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# GIS-based landslide susceptibility mapping of Bonab city, NW of Iran by using fuzzy AHP

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**ABSTRACT**

The presented study is attempted to investigate the landslide susceptibility of the Bonab city located in Urmia lake basin in East-Azerbaijan, NW of Iran. As methodology the coupled method contain analytical hierarchy process and fuzzy logic, named FAHP was applied to risk-ability evaluation and prepares sliding potential maps. For this purpose, three main triggering factors identified for the susceptibility assessment which is classified as geomorphology, geology and human activities where each class has several sub-classes. According to the landslide susceptibility assessment and zonation map, the main risk zone is located in east to southeast part on the Bonab city in Malekan-Bonab highway route.

## 1. Introduction

Natural catastrophes like earthquakes, landslides, floods, avalanche, hurricane, tsunamis, etc. are cause catastrophic damage and lost lives or property (Okalp and Akgün, 2016). Landslide is a complex earth movement which effected on floods, mud flow, rock-falls and debris occurrence (Castellanos Abella and Van Westen, 2007) were considered as second high frequent geo-hazard (Highland and Bobrowsky, 2008). These geological disasters happen in frequent which by monitoring and indentifying the prone and risk-able areas can save lives and reduce damages (Pereira et al., 2016; Harrison et al., 2017). The susceptibility assessment used for investigate the prone area with high risk potential for geological disasters like landslide which conducted by various quantitative and qualitative procedures (Eker et al., 2015; Zêzere et al., 2017; Harrison et al. 2017; Azarafza et al., 2018). These procedures can be divided in several approaches such as deterministical, statistical-probabilistical, heuristical, geostatistical, inventory and knowledge-based analysis (Nefeslioglu et al., 2010; Atkinson and Massari, 2011; Azarafza et al. 2013; Akgun, 2012; Jing et al. 2015; Pereira et al., 2016).

In recent years, application of new methodologies with high accuracy and low errors are received the attentions from the geo-scientists and engineers. In mean times, application of knowledge-based procedures are more comment than others which is used artificial intelligence technology to identification of high risk potential area for landslide occurrence and hazard risk assessment (Rossi et al., 2010). The different computational methods like fuzzy logic, artificial neural network, recurrent neural network, k-nearest neighbors, support vector machines, genetic algorithm, logistic regression, decision tree, random forest, naïve-bayes classifiers, etc. These techniques help to cover more uncertainties which are appeared in susceptibility assessments. By reducing the uncertainties in evaluations, the rate of error is decrease and results obtain more accurate. The presented study attempted to use knowledge-based intelligence technique for investigate the landslide susceptibility assessment in Bonab city. To this end, fuzzy analytical hierarchy process (FAHP) was used. For this purpose, various components related to landslide and earth movements are defined as triggering factors which are classified in criteria, sub-criteria and alternatives. These

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classes hierarchically evaluate, weighted and pairwise compared and results used for multi-criteria decision-makings. As fuzzy part, the identified triggering parameters are defined by membership/non-membership functions in each criterion/sub-criterion in three different steps such as fuzzification, process and defuzzification. At the end, the results of classification and decisions are converting to GIS environment and prepare risk-ability maps for landslide occurrence potential evaluations.

## 2. The studied area

The Bonab city and Bonab county is located in west of Maragheh county on the outwash Urmia Lake plain in East-Azerbaijan province, NW of Iran (Statistical Center of Iran, 2012). The location of the Bonab city in Iran is shows in Fig. 1. Geologically the Bonab located on the Quaternary alluvial which include detached sediments and organic/inorganic soils. The Fig. 2 is presented the geological map of the studied area and Urmia Lake (Azarafza and Mokhtari, 2013; Azarafza and Ghazifard, 2016). The main rocky outcrop of the studied area is located in east and southeast part of the Bonab city. The region in term of the meteorological condition is mainly moderate and alpine climate which aren't many changes throughout the year. The city has very low seismic activity and is generally inactive. Therefore, this factor is not included in the analysis of landslides in the Bonab region.

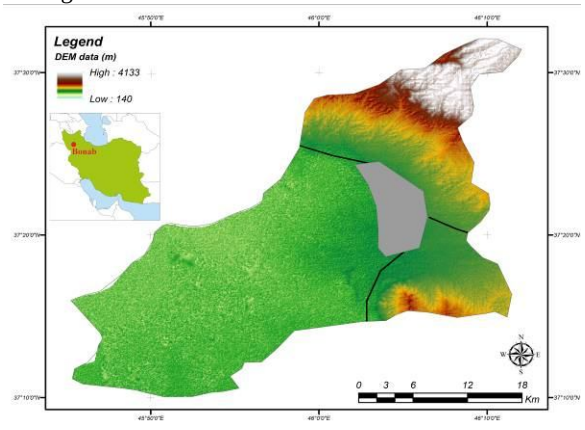


**Figure 1.** Location of the studied area

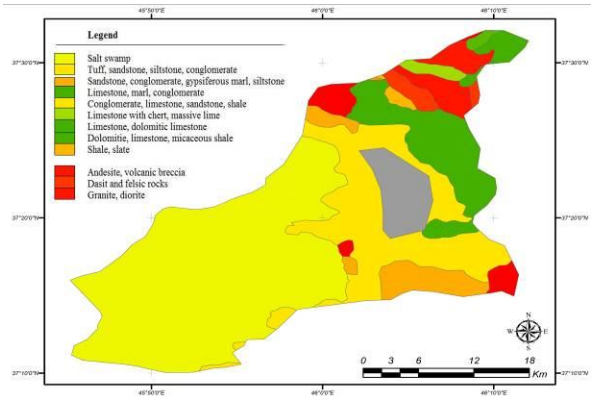


**Figure 2.** Geological map of the Bonab region

## 3. Material and Methods

In hierarchical process and fuzzy decisions for extract appropriate data mainly used expert system. After of triggering factors identification which target landsides movements is studied area, the parameters are ordered as hierarchical form as criterion, sub-criterion and alternatives and weighted based on importance and sensitivity. The perceived model includes syncretist of fuzzy logic which is originally developed by Prof. Zadeh in 1965; and AHP-based decision-making system approaches which are having well advances in geological hazard analysis especially landslide susceptibility analyses. AHP has good performance to identify interdependent criteria/sub-criteria for solving quantitative and qualitative problems and fuzzy logic is successfully used for categories the alternatives and preparing the limits of variations for fuzzified sets based on membership functions to achieve more accurate classifications. The combination of AHP and fuzzy logic is presented by several scholars where named as fuzzy analytic hierarchy process (FAHP) which is highly efficiency for estimation of multiple attribute decision-making problems. The FAHP used for solve such these problems. The presented work is used these advantages to prepare an appropriate decision matrices for investigate the landslide risk assessment in Tajan drainage basin. The used model is used for multi-criteria decision-making based on F-AHP based on triangular fuzzy importance scale. Figure 3 present the flowchart of the FAHP used for prepare the landslide risk assessment. As seen in this figure, the operation mechanism of fuzzy process is divided into several stages as explained below:

- *Fuzzification*: the preparing the input parameters as fuzzy sets for conducting the fuzzified sets based on fuzzy member and functions,
- *Main inference*: application of design protocols, defined rules implementations,
- *Defuzzification*: converting the processed fuzzified sets after making right weighted decision matrices to producing the crisp logic members.

In the main process or inference system application where named FIS as fuzzy inference system or ISO inference system operator (Sivanandam et al., 2007; Dadios, 2012) has been successfully developed by several aspects such as automatic control, logic classification, expert systems, etc. (Wang et al., 2011; Azarafza et al., 2017). This study has used the expert systems to define fuzzy rules-bases and the Mamdani fuzzy logic controller (Mamdani, 1977).

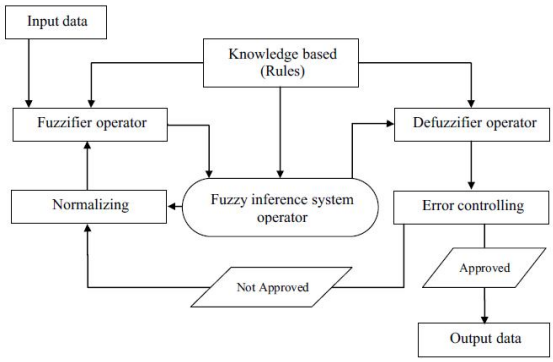


**Figure 3.** Flowchart of the studied methodology

## 4. Landslide triggering factors

Three main triggering factors are established for landslides susceptibility assessment in Bonab city region which is classified as geomorphology (slope gradient, slope aspect, slope curvature), geology (drainage patterns, hydraulic gradient, weathering), and human activities (distance to roads, distance to the cities). According to the Iran meteorological organization (2018), the climatological condition of studied area is mainly moderate to warm which is not shows significant changes. Also, in term of the seismicity the region is inactive for decades. In term of geomorphological aspect, the altitude changes and its concentration affect on the earth-curvature which lead to provided prone area for slope instabilities and earth movements. Figure 5 is presents the geomorphological status for studied area. In this orders the geological and human activities, the sub-factors variations are investigated and used for landside susceptibility triggering factors assessment which are presents in Figs. 6 and 7. Also, Tables 1 to 3 presents hierarchical analysis results that give the effective weighted parameters for each triggering factors in landslide occurrence.

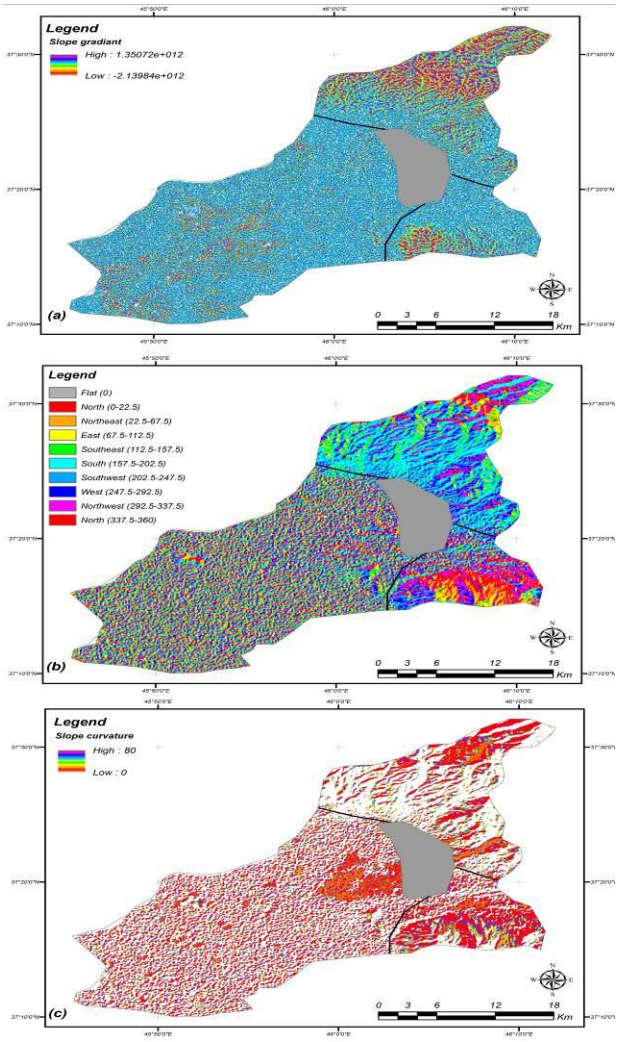


**Figure 5.** The geomorphological-based triggering parameters: (a) slope gradient, (b) slope aspect, (c) slope curvature

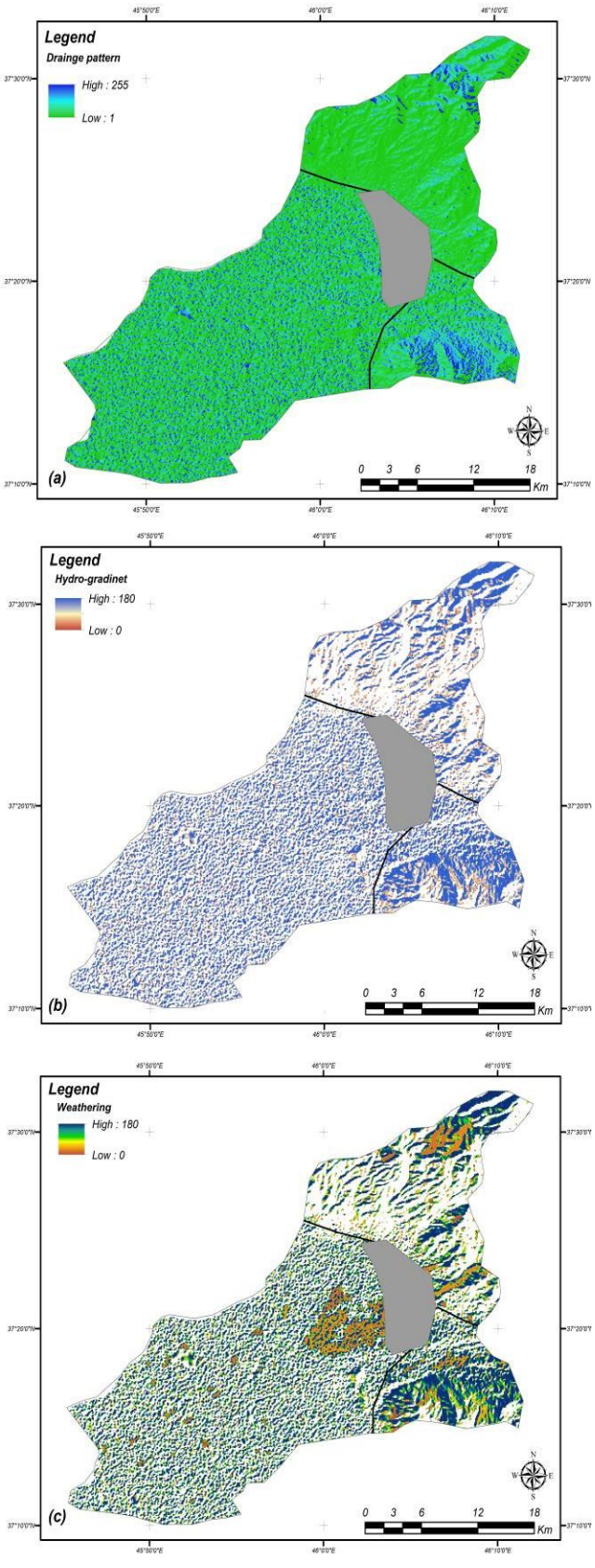


**Figure 6.** The geological-based triggering parameters: (a) drainage patterns, (b) hydraulic gradient, (c) weathering

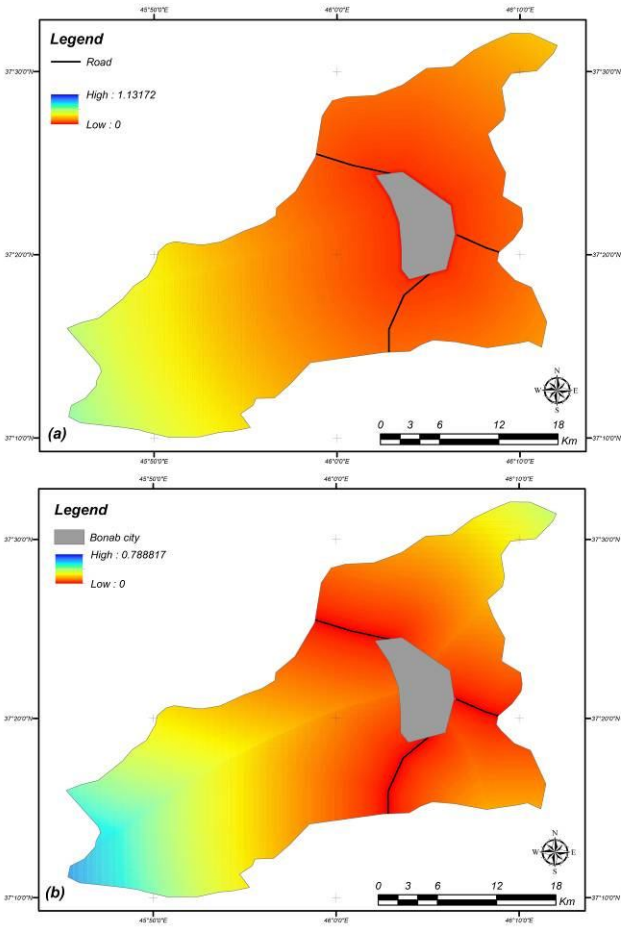


**Figure 7.** The man work-based triggering parameters: (a) distance to roads, (b) distance to the cities

**Table 1** AHP description for geomorphological parameters

| Parameters | Importance level | AHP description | |
|---|---|---|---|
| | | Weighted | Scored |
| Slope gradient | Level -2 | 0.336 | Moderate |
| Slope aspect | Level -3 | 0.212 | Low |
| Slope curvature | Level -1 | 0.452 | High |

**Table 2** AHP description for geological parameters

| Parameters | Importance level | AHP description | |
|---|---|---|---|
| | | Weighted | Scored |
| Drainage patterns | Level -2 | 0.309 | Moderate |
| Hydraulic gradient | Level -3 | 0.220 | Low |
| Weathering | Level -1 | 0.471 | High |

**Table 3** AHP description for man-work parameters

| Parameters | Importance level | AHP description | |
|---|---|---|---|
| | | Weighted | Scored |
| Distance to roads | Level -2 | 0.439 | Moderate |
| Distance to the cities | Level -1 | 0.561 | High |

## 5. Landslide susceptibility assessment

The landslide susceptibility is mainly processed in qualitative or quantitative methods (Ercanoğlu and Gökçeoğlu 2004). Application of FAHP is prepared the quantitative perspective on intuitive parameters and uncertainties in input-data which is increases error and decreases accuracy. Fuzzy logic improved the landslide susceptibility process with consideration of quality and continuous–discrete parameters in multivariate decisions. These advantage help to provide the fuzzy index maps which are indicate the main involved triggering factors in landslide susceptibilities. The index maps concluded as fuzzified-defuzzified susceptibility index maps were used for evaluate the landslide risk zonations. The main triggering factors groups after fuzzification are convert to GIS environment and used for preparing the fuzzified index maps. In fuzzy description, “1” is considered as high potential for landslide occurrence and “0” is considered as low potential for landslide occurrence. Figure 8 is illustrated the fuzzified index maps for Bonab region. As known after preparing the fuzzified index maps, these maps can’t be used directly for landslide susceptibility analysis. So, after conducting the decisions processes, the fuzzified maps is defuzzified and provide the defuzzified index map which is used for landslide susceptibility assessment. Figure 9 is present the defuzzified index map for studied area. After preparing the defuzzified index map, this map can be used for evaluate the risk-ability of landslides occurrences and identified the critical zones. The results of critical zones classification based on landslides occurrences risk is presented in Fig. 10. According to the landslide susceptibility assessment and zonation map, the main risk zone is located in east to southeast part on the Bonab city in Malekan-Bonab highway route.

## 6. Conclusion

Landslide is the geological phenomenon which is known as seconded global natural disaster in the world. This geological phenomenon like others has a frequency and a coordinated return period that can be predicted by identifying the causative factors which affecting its occurrence. Landslide susceptibility provides an important data concluding the identifications of triggering factors, landslide prone area and critical zone classifications. This study focused on susceptibility assessment of landslide in Bonab region located in Urmia lake basin in East-Azerbaijan, NW of Iran. As methodology, the coupled method contains AHP and fuzzy logic methods, named FAHP are applied for investigates the relation between triggering factors and landside susceptibility. The three main triggering factors are established for landslides susceptibility assessment in Bonab city region which is classified as geomorphology (slope gradient, slope aspect, slope curvature), geology (drainage patterns, hydraulic gradient, weathering), and human activities (distance to roads, distance to the cities). These factors utilized by FAHP to produced the landslide risk zonation maps. According to the landslide susceptibility assessment and zonation map, the main risk zone is located in east to southeast part on the Bonab city in Malekan-Bonab highway route.

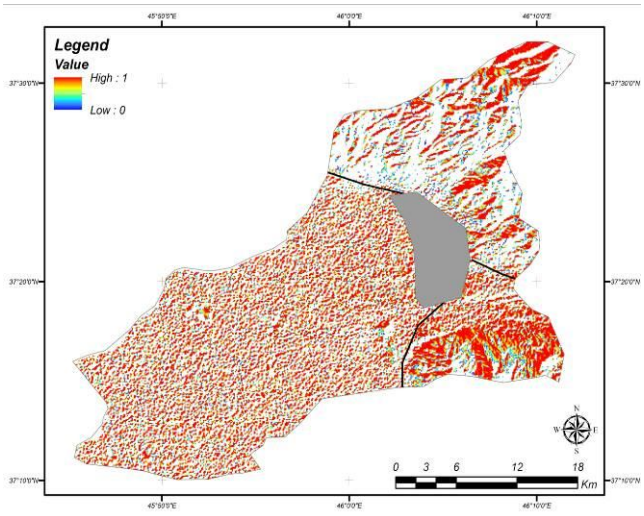


**Figure 8.** Fuzzified index map for Bonab region

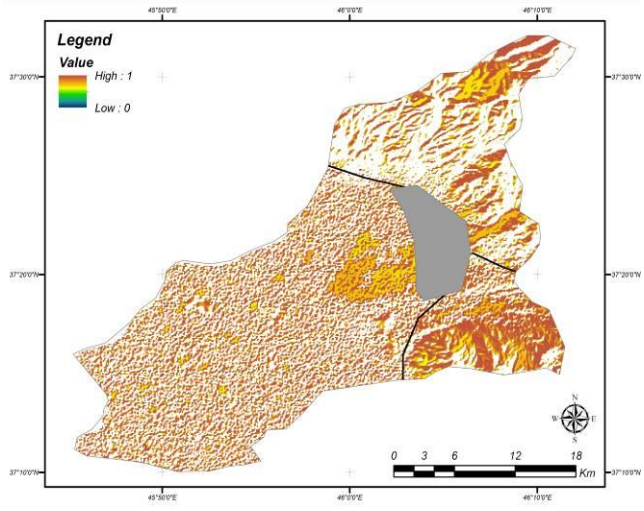


**Figure 9.** Defuzzified susceptibility index map for studied region

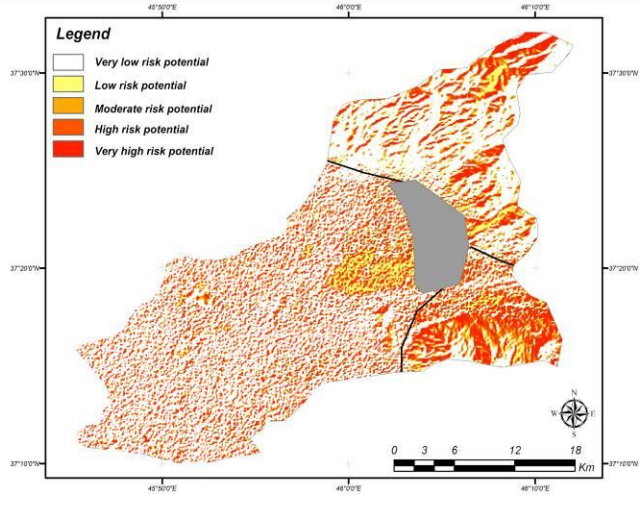


**Figure 10.** The landslide risk zonation map for Bonab region

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