Landslide hazard zonation of the Khorshrostam area, Iran

A. Uromeihy · M.R. Mahdavifar

Abstract Landslide hazard zonation is a method to evaluate the risk where there is the potential for landslides. The factors contributing to the hazard in an area can usually be identified, results of the investigations frequently being presented as a landslide hazard zonation map indicating zones of similar risk of the occurrence of a landslide. Korshrostam is one of the areas most susceptible to landslides in Iran with more than 13% of its surface being affected by landslide activity. The effects include damage or disturbance to villages, farmlands and roads as well as the exacerbation of erosion of the land surface and consequently an increase in the rate of sedimentation in the water flowing into the reservoir of the Manjil dam. The method of landslide zonation used in this study was based on a simple grid unit. A number of factors contributing to the likelihood of landsliding were considered, including lithology, slope, tectonic activity, land use and groundwater. For each grid unit, the incidence of landsliding and an assessment of the likely contributory factors were recorded in terms of a surface percentage index (SPI). A computer program was written using fuzzy sets to calculate the hazard potential index (HPI) for each unit. This was used to prepare the landslide hazard zonation map.

Résumé La cartographie de l'aléa glissement de terrain contribue à l'évaluation du risque dans les régions où la prédisposition au glissement est reconnue. Les facteurs explicatifs de l'aléa sont généralement identifiables, et les résultats de ce type d'étude sont souvent présentés sous forme d'une carte de zonage précisant les zones d'égal risque d'occurrence de glissement. Korshrostam est l'une des régions les plus concernées en Iran par les glissements de terrain, avec plus de 13% de sa surface affectés par ceux-ci. Les effets des glissements comprennent des dommages aux villages, terres agricoles et routes, ainsi qu'une érosion intense des sols et, en conséquence, une sédimentation importante dans le réservoir du barrage de Manjil. La méthode de cartographie de l'aptitude au glissement utilisée dans cette étude s'appuie sur une simple grille. Un certain nombre de facteurs de prédisposition ont été considérés, comprenant la lithologie, la pente topographique, l'activité tectonique, le type d'occupation des sols et l'eau souterraine. Pour chaque cellule de la grille, l'évaluation des facteurs de prédisposition a été notée sous forme d'un indice en pourcent (SPI). Un logiciel a été écrit, utilisant les ensembles flous, pour calculer un indice d'aptitude au glissement (HPI) pour chaque cellule de la grille. Cette méthode a été utilisée pour préparer la carte de zonage de l'aléa glissement de terrain.

Key words Landslides · Hazard zonation · Weightings · Fuzzy sets · Iran

Mots clés Glissements de terrain · Zonage d'aléa · Pondération · Ensembles flous · Iran

Received: 10 June 1999 · Accepted: 16 September 1999

A. Uromeihy (✉)
Tarbiat Modarres University, P.O. Box 14155–4838, Tehran, Iran
e-mail: uromeiea@net1cs.modares.ac.ir

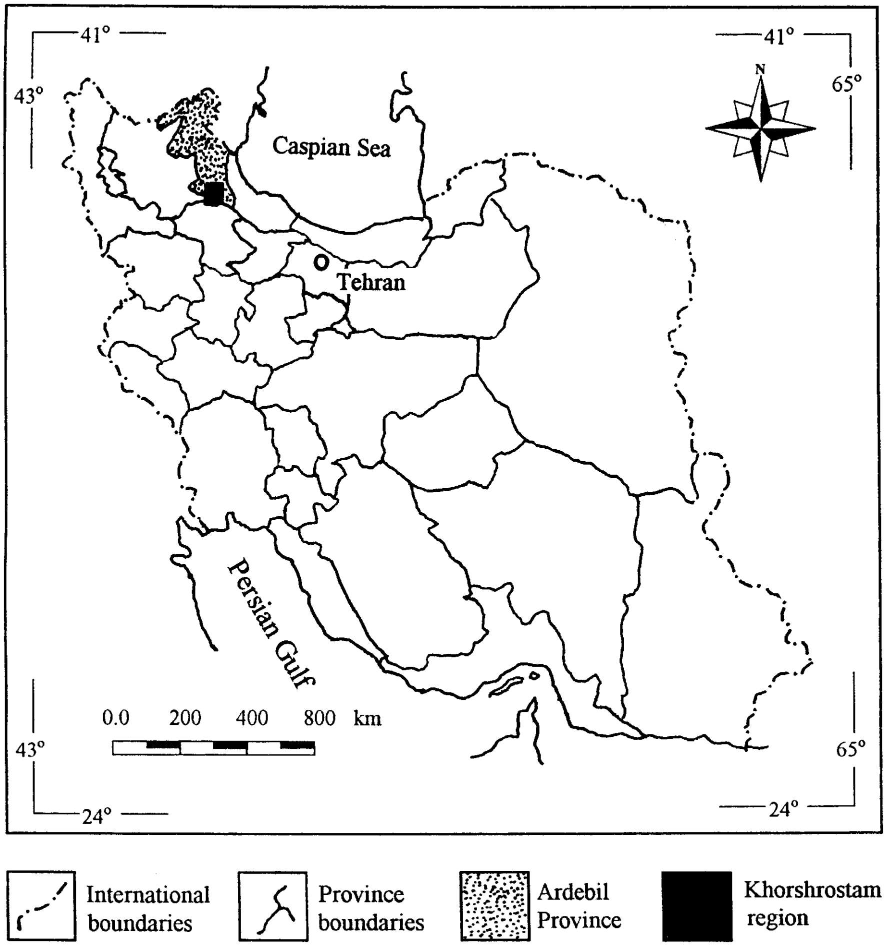
M.R. Mahdavifar
Res. Assist. of IIEES, P.O. Box 19395–3913, Tehran, Iran

Introduction

Iran is a developing country with a complex geology, active seismicity and seasonal rainfall. These factors have a great influence on the development of natural hazards, including landslides and other types of ground mass movements which may result in loss of life and damage to the economy. The preparation of a landslide hazard zonation map is the first step in assessing the degree of hazard and evaluating its potential.

Korshrostam, an area of some 1268 km^2, is situated in the southern part of Ardebil province, north-west Iran (see Fig. 1). It is located between longitude 48°00′ and 48°40′

Fig. 1
Geographical location of the Khorshrostam area



east and latitude 37°00′ and 37°40′ north. The temperature variation is between −9 °C in winter and 18 °C in summer. The mean annual rainfall is 450 mm, the maximum precipitation falling between November and May, coincident with the main landslide activity.

The area drains into the Qezel Owzan river system which terminates in the reservoir of the Manjil dam. It has been estimated that more than 14 million tons of sediment and suspended materials are carried from the study area into the dam's reservoir each year (Mahdavifar 1996).

The aims of the study reported here were to identify and zone the areas susceptible to landslides, to evaluate the hazard, to determine the principal factors involved in the initiation of the instabilities and to consider ways in which their effects may be reduced.

Ground slopes

Slope angle is a major factor influencing the development of landslides in an area. As the slope angle increases, the weight and consequently the volume of material affected per unit area will also increase. The type of slope in any area is closely related to the strata and geological history of the region (Varnes 1984).

A slope map of Khorshrostam is shown in Fig. 2. This divides the area into regions where <25, 25–45 or 45–100% of the ground surface has a measurable gradient. As can be seen from Table 1, more than half of the study area has a slope angle of less than 14° while only 19% has slope angles of more than 24°.

Geological setting

The general geological setting of the area is shown in Fig. 3 and summarised in Table 2. The study area is located in the west of the Bandar-e-Anzali quadrangle map of the northwest of the Alborz Mountain. According to Davies (1975), the oldest rock units are limestones and volcanic rocks with a limited distribution of sandstones of Carboniferous to Permian age. Lower Jurassic sandstone, shale and conglomerate have a surface distribution of only 2% and over approximately 1% of the area limestones of Upper Jurassic age are found. The majority of the area (94%) is covered by Tertiary rocks of different lithologies, mainly volcanic tuff and lava of Eocene age and marlstones and sandstones of Neogene age.

As indicated in Table 2, some 65% of the area is covered by volcanic rocks (dominantly andesitic to rhyolitic tuff and

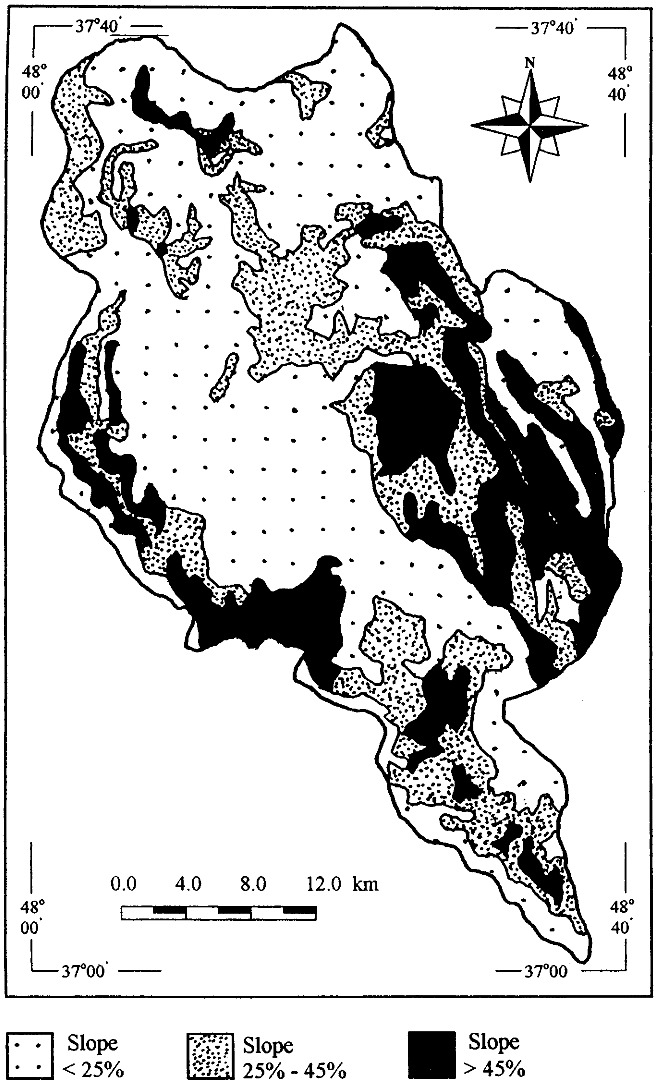


Fig. 2
Land slope map of the Khorshrostam area

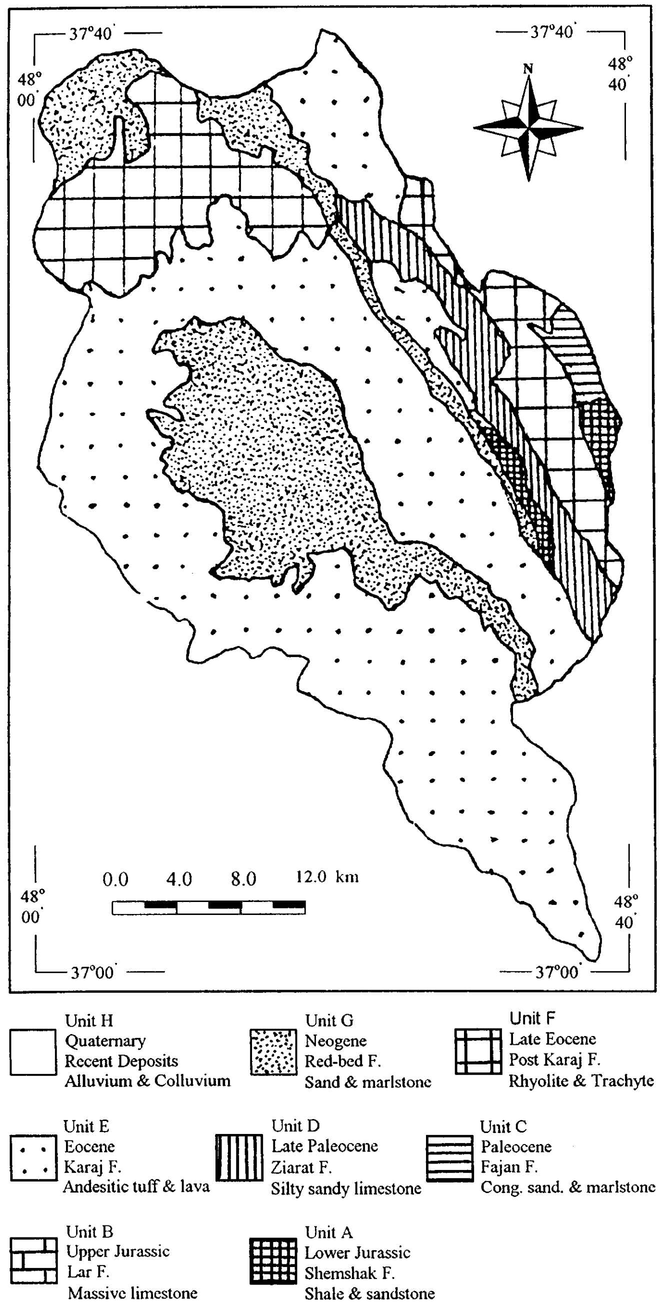


Fig. 3
Geological setting of the Khorshrostam area (units B and H are not shown in view of their limited distribution)

lava) and approximately 21% by red-bed rocks, mainly marlstone and conglomerate. These units are very susceptible to landslides and other mass movement.

Tectonic characteristics

The structural geology of the area is shown in Fig. 4. Three structural zones are identified:

1. Mountain uplift: this zone, in the north-east of the area, is part of the Alborz Mountain range. It is characterised by faults and folds, having been elevated by pre-Alpine orogenic activity. Lithologies from Carboniferous to Neogene age are present.
2. Elevated plateau: this zone consists of Palaeogene rocks, mainly volcanic lava and tuffs of the Eocene. Most have been altered by the late intrusion of hydrothermal solutions.
3. Depressions: this zone consists mainly of Neogene red beds of marlstone, sandstone and conglomerate which are very susceptible to weathering and erosion. A

Table 1
Range and distribution of slopes in the Khorshrostam area

Slope range (%)	Slope angle (degrees)	Surface area (km^2)	Distribution (%)
<25	<14	672	53
25–45	14–24	355	28
>45	>24	241	19

Table 2
Description of geological units of the Khorshrostam area

Unit	Geological age	Formation	Lithology	Surface area (%)
A	Lower Jurassic	Shemshak	Slate, shale and detritic rocks	2
B	Upper Jurassic	Lar	Massive and reef limestone	1
C	Paleocene	Fajan	Conglomerate, sandstone and marlstone	2
D	Late Paleocene	Ziarat	Silty and sandy limestone	6
E	Eocene	Karaj	Andesitic tuff, lava and agglomerate	55
F	Late Eocene	Post Karaj	Acidic volcanic rocks (rhyolite and trachyte)	10
G	Neogene	Red beds	Red sandstone, marlstone and conglomerate	21
H	Quaternary	Recent deposit	Alluvium and colluvium deposits	1

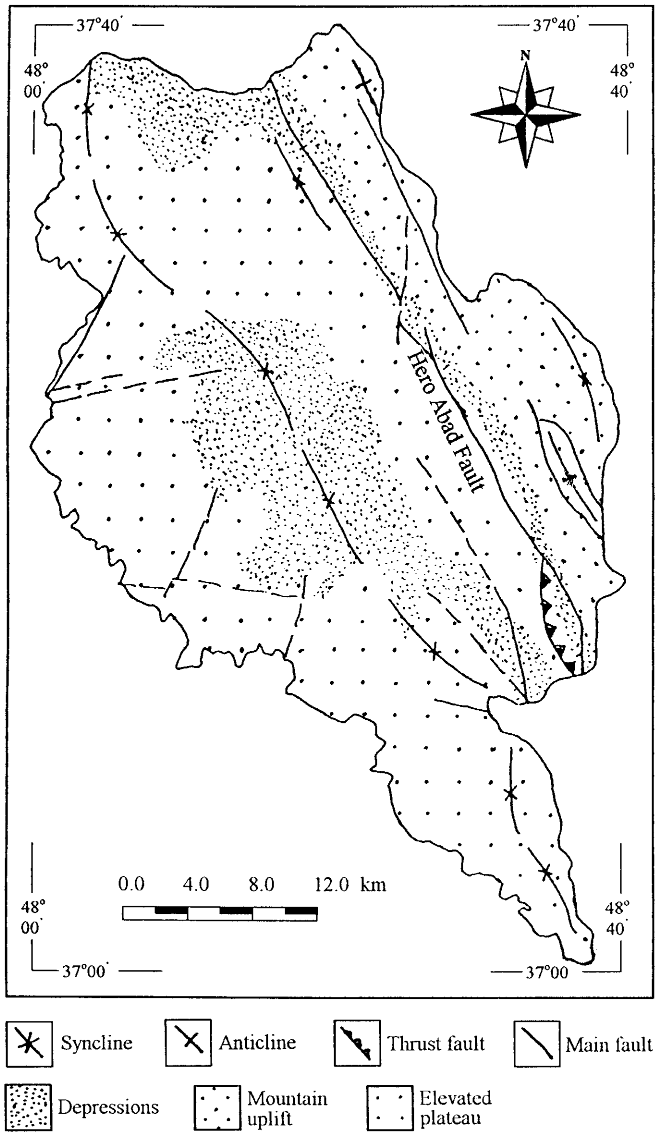


Fig. 4
Structural geology map the Khorshrostam area

number of major and minor faults and folds in the form of synclines and anticlines have been identified in the area. The longest fault, the Hero-Abad Fault, extends for some 150 km. The fault is a strike-slip type and has a trend of N 330°. No fault activity has been recorded since the beginning of the Quaternary

Landslide records

The study area has experienced many types of ground movement over a long period and more than 213 landslides have been mapped over 13% of the land surface. Three categories have been distinguished: single landslides, concentrated landslides and zoned landslides (Fig. 5). Initially, the location of the landslides was plotted onto 1:50,000 topographic maps using 1:20,000 aerial photographs. Site visits were then undertaken to confirm and complete this information and to identify the exact location of the landslides on the ground surface.

Distribution of landslides

Many factors influence the occurrence of landslides in the area, including lithology, tectonics, slope angle, land use and rainfall. As the rate of precipitation is almost equal for the whole region and hence the rainfall effect is similar, it was ignored in the present study. To evaluate the rate of landslide distribution with regard to each factor, a surface percentage index (SPI) was used. This can be defined as:

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

Using this formula, the SPI can be investigated and calculated for each individual factor and the susceptibility of the factor can be defined.
The whole area was divided into 5071 units of 500 × 500 m. The main factors influencing instability and assessed for each grid unit were as follows.

Lithology

The geology of the area is controlled by two main factors: the lithology and stratification. Different lithologies have a

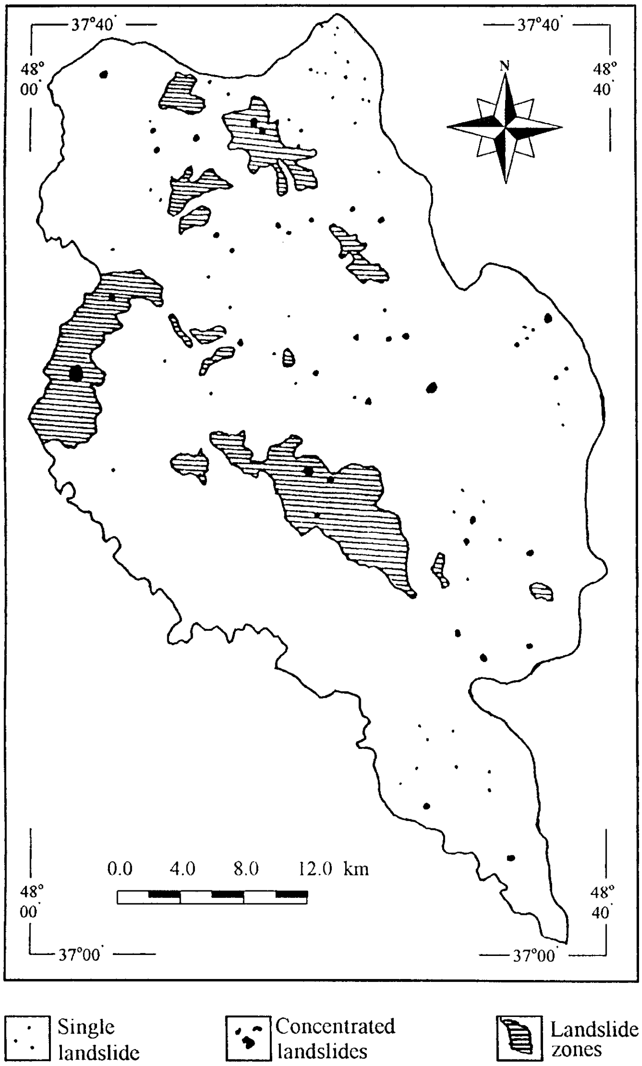


Fig. 5
Landslide distribution in the Khorshrostam area

different susceptibility to weathering processes and erosion agents and result in different types of weathering products, hence the possibility of different types of slope failure. The age and stratification of the rock unit are also important influencing factors.

Table 3 illustrates the effect of the geology on the development of slope failure in the area in terms of the SPI. As can be seen from the table, the Quaternary deposits are the most susceptible to slope failure, with 45% of the area where these materials are found being affected by landslides. In view of their limited occurrence (only 21 km^2 within the study area), however, they do not make a significant contribution to the overall hazard compared with the acidic volcanic rocks (rhyolite and trachyte) of Late Eocene age (SPI 37%) and the Neogene red beds (SPI 25%) which cover some 31% of the surface area. The dominant rocks are the volcanic tuffs and lavas of the Eocene which are present over some 55% of the study area and have an SPI value of only 9.5%.

Table 3
Surface distribution of landslides in relation to lithology. *SPI* Surface percentage index

Geological unit (see Fig. 3)	Total area (km^2)	Affected area (km^2)	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

Tectonic activity

The tectonic activity of the region, as indicated by the presence of major faults (Fig. 4), is also an important factor affecting the development of slope instability in the area. The distribution of landslides relative to the Hero-Abad Fault is shown in Table 4. It can be seen that as the distance from the fault increases, the number of recorded landslides also increases.

Slope

It has been noted that most of the recorded landslides occurred in areas with a slope of less than 25%. In general, the geology comprised red-bed units and acidic volcanic rocks which are less resistant 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 an inverse effect on the development of landslides in the area.

Table 4
Distribution of landslides in relation to distance from faults. *SPI* Surface percentage index

Distance from fault (km)	Total area (km^2)	Affected area (km^2)	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 distribution of landslides. *SPI* Surface percentage index

Slope range (%)	Total area (km^2)	Affected area (km^2)	SPI
Less than 25	672	120	18
25–45	355	32	9
More than 45	241	5	5

Table 6
Effect of land use on development of slope failure. *SPI* Surface percentage index

Types of land use	Total area (km^2)	Affected area (km^2)	SPI
Farmland	534	75	14
Pasture land	734	88	12

Land use

The two most common types of land use in the Khorshrostam area are farming and pasture. The landslide distribution in relation to these land uses is shown in Table 6. Although this does not indicate any correlation between the different land uses and the incidence of landslides, the effect of the land use on the development of slope failure should be considered further.

Groundwater

In this study area the groundwater is largely controlled by the rate of precipitation. This falls in the form of snow or rain and is relatively consistent across the whole region and throughout the seasons. For this reason, it was not taken into account in the present analysis, although it is appreciated that groundwater affects the engineering geological behaviour of the soils and rocks and can have an important influence on landslides.

Hazard zonation

In order to evaluate the potential for slope failure, the weight of each contributory factor was considered with reference to its surface distribution (SPI). A value of hazard potential index (HPI) for each of the defined factors was calculated on the basis of fuzzy sets computation using a modification of the Monte Carlo simulation technique (Juang 1992). A computer program was written specifically for this purpose and to accelerate the calculation procedure (Mahdavifar and Fatemi-Agda 1996).

Table 7
Hazard potential index (*HPI*) values and their surface percentage index (*SPI*)

Rate of weighting	Hazard potential	HPI value	No. of units	No. of 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 7 summarises the results. It can be seen that the HPI varies between a maximum of 0.7 and a minimum of 0.55. Five levels of hazard potential were distinguished in the 550-m^2 grid units and by relating these to the number affected by landslides, the SPI for each hazard potential value could be calculated.
These results were used to prepare a landslide hazard zonation map for the Khorshrostam area (Fig. 6). To evaluate the accuracy of this map, the SPI value of each contributory factor was compared with the values of the HPI groups (Table 7). The map shows a good correlation between the defined high hazard potential and the landslides actually recorded in the area, with 24% of the areas classified as of very high hazard potential (HPI >0.7), having been affected by landslides, compared with only 5% of the areas designated of very low hazard potential (HPI
Table 8 shows the weightings given to the main factors affecting sliding. It can be concluded that geological units F, G and H, slope ranges of less than 25% and a distance from the Hero-Abad Fault of between 7 and 10 km are the most likely conditions in which slope failures will occur.

Conclusions

A method of producing a landslide hazard zonation map is proposed. This should be a useful tool for developing a

Table 8
Rate of weighting of 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 weighting	E	E	D	E	C	A	A	A
Slope factor								
Slope range (%)	<25	25–45	>45					
SPI	18	9	5					
Rate of weighting	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 weighting	E	E	D	A	B			

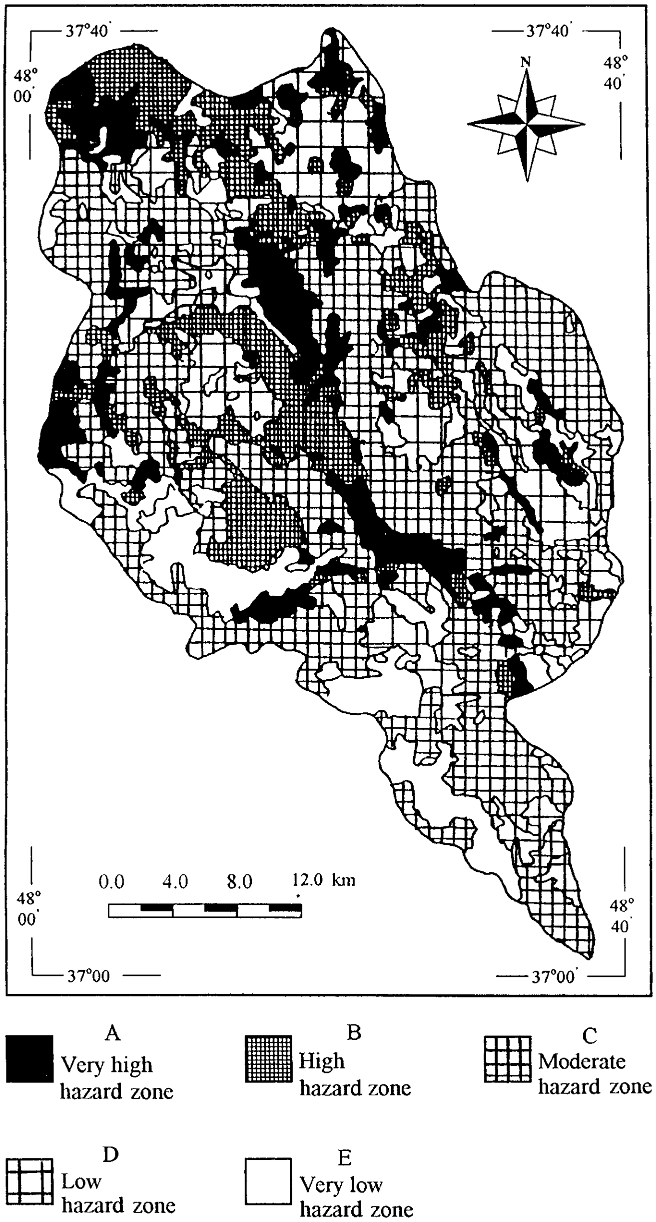


Fig. 6
Landslide hazard zonation map of the Khorshrostam area

basic understanding of the distribution of instability. Such a map will also be valuable when planning future development schemes. A good correlation has been shown between the landslide hazard zonation map produced for the Khorshrostam area and the actual occurrence of landslides in this region.

From the surface distribution of landslides represented by the surface percentage index (SPI) it has been shown that the lithology is the most important factor affecting landslides in the area, where the less resistance rock units such as the acidic volcanic rocks of Late Eocene age and the marlstones, sandstones and conglomerate of Neogene age are very susceptible to landslides.

The use of fuzzy sets was found to be helpful for the calculation of the hazard potential index (HPI) values and to evaluate the weighting of each contributory factor.

References

Davies RG (1975) Explanatory text of the Bandar-e-Anzali quadrangle map, 1:250,000. Geological Survey of Iran, Report no D3, 203 pp

Juang CH (1992) Mapping slope failure potential using fuzzy sets. J Geotech Eng 118(3), March 1992, Paper no 26586

Mahdavifar MR (1996) Landslide hazard zonation in Khorshrostam region (south west of Khalkhal county) (in Persian). MS Diss, Tarbiat Modarres University, Tehran, 154 pp

Mahdavifar MR, Fatemi-Agda SM (1996) Application of fuzzy sets analysis in landslide hazard zonation (in Persian). Proc 2nd Seminar on Landslides and their Hazard Reduction in Iran, IIEES, Tehran, vol 1, pp 127–146

Varnes DJ (1984) Landslide hazard zonation: a review of principles and practice. UNESCO, Paris, 63 pp