Research Journal of Applied Sciences 12 (2): 161-173, 2017
ISSN: 1815-932X

Landslide Hazard Zonation by Using AHP (Analytical Hierarchy Process) Model in GIS (Geographic Information System) Environment (Case Study: Kordan Watershed)

[1]Ehsan Amir Yazdadi and [2]Ezatollah Ghanavati
[1]Department of Geomorphology, Azad Eslami University, Tehran Center Unit, Tehran, Iran
[2]Department of Geomorphology, Kharazmi University, Tehran, Iran

Abstract: Landslides are one of the critical phenomena that frequently lead to loss of human life and property as well as causing severe damage to natural resources. Kordan watershed located in the Alborz Province which including areas that are prone to landslide. The area under investigation is located from 50°45-05°51' East longitude and 35°55'-36°05' North with expansion of about 488 km^2 and elevation ranges from 1320-3900 m. The purpose of this study is to identify factors in landslides and zonate landslide hazard of Kordan watershed using AHP (Analytical Hierarchy Process) model in GIS environment. In this study, 4 factors, namely geology, hydrology, human and geomorphology were identified as important factors that could play an important role in Landslide watershed. In this study, geological mapping, using topographic maps and satellite images of the study area and data layers of various factors including lithology, fault, land use, roads, residential areas, slope aspect, elevation, rainfall, temperature, congestion and drainage system in GIS using ArcGIS Software has been developed and weight and relative importance of each factor in landslide hazard zonation with Analytical Hierarchy Process (AHP) were determined. Among the effective factors, sub-criteria of lithology, distance from the river, distance from fault, landuse and rainfall, respectively with weights 0.314, 0.219, 0.105, 0.086 and 0.054 have been identified as the most important factors in the development of landslide in study area that In total, form up >75% of the total weight. The role of other factors reduces according to their weights in landslide. The final cumulative map of study area was categorized into four hazard zones and classified as zone 1-4 (very low risk, low risk, medium risk and high risk). According to presented model and final zonation map, about 34% (30 km^2) of Kordan watershed area have the occurrence of high risk and about 29.16% (142.386 km^2) have the occurrence of moderate risk. As a result of the zonation performed according to the layers, most sensitive parts of the landslides are locted in the basin quaternary deposits and the banks of rivers. The landslide hazard zonation map is useful for landslide hazard prevention, mitigation and improvement to society and proper palnning for land use and construction in the future.

Key words: Zonation of landslide, Alborz, Kordan, analytical hierarchy, process

INTRODUCTION

Landslide is the major disaster event which frequently occure in the hilly areas. Outward and downward movement of mass consisting of rocks, slop instability and soils due to natural or manmade causes is termed as landslides. These events are associated with pre and post of earthquake, soil erosion, rainfall and anthropogenic activities (Rahamana *et al*., 2014). Mass movements, especially landslides are one of the most damages of them that have had the increasing momentum together human manipulation in natural systems in recent decades. So that is one of the prinicipal geomorphic processes in the mountainous areas. Landslides phenomenon occurring in many parts of the world and Iran in the favorable conditions couses the destruction of vegetation, orchadss, farmlands and even human casualities (Hatamifar *et al*., 2012). According to UNESCO, about 2,378 people worldwide in 1971, 4 years have died due to landslides. The giant landslide of Seimareh (in Luristan province) one of the great and well known landslides in the world (which is 20 and a width of 15 km) that happened in Zagros Mountains SouthWest of Iran (Shayan, 2006). Of course it did not reportany direct damage (Boroushaki and Malczewski, 1999).

Because of its specific geologic, morphologic, climatic and tectonic settings, Iran is one of the most landslide-prone areas in the world. This phenomenon

Corresponding Author: Ehsan Amir Yazdadi, Department of Geomorphology, Azad Eslami University, Tehran Center Unit, Tehran, Iran

every year in most provinces economic damages to roads, railways, power lines and communications, irrigation canals and water supply, mining facilities, mining facilities, oil refining and gas networks vital arteries of the cities, factories and industrial centers, dams and artificial lakes and natural forests and natural resources and rural farms and residential areas have been or are threatened that they. According to estimates, landslides have imposed much financial damages about 500 milliard Rials to Iran, annulaly (Hatamifar *et al*., 2012).

In Iran, most of the landslides are concentrated on the rim of the Alborz and Zagros mountains. Landslides are common features in the Alborz Mountains of Iran. The Kordan watershed in the Alborz Basin, due to its geological location, geomorphology, topoghraphy, climate, active tectonics, vegetation and dense population, the area suffers a number of natural hazards of different types, including all kinds of mass movement. Since, it is difficult to accurately prediction of the time of the landslide hence it is important identify areas susceptible to this phenomenon and its zoning according to the potential (Mostafaei *et al*., 2010).

Since, the exact prediction of landslides occurrence isn't possible by human sciences thus, we can prevent from the damages of this phenomenon by identification of landslide susceptible areas and prioritizing them.

Landslide hazard zonation maps can help the environmental designers and engineers to select a suitable place for development projects implementation. The results of these studies can be used as fundamental information by environmental managers and planners (Pradhan, 2011). Finally, identify areas with landslide high potential and avoid possible dangers that can be done.

Landslide hazard zonation was challenged by several researchers in recent years. In order to provide landslide hazard zonation maps various methods such as fuzzy logic, statistic methods and Analytic Hierarchy Process (AHP) can be used. Since, the early 1970s, many scientists have attempted to assess landslide hazards and produced hazard zonation maps portraying their spatial distribution by applying many different GIS based methods. Different models and methods have been proposed to produce landslide hazard zonation. One of these methods is the AHP that was used by Saaty (1980), Barredo *et al*. (2000) and Yalcin (2008). Complete overviews of the use of GIS for landslide hazard zonation can be found by Dai *et al*. (2001), Ayalew and Yamagishi (2005) and Moradi and Rezaei (2014). The AHP is a theory of measurement for dealing with quantifiable and intangible criteria has been applied to numerous areas such as decision theory and conflict resolution (Vargas, 1990). Using this method, each layer used in landslide susceptibility zoning is broken into smaller factors, then these factors are weighted based on their importance and eventually the prepared layers are assembled and the final map is produced. It is based on three principles: decomposition, comparative judgment and synthesis of priorities (Malczewski, 1999). In this method, weight of each layer depends on the judgment of expert, so that the more precise is the judgment, the more compatible is the produced map with reality (Moradi *et al*., 2012).

In Iran, studying in the field of landslides and mass movements is very young and have been started seriously from the early of 90 decade (1992-2002). Among the Iranian researchers involved in the issue of landslides and mass movements can be named Shemirani, Moghaddasi, Haghshenas (Shariatjafari, 1997) Karam, Shamsipour and Ghanavati.

The purposes of this study are the recognition of effective factors in landslide and the zonation of Kordan watershed in terms of the occurrence of this phenomenon using AHP model and GIS technique. Therefore, selection of criteria and standards, providing of factors raster layers, determining of relative and final weight od factors, overlaying of layers and preparing landslide hazard zonation map are the major objectives of this research to determine sensitive sites that have the maximum occurrence probability of landslide.

Discription of the study area: The study area is Kordan watershed that is located at the Central Alborz region. Present study area fallows under 35°55'-36°05' North latitudes and 50°45'-05°51' East longitudes covers an area of 488 km^2 (Fig. 1). Topography of the study area is relatively steep with elevation range from 1320-3905 m. The higher elevations are in the North. The main stream is the Kordan river which flows from North to South are used for agricultural activites.

Rainfall means in the study area is 450 mm that the most rainfall in Esfand and the lowest rainfall on summer 141, 20 mm, respectively. The absolute maximum and minimum tempreture in the study area is 38 and -13°C, respectively and the yearly average temperature is 13°C. The original climate is semi-arid, Mediterranean, semi-humid and very wet climates in Domarten view climate. The study area is located in the Central Alborz. This area is one of the most active seismo-tectonic provinces in Iran. The mountain belt is part of Alps-Himalayas mountain chain with similar seismic

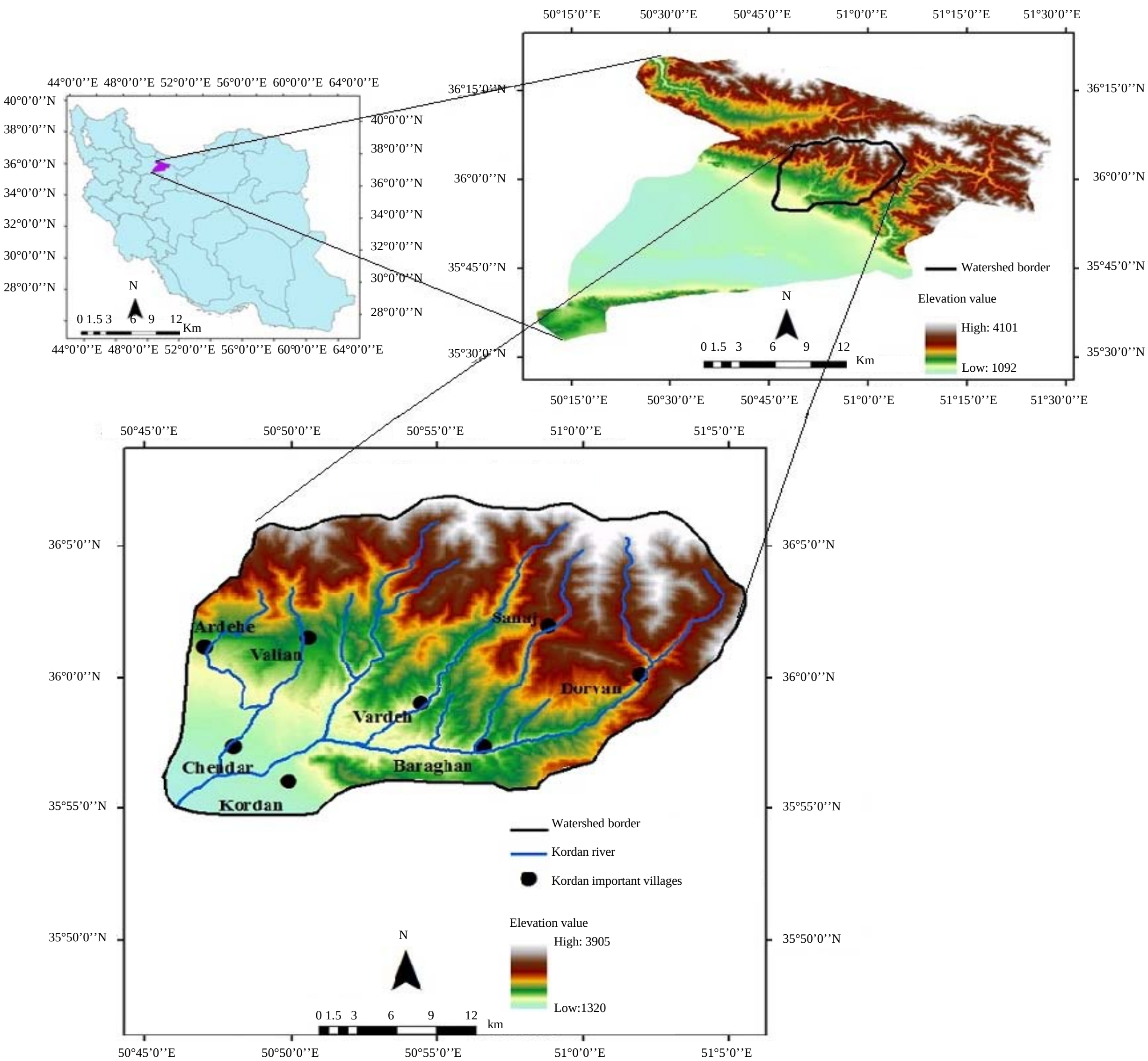

Fig. 1: The location map of the study area in Iran

activity which comes as a direct consequence of its tectonic setting. The geology of the area consists of tuff formations andesite, sandstone, shale and aging from the the precambrian to the quaternary.

MATERIALS AND METHODS

At first, study area was investigated and determined its extent using satellite images of google earth and 1:50000 topographic maps. Then, according to geological, geomorphologic, hydrological, climatic, human and environmental characteristics of study area and using comparative studies and results of other researchers, 5 criteria and 13 sub-criteria were identified to achieve the goals. The needed layers of landslide hazard zonation were prepared using ArcGIS9.3 Software. These layers are slope, aspect, elevation class, lithology-geology, distance from fault, rainfall, distance from village, distance from stream, stream density, distance from road, soil type (land units), landuse, isotherm map (Fig. 2). Also, effecting factors were evaluated through AHP model and their weights were determined. Finally, the landslide hazard zonation map of study area was presented using weight exertion of factors in their layers and integration of them by ArcGIS Software.

The next step after the selection of factors was the prepration of the thematic maps in which the factors were classified into several classes. The data used for the preparition of theses layers were obtained from

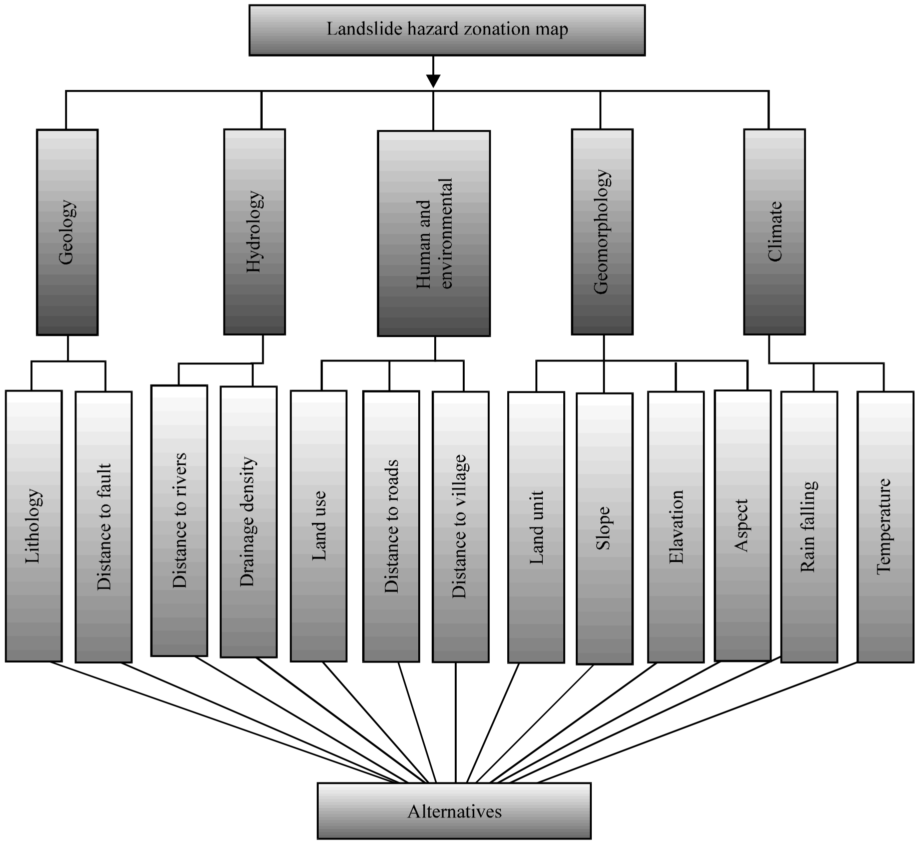

Fig. 2: Evaluation criteria for landslide hazard zonation map

topographical base maps, geological maps, satellite images, rainfall data, personal feildwork. The thematic maps corresponding to slope and aspect and elevation were derived directly in raster format from the produced Digital Elevation Model (DEM) while the others were produced by the vector format digitization transformed into the raster format.

The next step was to assign weight values to the raster layers (representing factors) and to the classes of each layer, respectively. This step was realized with the use of the AHP method. The AHP is a structured technique for dealing with complex decisions that was developed by Thomas. This technique is based on pair-wise comparison of the contribution of different factors and gives various scenarios to the decision-makers.

This technique is one of the most comprehensive algorithms designed for decision-making with multiple criteria because the possibility of formulating a hierarchy provides natural complex issues and also consider the issue of qualitative and quantitative criteria (Satty, 1986). Since, there is no linear relationship between the landslide and the factors influencing them therefor, the usual statistical approach can not solve all the problems. In this respect AHP model provides conditions that can to determine the landslide hazard zonation map with more details.

RESULTS AND DISCUSSION

In this study, AHP is used to determine the weights of each of the layers in landslide hazard zonation in the Kordan watershed. First step in AHP is the decomposing of decision problem into a hierarchy of more easily comperhenced sub-problems, each of which can be analyzed independently. Overall form of hierarchy can be as following (Bowen, 1990; Dyer and Forman, 1990):

- The goal, criteria, sub-criteria, alternative
- The goal, criteria, factors, sub-factors, alternative

Present study has been used first structure for landslide hazards zonation of Kordan watershed. So that, the overall goal is to identify areas of landslide as the first level, five criteria are geological, human environmental, geomorphological, hydrology and climate as the second level and 13 sub-criteria have been considered as the third level (Fig. 2).

Alternatives are the result of the analysis in the GIS database. Each layer contains attribute values that are assigned to alternatives and each alternative (cell or polygons) is associated with a high level elements.

AHP is a well-known multi-attribute weighting method for decision making. The analytic hierarchy process is a theory of measurement for dealing with quantifiable and intangible criteria and has been applied to numerous areas including decision theory and conflict resolution (Vargas, 1990). AHP is a multiobjective, multi-criteria decision-making approach that enables the user to arrive at a scale of preference drawn from a set of alternatives. AHP has gained wide application in site selection, suitability analysis, regional planning and landslide susceptibility analysis (Ayalew and Yamagishi, 2005). To apply this approach, it is necessary to break a complex unstructured problem down into its component factors, arrange these factors into an order hierarchy, assign numerical values to subjective judgements on the relative importance of each factor and synthesize these judgements to determine the priorities to be assigned to these factors (Saaty, 1986). Pairwise comparisons are used in this decision-making process to form a reciprocal matrix by transforming qualitative data to crisp ratios. The reciprocal matrix is then solved by a weight finding method for determining the criteria importance and alternative performance (Vahidnia *et al*., 2009). Once the pairwise comparison matrix is obtained based on the problem elements, the aim is to summarize preferences so that each element can be assigned a relative importance (Boroushaki and Malczewski, 2008). The eigenvalue method is one way to access ultimate weights of criteria. In the AHP, measure of weighting to each informational unit is based on which role that this unit plays in this layer and the most weight is for which layer that has maximum effect in determination of goal.

In this method, weight of each layer depends on the judgment of expert, so that the more precise is the judgment, the more compatible is the produced map with reality (Moradi *et al*., 2012). To weighting determinant parameter in landslide, a questionnaire containing table of paired comparisons in critera and sub-critera were presented to experts. In these comparisons, the decision makers use oral judgment. Such judgments has become slightly between zeros to nine by Saaty (2000). In the construction of a pair-wise comparison matrix, each

Table 1: Nine-point scale of preference between two parameters in AHP (Saaty, 1980)

Scales	Degree of preferences	Explanation
1	Equal Importance	The two criteria have the same importance in attaining the goal
3	Moderately more important	Based on experience, i is more important than j in attaining the goal
5	Strongly more important	Based on experience, i is strongly more important than j in attaining the goal
7	Very strongly more important	Based on experience, i is very strongly more important than j in attaining the goal
9	Extremely important	Absolute importance of i over j has been proved
2, 4, 6, 8	Intermediate values	When intermediate intervals exist
Reciprocals	Opposites	Used for inverse comparison

Table 2: Pairwise matrix of landslide controlling criterias in expert choice 11

Variables	Geology	Hydrology	Manmade	Geomorphic	Climate
Geology	-	2	3	4	5
Hydrology	-	-	2	3	4
Manmade	-	-	-	2	3
Geomorphic	-	-	-	-	2
Climate	Incon: 0.02	-	-	-	-

Table 3: The list of Effective and important alternatives recognized in the each sub-criteria and their final weights

Final weight	Score	Effective alternative (class)	Sub-criteria
0.1046	5	Quaternary sediments	Lithology
0.0730	5	0-100 m	Distance to river (m)
0.0350	5	0-500 m	Distance to fault (m)
0.0287	5	Low and moderate density pasture	Landuse/land cover
0.0180	5	>800 mm/year	Rainfall
0.0157	5	0-50 m	Distance to village (m)
0.0150	5	Mountain	Soil type (land unit)
0.0147	5	>25 km^{-1}	Drainage density
0.0090	5	>30°	Slope (°)
0.0087	5	0-50 m	Distance to road
0.0053	5	3388-3905 m	Elevation (m)
0.0030	5	North	Aspect
0.0027	5	-0.3-3°C	Tempreture
0.3334	Sum	-	-

factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell (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 (Table 2).

After identifying the main factors that affect landslides in the study area and weighting factors for prioritizing these factors relative to each other pairwise comparison matrics formed for criteria and sub-criteria. After the formation of pairwise comparison matrices, using the exeprt choice 11.0 Software the relative weight and final parameters were calculated. The resulting pairwise comparison matrix for landslide analysis in Kordan watershed is shown in Table 2.

The final result consists of the derived factor weights and class weights and a calculated Consistency Ratio (CR) as seen in Table 3. In this research, we used standard weights obtained from the AHP. One of the strengths of AHP is that it allows for inconsistent relationships while at the same time, providing a Consistency Ratio (CR) as an indicator of the degree of consistency or inconsistency. In AHP, the consistency used to build a matrix is checked by a consistency ratio which depends on the number of parameters. For a 5×5 matrix, the CR must be <0.1 to accept the computed weights. The models with a CR >0.1 were automatically rejected while a CR <0.1 were often acceptable (Rahamana *et al*., 2014). In this study, the CR is 0.02, the ratio indicates a reasonable level of consistency in the pair-wise comparison that is good enough to recognize the factor weights. The criterias final weight calculated using expert choice software and is shown in Fig. 3.

Due to Fig. 3, the relative weight of geological criteria is calculated 0.419 and allocated the highest relative weight. Then the hydrology, human and environmental, geomorphology and climate citerias respectively allocated 0.263, 0.160, 0.097 and 0.062 weights. In the second step, pairwise comparison is repeated as critera for sub-criteria. Finally the sub-criterias final weight calculated using expert choice software and is shown in Fig. 4.

The final results extractd from AHP model showed that among the criteria and sub-criteria, geological factor and lithology factor with 0.419 and 0.314 allocated the greatest weights to each others. With using of landslide area percentage in each class of different factors, all classes were valued from 0-5. In this case, the class of each factor that had a maximum percent of landslides area was contained the maximum value 5 and proportional with that to each the other classes with regard to their landslides percentage were given different values.

In the next step, the map layers used in the landslide analysis were weighted using the weights derived from through the AHP process. Effecting factors were evaluated through AHP model and their weights were determined. Finally, the landslide hazard zonation map of study area was presented using weight exertion of factors in their layers and integration of them by ArcGIS Software. According to Fig. 5 and Table 4 landslide hazard zonation map of Kordan watershed is categorized into four zones: high, medium, low and very low. The obtained landslide hazard zonation map indicate that the high risk zones cover about 6.34% (30 km^2) of the total area while about 29.16 % (142.386 km^2) were classified as being the moderately risk and 50.18% of the case study area (244.994 km^2) are classified as low susceptible and 14.32% of the case study area (69.957) are classified as very low risk. The layer of effective above factors in landslide hazard zonation along with comparison and their impact on the final map is given.

Lithology: Lithology is one of the most important parameters in landslide studies because different lithological units have different degrees of susceptibility (Dai *et al*., 2001). In this study, the basic data used to

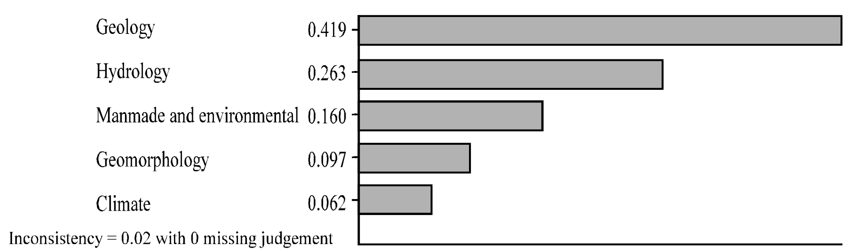

Fig. 3: Expert choice 11 outputs indicating final weights of criterias; priorities with respect to; goal, landslide hazard zonation

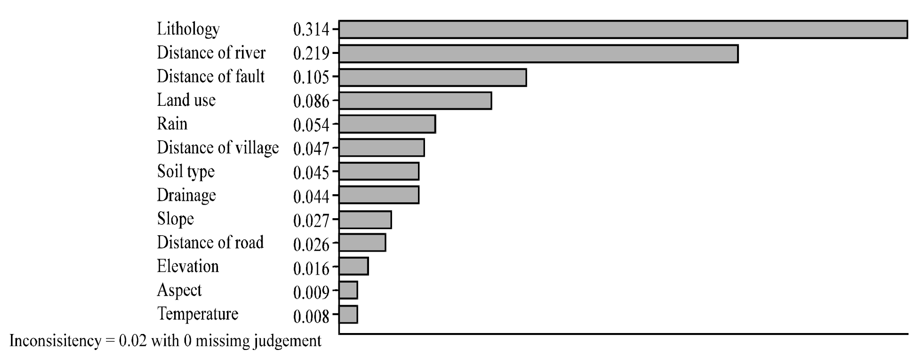

Fig. 4: Expert choice 11 outputs indicating final weights of sub-criteria; synthesis with respect to: goal: landslide hazard zonation; overall inconsistency = 0.01

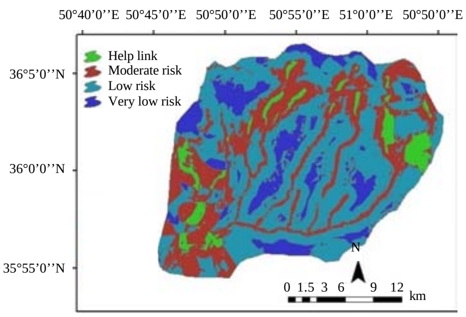

Fig. 5: The landslide hazard zonation map produced by the AHP

Table 4: The classes of landslide hazard zonation and each area percent

Hazard zones	Area (km^2)	Area (%)
Very low hazard	69.975	14.32
Low hazard	244.994	50.18
Medium hazard	142.386	29.16
High hazard	30.875	6.34

generate the original map in a vector format were obtained from existing geological maps published by national geoscience database of Iran organization (scale: 1: 100,000). In the geological map produced, formation was grouped into lithological units based on dominant lithology to the following five categories which have different susceptibilities to landsliding (Fig. 6).

In this classification, the most score belong to quaternary rocks and sediments (13.4% of study area) that is quaternary rocks and sediments are more reliable to landsliding. Because of the geologically reason quaternary rocks and sediments are very young, not very stiff and are unstable. Most of study area (over 69%) is formed of the geological formations (for example; Karaj, Kohar and ...) that composed of shale and limestone with tuff units have a moderately susceptible to landslides (Fig. 6). Due to that the lithology factorallocated of the highest weight (0.314) compared to other factors, the regions withmedium and high susceptibility to landslides, coincide with areas containing quaternary sediments (green areas) and central of watershed including shale and limestone units have a less susceptible to landslides and this is reflected in the final map. Because of the proximity to rivers that after lithology have the second weight (0.219), the central of watershed show moderate to high risk of landslides.

Distance to rivers: distance from rivers is one of the controlling factors for slope stability. The saturation degrees of the materials directily affect slope stability. The proximity of the slopes to drainage structures is also an important factor in terms of stability. Rivers may negatively affect stability by eroding the slopes or by saturating the lower part of the material until the water level increases (Dai *et al*., 2001). The study area was divided into five different buffer ranges. Classes were defined for 0-100, 100-200, 200-500, 500-1000 and >1000 m (Fig. 7). Consequently as the distance from rivers increases, the risk of a landslide decreases. Hence, the classes of the buffered map have been given rating values in a decreasing order based on the distance from the rivers. As Fig. 7 shows closest zones to rivers, identifies areas with medium sensitivity to the landslide.

Distance to fault: It is observed that landslides are more abundant along minor and major faults. Fault zones increase landslide potential by creating steep slopes and sheared zones of weakened and fractured rockes. The major faults and thrusts included in the study area have been digitized from the geological maps (1: 100,000) and superimposed to form a vector layer. On this layer, we applied a distance function to define buffer zones along the structural discontinuities. We created five buffer zones, each 500 m wide. Classes were defined for 0-500, 500-1000, 1000-1500, 1500-2000 and >2000 m (Fig. 8). As the distance from the tectonic lineaments increases, landslide frequency decreases (Fig. 8). Thus, the bufferd regions were rated according to their distance from faults. The final weight of this factor is 0.105.

Land use/land cover: The effect of land cover on slope stability has been studied, since 1960s (Moradi *et al*., 2012). The effect of land cover on slope stability can be clarified by a number of hydrological and mechanical effects. Land cover acts as a shelter and reduces susceptibility to soil erosion. Several researchers (Yalcin, 2008) have emphasized the importance of land cover on slope stability (Moradi and Rezaei, 2014). Land cover absorbs the water of soil and decreases the potential of landslide (Moradi *et al*., 2012). Also, the main units of landuse of study area are pastures, farming land and their different combination or derivate and a little urban regions. The study area was divided into seven land cover classes (Fig. 9). Areas are covered with pastures of low and moderate density because of their poverty coverage have the highest score of 5 (Fig. 9). Land use is 0.086 weights so that when coupled with the other factors described above has been effective. As poor pastures in the Northern watershed is consistent with fault and rivers has created a moderate to high risk.

Rain falling: Most of the landslides occur after the heavy rain falls, thus the rainfall is one of the main parameters in producing landslide maps. Water infiltrates rapidly upon

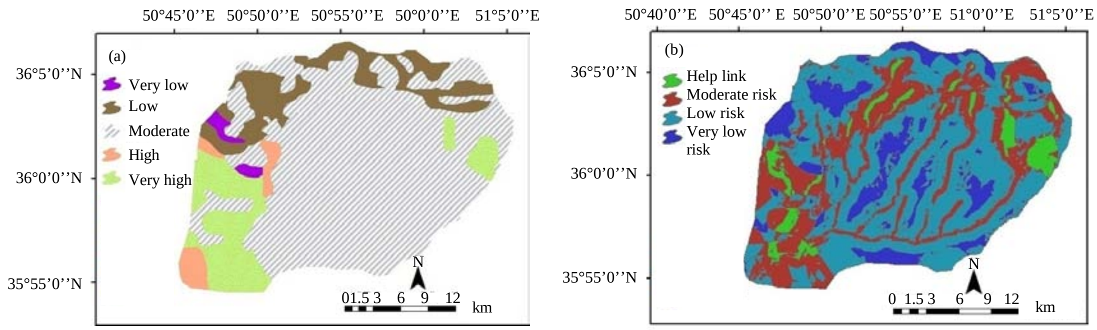

Fig. 6: a) Lithology map and b) The landslide hazard zonation map

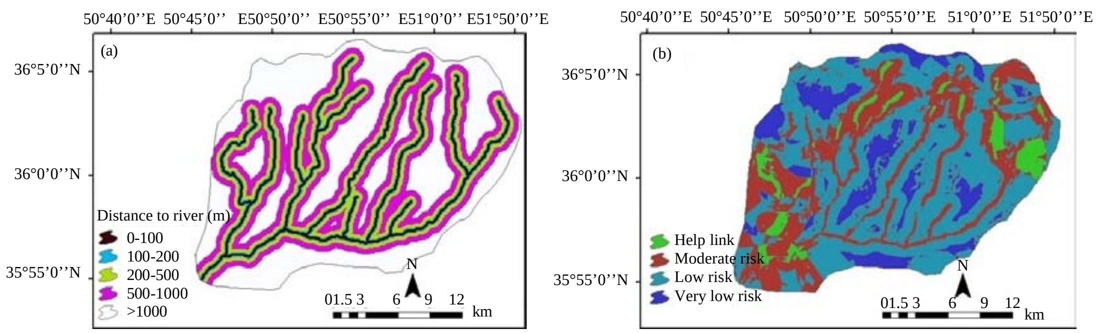

Fig. 7: a) Distance to rivers map and b) The landslide hazard zonation map

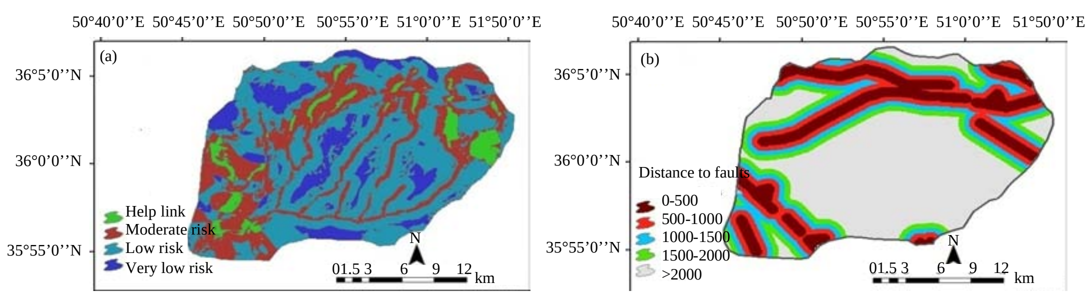

Fig. 8: a) Distance to Faults map and b) The landslide hazard zonation map

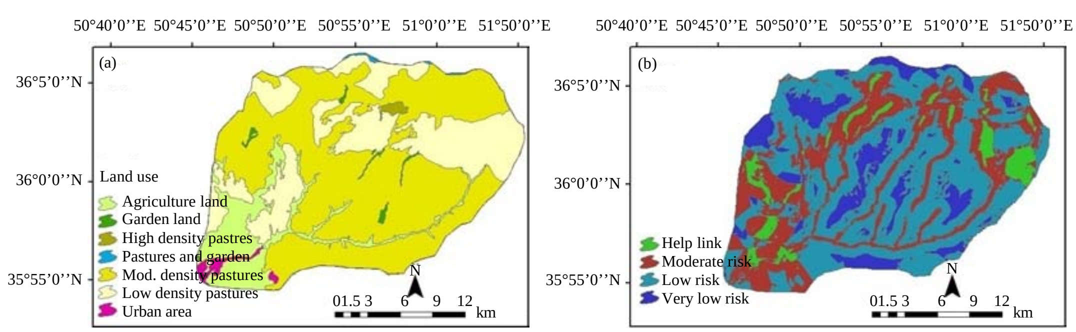

Fig. 9: a) Landuse map and b) The landslide hazard zonation map

heavy rainfall and increases the degree of saturation and potential of landslide occurrence (Moradi *et al*., 2012).

Due to the lack of detailed data such as maximum daily rainfall only mean yearly precipitations were taken into consideration stations in the study area. This value changes scientifically along with the elevation gradient reaching up to 800 mm at high mountainous areas. Taking this factor into account, the territory in the thematic map created was divided into five classes with different mean monthly rainfall rates: <350, 350-500, 500-650, 650-800 and >800 mm (Fig. 10). Potentially, the higher rate of the rainfall, the more favourable the conditions for landslides. The weight of rainfall factor is obtained 0.054 its impact on the final map is relatively high. But in this study due to the greater impact of lithology in the South West of Kordan watershed in the center of the region, despite the low rainfall in the region were moderate and high risk.

Distance from the village: The proximity to villages or settlements of other factors that affect on the mass movements. Human activities always play a important role in a changing environment. Figure 11 villages in the area and classified map shows the distance from the village. To analyze the relationship between the village and landslide event in the basin was created five buffer zones each 50 m wide. Classes were defined for 0-50, 50-100, 100-150, 150-200 and >200 m (Fig. 11). The greatest weight was given to the class of 0-50 m. Because sediments and river banks are fertile naturally villages and settlements have been developed in this area and >50% weights of this factors formed final weight, therefore villages mostly place in areas with moderate to high risk while village factor weight (0.047) is not very high.

The type of soil (land units): Watershed soil has done based on the main types of physiographic separation and standards-based on the Soil and Water Research Institute (SWRI). This type includes types: mountains, plates, alluvial and scree (Fig. 12). Alluvial plain are consistent with high-risk areas.

Drainage density: Drainage density is defined as the proportion of the total length of the water flow to the total area of the drainage basin. Drainage networks also as one of factor used in this study were extracted directly from the Digital Elevation Map (DEM) in the ArcGIS9.3 Software. Five drainage buffer zones were produced to define the extent of slope instability caused by streams. These drainage buffer zones were: <10, 10-15, 15-20, 20-25, 25 km^{-1}. There is positive correlation between the density of drainage and occurrence of landslide. In the Kordan watershed two high zone (D&E) coincide with moderate to high risk areas that could result from coincide of high drainage zones with banks of rivers (Fig. 13).

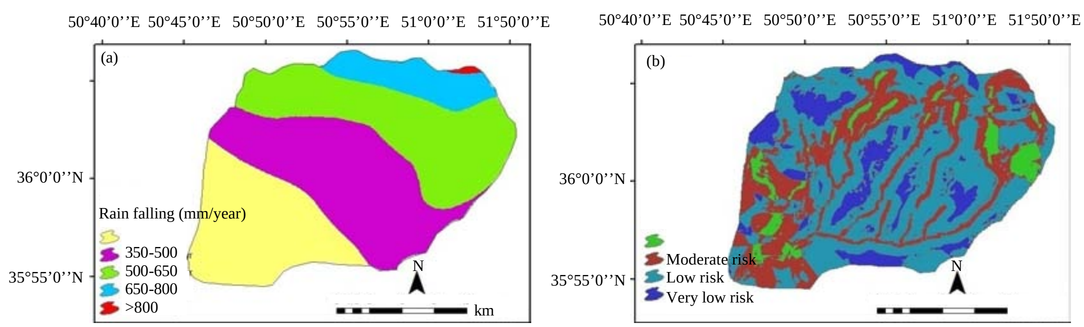

Fig. 10: a) Isohyets map and b) The landslide hazard zonation map

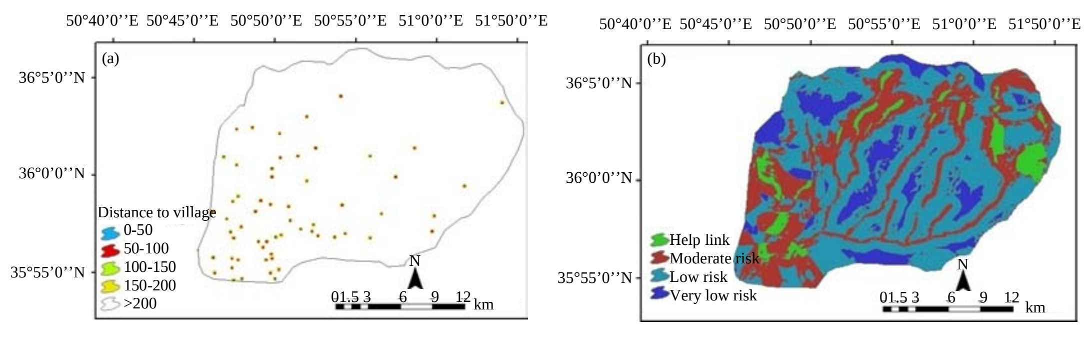

Fig. 11: a) Distance to villages and b) The landslide hazard zonation map

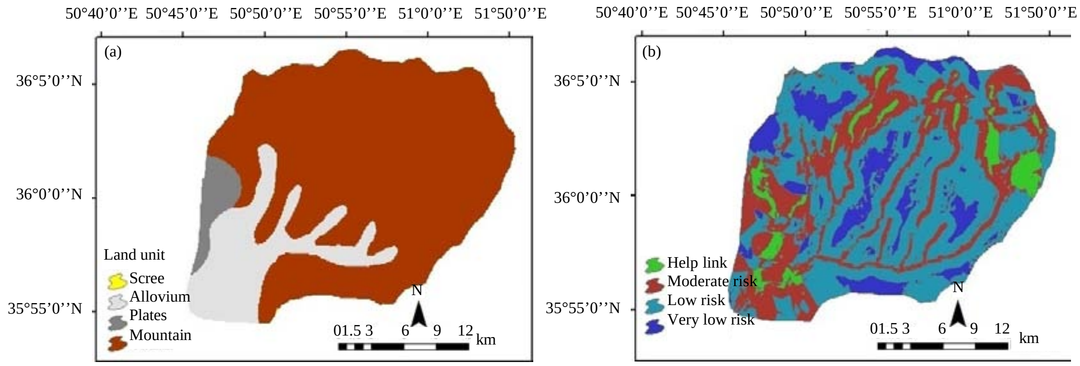

Fig. 12: a) Land unit and b) The landslide hazard zonation map

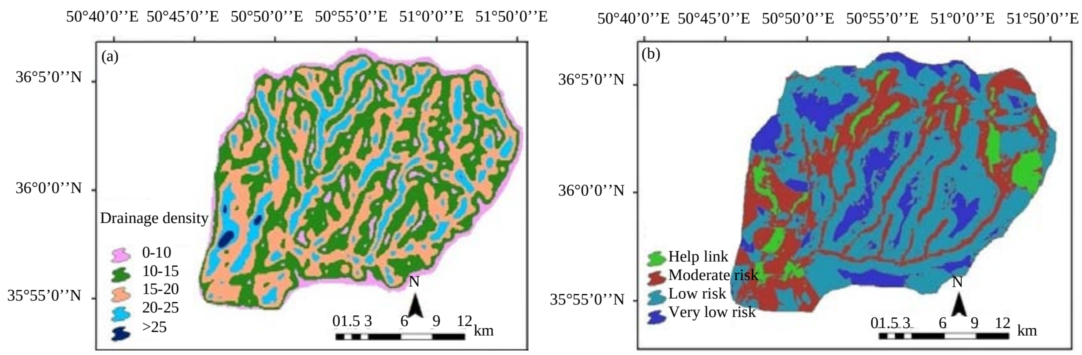

Fig. 13: a) Drainage density and b) the landslide hazard zonation map

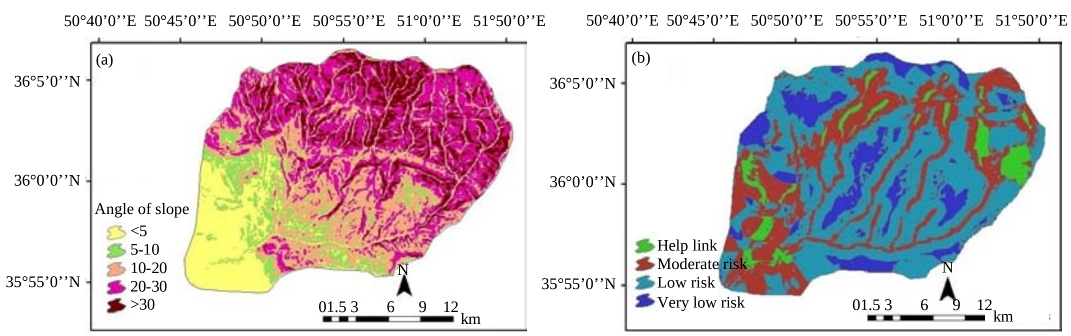

Fig. 14: a) Slope map and b) The landslide hazard zonation map

Slope gradient: The main parameter of slope stability analysis is the slope angle (Lee and Min, 2001). In this study, the original raster format file was obtained directly from the Digital Elevation Map (DEM). Then by ArcGIS Software slope values were subdivided into the following five classes: very gentle slopes, <5°, gentle slopes, 5-10, moderately steep slopes, 10-20, steep slopes 20-30 and escarpments, >30 (Fig. 14). Generally, landslides are not expected to occure on gentle slopes due to lower sheer stress. But based on the results of this study due to the greater impact of lithology in areas with relatively low slope (<5°) were at high risk area.

Distance to road: The distance to road is one of the main parameters in preparing landslide hazard zonation maps. Roads can be one of the reasons of occurring landslides (Ayalew and Yamagishi. 2005; Leventhal and Kotze, 2008; Yalcin, 2008). In this study, main roads are investigated and this factor is divided into the following five distances to road categories: <50, 50-100, 100-150, 150-200 and >200 m (Fig. 15). Roads in areas with moderate to high risk with that because it can be positioned close to the river and quaternary sediments and agricultural land in the South West region which has noted (Fig. 7, 8 and 10).

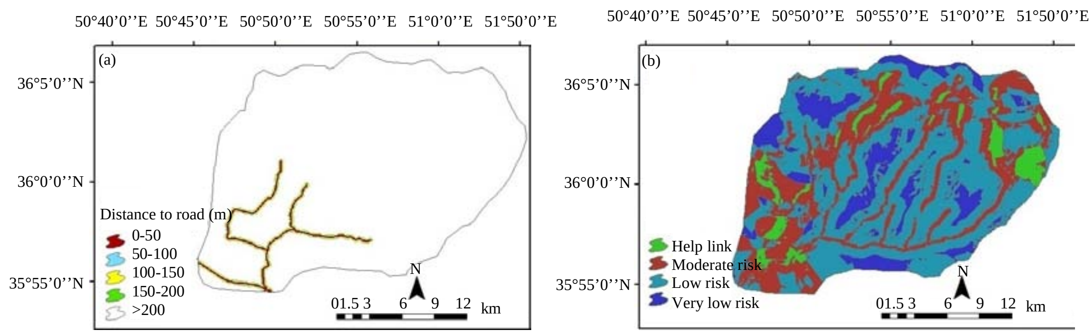

Fig. 15: a) Distance to road map and b) The landslide hazard zonation map

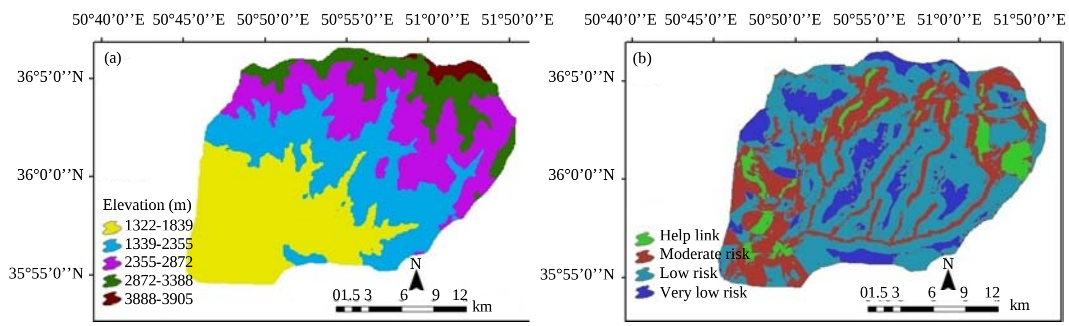

Fig. 16: a) Elevation map and b) The landslide hazard zonation map

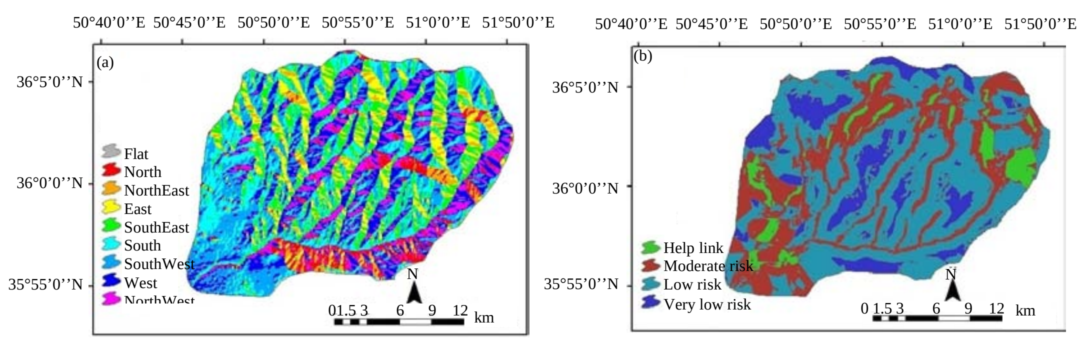

Fig. 17: a) Slope aspect map and b) The landslide hazard zonation map

Elevation: Elevation is one of controlling factors in the stability of the slope. Elevation influences to landslides are often displayed as indirect relationships or by means of other factors (Moradi and Rezaei, 2014). The thematic map of elevation was divided into five classes with different ranges each 500 m wide (Fig.16).

Slope aspect: Aspect is also considered an important factor in the preparation of landslide hazard zonation maps (Lee and Min, 2001; Yalcin, 2008). Aspect of study area was generated from a DEM which was derived from the 1:50000 topographical maps in GIS environment. The association between aspect and landslide is shown using aspect maps. Aspect regions are classified in nine categories according to aspect class: flat (-1°), North (0-22.5°; 337.5-360°), NorthEast (22.5-67.5°), East (67.5-112.5°), SouthEast (112.5-57.5°), South (157.5-202.5°), SouthWest (202.5-247.5°), West (247.5-292.5°) and North West (292.5-337.5°) (Fig. 17). Aspect-associated parameters such as exposure to sunlight, drying winds, rainfall (degree of saturation) and discontinuities may affect the occurrence of landslides.

Ramp to the South in the Northern hemisphere receives more energy. As a result ofincreasedenergy, decreased soil moisture range and caused less instability.

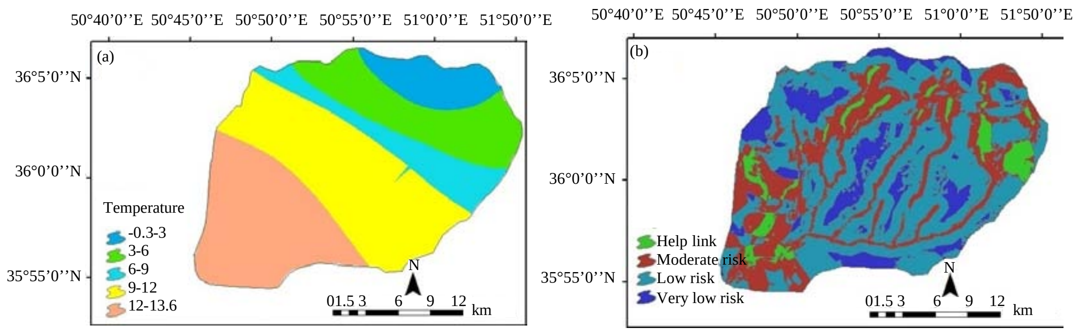

Fig. 18: a) isotherm map and b) the landslide hazard zonation map

But the results of this study showed due to the greater impact of lithology in areas with sloping to the South (<5°) were at high risk area.

Temperature: The temperature of the melt-freeze plays an important role in the occurrence of landslides. To find out about the effects of temperature on the occurrence of landslides, five buffered zone was created which most weight given to buffer zones -0.3-3°C data (Fig. 18). Temperature has minimum weight (0.008) among the factors affecting the risk of landslides in the area allocated. South West the watershed despite the high average temperature due to the influence of lithology show high-risk areas.

CONCLUSION

Due to own characteristics including geological, location, geomorphology, topography, climate condation, active tectonics and vegetation, Kordan watershed is a one of the landslide and all kind of mass movement prone zone. In order to provide landslide hazard zonation maps various methods such as fuzzy logic, statistic methods and Analytic Hierarchy Process (AHP) can be used. In this study, GIS technique and AHP model have been used to achieve goals. The results have been showed that integration of GIS technique and AHP model is a mighty method for preparation of landslide hazard zonation map in to other models.

According to effective factors in landslide occurrence, the study area was zoned as various layers. Finally, landslide occurrence zones were recognized from very low risk to high risk. The investigations showed that >35% of the basin (173.261 km^2) located in the zones of moderatly and high risk.

The investigations showed the zones of moderate and high risk are often coinciding with settlement sensitive areas, especially in the South Western part of the watershed where construction and population density is high. Landslide hazard zonation maps can help the environmental designers and engineers to select a suitable place for development projects implementation. The results of these studies can be used as fundamental information by environmental managers and planners (Pradhan, 2011).

Among the effective factors, sub-criteria of lithology, distance from the river, distance from fault, landuse and rainfall, respectively with weights 0.314, 0.219, 0.105, 0.086 and 0.054 have been identified as the most important factors in the development of landslide in study area. That sum of this factors weights form >75% of total final weight. The role of other factors reduces according to their weights in landslide that has been showed in Fig. 5.

Kordan watershed that is located at the mountainous region with elevation range from 1320-3905 m. Due to the mountainous area, steep slopes are one of the main characteristics of the basin. So that >46% of the area has slopes >20°. According to past experiences usually landlides increases with increasing the slope of the slip. But based on the results of this study due to the great effect of lithology, the areas with relatively low slope (<5°) were at high risk area.

As a geological pointview, this region is located in central Alborz tectonic units with their lithology that affected by other factors such as the intensity of weathering, joint system and fragmentation in the region and is closely associated with different climates. The main formatiom of lithology in this region from old to new are consist of Kahar, Soltanieh, Zaigun, Mila, Ruteh, Shemshak, Dalichai, Lar, Ziarat, Karaj and Quaternary deposits (Recent) includes old and new alluvial terraces of rivers.

The main units of lithology in this region are consisting of shale rockes, marn and tuff of karaj formation and recent alluvial deposits. These units form >86% of region and the other hand were found to be a moderate to very high susceptible lithology. Therefore, due to high exposures of these rocks and their susceptibility to slip, other factors such as slope and elevation haven't more effect.

REFERENCES

Ayalew, L. and H. Yamagishi, 2005. The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. Geomorphology, 65: 15-31.

Barredo, J.I., A. Benavidesz, J. Hervhl and C.J. van Westen, 2000. Comparing heuristic landslide hazard assessment techniques using GIS in the Tirajana basin, Gran Canaria Island, Spain. Int. J. Applied Earth Observ. Geoinform., 2: 9-23.

Boroushaki, S. and J. Malczewski, 2008. Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. Comput. Geosci., 34: 399-410.

Bowen, W.M., 1990. Subjective judgements and data envelopment analysis in site selection. Comput. Environ. Urban Syst., 14: 133-144.

Dai, F.C., C.F. Lee, J. Li and Z.W. Xu, 2001. Assessment of landslide susceptibility on the natural terrain of Lantau Island, Hong Kong. Environ. Geol., 43: 381-391.

Dyer, R. and E. Forman, 1990. Analytical Approach to Marketing Decisions. Prentice Hall Press, Old Tappan, New Jersey, USA., Pages: 496.

Hatamifar, R., S.H. Mousavi and M. Alimoradi, 2012. Landslide hazard zonation using AHP model and GIS technique in Khoram Abad City. Geogr. Environ. Plann., 23: 43-60.

Lee, S. and K. Min, 2001. Statistical analysis of landslide susceptibility at Yongin, Korea. Environ. Geol., 40: 1095-1113.

Leventhal, A.R. and G.P. Kotze, 2008. Landslide susceptibility and hazard mapping in Australia for land-use planning-with reference to challenges in metropolitan suburbia. Eng. Geol., 102: 238-250.

Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, London, ISBN: 978-0471329442.

Moradi, M., M.H. Bazyar and Z. Mohammadi, 2012. GIS-based landslide susceptibility mapping by AHP method, a case study, Dena City, Iran. J. Basic Appl. Sci. Res., 2: 6715-6723.

Moradi, S. and M. Rezaei, 2014. A GIS-based comparative study of the analytic hierarchy process, bivariate statistics and frequency ratio methods for landslide susceptibility mapping in part of the Tehran metropolis, Iran. Geopersia, 4: 45-61.

Mostafaei, J., M. Ownegh, M. Mesdaghi and M. Shariatjafari, 2010. Compared the performance of experimental and statistical modeling of landslide hazard zonation. J. Soil Water Conserv., 16: 43-61.

Pradhan, B., 2011. An assessment of the use of an advanced neural network model with five different training strategies for the preparation of landslide susceptibility maps. J. Data Sci., 9: 65-81.

Rahamana, S.A., S. Aruchamy and R. Jegankumar, 2014. Geospatial approach on landslide hazard zonation mapping using multicriteria decision analysis: A study on coonoor and ooty, part of Kallar Watershed, The Nilgiris, Tamil Nadu. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., 40: 1417-1422.

Saaty, T.L., 1980. The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation. 1st Edn., McGraw-Hill, New York, ISBN: 0070543712.

Saaty, T.L., 1986. Axiomatic foundation of the analytic hierarchy process. Manage. Sci., 32: 841-855.

Saaty, T.L., 2000. Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. 2nd Edn., RWS Publications, Pittsburg, USA. .

Shariatjafari, M., 1997. Landslides (Fundamental and Principles of Natural Slopes Stability). Sazeh Publication, Tehran, Iran,.

Vahidnia, M.H., A.A. Alesheikh and A. Alimohammadi, 2009. Hospital site selection using fuzzy AHP and its derivatives. J. Environ. Manage., 90: 3048-3056.

Vargas, L.G., 1990. An overview of the analytic hierarchy process and its applications. Eur. J. Operat. Res., 48: 2-8.

Yalcin, A., 2008. GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations. Catena, 72: 1-12.