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Landslide Hazard Zonation Studies of Asaluyeh Region Using AHP and Fuzzy Logic Methods

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Abstract

In this paper, a map zonation of landslide hazard and mass movements risks at the Asaluyeh area (South of Iran), using Analysis Hierarchical Process (AHP) and Fuzzy Logic approaches was performed based on the parameters of slope, slope direction, elevation, rivers, precipitation, faults, roads, geological unit and land usages. For optimization of the various parameters effect that would lead to landslide occurrence, the effect dimensions of each of these layers were applied and the zonation of landslide risk in the region was mapped. The AHP operations were attributed with effect numbers between 1 and 9 in accordance with their weight. Then by pairwise comparison of the parameters, the slope of effect of these functions was determined. According to the fault and lithology parameters the most effective layer and human functions including road and land usage are of second priority, topography functions including slope direction, and height are of third level of significance whilst the hydrology function is ranked fourth and thus being in consistency with the land reality. The results illustrated that the Analysis Hierarchical Process (AHP) was appropriate for landslide zonation in this dense vegetation and with the natural geography of the area is consistent. In map zonation of landslide risk using fuzzy membership variants and fuzzy logic all the data were stored in ILWIS software and when the values and fuzzy membership variants were determined, the fuzzy analysis was performed by IDRISI software. In this research different fuzzy operators (And, Or, Sum, Product and Gamma) were used. According to the results, the gamma operator produced the best map of sensitivity to landslide risk in the region. The average depth of the investigated landslides is about 6 m which illustrates the shallow depth of the slide layers and the significant effect of lithology at depth and thickness of the sliding domain.

Key Words

Fuzzy logic; Analysis Hierarchy Process (AHP); Asaluyeh; Landslide zonation; Pair wise comparison

1. Introduction

Landslide is one of the important and dominant natural hazard which is common in the world especially in the mountainous regions (Kanongo et al. 2008). Landslides contain 17% of all natural hazards in the world (Cohorst et al, 2005) which are caused the most tragic events. This phenomenon brings about high annual detriments on natural and rest of resources in the mentioned regions (Guariguata, 1990; Walker et al, 1996; Aleott et al, 1999; Zhou et al,

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2003; Wang et al, 2006; Wang, 2010; Akgun and Turk, 2010); and also, it causes injuries to hundreds of people (Aloetti and Laudhari, 1999; Yesilnacar and Topal, 2005; Emdat, 2010). Landslides and related processes in the world have taken the lives of 61000 people during 1900 and 2009 (Emdat, 2010). In case review, on 2nd May, 2014 in Badakhshan region (NE Afghanistan) a great landslide buried up a village and at least 350 people were killed (Bowden, 2014). Landslide is the most significant and intricate geomorphological processes that has affected the landscape evolvement in mountainous regions (Roering et al, 2005; Hattanji and Moriwaki, 2009; Guzzetti et al., 2003) being a process involving complex interrelations between different conditions, traits and resulting from internal non-linear correlations (Wang, 2010) and verification of fuzzy algebraic operators to landslide susceptibility mapping (Lee., 2007). The inherent characteristics of the slope attributes and external factors such as topographical characteristics, hydrology, lithology, discontinuities, faults (faults and joints), soil texture, depth, variety and extent of vegetation controlling the location, frequencies and type of landslides affect the slope behaviors against run out. In order to model the instability of the slope gradient in Lantao Island in Hong Kong for describing both physical characteristics of landslides and their statistical frequency relationship with physical functions used a database created in the GIS and described the pile behavior resulting from run out using the characteristics of traversed horizontal length and frame angle (Ohlmacher and Davis., 2003). Gouzetti et al., 2008 determined a relationship between the size of a slope gradient and the landslides dimension based on regional landslides distribution in center of Italy. Furthermore, the spatial relationship analysis between landslides and geological particulars showed that most events in the slope occur in the weak and soft rocks (Uromeihy and Mahdavifar, 2000). However, the landslides in mountainous regions of Iran carried out great damages and losses. Due to 4900 recorded landslides until January 2007 by Landslide Research Group of Watershed Deputy Management of Iran, there were an estimated 187 deaths and about 4,554,547 $ damages (Haghshenas, 2009). The researches carried out in Iran imply that the conditions for landslide occurrence in various points and at watershed zones vary and natural causes and/or human could be influential. Change in land utilization and road-construction (Hasanzadeh-Nafooti et al. 2001; Feyz et al, 2003; Kelarestaghi et al, 2007); faults (Ahmadi and Mohammad-Khan, 2002) can be considered as influential functions for the occurrence of landslide especially in the northern slopes of Iran (Sadoddin, 1994; Garaei, 2006; Garaei et al. (2009; Khatir et al. 2009). Potentiality for slide occurrences in the north of Iran especially Asaluyeh province is high, due to landslide reasons consisting of the existing terrestrial soil, the significant amount of precipitation, high level of underground water, active tectonics, agricultural land usages and construction of residential areas and connection of pathways without due regard to the direction of slope layers (Fig. 1).One of the important strategies for reduction of damages due to occurrence of landslides is to prepare a zonation map of landslide risk in these regions and prevention of making residences near the risky regions. Undesired land usages including increasing destruction of farmlands, forests and agricultural lands and wrong civil project works in potential landslide regions and variety of instable geological units has been effective in occurrence of slides in this area. Various classifications are presented for generation of

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map zonation for slides and pile movements. These include the classification that uses linear regression method for map zonation of landslide in the South Korea by Saroli (2001) and landslide hazard mapping with using of Fuzzy Logic and GIS in Iran by Pourghasemi et al (2008).Mohammad-Khan (2001) and Ismaeeli and Ahmadi (2003) investigated the functions affecting the occurrence of landslide and map zonation using the two multi-variant regression method and hierarchical analysis involving seven parameters and illustrated that the Analysis Hierarchical Process (AHP) is more accurate than the regression multi-variant method. The investigation of slope instability due to a variety of effective functions there is a very complicated process. The uncertainty due to ambiguous conditions and concepts of such parameters as the geology, hydrology, tectonic, vegetation, precipitation and corrosion in slope instability makes it necessary to use exact and appropriate methods for investigation of slope and logic instability. The fuzzy logic established by Zadeh (1965) is an efficient tool for solving issues related to system complexities and or issues related to reasoning, decision-making and human deference (FatemiAghda et al., 2003; FatemiAghda et al., 2005; Binaghiet al, 1998; Chi et al., 2002; Ercanoglu and Gokceoglu, 2002; Ercanoglu and Gokceoglu, 2004; Schernthanner, 2005 and Lee, 2007; Lee., 2007; Ohlmacher and Davis., 2003).

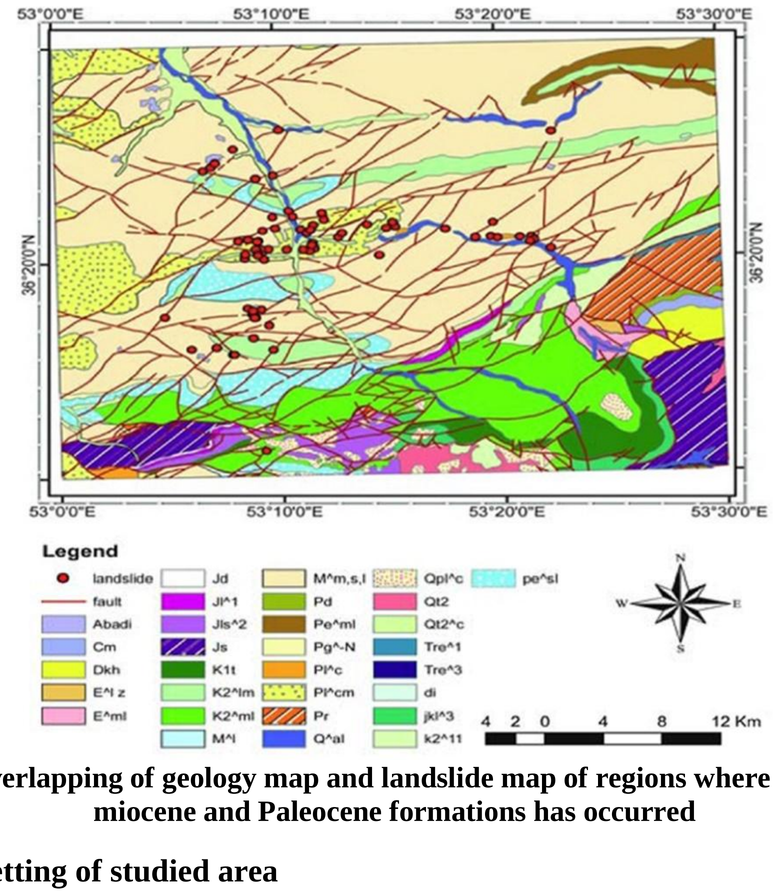

Figure.1. The overlapping of geology map and landslide map of regions where the most slides in miocene and Paleocene formations has occurred

2. Geological setting of studied area

Located on the shore of the Persian Gulf some 270 km SE of the provincial capital of Bushehr, it is best known as the site for the land based facilities of the huge PSEEZ (Pars Special Energy Economic Zone) project. The town itself is of minor significance, although it is common practice to refer to PSEEZ (established 1998) and Asaluyeh town collectively as

Asaluyeh. Asaluyeh was chosen as the site of the PSEEZ facilities due to it being the closest land point to the largest natural gas field in the world, the South Pars / North Dome Gas-Condensate field. In addition, an existing airport and direct access to international waters via a deep water port were already present. There are quaternary formations especially alluvial, medium to thick limestones, sandy limestones, conglomerate, sandstone, silt, marls and shales (Fig. 1).Moreover, the lithological formations with landslides consist of upstream cretaceous rocky unit composed of marly limestone (K2lm), marl-silty marl (K2m,l) and marly limestone, limestone with intermediate (K2l,l) marl layers, calcic sandstone and (Pe sl) Paleocene sandy limestone, (Mm,s,l) unit with dominant marl litheology, calcic sandstone, sandy limestone and a little conglomerate with seldom cases of with intermediate gypsum layers, (Plc,m) unit with conglomerate, marl and silty marl compound together with intermediate layers of coarse aggregate sandstone within clayish sandstone, quaternary depositions (Qt2c) in the form of corrosive clay and silt material shaped as a thick layer profile of rock base (Vahdati-daneshmand, 2005).

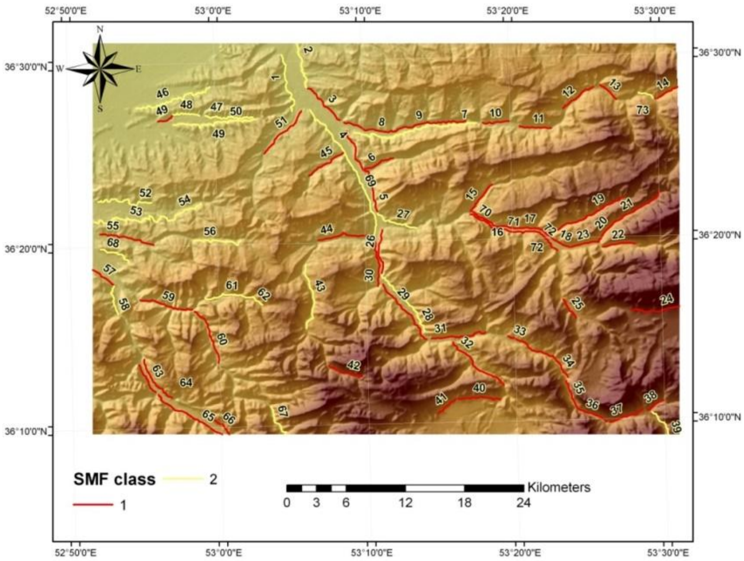

Figure .2. Plots of 73 mountain front to check Sinuosity mountain front (Smf) (red represents high mountain front (1) and yellow lines represent medium activity).

3. Methodology

This paper presents the collected data from the field observations and remote sensing studies and by combining these with layers of quantity and direction of slope gradient, the elevation of the river, road, rock types, land usages, faults and precipitation, the effect of influential functions for occurrence of slides and the amount of each of these were separately investigated and compared with one another. In the hierarchical analysis of various layers, by overlapping these geology maps with the zone under study and making a layout of the slide vectors in this zone using Google Earth software, the location of slides were specified and the map zonation of slide risks is prepared. The layers were analyzed by the Expert Choice software, the layers are distinguished into four sections: hydrology, geology, topography and usage and their members' values were determined between 1 to 9 due to their importance and affection. Moreover, the level of effect by each of the layers and their members is specified by precise modulation of the layers. For risk analysis of landslide by fuzzy method, remote sensing data were used to locate the slide locations and in order to evaluate the interpretation

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results of these data a field inspection of the region was performed. Each of the functions affecting the landslide occurrences of the survey region and the related maps including topography, geology and land usages were digitalized in ILWIS software. The effective parameters on sliding were verified utilizing probability model of frequency ratio the level of correlation between existing slide points and each of the effective functions were specified. For calculation of frequency ratio, each of the functions influencing the landslide occurrence were specified and using a geographical data system, the percentage of sliding and non-sliding pixels in the studied region were specified and the frequency ratio for each of the functions and classes related to it were calculated by dividing the ratio of slide regions (pixel percentages in that slide event) by the non-sliding regions (percentage of non-sliding pixels). Then, the slide risk sensitivity parameter was calculated as following (Lee, 2007):

$$LSI = \sum Fr \quad (1)$$

Where, the LSI shows sensitivity to landslide risk parameter, and also, Fr is weight of each effective function for landslide occurrence. If Fr>1, then value of LSI is very low. According to fuzzy analysis, the obtained weights were normalized using frequency ratio method (between 0 and 1) by IDRISI software. Then, using statements 2 to 6, the map of risk for the region under study using fuzzy operators And (Eqi. 2), OR (Eqi. 3), Product (Eqi. 4), Sum (Eqi. 5), and Gamma (Eqi. 6) were prepared (An et al, 1991; Chi et al, 2002; Lee, 2007) as following:

$$\mu_{combination} = MIN(\mu_A, \mu_B, \mu_C, ...) \quad (2)$$

Where: function $\mu_{combination}$ is the fuzzy membership estimate, μ_A is the amount of membership function A, μ_B is the amount of membership function of B, and operator fuzzy and is the factor for sharing of the member sets; that is to say, the minimum degree of membership of the members is extracted. This means that, between all of the minimal data layers (weight) extraction of each pixel is performed and adapted in the final map. For this reason, this operator in the landslide risks map-zonation, places just about the entire region in the risk class.

$$\mu_{combination} = MAX(\mu_A, \mu_B, \mu_C, ...) \quad (3)$$

Fuzzy operator or extracts the maximum membership degree of the members and with the entire maximum data layers (weight), extracts each pixel and applies it to the final map. For this reason, this operator would place nearly the entire region in the very high-risk class.

$$\mu_{combination} = \prod_{i=1}^{n} \mu_i, \quad (4)$$

Where μ_i is: the function fuzzy membership function. In this operator, all of the data layers are multiplied together so that the output shape become smaller numbers are inclined towards zero and therefore lesser pixels are placed in sensitivity to high slide risk class which is expressed as follows:

$$\mu_{combination} = 1 - \prod_{i=1}^{n} \mu_i (1 - \mu_i) \quad (5)$$

In this operator, the multiplication complement of the member sets complement is calculated. Thus, in the output shape, the value of pixels tends towards 1 and so more pixels fall into the high and very high risk class and for this reason this operator has very little sensitivity in the map zonation. For balancing the very high sensitivity of the fuzzy multiplication operator (product) and for the very little accuracy of the fuzzy sum operator, another operator called fuzzy gamma is introduced which is illustrated below:

$$\mu_{combination} = (Fuzzy\,algebraic\,sum)^{\lambda} * (Fuzzy\,algebraic\,product)^{1-\lambda} \quad (6)$$

According to equation 6 if $\lambda = 1$, the output map is the same map resulting from the fuzzy sum and if $\lambda = 0$, the output map is the map resulting from fuzzy product. Thus, the approximation of the changes λ would be between 0 and 1.

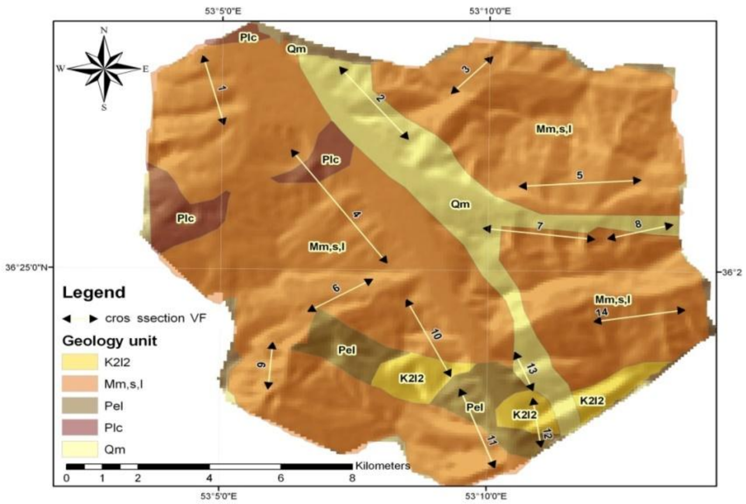

Figure .3. Map of lithologic units types and levels of analysis morphotectonic on it thick layers of limestone and marl layers K2L2, alternation of limestone, marl and sandstone Pel, alternation of sandstone, shale and conglomerate Mm,s,l, alternation of limestone, sandstone and shale and silty clay PLc and quaternary sediments Qm (Adapted from the geological map 1: 100,000 white bridge with changes).

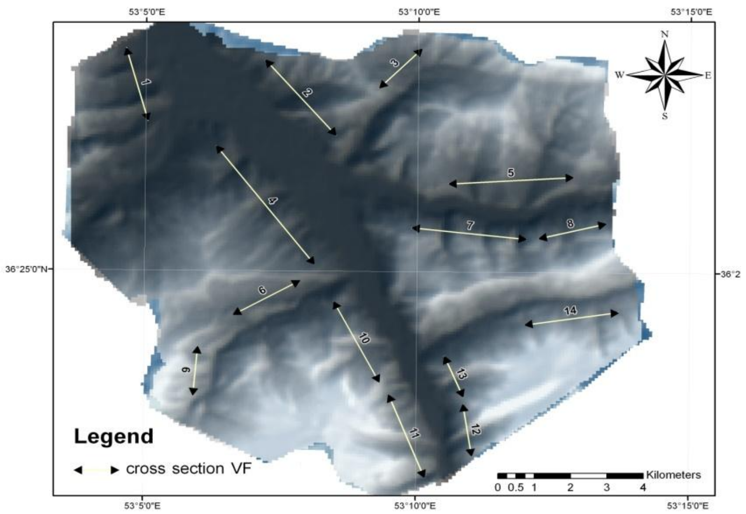

Figure. 4. Sections index Vf On the Digital Elevation Model (Dem)

4. Tectonic activity

Tectonic and seismic activities can provide conditions for the occurrence of landslides with unstable slopes. The studied area locate at the north of the mountains which affected by recent tectonic processes. Calculation of morphometric indicators is appropriate method in the investigation of tectonic activities (Keller and Pinter, 1996; Burbank and Anderson, 2001). However, two morphometric important indexes have been investigated (Mountain Front Sinuosity: Smf., and Valley floor width - to - weight ratio :Vf ., Keller and Pinter, 2002; Bull, 2007). The Mountain and valleys is depicted in Fig. 2. The low values of the mountain front sinuosity index (Smf<1.1) refers to higher tectonic activity (Keller and Pinter,

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2002; El Hamdouni et al., 2008). The calculation of areas of 73 mountain front in the region is greater than area of the digital elevation model that reflects two tectonic activity categories (Fig. 2 and Table. 1). The both categories represent high and moderate tectonic activities, respectively. The eastern and SE mountain peak indicate often a high level of tectonic activity, as shown in the Fig. 2.Comparison between the location of categories and geological units shows that these mountain front are consistent with the tectonic structures, in particular main faults. These faults in the southern are the most faults of this region. The recent movements along this fault can lead to geomorphic significant changes of tectonic in the region. Various areas of Vf were assessed along the mountain front for identification of the effect of structures on Digital Elevation Model (DEM). Because of lithology conditions is effective in value of this index (Bull, 2007), it is tried that these cross sections in the mountain front to be investigated with conditions of lithology relatively equal. Sections 6, 8, and 13 in the southern part of the region reveal low values of this index (Vf) relative to the other cross sections that it implies the higher rate of tectonic activity in the region (Figs 3,4 and 5).

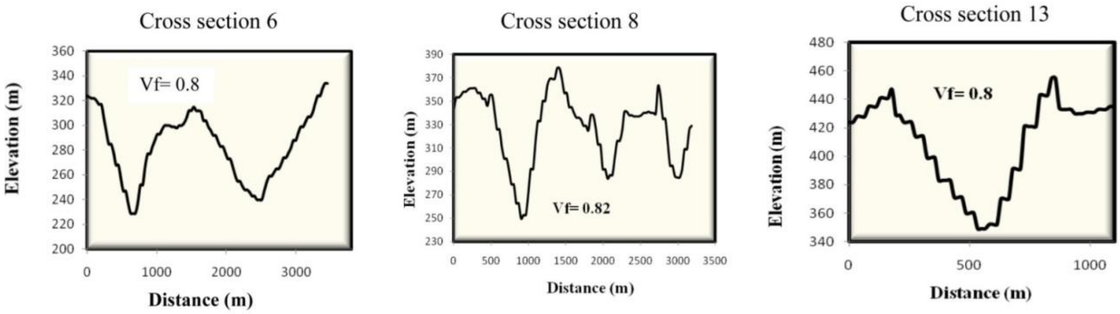

Figure. 5. Cross sections 6, 8, and 13 of Vf on the Digital Elevation Model (Dem)

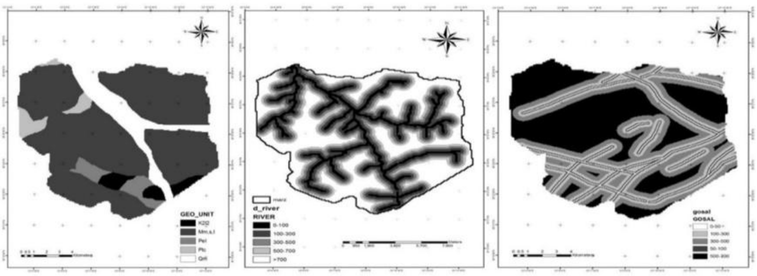

Figure. 7.Map of formation segregation and the role of this in occurrence of landslides in the slope together with the maps of rivers and faults at the region for AHP process.

5. Preparation of layers

Since the quantity and quasi-quantity methods in landslide risk map zonation engenders more reliable results than the other method presented, the use of these methods compared to others is scientific more valid (Fig. 6). By specifying a set of standards for evaluation of decision-making options, each standard must be displayed in the form one map layer in the GIS oriented database and these maps can be classified as quantity and quality standard maps (Parhizkar, 2006). The classified maps which show the variation of soils, land usages and vegetation are samples of layers based on quality data. Among the related quality standard samples, mention can be made of DEM, the slope and distance-from-fault map can be mentioned. After selection of required layers, it is time for required weighting of used layers. The mutual-scale based method is considered as the input and the relative weights are produced as the output. Precipitation and wind directions are happened erosion usually move

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from west to east in Iran which are affected on the dangerous of slopes. In the studied area, nine slides occurred in the eastern slopes which is demonstrates the effect of direction. Elevation is another parameter which affected the occurrence of landslide specifically for erosion. In the Asaluyeh region, most of the slides occurred at elevation between 175 - 375 m. The locality of the slides at this elevation is affected by the structural material of the slopes and the expansion of the geological units (Fig. 7). Furthermore, most slides have been occurred in the limestones with alternating marl, sandstone, conglomerate, shale, marl and sandy limestones. The Asaluyeh region is located on weak sedimentary rock types and the sedimentary basin has active tectonics which caused the slope instability is high level. The thickness of slide's soil layers in most cases is less than 6 m which requires lesser stimulus for slide occurrence. Many rivers crosscut this region which is a major parameter for sliding. In this study, the most slides were situated in adjustment of the rivers with distances between 100 and 500 m (Fig. 8). Additionally, most of the slides are occurred in distances between 0 and 500 m which it increased the potentiality of the sliding of the sedimentary layers. Overlapping between the fault map and landslides reveals that twenty slides have been occurred in the neighbor of the faults. The region based on land usage aspect (land use) is divided into the four groups including agricultural, residential, dense forestry and scanty forestry. Most of the slides occur in the two agricultural and scanty forest slopes and demonstrate the deterioration of vegetation areas due to interference of mankind that result from agricultural activities. However, road construction at the slopes results in reduction of solidarity and causes instability of the slopes. Most of the slides were built up in distances between 200 - 600 m from the road which proves the effect of road-construction in slide occurrence.

Table .1. Index of mountain front sinuosity (Smf) for 73 piece of mountain front (Lmf over mountain front in the range of mountain front and Ls is the length of the straight. The following table Smf<1.1 belongs to class 1, 1.1 <Smf<1.5 belongs to the category 2 and Smf> 1.5 belonging to category 3 is relative tectonic activity (El Hamdounietal., 2008).

NO	Lmf(m)	Ls(m)	SMF	NO	Lmf(m)	Ls(m)	SMF
1	6774.5	5838.9	1.16	36	3254.5	3154.9	1.03
2	5254.5	4591.8	1.14	37	3825.4	3619.3	1.06
3	4975.4	4602.8	1.08	38	1987.7	1901.2	1.05
4	6242.1	5580.1	1.12	39	3203.9	2806.0	1.14
5	9543.3	8691.6	1.09	40	4597.8	4284.5	1.07
6	3246.7	3118.4	1.04	41	2464.2	2343.4	1.05
7	13823.6	12416.0	1.11	42	3729.7	3551.7	1.05
8	5719.1	5360.8	1.06	43	7165.2	6465.7	1.11
9	7876.2	7343.6	1.07	44	5412.7	5076.9	1.06
10	2841.1	2697.7	1.05	45	4416.2	4175.5	1.06
11	3303.1	3228.0	1.02	46	9542.3	7790.7	1.22
12	3944.3	3775.8	1.04	47	5547.4	4848.0	1.14
13	2261.3	2199.9	1.03	48	3014.8	2678.8	1.12
14	2624.5	2536.9	1.03	49	1725.0	1586.0	1.08
15	3600.8	3490.9	1.03	50	9956.1	8324.7	1.19
16	2771.9	2649.8	1.04	51	6027.4	5720.4	1.05
17	4361.4	4268.0	1.02	52	6779.2	5435.1	1.24
18	3936.0	3698.8	1.06	53	10387.5	8136.1	1.27
19	8562.1	8159.7	1.04	54	3551.3	3137.3	1.13
20	2770.4	2707.6	1.02	55	5840.9	5508.2	1.06
21	5822.8	5546.2	1.04	56	5552.4	4804.7	1.15
22	3367.1	3294.5	1.02	57	2904.6	2844.7	1.02
23	2868.1	2841.8	1.01	58	3303.4	2903.9	1.13
24	5166.1	4920.9	1.05	59	5716.1	5362.9	1.06
25	2453.6	2289.2	1.07	60	6183.5	5752.8	1.07
26	4660.7	4373.8	1.06	61	3985.5	3612.9	1.10
27	4885.4	4231.2	1.15	62	2533.0	2290.7	1.11

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28	8064.9	7170.2	1.12	63	5237.2	4814.7	1.08
29	7679.9	7113.9	1.08	64	3410.5	3259.9	1.04
30	5173.5	4799.4	1.07	65	9907.2	9518.4	1.04
31	5927.9	5517.2	1.07	66	5223.6	4892.6	1.06
32	7309.2	6728.8	1.08	67	5557.4	4673.1	1.19
33	5246.2	4957.7	1.06	68	3609.0	3154.7	1.14
34	2730.2	2644.4	1.03	69	10498.3	9438.1	1.11
35	3160.6	3071.9	1.03	70	2798.0	2656.9	1.05

Table. 2.Priority of effective factors in occurrence of landslide in comparison with each other

Digital value	Factor priority in comparison with other factors
9	Optimal priority
7	Extremely high priority
5	High priority
3	Medium priority
1	Weak priority
2-4-6-8	Mediocre priorities

Table. 3.Amount of co-linearity of sub-layers and slides.

Slope	11 Slides located at steep and/or relatively steep slopes
Direction	9 Slides located at western direction
Height	4 Slides at relatively elevated heights
Lithology	20 Slides along regions with alternating shale and sandstone layer and calcic with marl
Fault	20 Slides located at exactly the fault border
River	16 Slides along the river path
Rainfall	12 Slides along highly rainy regions
Road	19 Slides along border of roads and near them
Land usage	17 Slides along agricultural regions and half-dense forests under human utilization

Table. 4.Mutual comparison of effective functions for occurrence of slide

Lithology	Rainfall	Land Use	River	Fault	Slope	Direction	Height	Road	Parameter
1	0.5	4	6	6	4	2	2	6	Lithology
2	1	2	1	1	2	0.5	0.6	2	Rainfall
2	0.7	0.7	0.4	6	0.5	2	0.4	1	Land Use
2	2	1	1	2	2	0.5	0.5	2	River
6	0.2	0.4	0.2	1	0.5	1	1	2	Fault
6	0.2	1	0.4	2	1	2	1	3	Slope
1	0.6	2	2	2.6	2	1	2	0.5	Direction
1.5	0.8	0.6	2	2	1	2	1	0.5	Height
1	1	1	2	1	1	2	0.5	1	Road
22.5	7	12.7	11	23.6	14	13	9	18	Sum

Table. 5.The weight of effective functions for occurrence of landslide.

Parameter	Lithology	Rainfall	Land Use	River	Fault	Slope	Direction	Height	Road	Average
Lithology	0.191	0.191	0.191	0.191	0.221	0.224	0.187	0.221	0.221	0.191
Rainfall	0.016	0.019	0.014	0.015	0.018	0.012	0.016	0.011	0.017	0.016
Land Use	0.234	0.234	0.234	0.240	0.236	0.231	0.234	0.232	0.234	0.234
River	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
Fault	0.202	0.204	0.202	0.204	0.204	0.206	0.204	0.206	0.204	0.204
Slope	0.058	0.063	0.062	0.066	0.062	0.061	0.062	0.060	0.064	0.062
Direction	0.042	0.038	0.042	0.046	0.042	0.040	0.044	0.042	0.042	0.042
Height	0.014	0.011	0.015	0.016	0.017	0.018	0.014	0.012	0.015	0.015
Road	0.135	0.137	0.141	0.139	0.138	0.137	0.138	0.138	0.139	0.138

Table. 6.Fuzzy membership related to slope gradient functions

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
5-0	40251	1.43	0	0	0	0
15-5	168497	5.99	2	3.64	0.608	0.34
30-15	341948	12.16	12	21.82	1.794	1
50-30	681028	24.23	20	36.36	1.501	0.84
70-50	741812	26.39	10	18.17	0.689	0.38

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>70	837535	29.79	11	20	0.671	0.37

Table. 7.Fuzzy membership related to precipitation functions

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
400-300	582993	20.62	26	47.27	2.292	1
500-400	1623721	57.44	24	43.63	0.759	0.33
>500	620076	21.94	5	9.1	0.415	0

6. Discussion

6.1. Weight standards and map zonation of landslide risk using AHP process

The weight of each standard (W) indicates the importance of each function compared to other functions. The total value of these functions must be equaled to 100 percent. In this method, the professional judgment was used and the results of researches of neighboring river basin and regions with similar conditions (Shirin river basin, Sarry river: Kelarestaghi, 2003), the functions respectively from weak to the highest priority were ranked and for making a better conclusion, these ranks were converted into quantity values between 2 and 10 (Table. 2). For mutual comparison of the factors and for prioritization according to their weight, the factors were compared with each other and the value of each column of the matrix were mutually compared with each other and by summing them up pair matrix were produced. The level of importance of each class (R) according to PI calculation and after standardization, were indicated with digital between 1 and 9 as following (Yin & Yan, 1988):

$PI = \ln A/B$

A: Geometrical area of landslides at each class divided by the area of the same class.

B: Geometrical area of landslides in the region divided by the area of the region.

The compatibility testing using the following statement:

$CI = (\mu max-n) / (n-1)$, $CR = CI/RI$

Compatibility function (CR) with comparison (CI) is induced from a suitable case from the total of numbers and each of them is considered thus a random compatibility indicator (RI) which using an scale is obtained from a random sample from two-ended matrix. If the value is less than 10%, then it must be re-inspected. The functioning must be normalized and the aim of normalization is to assimilate the key functions with each other. Then, the final value of the compared vector parameters is determined in the matrixes. The vector value must be between +1 and -1. The parameter would be in a strong and in advantage situation when the vector value is higher than the value (bench mark), and also, if the vector value is less than the bench mark value then the parameter is weak and faces threats (Mafi and Sadghaee, 2009). The co-linearity value of sub-layers and slides is illustrated in Table. 2. In addition, the map zonation and professional investigation of the data were generated by the Expert Choice software and all the data layers are weighed and also, the output is mutually compared with the factors and prioritization is made according to their weights. Subsequently, the values related to each column of the matrix are compared and are mutually summed up (Table. 3).Each matrix is divided with the value of the total column and a standard matrix is prepared and the significant average elements in each raw of the standard matrix is calculated in the software. These averages as an estimation of the relative comparable weights are considered the average of all possible ways for comparison of the standards (Table. 4). In this weighting on the basis of value 1 is the highest weight that more weight the allocation of weighting to the geological, land use, topography and hydrology functions are 0.425, 0.359, 0.119 and 0.097.Moreover, each layer are changed from vector type to raster mode and according to R values they were reclassified and ultimately by ArcGis software, and also, the final weighting and overlapping was accomplished. As a result, the data were summing up in the Asaluyeh region and five zones for slides was divided which consisting of the regions with extremely, high, medium, low and very low risk (Fig. 8). It is shows that the rock and material are very important functions in the occurrence of landslides in this area which are generally including marl, shale, clay, sand, silt and alluvial deposits which due to their physical structure, have high water absorption, weakness and affectability to weight of instable upstream layers and they have the potentially for land sliding.

6.2. Standards and map zonation of landslide risk using variants and fuzzy logic

In the frequency ratio approach, the weight was given to the data layers through distribution map of pile movements in the region. After preparation of the weighting maps according to the model relationship, the map zonation of the pile movement was prepared and then was classified according to the trend of the curve histogram changes. In this type of studies for the evaluation of map zonation of pile movement the distribution map of pile movements of the zone cannot be used (Remendo et al, 2003). For solving this problem, 55 slide were used for modeling and 25 slide points were utilized for validation and the obtained map was compared with the distribution map of land movements. However, a number of risk maps were prepared in the region using the sum value of quality sum (Qs) more flawless and precise maps were discerned. A desired risk map is a map that provides the best separation between regions with densely populated and scarcely populated landslide regions. The value of the (Qs) shows the deviation of values (Dr) for each of the maps that deviate from average value of 1 and the square sum of these deviations after applying a type of weighting. Higher (Qs) represents a better separation between various risk ranks. The quality sum (Qs) is defined as below (Gee, 1991):

$$Qs = \sum_{i=1}^{n} (Dr - 1)^2 * S \quad (7)$$

where n is number of risk ranks, Dr equaled to the density ratio which is calculated from dividing landslide density at an specific risk rank by average density of landslides based on surface density and/or number of landslides and S is the Geometrical area of risk rank percentage in the region. The results obtained from the values of fuzzy membership and the relationship between the effective functions in occurrence of landslide and already occurred slides in the region under study are expressed as follow (Tables 5 to 13):

EKtv: Green touf, flow of lava and sheared lava of andesite-basalt type lava.
Jd: Egg-destructive limestone with good layering, marly limestone.
J1: piled to layered chert containing limestone.
JS: Shale and dark sandstone with containing traces of vegetation.
K2: Biogenic and chert limestone.
Kt: Orubitolin containing limestone.
Pd: Quartzite sandstone with traversal strata formations.
PEf: Conglomerate, agglomerate, a little marl and limestone.
PEZ: Nomolite and alumina containing limestone, conglomerate.
Qag: Agglomerate.
Qb: Basalt olivine.
EKgy: Gypsum.
QSC: Debris.
Qt1: Dated alluvial terraces.
Qt2: Recent alluvial terraces.
Qta: Tracking-andesite lava flows.

TRe1: Thin layer of limestone.

Results of investigation on slope gradient percentage show that the regional slides in gradient class of 30% – 15% corresponding to the theory of (Lee, 2007) it should be mentioned that 30% – 50% class is of second importance. The results of investigation of the direction of the gradient slope show that most of already occurred slides are in the northern and western directions the reason for this can be associated to the effect of humidity as one of the effective factors in pile movements. AHP is one of complete methods which designed for multi-criteria decision making with consider to qualitative and quantitative criteria. Results of geomorphic and Smf index calculation and Vf the landslide hazard zonation map good agreement (Fig. 8). Measures of morphometric indicate the relative tectonic activity most of the southern part of the basin and mapping of landslide hazard zonation studies also suggests potential higher risk in the southern part of the basin is. Therefore it can be said that the recent tectonic activities and structures, especially the main fault as the fault North important role in the occurrence of landslides in the area of play.

Table. 8.Fuzzy membership related to direction functions

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
North	70891	2.53	6	10.91	4.312	1
North east	495110	17.67	7	12.73	0.720	0.17
East	354426	12.56	4	7.27	0.575	0.13
South east	384467	13.73	11	20	1.457	0.34
South	376390	13.44	7	12.73	0.219	0.22
South west	293013	10.46	9	16.36	1.564	0.36
West	216337	7.72	7	12.73	1.649	0.38
North west	373260	13.33	4	7.27	0.545	0

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
1500-1200	69392	2.45	0	0	0	0
1800-1500	387202	13.70	19	34.54	2.521	1
2100-1800	747934	26.46	22	40	1.512	0.56
2400-2100	755615	26.73	7	12.73	0.476	0.19
2700-2400	516158	18.26	6	10.91	0.597	0.24
3000-2700	310185	10.97	1	1.82	0.166	0.07
>3000	40304	1.43	0	0	0	0

Table. 10.Fuzzy membership related to lithology functions

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
Mm,s,l	471787	15.99	19	24.55	2.161	0.5
Pesl	21049	0.74	0	0	0	0
K2L2	139363	4.93	3	5.45	1.105	0.26
K2l,l	7279	0.26	0	0	0	0
PL_c,m	734	0.03	0	0	0	0
Q^{ag}	31131	1.1	0	0	0	0
Q^{SC}	838645	29.63	15	27.26	0.920	0.21
Q^{t}_{1}	185960	6.58	13	23.64	3.593	0.83
Q^{t}_{2}	111355	3.94	0	0	0	0
Q^{ta}	321263	11.37	3	5.45	0.479	0.11

Table. 11.Fuzzy membership values related to land usages function

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
Good pasture	617482	21.91	10	18.18	0.830	0.03
Medium pasture	1812810	64.32	24	43.62	0.678	0

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Gardening and Agriculture	379777	13.47	16	29.1	2.160	0.07
Residential	8337	0.3	5	9.1	30.333	1

Table. 12.Fuzzy membership values related to distance from fault function

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
100-0	111390	3/94	4	7.27	1.845	0.77
200-100	106860	3/78	4	7.28	1.923	0.80
300-200	107004	3/79	5	9.1	2.4	1
400-300	108931	3/85	2	3.64	0.945	0.39
400>	2392605	84/64	40	27.72	0.860	0

Table. 13.Fuzzy membership values related to distance fromwater canal network function

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
100-0	668786	23.66	33	60	2.536	1
200-100	498566	17.64	5	9	0.516	0.20
300-200	392992	13.90	8	14.53	1.046	0.41
400-300	321990	11.39	2	3.64	0.319	0
400>	944456	33.41	7	12.72	0.381	0.15

Table. 14.Fuzzy membership values related to distance from road function

Classes based on the percentage	Number of pixels of without sliding	Percent pixels of without landslide	Number of pixels of sliding	Percent pixels of landslide	Frequency ratio	Fuzzy membership values
100-0	334703	11.84	24	43.64	3.686	1
200-100	270178	9.56	3	5.45	0.570	0.16
300-200	232200	8.21	4	7.27	0.885	0.24
400-300	206760	7.31	4	7.27	0.994	0.27
500-400	187642	6.64	3	5.45	0.821	0.22
>500	1595307	56.44	17	30.92	0.548	0

7. Conclusion

In the AHP, geological impacts including fault and lithology are considered to be most effective data layer and the next significant effect is attributed to human functions including road and land usages; the topographical impacts including gradient slope, direction and height are regarded to have a lower level of influence and finally hydrology impact including river and precipitation is given the least importance in landslide occurrences. In this investigation, the difference in the weight of the parameters corresponds with the reality. The geological impact is far beyond the other three impacts, and the human impact is of much importance compared to the other two impacts, and the level of influences of topography and hydrology are not so much different form each other. The substances involved in 80% of the slide occurrences are influenced by such functions as fault, erosion, runoff, road-construction, and also by lithology (sedimentary) medians becoming self-excited and causing rotary slides in the rock. Also based on Warner classification in 20% of the slides the substances are of fine aggregate debris where the insufficient resistance of the layers against run outs, the permeable condition of the constituting material, the elevation of the underground water level, erosion of the slope surfaces, road-construction and the terrestrial slope gradient have caused rotary slides occurring in the soil. The average depth of the sled slopes is approximately 6 m which illustrates the effect of lithological borders on the thickness of the sliding layers.Results of fuzzy membership values and the relationship between the effective functions for the occurrence of landslides in the region shows that most of the slides in the region have occurred in defined class of 15% - 30% slope and class of 30% - 50% slope is of second importance. The results of investigations on the direction of the gradient shows that most of the occurrences of slides are in north and west directions the reason for this can be associated with the humidity as one of the effective functions for the occurrence of pile movements. This in despite the fact that the slide frequency in south eastern direction is mostly from other directions. The lithology investigation of the zone demonstrates that slides mostly occur in shale, sandstone with vegetation traces of comprising coal being very sensitive to pile movement and this result corresponds with results from other researchers in the region. Investigation of land usages of the region shows that most of the slides of the region occurred in residential lands. The reason could be associated with the role of mankind in natural echo-system and destructions due to changes in land usage including construction works in the region. By reviewing the results of fault departure it can be concluded that most slides occurred at a 200 m - 300 m distance from the fault and this is in spite of the fact that 72% of slides in the region are witnessed at a 400 m distance away. However, they have the least weight (Fr = 0.860). Studying the impact of departure from water canal network and the distance from road has indicated that 60% and 44% of the occurred slides in the region are witnessed at 100 m distances having the highest frequency of sliding. The results of the review of precipitation function indicates that most of the slides have occurred in regions with 300 mm - 400 mm precipitation and the fact worth of consideration is that there is no meaningful relationship between the amount of precipitation and the amount of landslide and this fact can be due to the effect of other important functions upon landslide risk in the region where the effect of precipitation has been investigated.

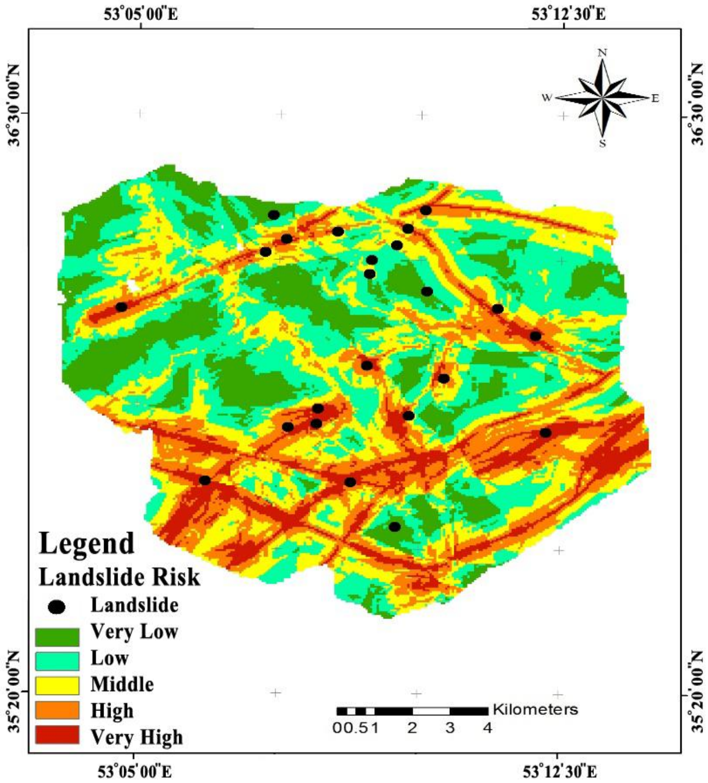

Figure 8. Zonation map at the Asaluyeh watershed basin and analysis of data layers and regions with various levels of slide risks derived via AHP.

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