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Zonning susceptible areas of landslide using WLC and OWA methods (A case study in Mountain cliff Khan, Iran)

Hamid Ganjaeian[a*], Morteza Rezaei Arefi[a], Tina Peysoozi[b], Kamyar Emami[a]

[a] Department of Physical Geography, Faculty of Geography, University of Tehran, Tehran, Iran
[b] Departmet of Geography, Faculty of Physical Geography, Kharazmi University, Tehran, Iran

A B S T R A C T

Landslide is among the most damaging ones, which has been accelerating in recent decades as human manipulation of natural systems has occurred. Mountain cliff Khan is located on the path of Saghez-Baneh and is considered as a highway to the west of the country and given the fact that it is located in mountainous areas and the probability of occurrence mass movements in the region are high, for this reason in this research, we have attempted to identify areas susceptible to mass movements in the studied area. Therefore, the method of descriptive-analytical work is considered as a type of component of applied research. The methodology is that after the preparation and insertion of information, the information layers are standardized by fuzzy logic method. And then through the AHP model, the information layers are weighed and then combined with the two methods of OWA and WLC. As a result, areas susceptible to mass motion are identified using these two methods. The results of the evaluations indicate that the areas around mountain Khan Tunnel due to the high slope, high altitude, proximity to the drainage network, adjacent proximity to the fault lines, there is a high potential for mass movement. The results of the comparison of the two methods indicate that in general, the areas around the mountain Khan tunnel because of slope and height and human interference have the highest potential and the risk is reduced to the surrounding area.

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*corresponding author.
E-mail address:
h.ganjaeain@ut.ac.ir

1. Introduction

One or more factors might be involved in the occurrence of any natural phenomenon, these factors plays a certain role in this regard (Saffari and Akhdar, 2012) and include a set of variables whose joint and simultaneous effects cause mass movements and, as a result, the sudden displacement of large volumes of material at the amplitude level (Alaei Taleghani, Rahimzadeh, Amini, 2011). Landslide is one of the most important and widespread dangers in mountainous areas, ranging from gentle hills to steep mountains (Gruber et al., 2009). These movements are among the most damaging ones, which have increased rapidly with human intervention in natural systems in recent decades (Emami and Ghoumian, 2003). It is known as one of the major geomorphic processes in the landscape of mountainous areas (Hattanji and Moriwaki, 2009). Mass movement hazards are natural and cause great financial and human losses all over the world every year (Qanavati et al., 2012). This phenomenon also causes damages and problems such as increasing the cost of road construction, increasing the cost of maintenance and repairs, and increasing the damage to used cars, etc. for roads (Shadfar et al., 2007); therefore, it is necessary to identify the ability of mass movements to plan and develop road activities (Kanungo et al., 2006). It is very difficult to predict the exact time of mass movements, it is very important to identify these hazardous areas (Masfaei et al., 2009). Cliff Khan is located on the Saqez-Baneh road and is one of the crowded roads in the west of the country; due to the fact that it is located in mountainous areas, it has the necessary conditions for the occurrence of a variety of range of motions, especially landslides.

In recent years, there have been many landslides in the area, blocking roads, damaging facilities and infrastructure; therefore, in this study, an attempt has been made to identify the areas prone to mass movements in the study area using two models of WLC and OWA. Various studies have been conducted in the field of study in Iran and around the world. External research includes Yoshimatsu and Abe (2006) who, using an analytical hierarchy process model, have zoned and assessed the risk of landslides in Japan and have finally proposed a method for predicting areas affected by landslides. Also, Lee (2007) uses fuzzy logic to study areas prone to landslides in the Ganjang, Korea. In this study, first the FR method was used to evaluate the landslide in the area and then using the combination of fuzzy membership operators and frequency ratio method, the areas prone to landslides were determined. After matching the generated map with the landslide distribution map, along with the field visit, the Gamma 0.9 operator was introduced as the best operator with 84% confidence. Based on the Geographic Information System and using two-variable analytical hierarchy process and statistical methods, Yalcin (2008) prepared a landslide sensitivity map for the Ardesen, Turkey. Yalcin concluded that the lithological, weathering, land use, and slope factors are the most important criteria in the occurrence of landslides in the region. Also, based on the obtained results, the analytical hierarchy process was introduced as the most appropriate model. Using a statistical two-variable distribution, Bednarik et al., (2010) assessed the susceptibility of landslides in the Carl Onri, Slovakia. To calculate the weight of the studied layers, they used an entropy index and finally presented a zoning map of the region's danger. Wang et al., (2012) used geographic information system and weighing method to zone the risk of landslides in the South China Sea coast. Finally, after weighing the information layers and combining the layers based on the obtained weight, they prepared a risk zoning map of the region's landslide. In Iran, Yamani et al., (2011) zoned the risk of landslides in the Gratte Karoun watershed using analytical hierarchy process model. In this study, after weighting, the layers were combined using Arc GIS software and ultimately the final zoning map of the danger zones was prepared. The results show that very high-risk and high-risk areas are often adjacent to pastures and hills with high and medium-range slopes adjacent to villages. Also, Roustaei and Ahmadzadeh (2012) zoned the areas affected by the landslide along the Tabriz-Marand road. Using lithology, hillside slope, land use, land cover, distance from linear land structures (road, river, and fault) and their overlap, they concluded that the specific geological structure, local climatic conditions, and density of quaternary deposits along with the slope gradient were the main causes of landslides. Yamani et al., (2013) determined the risk zone for landslides on the Khorramabad-Pol-e-Zal freeway. In this research, fuzzy logic and analytical hierarchy process (AHP) method has been used. The results show that while this model is suitable for detecting areas disposed to landslide, along with the slope and lithology factor as the main causes of landslides, road construction has intensified the occurrence of landslides. Asghari Kaljahi et al., (2016) zoned the risk of landslides in the western region of Khoy city. In this research, Anbalagan method has been used. The results show that about 5.6% of the region is in the very-high-risk zone and 23% of the region is in the high-risk zone. Nairi et al, (2016) zoned the risk of landslides in Bijar city. In this research, Analytical Network Process (ANP) has been used. The results show that 41% of the Bijar city is one of the areas at risk of landslides. More accurate results have shown that among the effective variables, the distance from the fault and the altitude have the most influence and the land use has the least effect. These study has been made to identify the areas prone to mass movements in cliff Khan and to make the necessary plans to control slide movements and proper induction of facilities and infrastructures in the area.

2. Material and Methods

2.1. Study Area

In the present study, cliff Khan in Kurdistan province has been selected as the study area. This area is located between Saqez and Baneh counties and in the communication route between these two counties, in the northwest of Kurdistan province. Cliff Khan is located on the hillsides of Mount Khan, which is about 3150 meters high. In terms of climate, this region is one of the coldest and snowy area in Iran in the cold seasons of the year (Fig. 1).

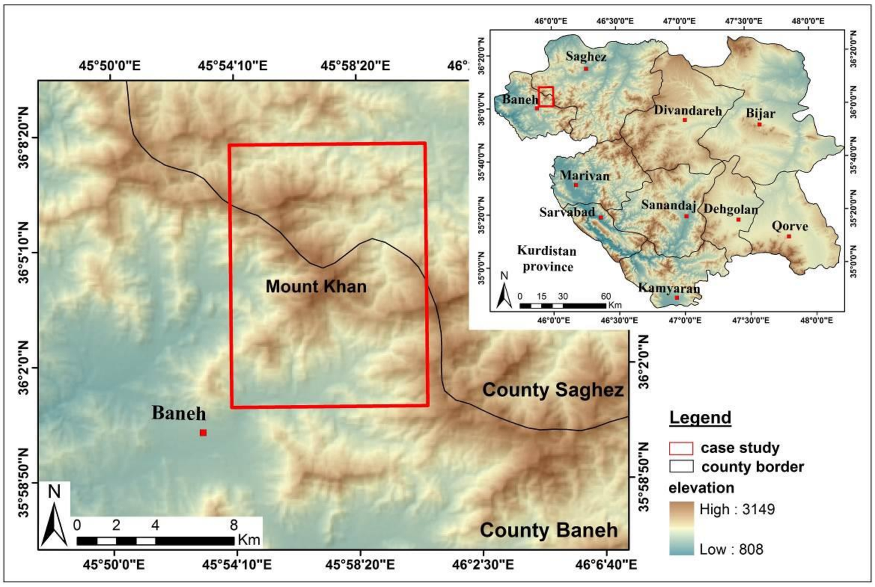

Fig. 1. Location map of the study area

The aim of the present study is to determine the areas prone to mass movement in the study area; therefore, the descriptive-analytical method is considered as an applied research component. To identify areas prone to mass movement, based on the opinion of relevant experts as well as the geomorphological status of the area, eight criteria including distance from the road, distance from the river, distance from the fault, type of lithology, type of land use, elevation, slope, and slope direction have been used. After preparing the information layers in the ARCGIS environment, the data layers have entered in to the IDRISI software and the zoning has been done in this software. After preparing and entering data, layers are standardized by fuzzy logic method and then the information layers are weighted through AHP model. Afterwards, they were combined using two OWA and WLC methods, and as a result, areas prone to mass movements were identified using these two methods. The purpose of using the two methods was to compare the results of the methods. In the following, two methods of WLC and OWA are introduced and then in Fig. 2, the general chart of the current research process
Is shown.

Weight Linear Combination (WLC): This method is one of the most common multi-criteria evaluation techniques, which is also called collectible weighting or scoring method. The basis of this method is based on average weight, and decision-makers give them weights directly based on the relative importance of the criteria. Afterwards, by multiplying the relative weight by the value of that criterion, a final weight is obtained for that criterion. Once the final weight of the options is obtained, the option with the highest value will be the most suitable option for the intended purpose (Rasouli et al., 2012). The WLC technique is one of the multi-criteria evaluation methods of MCE, which is calculated according to Eq. 1 (Taghizadeh Diva et al., 2013):

$$S=\sum wtxi \quad (1)$$

In this equation, S is the representator, xi is proportion of the earth, wi represents the weight of the i'th factor, and xi represents the i'th limit.

Ordered Weighted Averaging (OWA): It is a way to rank criteria and address the uncertainty of their interaction. This method involves sequential weighting with different standard weights. Arranged weights are assigned to the value of the criteria, but the weights of the criteria are assigned to the criteria used. In the OWA method, a wide range of results can be obtained, so that this method leads to the continuous grading of scenarios between the common operator (risk of incompatibility) and the community operator (risk-taking). The common operator indicates low risk and the community operator (OR) indicates high risk in decision making (Rahnama et al, 2012). The

OWA operator can be inferred using Eq. 2 (Talei et al., 2014):

$$\textbf{OWAt: } \sum_{j}^{n} = 1 \left(\frac{wjuj}{\sum_{j}^{n}=1\, wjij} \right) zij \qquad (2)$$

In this equation, zi1 ≤ ... ≤ Zij is obtained by the values of a criterion (xij). vj is the sequential weight and wj is the standard weight. Sequential weights are used to combine weighted criteria in which weights are assigned to the location of the pixels of the layers. In other words, all pixels placed in the same position on multiple maps receive the same sequential weights. By using fuzzy conceptual quantifiers, sequential weights can be made. Conceptual quantifiers are divided into absolute and relative categories. Phrases such as (at least 4) and (about 5) are part of relative quantifiers with phrases such as generally, often, a lot of, half, small, and at least one. Quantifiers provide decision-makers with different decision-making strategies. By changing the parameter, *a*, a set of evaluation results can be obtained for the purpose of decision-making. In other words, reducing the amount of *an* increases the optimism of the decision-maker and increasing the amount of a reduces the optimism and increases the pessimism of the decision-maker (Taleh Jankanloo et al., 2015). After calculating the sequential weights and weights obtained through the AHP model, the combination map of the parameters based on the OWA model is obtained (Fig. 6).

Table 1. Corresponding quantifiers and α parameter

Q Linguistic Quantifier	At least one	A little	Some	Half	A lot	Generally	Very much	All
α	0.001	0.1	0.5	1	2	5	10	1000

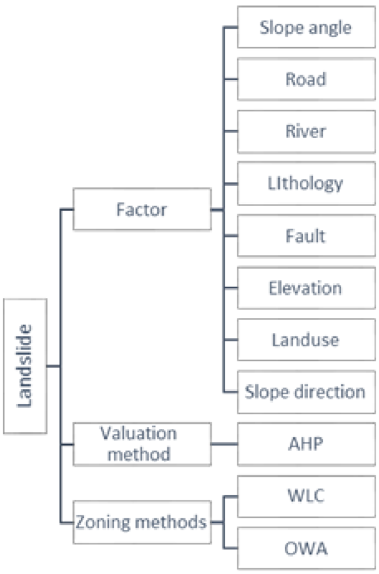

Fig. 2. Research process chart

3. Results and discussion

Introducing the Desired Criteria: In the present study, in order to identify the areas prone to mass movements, geomorphological, human, and geological criteria have been used, the following describes each of the criteria used:

Geomorphological Criteria: The geomorphological criteria considered in the present study include altitude, slope, slope direction, and river which can highly be effective in the process of mass movements of the study area. The study area is located between 1542 and 2679 meters. Due to the significant difference in altitude, there is a significant temperature difference between high altitudes and low altitudes. Therefore, altitude can indirectly increase the risk of landslide. Thus, with increasing altitude, especially above 2000 meters, the amount of snowfall has increased, and with its melting in the spring, waterways are flooded and play an important role in submerging steep hillsides in sand dunes. For this reason, altitude is considered as one of the effective parameters. Slope has also been one of the most important factors in the occurrence of landslides. If other conditions are available, the slip mass will move down the slope due to gravity (Westen, 2000). Also, due to the fact that the northern slopes receive less energy from the southern slopes, the amount of moisture in these slopes is higher than other slopes. Due to the fact that the presence of moisture can exacerbate the slip, the slopes are also considered as one of the effective factors.

The last geomorphological parameter is the river. Rivers play an important role in cutting the slope, and like communication roads, they affect the stability of the slope, and areas close to the waterways have a higher potential for wide-range movements.

Geological Criteria: Due to the variety of combinations of geological units in the region and the different sensitivity of geological units in landslides, the lithological factor has an effective role in the distribution of mass movements in the region. In the study area, the Chilean regions have high potential, and the Andesite regions have less potential for wide-range movements due to greater resistance. Also, because the system density of joints, fractures, and corrosions plays a very important role in instability and faults can cause corrosion, areas close to the fault line have a high potential for wide range of motion.

Human Criteria: Given that the study area corresponds to the communication path, the roads are considered as one of the parameters. Roads play an important role in creating and developing hillside movements, and hillside movements are one of the problems and challenges facing the development activities in mountainous areas (Rajaei, 2003). The impact of communication channels is particularly influential, especially in areas with quaternary sediments. Another human criterion is the type of land use. Land use can be effective in intensifying or reducing hillside movements. Areas with dense vegetation will be less prone to the landslide than uncovered areas. It is also possible that some unprincipled uses, especially in steep areas, may exacerbate hillside movements.

Standardization of Information Layers: In order to model and integrate information layers, these layers need to be standardized. The layers are standardized according to the intended purpose and given to the valuable information layers between zero and 1. Fig. 3 shows the standardized layers. Map a shows the slope of the area, with sloping areas close to 1 and low-slope areas close to zero. Map B shows the slope direction, with the north values close to 1 and the south directions close to zero. Map C shows the area altitude, with the higher areas having a value close to 1 (in this study, in order to study the geomorphological criteria of the region, a 30m high SRTM digital model was used). Maps D, E, and F show the distance from the river, fault, and road, with areas close to the river, fault, and road by amount of almost 1. Map G and H also show the lithological status (the geological map of 1: 100,000 areas have been used) and land use (Landsat 8 image of 2019 has been used) that low-resistance lithologies and uncovered fields are worth close to 1.

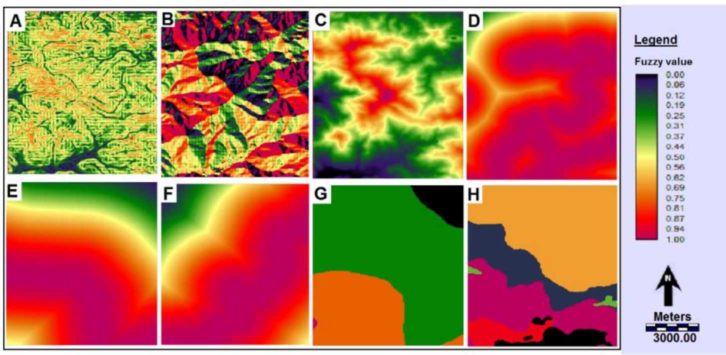

Fig. 3. Standardization of information layers

Weighing Information Layers: After obtaining the information layers, an analytical hierarchy process (AHP) was used to weigh them. In order to score the criteria, the questionnaires and the views of the experts have been used. Expert choice software was used to perform the calculations, and after obtaining the final weights, each of the criteria (Fig. 4) was applied to the data in IDRISI software.

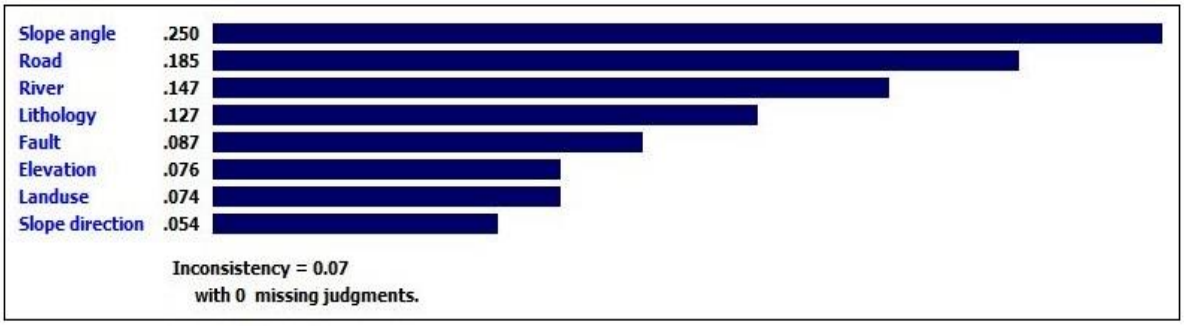

Fig. 4. Evaluation of information layers based on AHP model

Preparation of the Final Map Based on the Weighted Linear Composition Method (WLC): In order to prepare the map by weight linear composition method, after standardizing the layers in IDRISI software, the information layers are combined by combining the weight obtained through AHP model. In the end, the final map is prepared using the WLC model (Fig. 5). In this study, WLC technique was performed using MCE function.

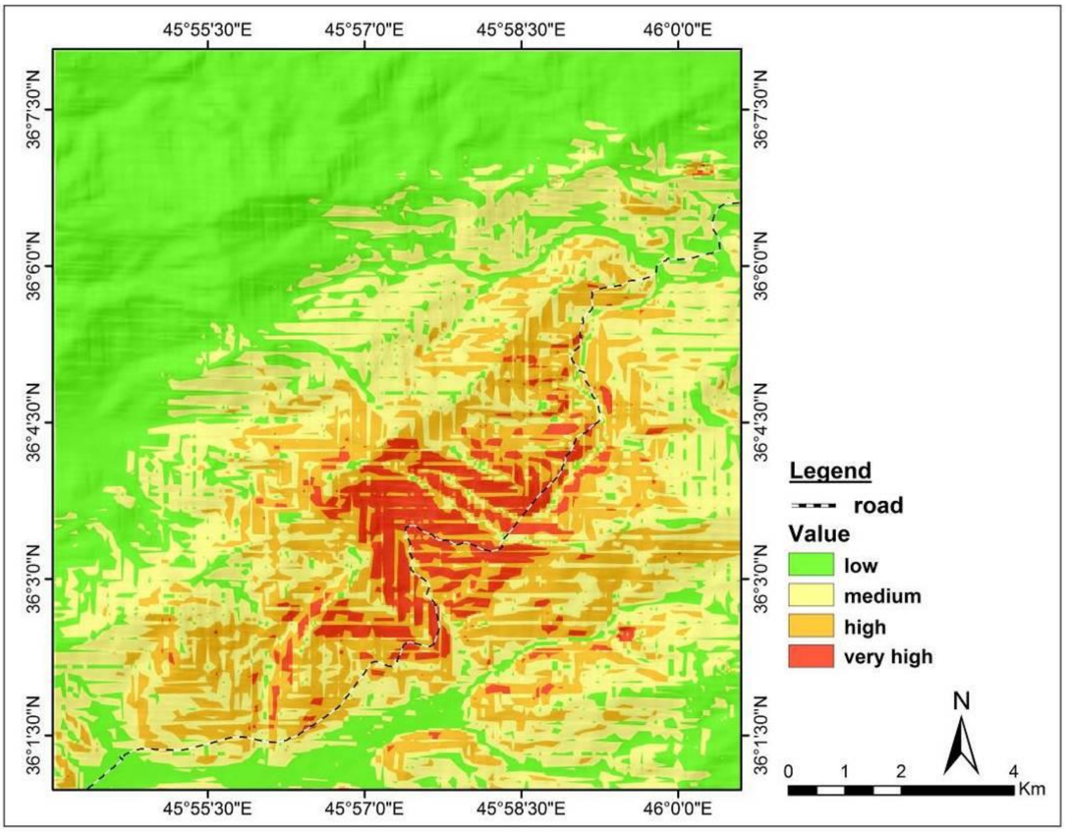

Fig. 5. Map of areas prone to mass movements using the WLC method

Preparation of the Final Map Based on the Ordered Weighted Averaging (OWA) model: To prepare the map using the ordered weighted average modeling method after standardization of the layers in IDRISI software, the information layers were combined by applying the weight obtained through AHP model. In the end, the final map is prepared using the OWA model (Fig. 6).

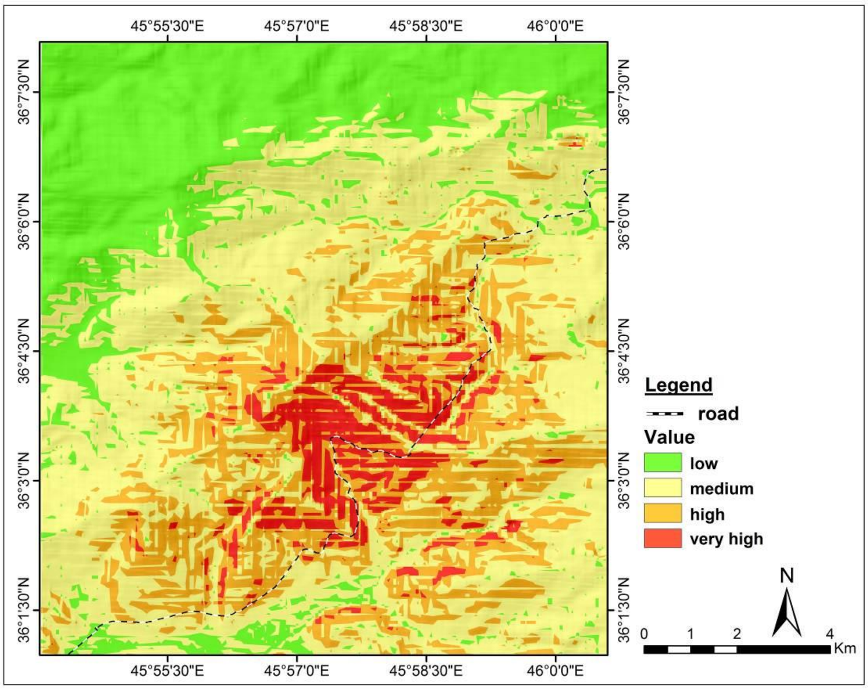

Fig. 6. Map of areas prone to mass movements using the OWA method

Evaluation of Results: In the present study, the aim is to investigate the situation of the region and then identify the areas prone to mass movements, based on which two methods of WLC and OWA have been used. After preparing and combining the information layers using the above two methods, the final maps are prepared. The results of the final maps based on the criteria indicate that the steep areas near the communication route have the highest potential for mass movements. Comparison of both WLC and OWA methods indicates that most of the high-risk areas correspond to the main road and the proximity of the Khan Mount tunnel. In general, the results of the two methods are very close, but due to the fact that the OWA model has adjusted to the obtained weights, there are differences in some areas. Table 2 calculates the area of each class in the two methods.

Table 2. The area of the classes in two OWA and WLC methods (square kilometers)

Class	OWA	WLC
Very High	7.8	6.7
High	27.1	23.2
Moderate	64.1	45
Low	33.6	57.6

4. Conclusion

Mountainous areas are considered as one of the areas prone to mass movements and the study area has a high potential in this regard due to its location in mountainous and steep areas. In the present study, in order to evaluate the potential of the region for mass movements, criteria have been considered and based on the desired criteria and based on two models of OWA and WLC, the potential areas of mass movement have been identified. The results show that the areas around Khan Mount tunnel have a high potential for mass movements due to their steepness, high altitude, proximity to the drainage network, proximity to the communication route, and proximity to fault lines. The results of comparing the two methods indicate that in general, the areas around Khan Mount tunnel have the highest potential and the risk is reduced to the surrounding area. Due to the fact that the two methods used have differences in the combination and composition of information layers, some areas have differences, which has led to differences in the classification of areas. The results of the area classification show that in the OWA method, areas with very high potential have an area of 7.8 square kilometers, while in the WLC method, this class has an area of 6.7 square kilometers. Also, the high class is 27.1 square kilometers in the OWA method, while this class is 23.2 square kilometers in the WLC method. In the OWA method, due to the adjustment made in the weights, the middle class has the largest area with 64.1 square kilometers, but this class in the WLC method has an area of 45 square kilometers; however, the low class WLC method has the largest area with an area of 57.6 square kilometers, and this class has an area of 33.6 square kilometers in the OWA method. The above set of factors indicates that the study area has a high potential for mass movements. Due to the communication position of cliff Khan and the passenger nature of Baneh city, a large number of people travel on the communication route of Khan Mount every year, and the occurrence of hillside movements can cause irreparable damages. Therefore, it is necessary for the authorities to pay attention to this important matter, and while identifying the areas prone to danger, take the necessary measures to control these areas. Unlike many previous studies, in the present study, considering that two methods have been used for zoning and one method for weighting, it has been tried to extract real and appropriate results as much as possible. Therefore, the results of the present study can be used by planners to be used in many projects and planning that takes place in the region.

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