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Landslide hazards zonation using GIS in Khoramabad, Iran

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Abstract
This research is concerned with the landslide susceptibility of Khoramabad area using Geographical Information System (GIS). Landslide susceptibility zonation (LSZ) is able to identify areas prone to failure based on the characteristics of past events. Satellite data, topographic maps, field data, and other informative maps were used as data layer in this study. These data layers are including lithology, slope, aspect, land use, distance from fault, distance from road and density of river. A numerical rating scheme for the factors was developed for spatial data analysis in GIS method. The resulting landslide susceptibility map delineates the study area are located into different zones of susceptibility classes including high, moderate and low. Based on the prepared landslide hazard zonation map some 32% of the study area shows high landslide susceptibility.

Key words: Landslide susceptibility, Data layer, Geographical information system, Khoramabad.

1. Introduction

Landslides are one of the destructive geological hazards which cause not only enormous damage to roads, bridges, and houses, but also lead to loss of people life. Hence, it is necessary to prepare landslide susceptibility maps for identification of landslide potential hazards. Landslides are resulted of a complex interaction among several factors, primarily involving geological, geomorphological, and meteorological factors. The first step of landslide zonation is identifying and evaluating landslideprone areas and constructing a landslide inventory map for future use. Landslide inventory mapping is the systematic mapping of existing landslides in a region using different techniques such as field survey, air photo interpretation and literature search for historical landslide records (Wieczorek, 1984). In last 10 years, different methods and techniques for evaluating landslide occurrence have been developed and proposed (Hansen, 1984; Varnes, 1984; Hutchinson, 1995; Crozier, 1995). These methods include inventory mapping (direct approach) and a set of indirect, quantitative methods, namely the knowledge-based (index), statistical (data-driven) and deterministic approaches (Carrara et al., 1998). Quantitative methods rely on observed relationships between controlling factors and landslides. Some researches such as Guzzetti et al. (1999, 2005), Van Westen et al. (1997, 2006), Dai & Lee (2002), Santacana et al.(2003), Lee & Pradhan (2006, 2007), Lee et al. (2007), Zhu & Huang (2006), Arora & Gupta (2004), Cheng & Wang (2007) and Farhoudi et al. (2012) have given a complete overview of the different methodologies commonly used in Landslide Hazard Zonation (LSZ). Generally, the purpose of landslide susceptibility mapping is highlighting the regional distribution of potentially unstable slopes based on a detailed study of the contributing factors (Ayalew et al., 2004). Since, susceptibility mapping involves the handling and interpreting of a large amount of data, the use of Geographic information system (GIS) is very important. GIS is a very powerful tool for the integration of different types of data. Over the past few years, there have been significant developments of GIS for spatial data analysis. Efficient landslide susceptibility mapping can be carried out by combining GIS with image processing capabilities. One advantage of assessing landslide susceptibility using GIS is the speed at which calculation can be performed. Additionally, complex techniques requiring a large number of map crossings and table calculations are feasible. The present study is an attempt towards development of a methodology for landslide susceptibility mapping in the study area. This involves the generation of thematic data layers and their spatial analysis within the Khoramabad region, Iran.

2. The study area characteristics

The Khoramabad with some 6322 km2 area and perimeter of 487 km is situated in the central part of Lorestan province, west of Iran (Fig. 1). Geologically, the study area consists of four main types of lithological units: conglomerate, sandstone and siltstone (Amiran and Kashkan formation), Limestone (Asmari and Shahbazan formation), marl and shale (Gurpi formation) and Low level piedmont fan and valley terraces deposits. General geological setting of the area is shown in Figure 2. It is located between longitude 48° 17' and 48° 21' east and latitude 33˚27′ and 33° 35' north. The temperature variation is between –8.5 °C in winter and 24.5 °C in summer and amount of annual rainfall is 499 mm. The aims of the study reported here were to identify and zone the areas susceptible to landslides. In the study area, different types of landslides have been recognized using topographic maps and field surveys. All identified landslides were classified based on their mechanism into four types including slides, rock fall, topple and debris flow (Fig. 3).

3. Material and methods

Because landslides are the result of the interaction of complex factors, the spatial prediction of landslide susceptibility is a difficult task. There are two basic approaches for such a study. One approach is the qualitative map combination where relative weighting values are assigned to the factors and their classes on the basis of field knowledge and experience. The other approach uses statistics to compute the weighting values based on the relationship of the factors with existing landslides. However, if the data set is small and sufficient landslide information is not available, the statistical approach may give erroneous results.

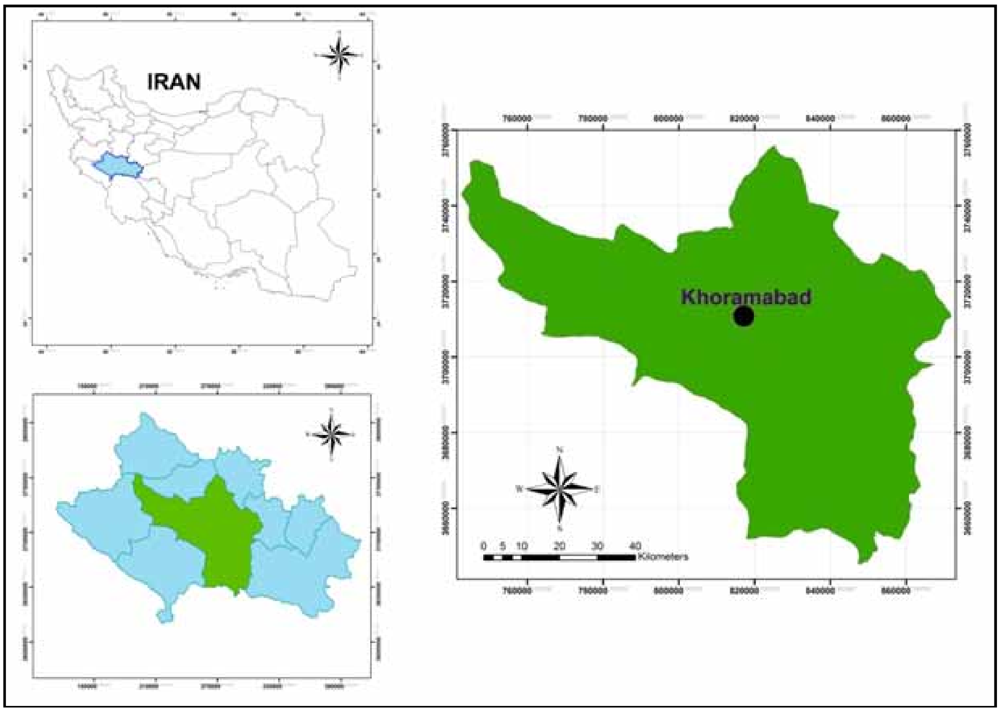

Fig. 1 Location of the study area

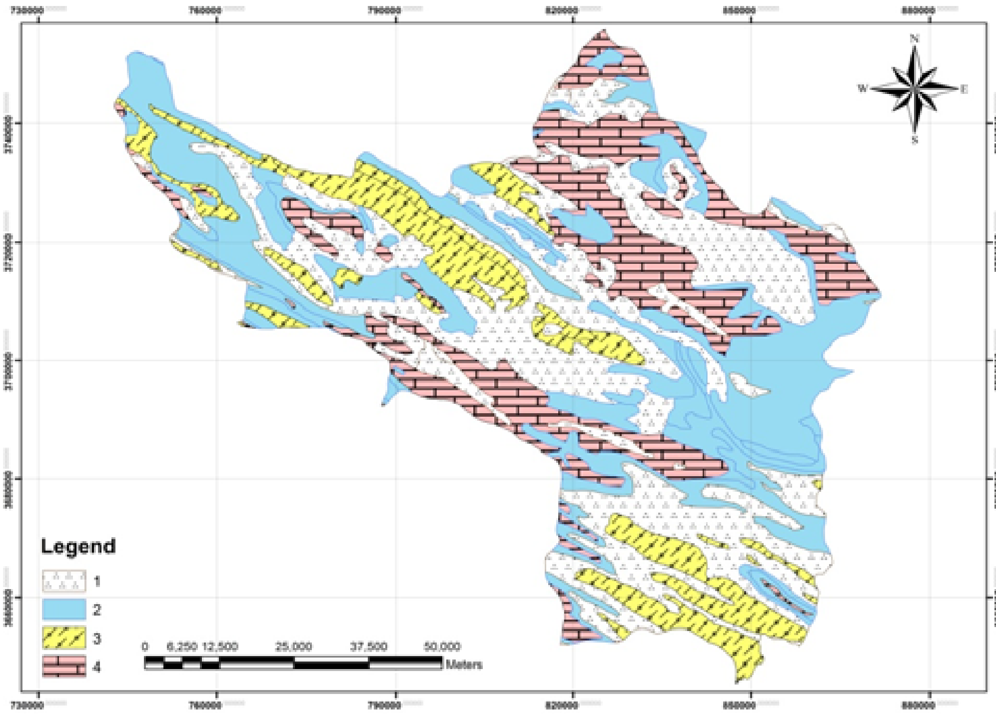

Fig. 2 Lithological classes of study area, 1 (Low level piedmont fan and valley terraces deposit), 2 (Conglomerate, sandstone and siltstone), 3 (Marl and shale), 4 (Limestone)

(a)

(b)

Fig. 3 Examples of landslide types in the study area, (a) Sliding, (b) Toppling and rock fall (Nooryazdan 2006)

In our study we have adopted a technique of qualitative map combination by developing a rating system, which is based on the relative importance of factors influencing slope instability in the study area. The methodology involved selection of factors, generation of data layers in the GIS, numerical rating assignment to factors, data integration in the GIS, computation of the landslide potential index, suitable classification of landslide susceptibility, and validation of the resulting map. An attempt was also made to validate the map with existing landslide distribution (Fig. 4). These steps are shown in a flow diagram (Fig. 5).

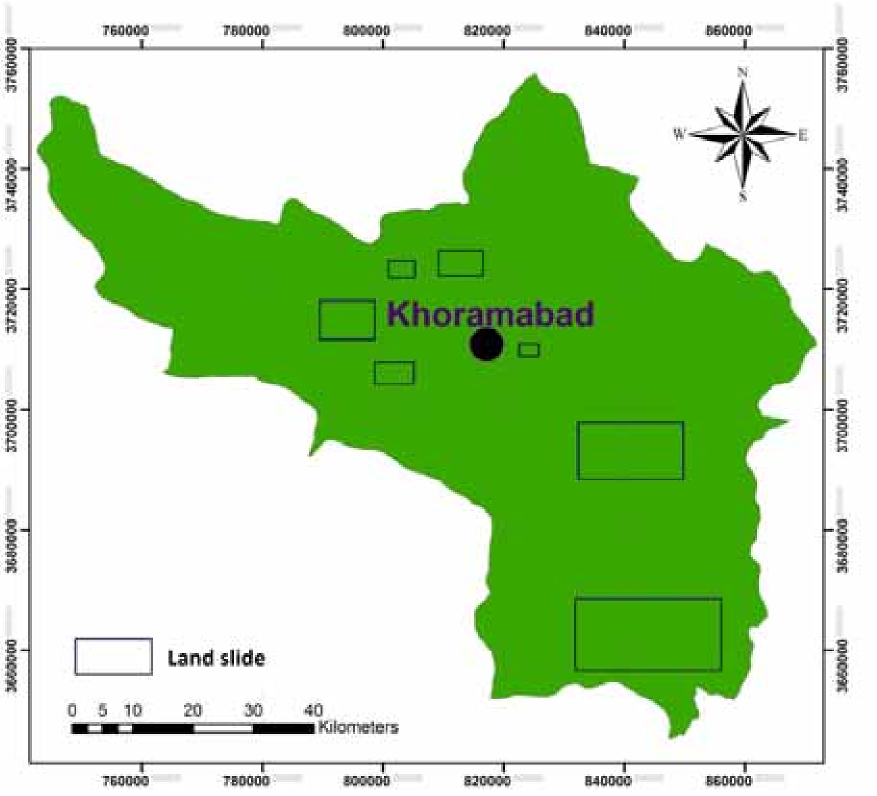

Fig. 4 Spatial distribution of landslides in the study area

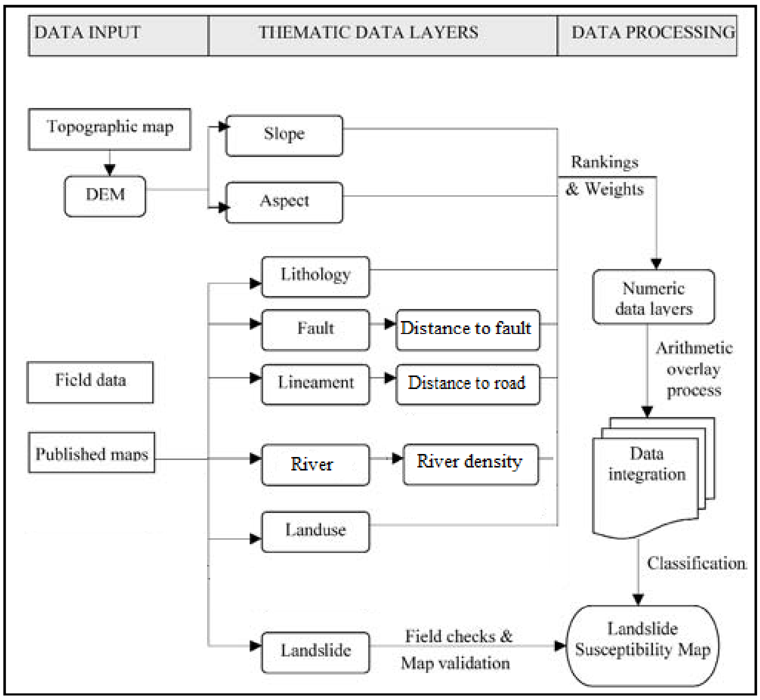

Fig. 5 Flowchart showing the methodology

4. Results and discussion

4.1 Thematic Data Layers

Selection of factors and preparation of corresponding thematic data layers are crucial components of any model for landslide susceptibility mapping. The factors governing instability in a terrain are primarily geology, slope morphology, drainage, land use, anthropogenic activity, seismicity, and climatic condition. These factors can be broadly grouped into two categories: the preparatory factors which make the slope susceptible to movement and the triggering factors which set off the movement (Crozier 1986).

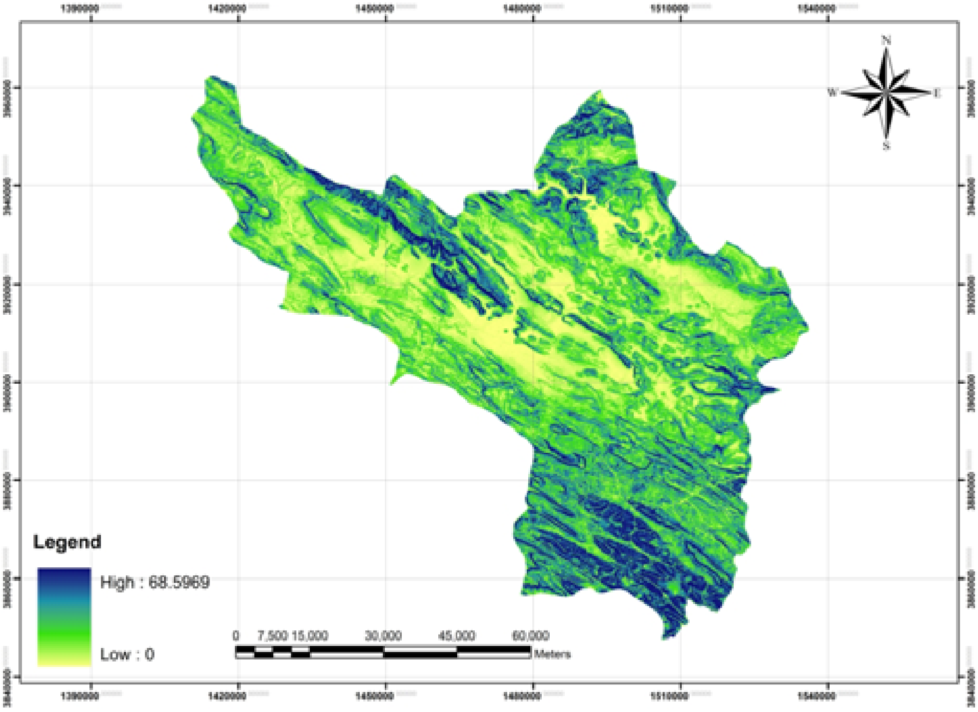

Fig. 6 Slope map of the study area

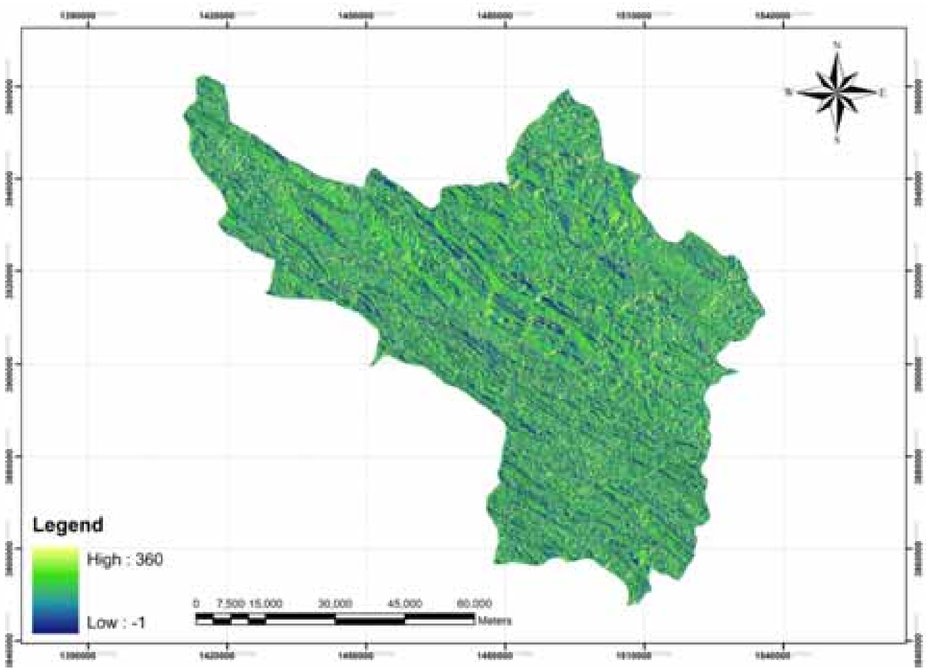

Fig. 7 Aspect map of the study area

The factors considered in this research are essentially the preparatory factors for which pertinent data can be collected from available resources as well as from the field. These were slope, aspect, lithology, drainage density, lineament density, presence of faults and land use. The selection of these factors and their classes was primarily based on the field observations of existing landslides and their associated terrain factors. Based on the information collected from available maps, satellite data, and field investigations, thematic data layers were generated. The mapping was done at a scale of 1:25,000. The details of these layers are described in the following paragraphs. Lithological data were obtained from the geological map of the region (1:100000). The lithology is a fundamental instability factor in landslides analysis. There are four lithological units types present in the study area. These are low level piedmont fan and valley terraces deposit: conglomerate, sandstone and siltstone, shale and marl, limestone (Fig. 2). Road maps were obtained from topographical maps of the basin. Most landslides occurred on cut slopes or embankments alongside roads in mountainous areas. The construction of the main and secondary roads on steep slopes can be considered as the most important causative factor in the basin (Table 1 and Fig. 8). Land use/cover greatly influences slope behavior at every scale. In this study, land use/cover map was obtained from satellite images in conjunction with supervised classification and field works.

Table 1 The summary of input layers used in analysis and their weights

Id	Factor	Classes	Weight
1	Lithology	1	4
2	Slope (°)	<5	1
		5-15	2
		15-25	3
		25-35	4
		>35	5
3	Fault (m)	<500	5
		500-1000	4
		1000-2000	3
		2000-5000	2
		>5000	1
4	Landuse	Low forest	5
		Agriculture	3
		Urban area	1
		Dense forest	2
		Dryfarming	4
5	Distance from Road (m)	<500	5
		500-1000	4
		1000-2000	3
		2000-5000	2
		>5000	1
6	Density of River (%)	<0.04	1
		0.04-0.2	2
		>0.2	3
7	Aspect	Flat(-1 – 0)	1
		N (0-90)	2
		(90-180)	3
		(180-270)	4
		(270-360)	5

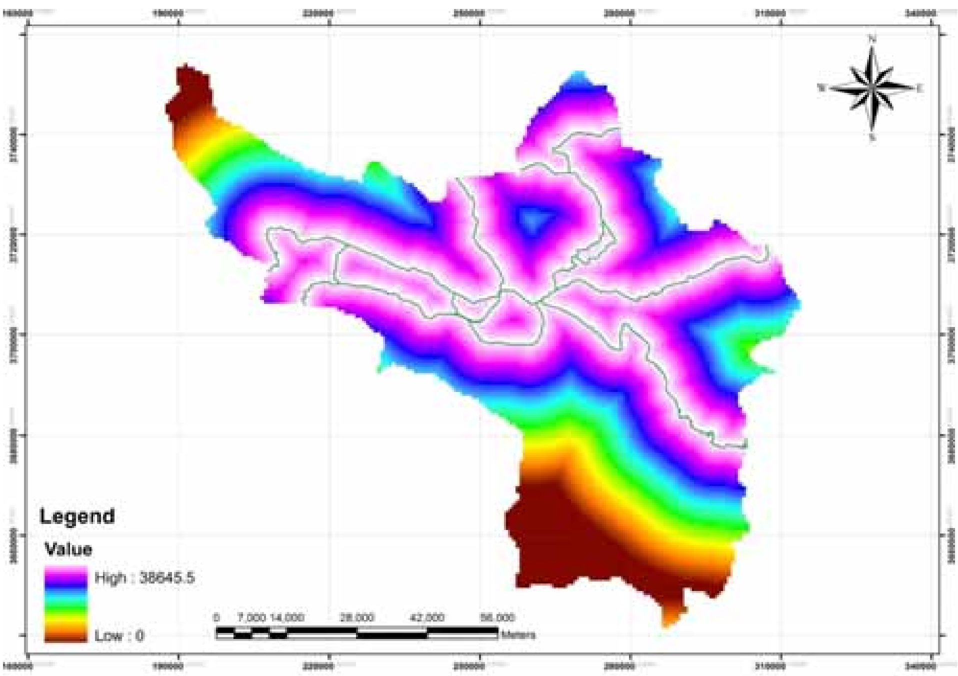

Fig. 8 Road map of the study area

Land use/cover was classified in to 5 classes including low forest area, dense forest area, agricultural area, urban area and dry farming area (Table 1 and Fig. 9). Data for fault and river layer were obtained from geological maps of the area (1:100000). The fault is an important factor in landslides hazard zonation. In this study, fault factor was classified in to 5 classes as shown in Table 1 and Figure 10. Also, based on the prepared rivers density map, the amounts of density were classified in to 3 classes which are shown in Table 1 and Figure 11.

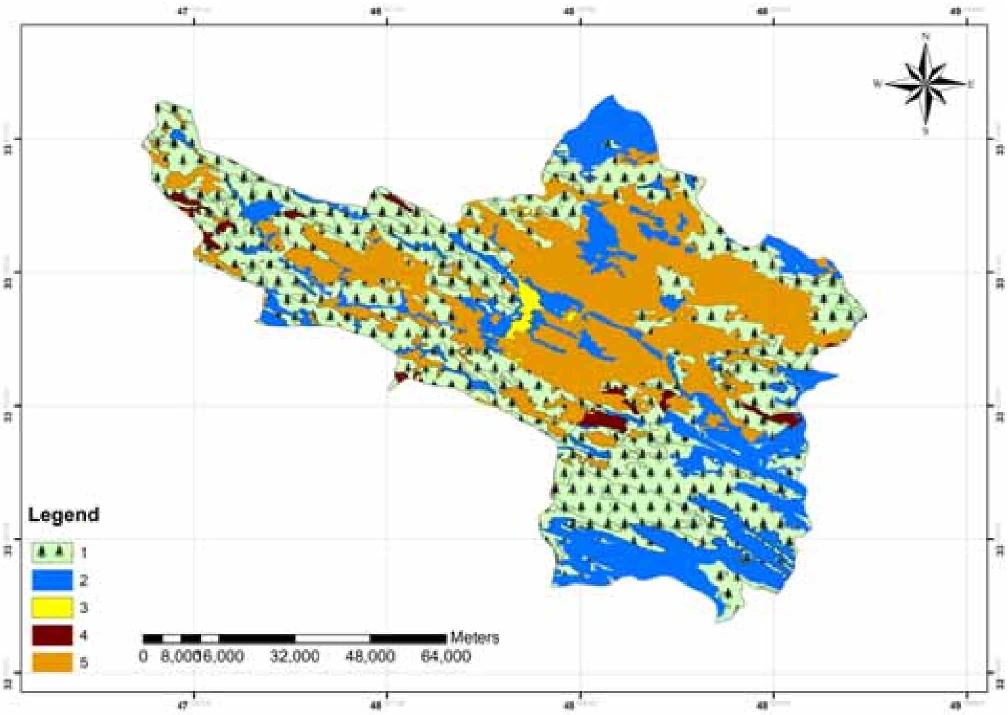

Fig. 9 Landuse map of the study area: 1 (Low forest), 2 (Agriculture), 3 (Urban area), 4 (Dense forest), 5 (Dry farming)

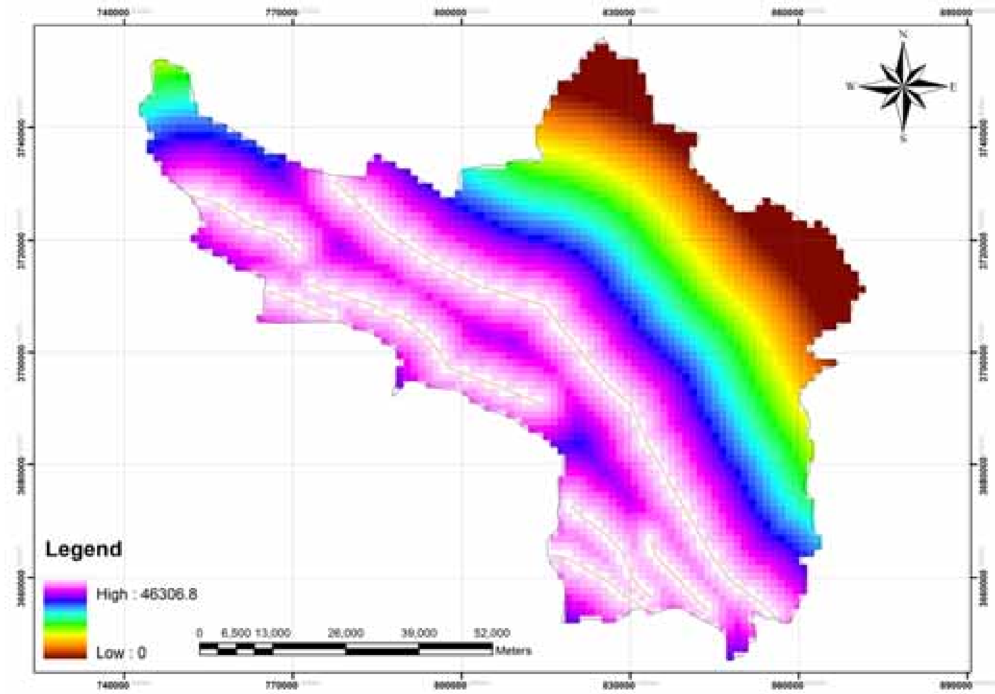

Fig. 10 Faults map of the study area

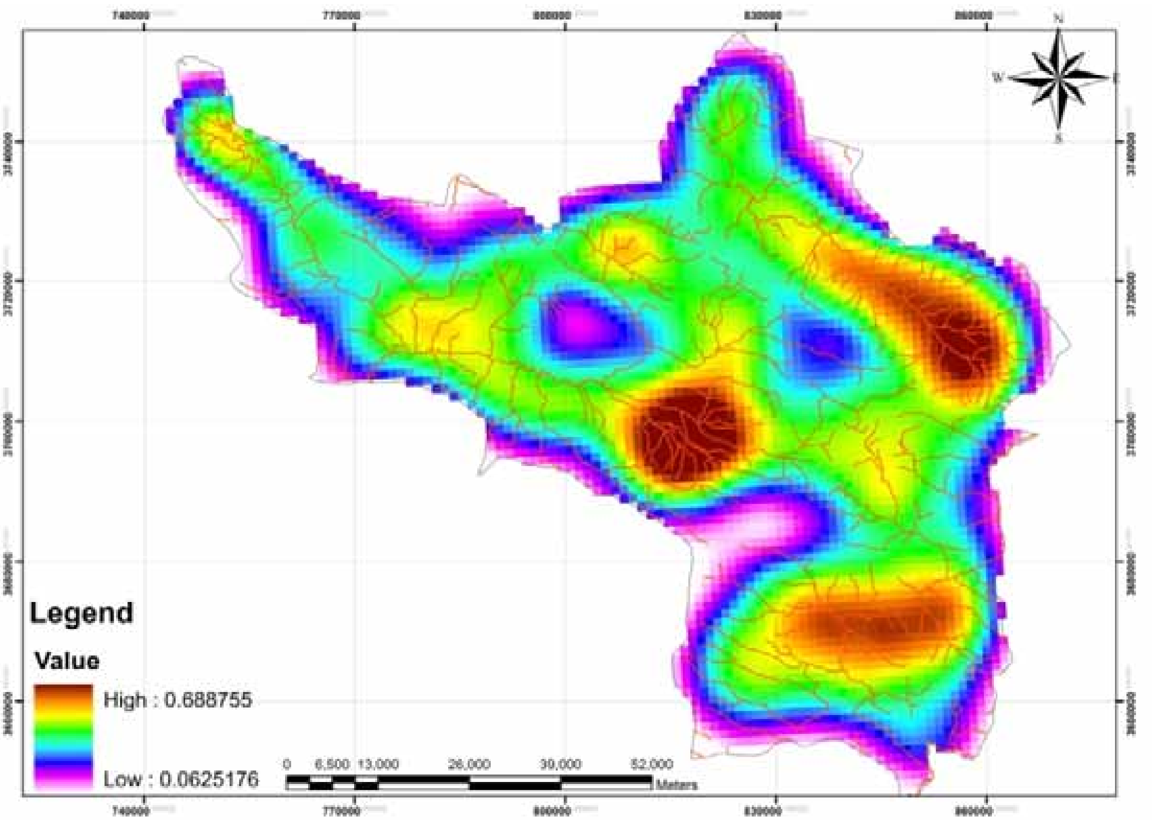

Fig. 11 Density river map of the study area

4.2 Numerical Rating Scheme

The identification of potential landslide areas requires combining the considered factors in accordance with their relative importance to landslide occurrence. This can be achieved by developing a rating scheme in which the factors and their classes are assigned numerical values. A rating scheme was developed based on the associated causative factors for landslides surveyed in the field and on the knowledge from previous work. In this scheme, the factors were assigned a numerical ranking on 1 to 5 based on their importance (Table 1). Weights were also assigned to the classes of the factors on 1 to 7 ordinal scales where higher weight indicates more influence towards landslide occurrence (Table 2).

Table 2: Attribute data of parameters for landslide susceptibility

Id	Factor	Rank
1	Lithology	7
2	Slope (°)	6
3	Fault (m)	5
4	Density of River (%)	4
5	Landuse	3
6	Distance to Road (m)	2
7	Aspect	1

The scheme was suitably modified by undertaking several iterations using different combinations of weights.

4.3 Landslide Susceptibility Mapping

The numerical data layers representing weight values of the factor classes as attribute information were generated from the thematic data layers for data integration and spatial analysis in the GIS. The input data layers were multiplied by their corresponding ranks and were added up to obtain the Landslide Potential Index (LPI) for each cell: i.e.,

$$LPI = \sum_{i=1}^{7} (R_i \times W_{ij}) \quad (1)$$

Where Ri is the rank for factor i and wij are the weight of class j of factor i. In this study, The area was classified into high, moderate and low landslide susceptibility. The landslide susceptibility map, which delineates the relative potential zones for landslide occurrence, is shown in Figure 12. Also distribution of susceptibility classes in the study area is shown in Figure 13. As it can be seen from Figure 13, the areas with medium to high susceptibility are dominant.

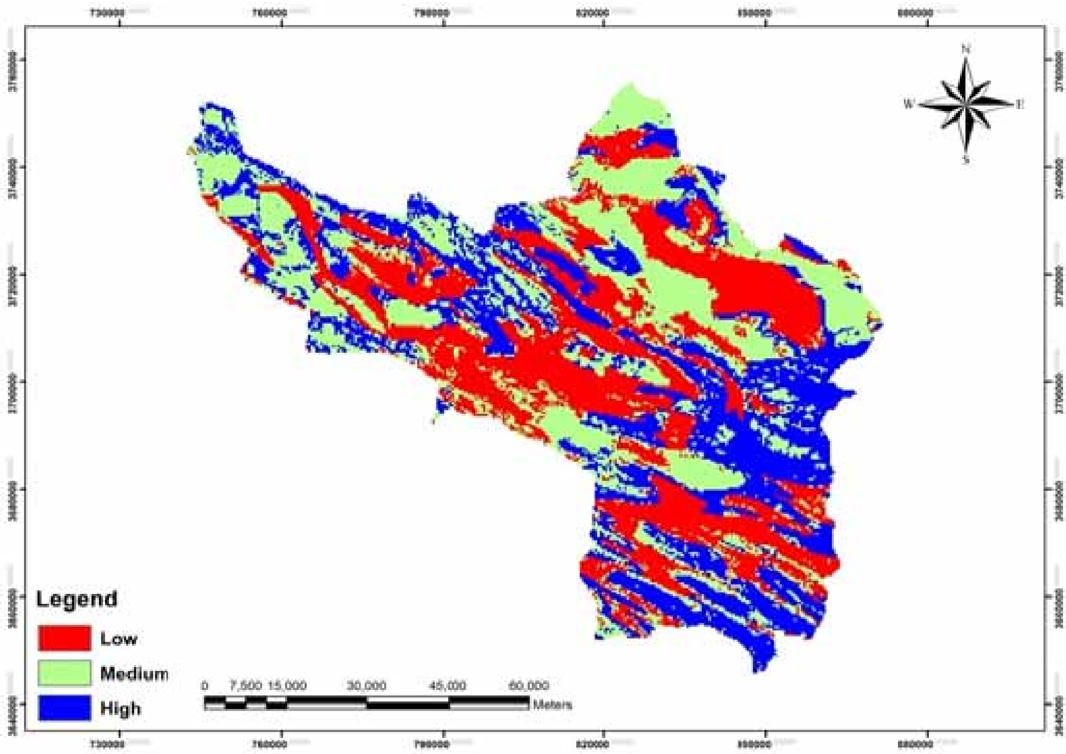

Fig. 12 Landslide susceptibility map of Khoramabad region.

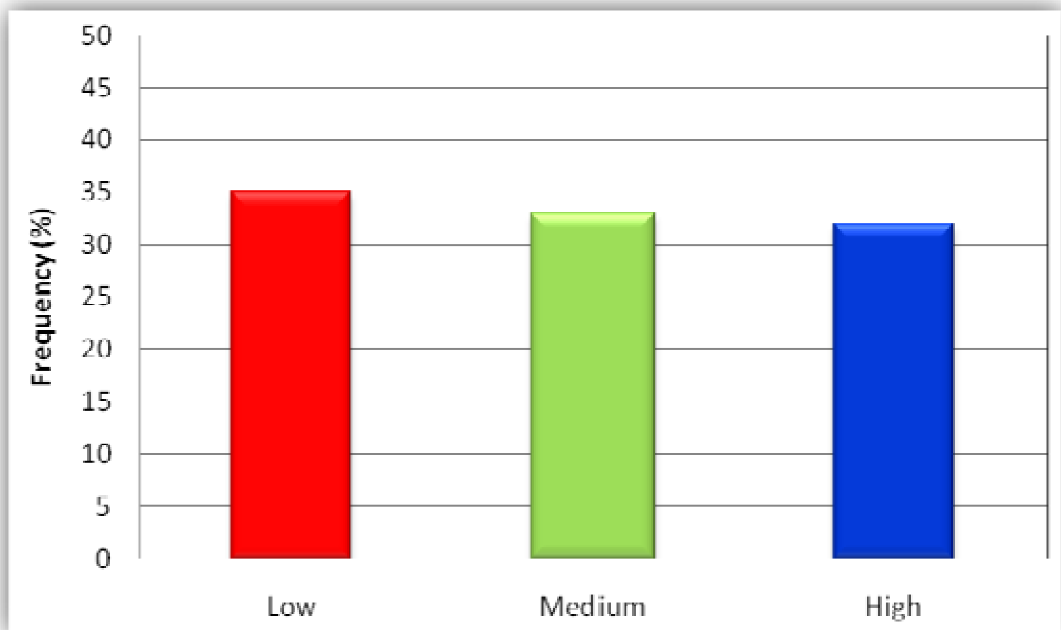

Fig. 13 Distribution of susceptibility classes

5. Conclusions

The methodology for landslide susceptibility mapping presented here involves the generation of thematic data layers, development of a suitable numerical rating scheme and finally spatial data integration. Based on the results, application of GIS was found immensely useful for thematic data layer generation and for their spatial data analysis, which involved complex operations. In this study, seven parameters such as lithology, slope, aspect, land use, roads, fault and river were considered. The results of the entire analysis and evaluation allowed dividing the study area into three zones of susceptibility: low (35%), medium (33%) and high (32%). The result was validated on the basis of landslide distribution in the area. Validity of the results shows that areas with high susceptibility are match with the occurred landslides. The landslide susceptibility maps help in decision making, while implementing a development project in the terrain. It is always better to avoid the highly susceptible zones but, if not possible, corrective measures must be worked out to minimize the probability of landslide occurrences.

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