Landslide Susceptibility Mapping for Yadak-Tevil Watershed (Northeast Iran), Using AHP Method

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Abstract

Landslides form major natural hazards in hilly terrain in the area, and caused extensive damages to road, human dwellings and agricultural lands. There is still a great danger of further landslides in the region. Therefore, it is important to prepare a landslide susceptibility map of the region. In this study a landslide susceptibility map of Yadak-Tevil watershed was prepared using the Analytical Hierarchy Process (AHP) with the help of GIS. For this purpose, thematic layers including landslide inventory, lithology, distance from drainage, slope, slope aspect, and elevation were the main contributory factors to be considered for landslides susceptibility zonation. The landslide susceptibility map was classified into four different landslide susceptibility classes. The four landslide susceptibility classes are: low 16.13 % (33.50 km^2), moderate 33.34 % (69.38 km^2), high 33.00 % (68.68 km^2), and very high 17.53 % (36.48 km^2), respectively. Results of this study show that the AHP method is precise method for evaluation of landslide potential due to the use of binary comparison affecting factors and considering numerous factors for landslide evaluation at the same time in comparison to the other prevalent method.

Keywords

Landslide • Susceptibility • Watershed • Analytical Hierarchy Process

Introduction

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 (e.g.,Carrara 1983; Carrara et al. 1991; Chung and Leclerc 1994; Djamaluddin 1994; Chung and Fabbri 1995; Guzzetti et al. 1999; Zaitchik and van Es 2003; Lee and Pradhan 2007) have been made to estimate the degree of landslide susceptibility and provided some procedures for landslide prediction modeling and quantitative hazard zonation. Recently, there have been studies on landslide hazard evaluation using GIS, and many of these studies have applied different methods to analyze landslide and to create landslide susceptibility mapping. Lee and Pradhan 2007, have used logistic regression method to model landslide distribution. Lee et al. 2006 and Gupta et al. 2008 have shown better results from application of artificial neural network black box approach. Bivariate statistical approach was used by Yalcin (2008) to compare each individual factor and landslide distribution map to assign weighting value to the various parameter and finally to prepare a landslide hazard map. Analytical hierarchy process (AHP) was another procedure that was applied by Barredo et al. 2000, to deal with the paradoxical role of different factors in landslide occurrence.

Iran is heavily exposed to natural hazard such as earthquake, landslide, and floods. Landslide is one of the

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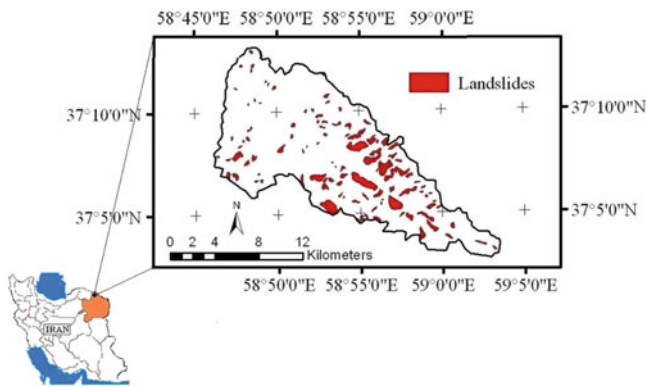e-mail: ghafoori@um.ac.ir

Fig. 1 A location map of the study area

most frequently occurring and devastating natural hazards in the mountainous region of Iran. They occur because of specific topographic and geological conditions (Lashkaripour and Ghafoori 2002). In hilly terrains of Iran, such as Yadak-Tevil watershed area in the Kopet-Dogh Basin, northeast of Iran, landslides are a major and widely spread natural hazards. In recent year, the population growth and the expansion of settlements over hazardous area have increased in the Kopet-Dogh Basin.

In this study, a landslide susceptibility map of the study area was prepared using AHP method with the help of the geographic information system. The study area occupies an area of about 208.1 km^2 and is located between N 37° 02′ to 37° 13′ and E 58° 46′ to 58° 03′ (Fig. 1).

Geology of the Study Area

Yadak-Tevil watershed area is located in a part of the Kopet-Dogh mountain physiographic province termed the Kopet-Dogh Basin. The Kopet-Dogh formed as an inter-continental basin in northeast of Iran and southwest of Turkmenistan (Berberian and King 1981), and contains more than 6,000 m thickness of Mesozoic and Cenozoic marine and fluvial sedimentary rocks. During the early Jurassic, an epicontinental sea transgressed (from NW to SE) across the study area and a thick series of siliclastic sediments was unconformably deposited over Triassic rocks in fluvial, deltatic and marine environments. The general stratigraphy of the Kopet-Dogh basin comprises 15 formations from mid Jurassic to Oligocene age (Fig. 2).

The watershed area is underlain by Quaternary deposits and rock units of Cretaceous age. A generalized geological map of the catchment site is shown in Fig. 3. This map shows the outcrops of the geological bedrock units and the various types of surficial deposits. They consist of the following stratigraphic formations.

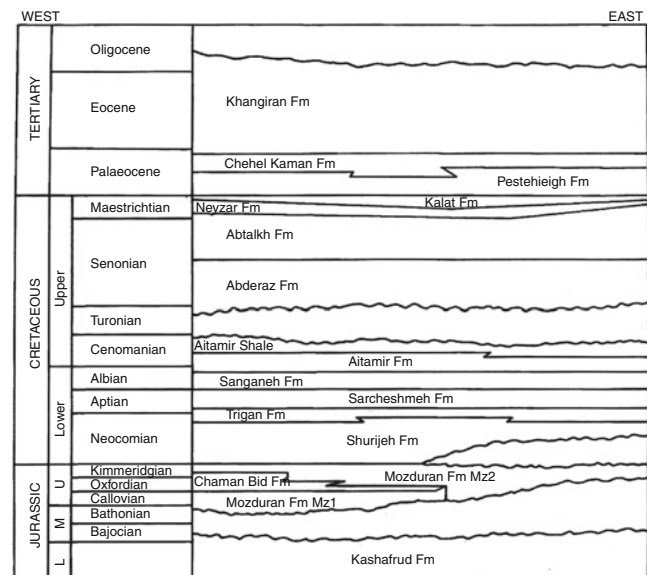Mouzdouran formation which refers to upper Jurassic time and it is mostly made of carbonate and dolomite stones.

Fig. 2 General stratigraphy of the Kopet-Dogh basin (After Afshar-Harb 1979)

Shurijeh formation mainly consists of reddish brown shale, sandstone, and quartzite sandstone of Upper Jurassic and Lower Cretaceous age. The Tirgan formation, of early Cretaceous age, is mainly formed of oolitic and bioclastic limestone with subordinate layers of marl and calcareous shale that conformably overlies and underlies the Shurijeh and Sarcheshmeh formations, respectively. Rock falls are frequent in this region. The Sarcheshmeh formation consists of two members. The lower member is characterized by uniform light green-grey pencil type weathered marl. The upper member consists of alternating shale and thin layers limestone. This formation is moderately resistant to weathering, and form a distinct white-grey weathered unit between the ridge formed by the brown weathered Tirgan formation and slightly weathered dark grey to black Sanganeh formation. The Sanganeh formation is a uniformly weathered dark grey to black shale with few very thin, light brown weathered siltstone beds. Septarian and cone-in-cone concretions are present. This formation, with its dark color, is a distinct rock unit in the region and forms badland topography. Quaternary deposits are mainly represented by alluvial and debris flow materials. The alluvium is composed of clay, silt and rounded to sub-rounded coarse-grained materials, mixed with large angular rock blocks. These deposits fill synclinal valleys and flood plains. Part of the area is covered by terrace deposits exposed at varying elevations.

Rock fall, creep and soil slide are slide types that are recognized during site investigations in the area. Steep slope, joint, and abundant fissures in limestones of Tirgan formation which has covered a great part of the area, caused numerous rock falls in this area.
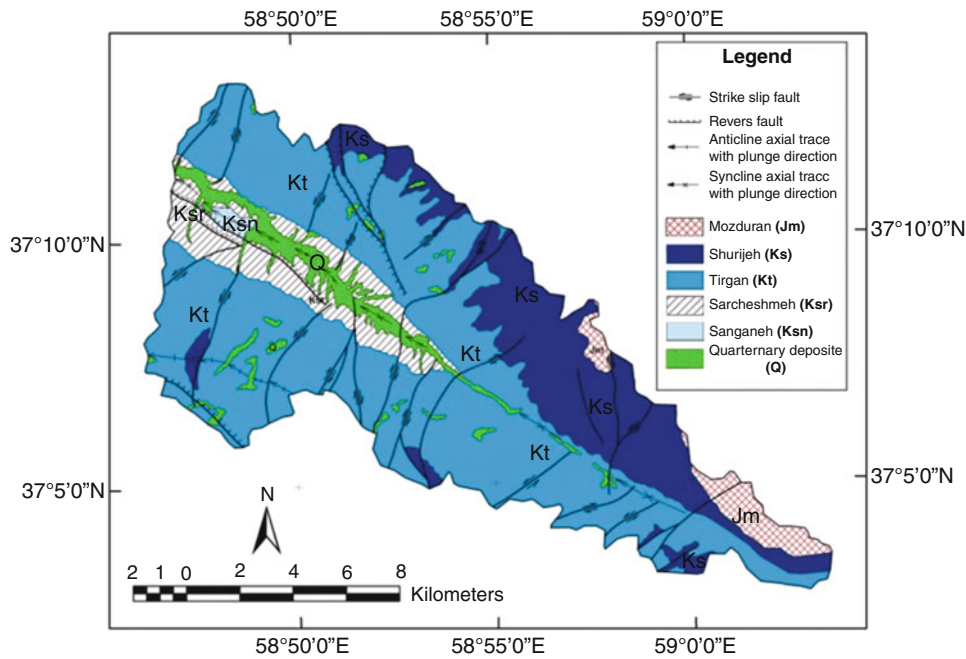
Fig. 3 Geology map of the study area

Rock falls were not considered in this paper. Therefore the study of creep and soil slide is only covered. Slide phenomenon is seen around the roads and in the alluvium. These alluviums contain a lot of clay and they are making more problems, especially in the parts which are cut by the road. The existing shale layers and marl of Sarcheshmeh formation underneath these alluviums are help to their slow movement.

Spatial Data Layers

In the present study, five factors namely, lithology, distance from drainage, slope, slope aspect, and elevation were considered to be the main contributory factors for landslides.

Thematic layers of the area, using topographic maps and published literature, were derived from the DEM with a 25 m cell size. The resultant grid of the study site has 759 rows and 1,034 columns. The total number of cells in the area is 332,974; the number of cells occupied by each category of all the factors was calculated to compute area density value in GIS. A digital elevation model (DEM) is the digital representation of a topographic surface with the elevation above a geodetic datum. The DEM of the study area was prepared from the contour information given in the topographic maps (in 1:25,000 scale) using ArcMap of ArcGIS 9.2 software. From this model, the maps showing slope and aspect were obtained. Lithology is a key parameter conditioning landslide occurrence because
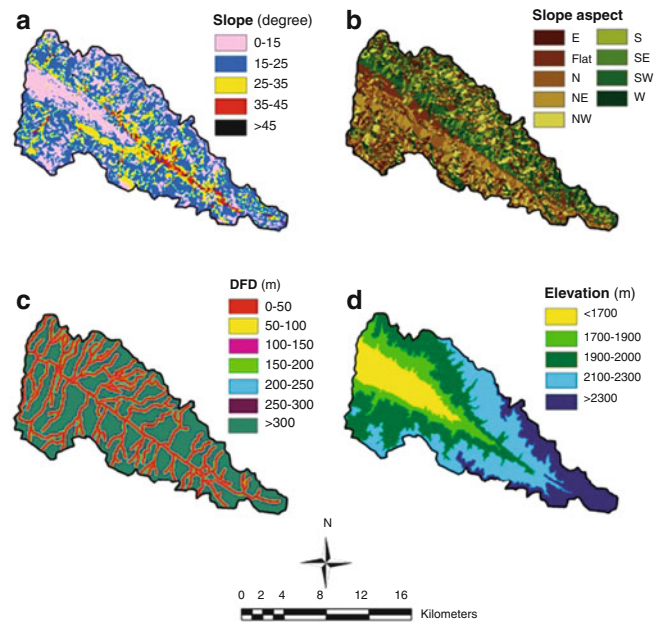

Fig. 4 The slope angle, slope aspect, distance from drainage and the elevation maps

different lithologic units have different sensitivities to active geomorphological processes such as landslides. The lithology layer has been derived through the digitization of the published geological maps (scale of 1:100,000) which display major rock groups and structural features. The slope angle, slope aspect, distance from drainage and the elevation maps are shown in Fig. 4.

Table 1 Pair-wise comparison matrix, factor weights and consistency ratio of the data layers

Factors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Weights
Lithology (formation)										
(1) Shurijeh	1	4	3	2	5	7				0.188
(2) Sanganeh		1	1/2	1/3	3	4				0.035
(3) Quaternary deposit			1	1	3	5				0.055
(4) Tirgan				1	3	7				0.068
(5) Sarcheshmeh					1	2				0019
(6) Mozduran						1				0.011
Slope angle (degree)										
(1) <15	1	1/3	1/4	1/5	1/2					0.018
(2) 15–25		1	1/2	1/3	2					0.048
(3) 25–35			1	1/2	2					0.072
(4) 35–45				1	3					0.118
(5) 45<					1					0.033
Slope aspect										
(1) NE	1	1	2	3	5	5	7	7	7	0.020
(2) SW		1	2	3	5	5	7	7	7	0.020
(3) N			1	2	3	5	7	7	7	0.014
(4) NW				1	3	2	5	5	5	0.009
(5) S					1	2	3	3	5	0.006
(6) SE						1	2	2	2	0.004
(7) E							1	1	1	0.002
(8) W								1	1	0.002
(9) Flat									1	0.002
DFD (m)										
(1) <50	1	2	2	3	3	3	8			0.065
(2) 50–100		1	1	2	3	3	8			0.045
(3) 100–150			1	1	2	3	8			0.038
(4) 150–200				1	1	2	7			0.028
(5) 200–250					1	1	7			0.022
(6) 250–300						1	6			0.018
(7) >300							1			0.005
Elevation (m)										
(1) <1,700	1	1/3	1/7	1/9	1/7					0.003
(2) 1,700–1,900		1	1/5	1/7	1/5					0.006
(3) 1,900–2,100			1	1/2	1					0.025
(4) 2,100–2,300				1	2					0.043
(5) >2,300					1					0.025

Analytical Hierarchy Process (AHP) for Landslide Susceptibility Mapping

The Analytical Hierarchy Process was developed at Wharton School of Business by Thomas Saaty 1980. The AHP overcomes the problems with arbitrary weights and scores approaches, by its ability to enable decision-makers to drive ratio scale properties or weights as opposed to arbitrary assign them (Yalcin 2007). Normally, the determination of the values of the parameters relative to each other is a situation that depends on the choices of the decision-maker. However, in this study, both the comparison of the parameters relative to each other and the determination of the decision alternatives, namely the effect values of the sub-criteria of the parameters (weight), were based on the comparison of landslide inventory maps constructed using aerial photos with the other data layers. Consequently the weight values were determined accurately for the real land data (Table 1). This is done by structuring complexity as a hierarchy and by deriving ratio scale measures through pairwise relative comparisons. AHP application for landslide susceptibility can be found in many applications (Chung and Leclerc 1994; Barredo et al. 2000; Ayalew et al. 2004; Komac 2006; Yalcin 2007). AHP is a multi-objective, multi-criteria decision-making approach which enables the user to arrive at a scale of preference drawn from a set of alternatives. AHP gained wide application in

Fig. 5 Landslide susceptibility map of the study area
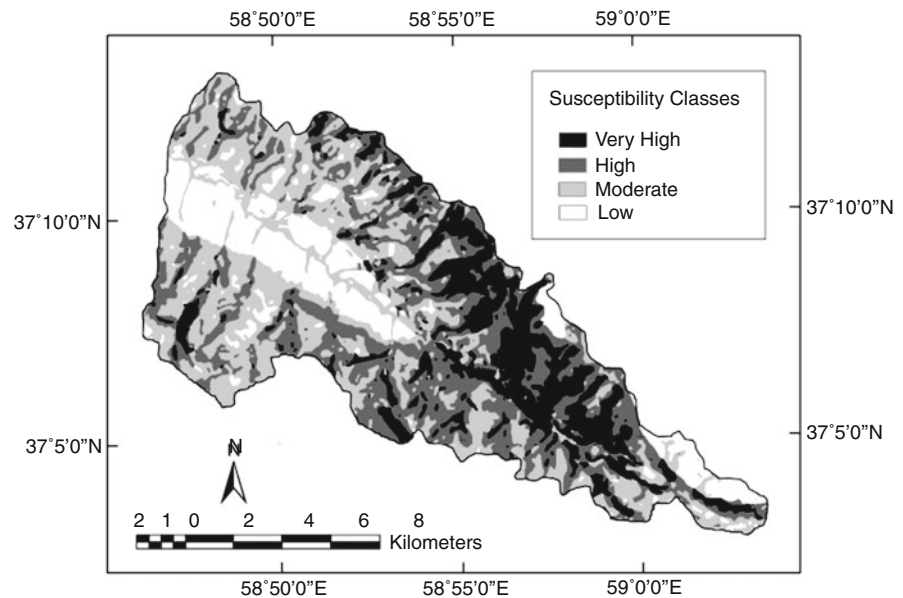
site selection, suitability analysis, regional planning, and landslide susceptibility analysis (Ayalew et al. 2005). In this study the AHP method was used for creating a map of landslide susceptibility zonation. In construction of a pairwise comparison matrix, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell (Table 1). These values are assigned by expert judgment to each pair of parameters yielding a square reciprocal matrix by rating rows relative to columns as shown in Table 1. When the factor on the vertical axis is more important than the factor on the horizontal axis, this value varies between 1 and 9. Conversely, the value varies between the reciprocals 1/2 and 1/9. In these techniques, firstly, the effects of each parameter to the susceptibility of landslides relative to each other were determined by dual evaluation in determining the preferences in the effects of the parameters to the landslide susceptibility maps. In this study, spatial databases were used, obtained as a result of the field, laboratory and office studies carried out to create landslide susceptibility maps. As a result of these analyses, the landslide susceptibility map was produced for the Yadak-Tavil region (Fig. 5). The landslide susceptibility map was classified into four different landslide susceptibility classes as shown in Fig. 5. The four landslide susceptibility classes are: low 16.13 % (33.50 km^2), moderate 33.34 % (69.38 km^2), high 33.00 % (68.68 km^2), and very high 17.53 % (36.48 km^2), respectively.

Discussion

This study includes method and application devoted to the construction of a landslide susceptibility map for Yadak-Tevil watershed, where landslides constitute an important natural hazard affecting not only the landscape but also human developments. The selection of a proper assessment method and the use of suitable parameters that affect landslide occurrence in the studied area are two important points that should be considered. When selecting the assessment method, existing data and their practibility to the method selected should be considered. However, the selection of the proper landslide-conditioning parameters plays an important role in a sensitive landslide susceptibility assessment.

In the study area using the weight values calculated by the pair wise matrix and assigning these weights to the relevant parameters, the weighted parameters were produced. By overlying these weighted parameters using a weighted linear combination method, the landslide susceptibility map was obtained. When examining this map, the southeastern part of the study area was revealed more prone to landslide occurrence. The reason for this is the presence of lithologies that are susceptible to landsliding due to their level of weathering, sensitive topography, and additional factors such as land use and land cover.

Conclusion

There are various possible causes for landsliding, with complex inter-relationships. Therefore, accurate landslide susceptibility mapping on a regional scale strongly depends on the selection of landslide causative factors, which can be quite different according to various researchers. In this study, the analytical hierarchy process (AHP) was used to develop landslide susceptibility map for the Yadak-Tevil watershed in Khorasan Razavi Province, in northeastern part of Iran. To achieve this objective, five landslide inducing factors were taken into consideration, which are the lithology, distance from drainage, slope, slope aspect, and elevation. The four

landslide susceptibility classes of the landslide suscepti-bility map of the AHP approach give 16.13 %, 33.34 %, 33.00 %, 17.53 %, for respectively low, moderate, high, and very high susceptibility. This study shows that when field conditions and characteristics are correctly deter-mined by good expertise, the AHP's approach gives better results.

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