	179	17	10
7–10	184	35	19
> 10	458	78	17

Table 5. Effect of slope on the distribution of landslides.

Slope Range	Total Area (km²)	Affected Area (km²)	SPI
< 25%	672	120	18
25%–45%	355	32	9
> 45%	241	5	5

Table 6. The effect of land use on the development of slope failure.

Types of Land use	Total Area (km²)	Affected Area (km²)	SPI
Dry farming land	534	75	14
Pasture land	734	88	12

Table 7. HPI values and their SPI.

Rate of Weighing	Hazard Potential	HPI Value	No. of Units	Affected Units	SPI
A	very high	> 0.70	749	182	24
B	high	0.65–0.70	853	196	23
C	medium	0.60–0.65	2030	398	20
D	low	0.55–0.60	1001	131	13
E	very low	< 0.55	438	20	5

Table 8. The rate of weighing of the main sliding factors.

GEOLOGICAL FACTOR								
Geological Units	A	B	C	D	E	F	G	H
SPI	3.0	0.8	6.8	2.6	9.5	37.0	25.0	45.0
Rate of weighing	E	E	D	E	C	A	A	A

SLOPE FACTOR			
Slope Range	< 25%	25%–45%	> 45%
SPI	18	9	5
Rate of weighing	A	D	E

DISTANCE FROM FAULT FACTOR					
Distance from fault (km)	0–2	2–4	4–7	7–10	> 10
SPI	8	8	10	19	17
Rate of weighing	E	E	D	A	B

CONCLUSIONS

The following conclusions are derived from the paper:

- Landslide hazard zonation map is found to be a basic level for understanding the nature of distribution of instability in the area. The map can be used for further planning of development schemes
- There is a good correlation between the landslide hazard zonation map and the actual landslide occurrence of the area. This indicates that the method used for hazard zonation is appropriate and suitable for the region.
- According to surface distribution of landslide which is presented by surface percentage index, SPI, it has been seen that lithology is most effective factor for landslide in the area where the less resistance rock units such as acidic volcanic rocks of Late Eocene, and marlstone, sandstone and conglomerate of Neogene are very susceptible to landslide.
- The use of fuzzy set is found to be helpful for the calculation of hazard potential index HPI values and to evaluate the rate of weighing for each factor.

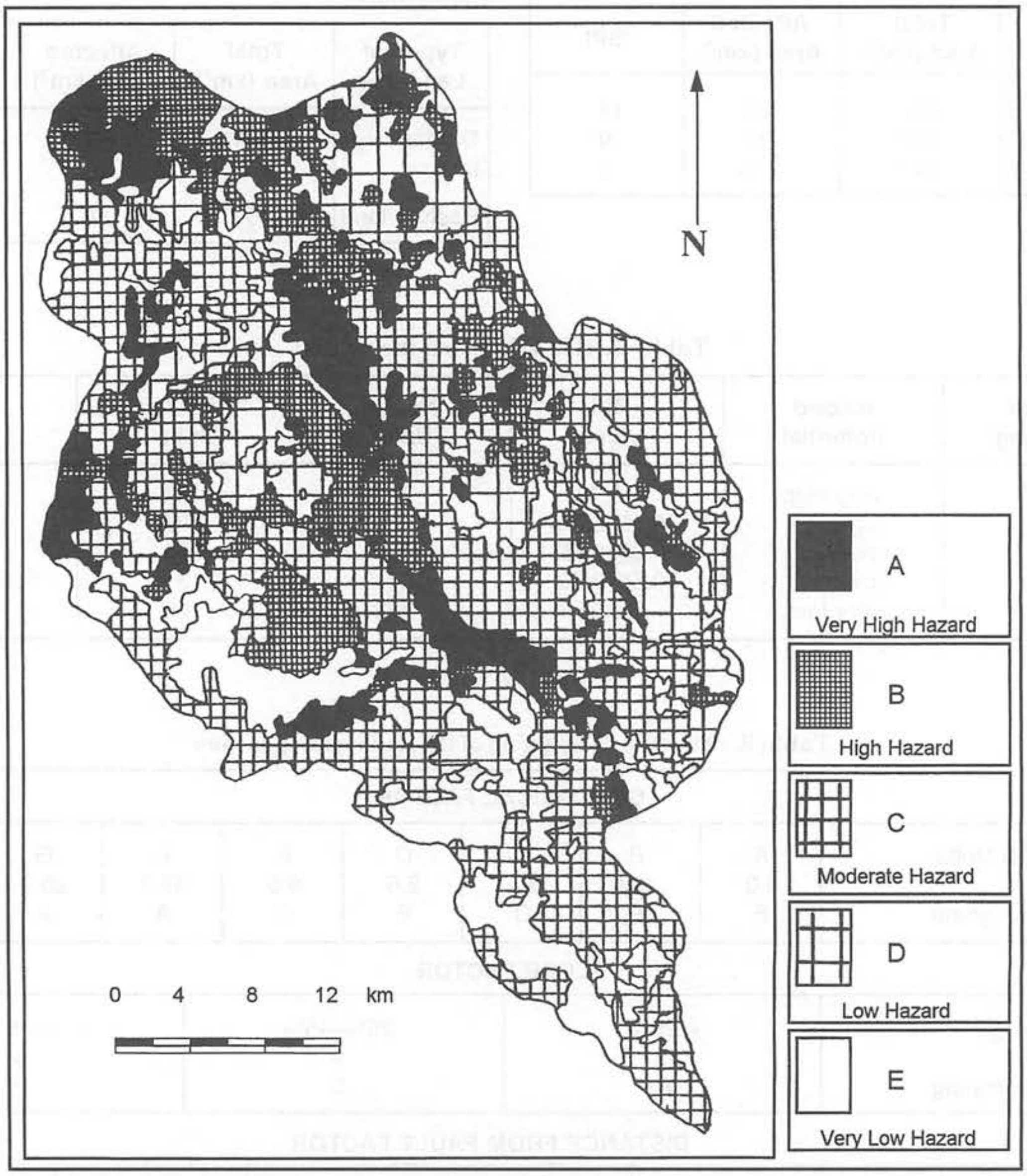

Figure 6. Landslide hazard zonation map of the Khorshrostam area.

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