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ORIGINAL PAPER

Landslide Susceptibility Mapping Using Fuzzy-AHP

Marzieh Mokarram · Abdol Rassoul Zarei

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Abstract Landslides are as the movement of soil on slopes that they are one of the most common natural hazards in many mountainous areas. Landslides are recognized as an important natural hazard in many countries. So in the study, the geographic information system-based the fuzzy quantifier is used to determinate the landslide susceptibility modeling in the north of Khorramabad, west of Kermanshah Province, Iran. To determine the landslide susceptibility modeling generated aspect, some input data were prepared such as the digital elevation model, lithology, slope, land use, river, road, fault, and precipitation maps. Fuzzy map showed that almost all of the area was medium landslide susceptibility that had the value close to 1. Fuzzy-AHP model showed that 77.62% of the study area had medium landslide susceptibility and this method was a useful tool for forecasting of landslide susceptibility status in each case study.

M. Mokarram
Department of Range and Watershed Management,
College of Agriculture and Natural Resources of Darab,
Shiraz University, Shiraz, Iran
e-mail: m.mokarram@shirazu.ac.ir

A. R. Zarei (✉)
Department of Range and Watershed Management,
College of Agricultural Science, Fasa University, Fasa,
Iran
e-mail: Ar_Zareiee@Fasau.ac.ir;
Ar_zareiee@Yahoo.com

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1 Introduction

Dangerous effects of landslides are in relation to the economic system of many countries (Nefeslioglu et al. 2008). Landslide is one of the most widespread hazardous phenomena (Aleotti and Chowdhury 1999). There are different methods for landslide susceptibility mapping such as probability and bivariate statistical modeling (Bai et al. 2008; Gonzalez et al. 2017; Kouhpeima et al. 2017; Kreuzer et al. 2017; Ercanoglu et al. 2016; Lee et al. 2016; Meten et al. 2015; Hölbling et al. 2015; Mokarram et al. 2015; Kayastha et al. 2013).

Shirani and Arab Ameri (2015) using logistic regression model generated landslide susceptibility zonation map. The results showed that elevation factor was importance data for prediction of landslide susceptibility. Entezari et al. (2015) sued entropy model to zoning of landslide hazard in zar'ab basin, Iran. The findings of this study show that 55% of the total landslide occurred in the medium-risk range, 37% in the high-risk range, and 8% in the low-risk range and the main reason for this was the effect of roads on the increase of landslide in the area. Hejazi (2015) evaluated landslide hazard in Ahar Basin using geographic information system (GIS) and analytic hierarchy process (AHP). Rahimzadeh and Alaiee

(2015) used regional model to assessment of hill side instability potential in Zagros. The results showed that the study area consisted of four zoning maps in four levels risk (very high risk, high risk, low risk and very low risk).

Mirnazari et al. (2015) used AHP model and fuzzy logic operators to assessment and zoning of landslide hazard. Result of this paper showed that based on weight of each factor in the AHP model showed that 36% of the catchment area is located in high and very high risk. While the operator of Gama fuzzy indicated 67% of area located in high and very high landslide zoning. model evaluating shows Gama fuzzy 0.7 models is more accurate than AHP model in the study area. Abedini et al. (2015) used statistical method of logistic regression to modelling the hazard of landslides. The results of the study area showed that landslide susceptibility map using SCAI index had high verification in the study area. Using these results can predict future landslides for decreasing their risks and planning for the land use. The review of landslide susceptibility and Fuzzy-AHP can be found in several manuscripts such as: Nowjavan and Hayati (2013), Jouri et al. (2014), Sarvati et al. (2014), Shabani et al. (2014), Dai et al. (2002), Drobne and Lisec (2009), Feizizadeh and Blaschke (2011), Fell (2008), Gorsevski and Jankowski (2008, 2010), Komac (2006), Malczewski (2006), Malczewski et al. (2003), Swets (1988), Van Westen et al. (2000) and Yager (1988).

Therefore the aims of this study is determinate the landslide susceptibility modeling in the north of Khorramabad, west of Kermanshah Province, Iran using fuzzy quantifier and GIS. To study the region, the fuzzy-AHP method was selected to investigate the landslide susceptibility. The rest of this paper is organized as follows; in Sect. 2, the fuzzy modeling is explained. Section 3 holds the case study and the input data properties. Section 3 describes the fuzzy-AHP results. Besides, in the last section that is Sect. 4 conclusions are presented.

2 Methods and Material

2.1 Case Study

The study area was located in north of Khorramabad, west of Kermanshah Province, Iran. It has an area of about 17,133.90 km^2, and is located at longitude of 33°11′ to 34°33′N and latitude of 46°40′ to 48°44′E (Fig. 1). The altitude is between 682 and 3487 m in the study area. According to suitable climate and fertile soil, the study area has good potential for agriculture. The principal agricultural crops consist of wheat, beans, barley and rice. Due to the area in Sanandaj Sirjan, impermeable base of the rocks, loose upper sediments, poor vegetation, grazing livestock, high altitude and abundant rainfall, the study area is exposed to landslides (Zareiee 2014; Maleki and Ghorbanpour 2008). Therefore, one of the important factors is the Landslide susceptibility in the study area. In order to forecast the Landslide susceptibility, data on the Aspect, DEM, lithology, slope, land use, river, road, fault, precipitation maps were obtained from the north of Khorramabad, west of Kermanshah Province, Iran.

2.2 Data Source

Slope represents the rate of change of elevation for each digital elevation model (DEM) cell that was prepared from DEM 90 m (2017). The lithology of a rock unit is a description of its physical characteristics visible at outcrop, in hand or core samples or with low magnification microscopy, such as colour, texture, grain size or composition that was prepared from geological map. A fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement as a result of rock-mass movement that generated from geology map. In the study was used precipitation as climatology factors for site select of suitable for landslide susceptibility from Iran Meteorological Organization. Elevation was prepared from DEM (90 m). Stream and aspect maps were extract from DEM in ArcGIS. Land use and road maps were prepared from Ministry of Agriculture Jihad in 2017.

2.3 Fuzzy Method

In the study using membership function prepared fuzzy maps for each parameter. A membership function (MF) assigns to each object a grade ranging between 0 and 1 (Zadeh 1965). The value 0 means that x is not a member of the fuzzy set, while the value 1 means that x is a full member of the fuzzy set. A sample of fuzzy set is shown in the following (McBratney and Odeh 1997):

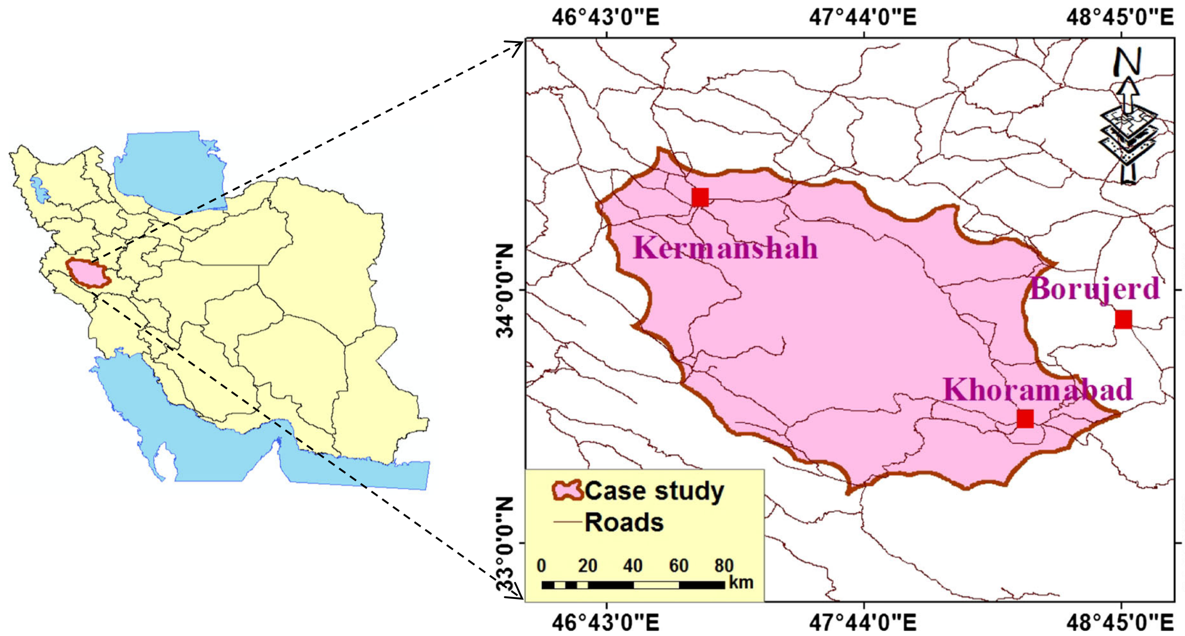


Fig. 1 Geographic position of the study area

Table 1 Scales for pairwise comparisons (Saaty and Vargas 1998)

Intensity of importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

$$A = \{x, \mu_A(x)\} \quad for\ each \quad x \, \varepsilon X \tag{1}$$

where μ_A is the MF (membership of x in fuzzy set A) so that:

If x does not belong to A then $\mu_A = 0$.

If x belongs completely to A *then* $\mu_A = 1$.

If x x belongs in a certain degree to A then $0 < \mu_A(x) < 1$.

According to Eq. 1 MF was used for slope, elevation, sensitive, land use, aspect, and precipitation (Feizizadeh and Blaschke 2013):

$$\mu_A(x) = f(x) = \left\{ \begin{array}{ll} 0 & x \leq a \\ x - a/b - a & a \prec x \prec b \\ 1 & x \geq b \end{array} \right\} \tag{2}$$

where x is the input data and a, b are the limit values.

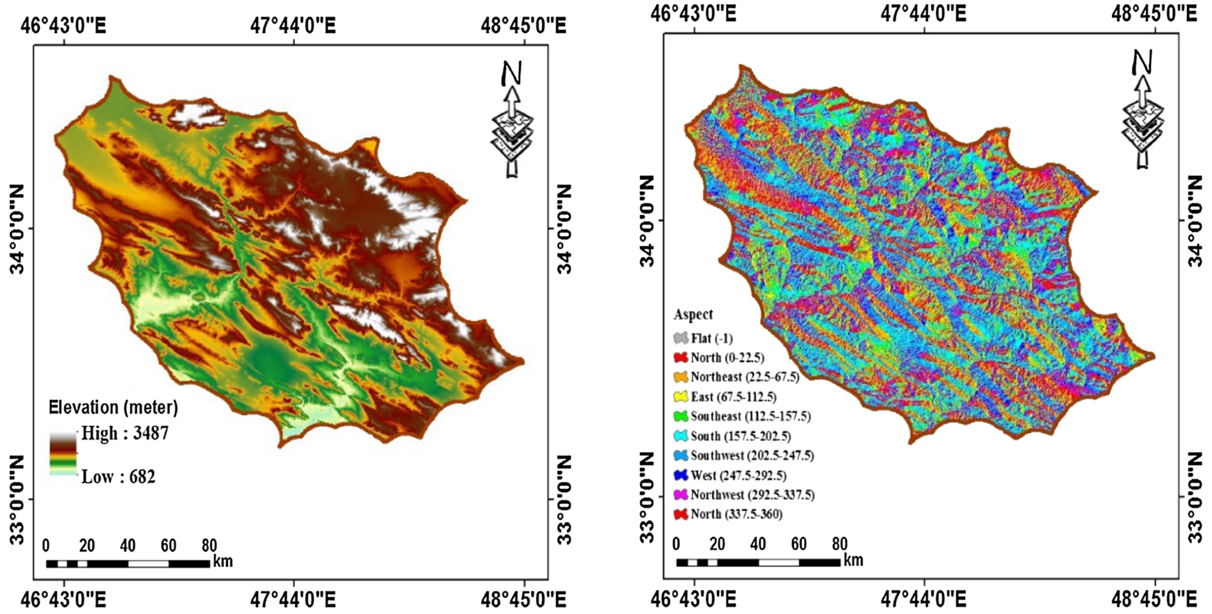
For distance of river, distance of fault, and distance of road the following MF was used (Feizizadeh and Blaschke 2013):

$$\mu_A(x) = f(x) = \left\{ \begin{array}{ll} 1 & x \leq a \\ b - x/b - a & a \prec x \prec b \\ 0 & x \geq b \end{array} \right\} \tag{3}$$

where x is the value of distance of river, distance of fault, and distance of road and a, b are the limit values.

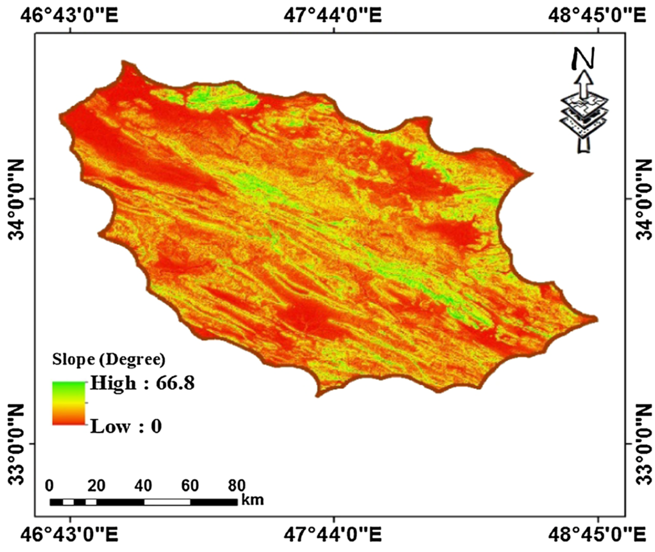
2.4 Analytic Hierarchy Process (AHP)

Analytic hierarchy process as the multicriteria decision analysis (MCDA) procedure is applied to elicit the criteria weights (Saaty and Vargas 1998). AHP is a pairwise comparison method for individual or group decision-makers (Malczewski 1999). In a pairwise



DEM

Aspect



Slope

Fig. 2 Slope, aspect, and DEM maps for the study area

each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell that show in Table 1.

3 Results and Discussion

3.1 Preparing Raster Maps

For determining the landslide susceptibility map of the present study, the fuzzy-AHP algorithm was applied on the input data known as the Aspect, DEM,

Table 2 Distance of fault, stream, and road for determination of landslide susceptibility

Feature				
Distance of fault (m)				
0–1000	1000–2000	2000–3000	3000–4000	> 4000
Distance of stream (m)				
0–50	50–100	100–150	150–200	> 200
Distance of road (m)				
0–25	25–50	50–75	75–100	> 100

lithology, slope, land use, river, road, fault and precipitation maps. To reach this aim, at first raster maps were prepared for each parameter. By using DEM with spatial resolution of 90 m (Source: http://earthexplorer.usgs.gov), the slope and aspect map in ArcGIS v.10.2 software were prepared that are shown in Fig. 2. In the same figure, many parts of the northeast of the present study area have elevations more than 2500 m. Besides, the slope value is between 0 and 66.8° which is considered as the most slope value among the northeast values and center of the study area (green color). The aspect value is between –

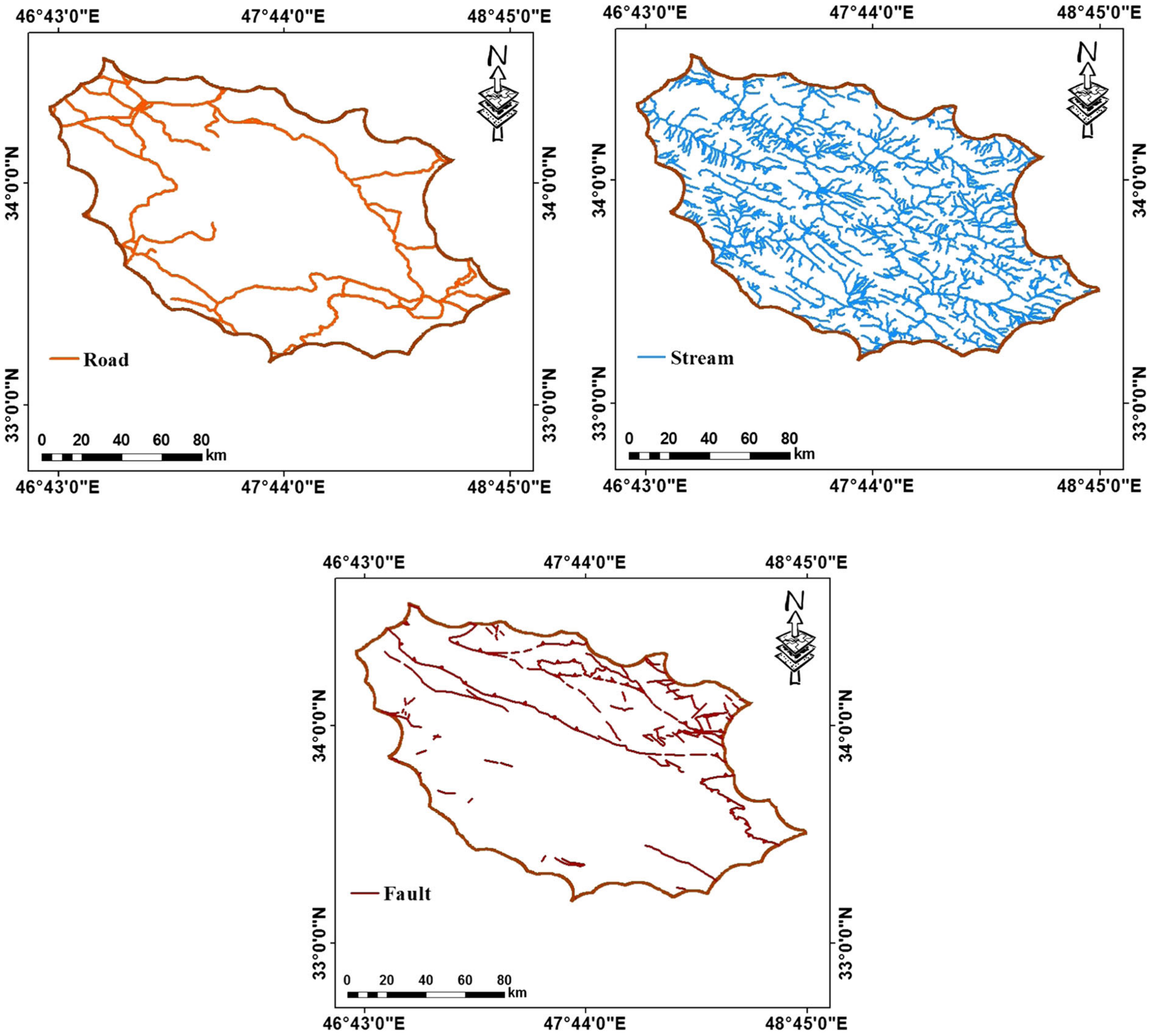


Fig. 3 Fault, stream, and road maps in the study area

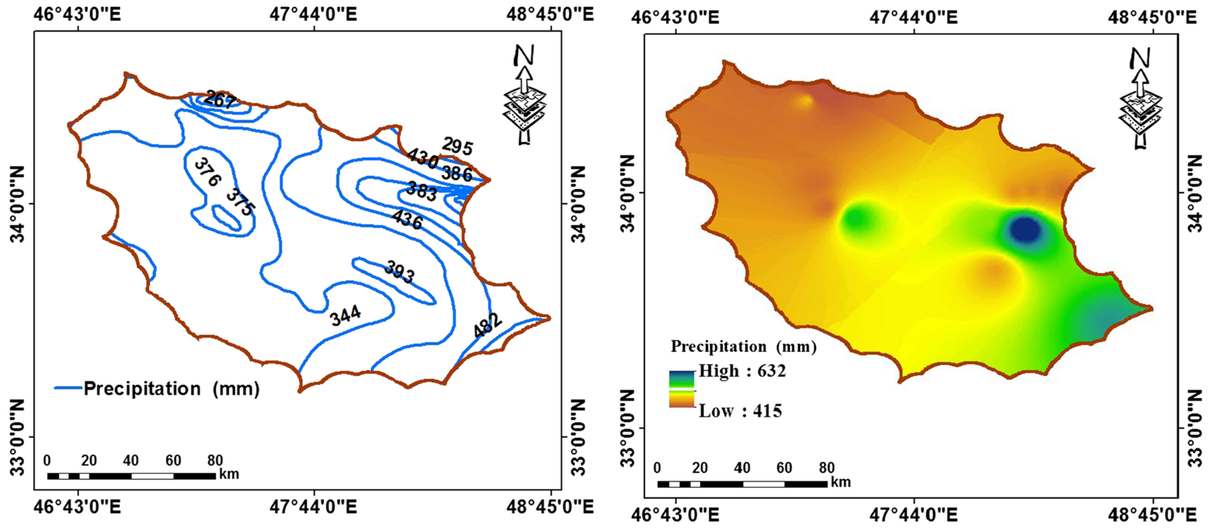
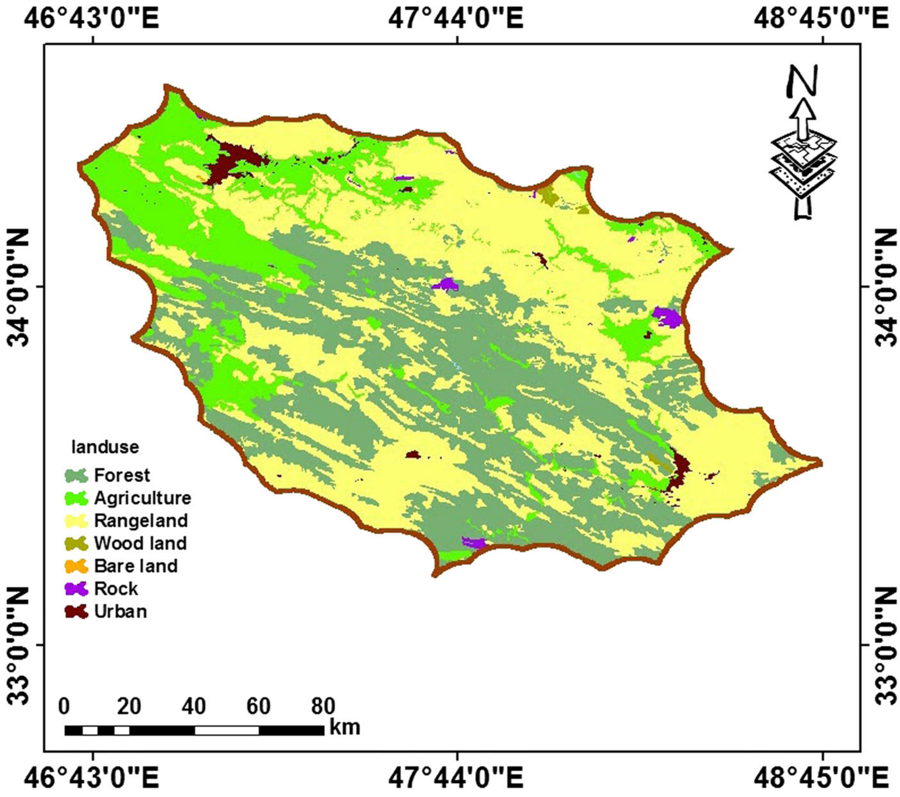


Fig. 4 Precipitation map of the study area

Fig. 5 Land use map for the study area



1 (flat) and 360 (north) in which aspects of the south and the west are sensitive to landslide (Feizizadeh and Blaschke 2013).

For preparing raster maps of the road distance, fault and river as well as their buffer maps, buffer tools of ArcGIS were used. As shown in Table 2, buffer maps were prepared by using distance from features (Fig. 3). To determine the precipitation map of the present study, the contour line was used that is shown in Fig. 4. The contour line was converted to the raster

Fig. 6 Sensitivity map of the study area

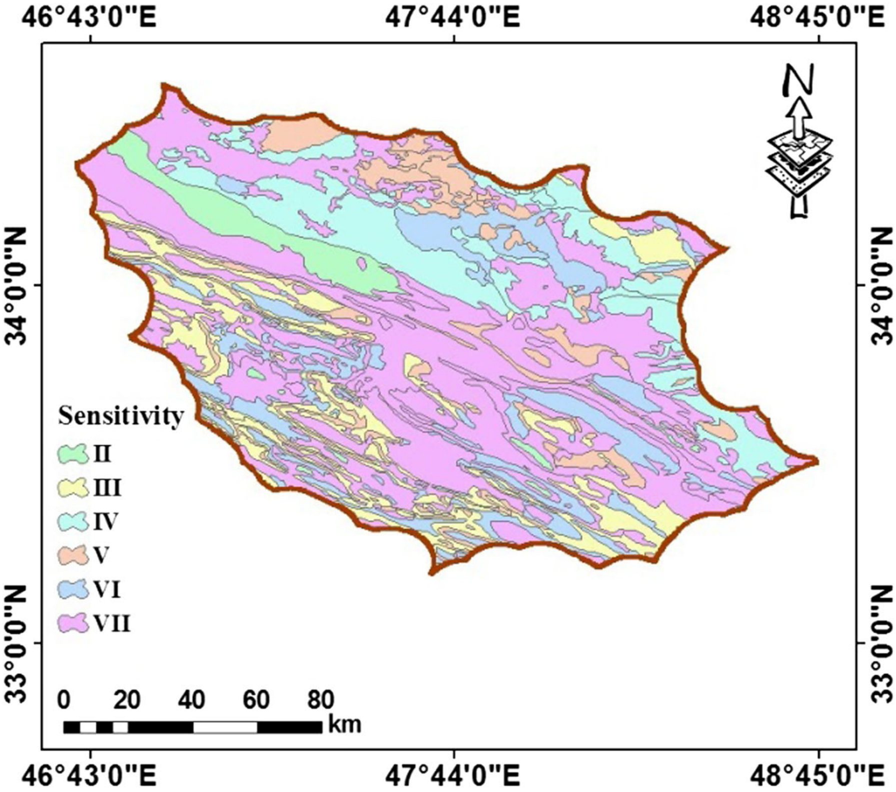


Table 3 Description of sensitive classes of lithology to erosion

Classes	Description
II	Limestone rock
III	Bedded to massive fossiliferous limestone
IV	Hale and chert, bedded to massive orbitolina limestone
V	Bedded argillaceous limestone and calcareous shale, bedded sandstone
VI	Piedmont conglomerate and sandstone, shelly limestone
VII	Bedded argillaceous –limestone, Low level piedment fan and vally terrace deposits

Table 4 Maximum and minimum values of criteria (Feizizadeh and Blaschke 2013)

Parameters	Minimum	Maximum
Land use	Forest, agriculture	Rock bodies, Bare soil
Precipitation (mm)	< 250	> 400
Distance of road (m)	> 100	< 25
Distance of fault (m)	> 4000	0–1000
Distance of stream (m)	> 200	0–50
Sensitive	VII	II
Aspect	South	Flat
DEM (m)	> 3000	< 1200
Slope (degree)	0–10	> 40

Table 5 Pairwise comparison matrix, factor weights and consistency ratio of the data layers used

	Lithology	Precipitation	Land use	Slope	Distance to fault	Distance to stream	Distance to road	Aspect	DEM	Weight
Lithology	1	2	3	4	5	6	7	8	9	0.31
Precipitation	1/2	1	2	3	4	5	6	7	8	0.22
Land use	1/3	1/2	1	2	3	4	5	6	7	0.15
Slope	1/4	1/3	1/2	1	2	3	4	5	6	0.11
Distance to fault	1/5	1/4	1/3	1/2	1	2	3	4	5	0.08
Distance to stream	1/6	1/5	1/4	1/3	1/2	1	2	3	4	0.05
Distance to road	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	0.04
Aspect	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	0.03
DEM	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.02

map in the ArcGIS software. According to Fig. 4, some parts of the south and the southeast of the study area have precipitations more than 500 m. Moreover for determining the landslide susceptibility, DEM, lithology, slope, land use, river, road, fault and precipitation maps were used which is shown in Fig. 5. According to Fig. 5 in the study area, there are six types of land uses (forest, agriculture, rangeland, wood land, bare land, rock and urban). The last method of preparing the landslide susceptibility map of the study area is preparing the sensitive map of water erosion. The sensitive map of five classes was shown in Fig. 6. According to Table 3, if the susceptibility is reduced to erosion, sensitive classes to landslide are increased.

3.2 Fuzzy Method

In the ArcGIS software, linear membership function (MF) is used in order to determine the fuzzy map of each parameter. The maximum and minimum values of the membership functions are determined in Table 4, for example the MF value for a DEM which is higher than 3000 is 1, the value of smaller than 1200 m is MF = 0 and MF is measured between 0 and 1 for the DEM values between 1200 and 3000 m. In the same example, the quantity of DEM for other parameters is defined by using minimum and maximum values of MF. Based on Table 5, membership functions were defined for each parameter between 0 and 1. The fuzzy maps prepared for the landslide susceptibility parameters are shown in Fig. 7, where MF is closer to 0 with decreasing the landslide susceptibility whereas MF is closer to 1 with increasing the landslide susceptibility. According to Fig. 7 all the parameters (aspect, distance of road, distance of stream, distance of fault, slope, DEM (g) land use, precipitation, and lithology) were closer to 1 in northeast of the study area. According to Fig. 9, the north and the northeast of the study area had a value close to 1 that showed the high landslide susceptibility.

3.3 AHP Method

In the present research, authors utilized the AHP method to incorporate different types of input data and the pairwise comparison method for comparing two criteria (Feizizadeh and Blaschke 2013). According to Table 5, the lithology and DEM have the highest and lowest weight, respectively.

3.4 Fuzzy and AHP Methods

According to the fuzzy maps in Fig. 7 and weight of each parameter in Table 5, the final fuzzy map for landslide susceptibility was determined that was shown in Fig. 8. Based on Fig. 8 landslide susceptibility map was between 0 and 1 that value more than 0.75 had high landslide susceptibility, values between 0.5 and 0.75 had medium landslide susceptibility,

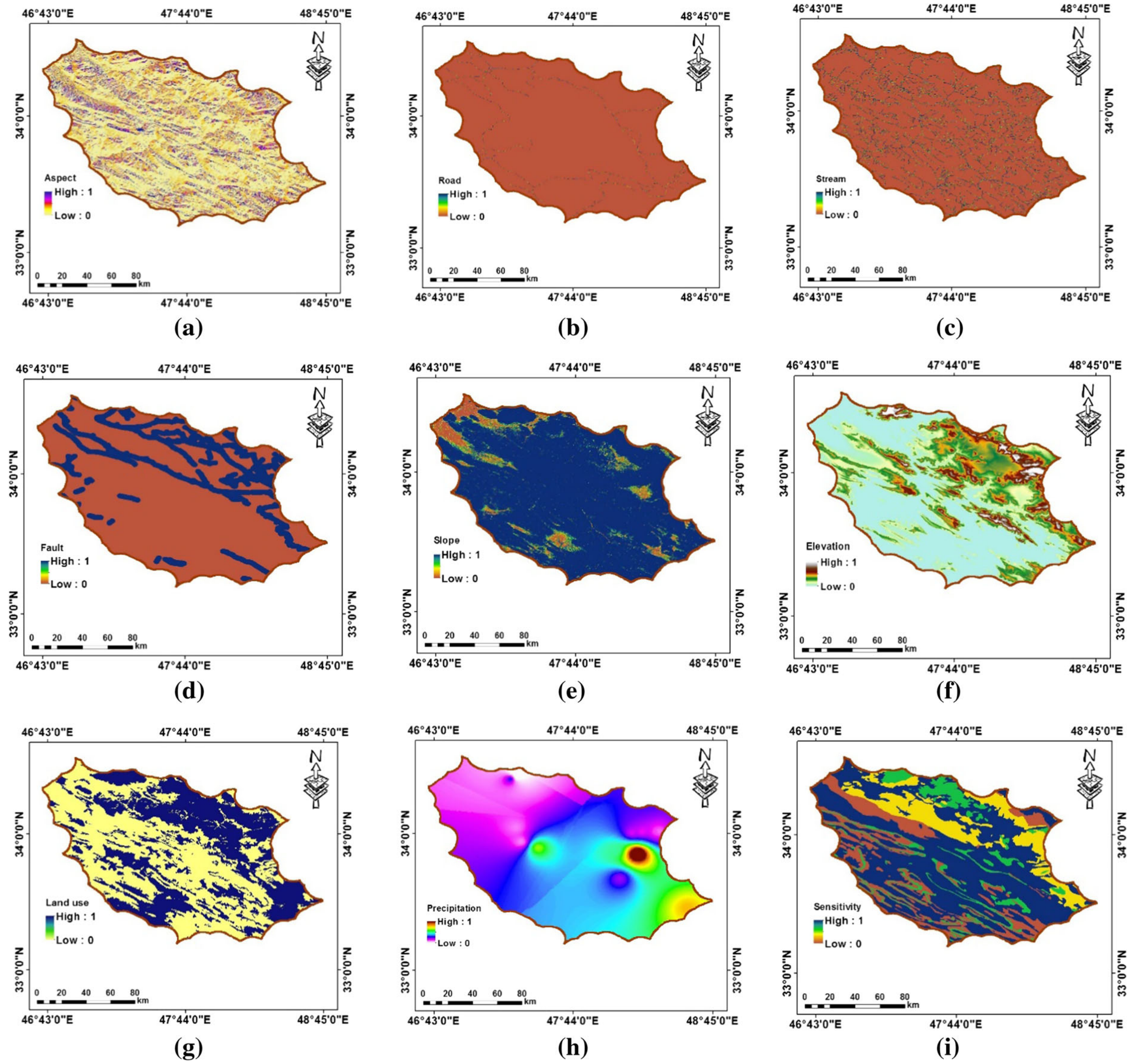


Fig. 7 Fuzzy map of studied area for each landslide susceptibility parameter: **a** aspect, **b** distance of road, **c** distance of stream, **d** distance of fault, **e** slope, **f** DEM, **g** land use, **h** precipitation, **i** lithology (sensitive)

value between 0.25 and 0.5 had low landslide susceptibility and value between 0 and 0.25 had very low landslide susceptibility. Then, the fuzzy map reclassified in four classes consisted of very low (0.73%), low (77.62%), medium (10.67%) and high (10.98%) (Figs. 9, 10 and Table 2).

Based on Fig. 10, for created of precision and accuracy of fuzzy and AHP method were used 150 sample points randomly. For 150 sample points nine parameters including, DEM, DEM, lithology, slope, land use, river, road, fault, and precipitation maps were evaluated. Also, the class of landslide susceptibility was forecasted by fuzzy-AHP model for each point. Then for determination of precision and accuracy of fuzzy-AHP method were compared the class of landslide susceptibility by fuzzy-AHP model with nine parameters values which showed in Table 3. Overall, based on Table 6, the model of Fuzzy-AHP was a benefit tool for prediction of landslide susceptibility status in each point of the case study. The results show that method was a useful tool for prediction of landslide susceptibility status in each

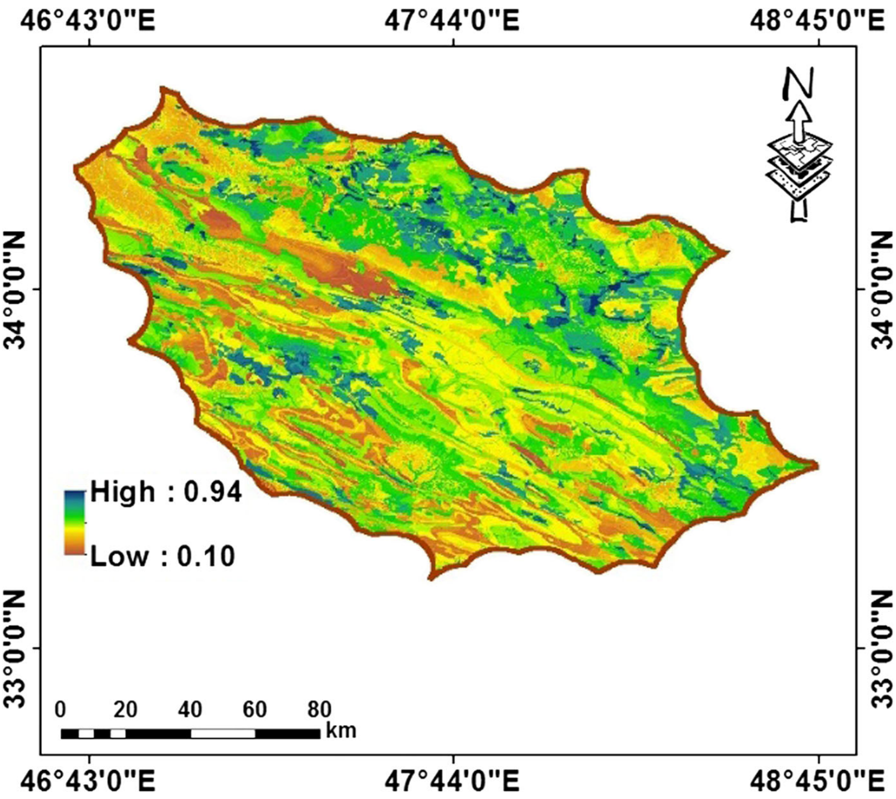


Fig. 8 The fuzzy-AHP combination map for landslide susceptibility classes

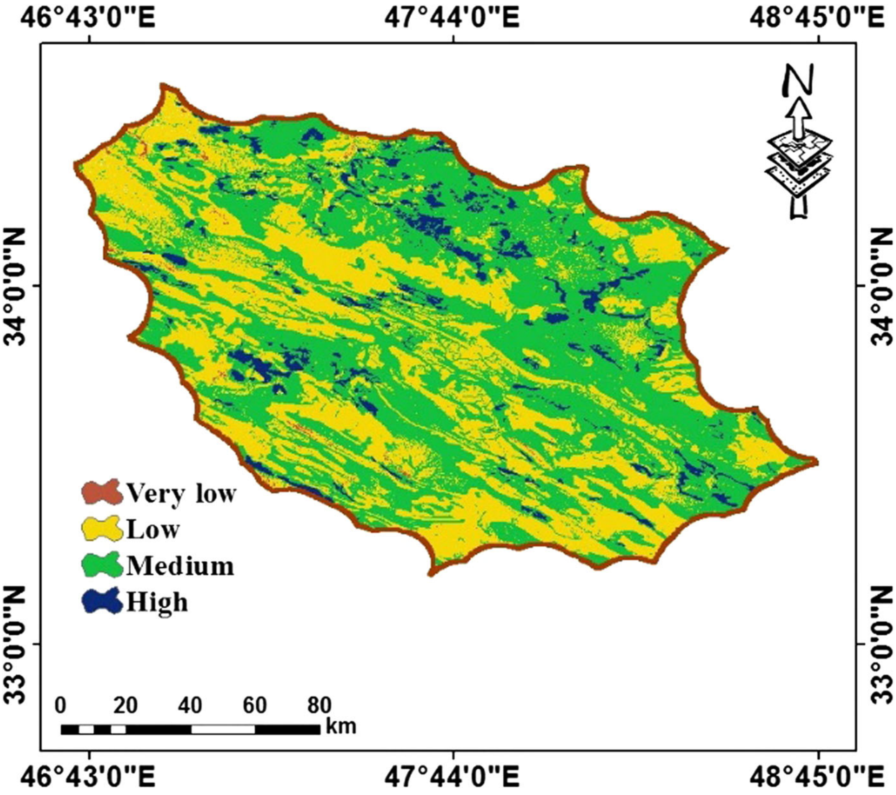


Fig. 9 Map of the fuzzy classification

Fig. 10 The area (%) for each class of the landslide susceptibility

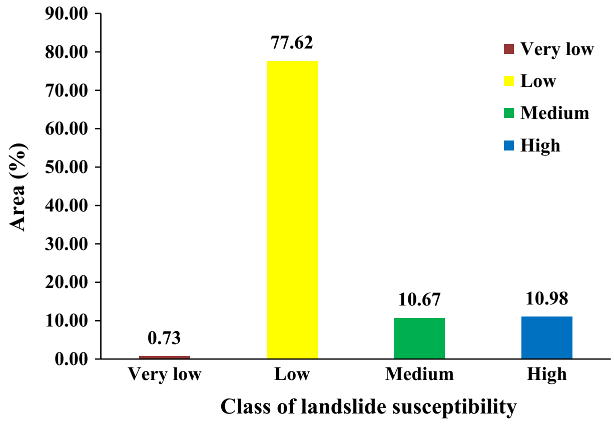


Table 6 The properties of sample points of the case study

Number	Lithology	Precipitation (mm)	Land use	Slope (degree)	Distance to fault (m)	Distance to stream (m)	Distance to road (m)	Aspect	DEM (m)	Classes of fuzzy
1	II	286	Forest	30	4000	520	1000	North	1200	Low
2	II	281	Forest	28	5100	320	1050	Flat	1210	Low
3	I	295	Forest	34	4200	1300	2000	Flat	870	Low
4	II	280	Forest	54	5732	480	1340	Flat	1340	Low
5	I	278	Agriculture	21	5643	2800	1500	Flat	1100	Low
6	II	273	Agriculture	43	5689	521	2010	Flat	1221	Low
7	II	289	Agriculture	52	4256	789	2000	North	1301	Low
8	II	290	Agriculture	18	3980	568	1323	North	1200	Low
9	II	290	Agriculture	32	5678	2345	1560	North	1131	Low
10	II	280	Agriculture	58	3245	645	1800	North	1304	Low
11	I	283	Forest	61	5678	679	1050	North	1225	Low
12	I	289	Forest	36	3456	321	2000	North	921	Low
13	II	280	Forest	61	3980	690	1780	North	871	Low
14	I	289	Forest	28	4620	2000	1920	North	1006	Low
15	II	301	Rangeland	14	1200	400	500	East	2001	Medium
16	III	320	Rangeland	17	2100	290	900	West	1800	Medium
17	IV	342	Rangeland	19	2300	321	570	East	2200	Medium
18	V	356	Rangeland	20	1500	450	920	West	2256	Medium
19	III	378	Rangeland	24	2100	421	480	West	1950	Medium
20	V	345	Rangeland	16	2050	320	456	West	1980	Medium
21	V	420	Rangeland	30	1120	210	89	South	2900	High
22	IV	298	Bare land	38	1400	76	87	South	3200	High
23	VI	280	Bare land	25	1000	79	83	South	3402	High
24	VI	301	Bare land	31	998	91	500	South	3100	High
25	VI	320	Bare land	28	998	30	420	South	3060	High
26	V	421	Bare land	44	876	270	95	South	3251	High
27	VII	400	Bare land	61	789	321	120	South	3400	High
28	VII	421	Bare land	46	2000	673	151	South	3200	High
29	VII	401	Rangeland	32	1400	230	132	South	2980	High
30	VII	420	Rangeland	28	3200	121	123	South	2959	High

case study (Feizizadeh and Blaschke 2013). Chacón et al. (2006), Chamaptiray ray et al. (2006) and Srivastava et al. (2010) using fuzzy to determined landslide susceptibility map that results show that fuzzy AHP is a useful method for prediction of hazardous phenomena such as landslide.

4 Conclusions

Landslide susceptibility mapping has been made possible due to the accessibility and variety of remote sensing and GIS data. Almost all of the landslides are referred to as significant geomorphic processes. This paper evaluated the spatial distribution of the landslide susceptibility with different risk levels by using the fuzzy-AHP method. According to AHP model, the most important factors in landslide susceptibility were lithology and precipitation the least important parameters were DEM and aspect in the study area. The class of landslide susceptibility was predicted by fuzzy-AHP model for each point which showed that 10.98% of the lands had high landslide susceptibility, 10.67% medium landslide susceptibility, 77.62% low landslide susceptibility and 0.73% very landslide susceptibility. Overall, more than half of the study area had medium landslide susceptibility. According the result, it can be concluded that fuzzy-AHP method was suitable for investigation of landslide susceptibility mapping.

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