



## Evaluating Hejr Karst Mass Development and Susceptibility Potential

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### ABSTRACT

Karst mass is of a great importance in supplying the residents and agricultural lands at its periphery with water. A substantial part of the elevations in Kermanshah Province is constructed of the carbonate formations one of which is Hejr Massif located in the structural zone of the hefty Zagros (overthrust). The present study aims at studying the surficial Karst development zoning through taking advantage of fuzzy logic model as well as investigating the susceptibility of its aquifer via making use of risk model utilized for the Hejr karst massif. In order to perform a karst development zoning, there is made use of eight factors, namely geology, elevation strata, slope, dip direction, precipitation, temperature, distance from fault, and vegetative cover. And, five parameters, to wit aquifer rock structure, infiltration, soil, and karst and epikarst development have been taken into consideration in an evaluation of the susceptibility. The final map of zoning operation is indicative of the idea that 32% of the region is situated in the strata featuring very high and high karst development and the model precision assessment by the use of sinkholes layer is suggestive of the existence of 85% of these sinkholes within these two areas. The developed karst zones have a great effect on absorbing the precipitations and feeding the aquifers, therefore, in order to prevent the ground water from being lost or contaminated, they need to be protected. According to Hejr Karst aquifer's susceptibility map, 30% of the region can be classified as featuring high rate of susceptibility and this is reflective of the high vulnerability of the aquifer to pollution. These regions are prone to pollution for their characteristics like their thin soil and spot water feeding in dolines, caves and fast transferring of water.

**Keywords:** karst, zoning, susceptibility, fuzzy gamma, risk model, Hejr Massif

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### INTRODUCTION

Karst is a term that points to a special type of landscape formed in the carbonated rock and the special landforms of such regions include dolines, Polje, cave, Uvulas, Lapje, dry valley and large springs (Gilli, 2011, 1). The karst phenomena and landscapes have been formed as a result of rock solubility and geomorphologic as well as climatic factors (Karimi, 2012, 2). The karst development depends on the geographical and geological conditions and the available time to the development process (Bosak, 2008, 19). The ground water in karst aquifers is the most important source of water supply in karst regions in such a manner that the life of 20% to 25% of the world population largely or completely depends on the ground water yielded from the karst (Ford and William, 1989, 1). About 11% of the land in Iran is covered by karst formations that play a considerable role in supplying the water to the regions in their vicinity (Afrasiabiyan, 1998, 127). The existence of the karst springs with high discharge rate is of a great importance in supplying the villages and the cities in the proximity of the karst massifs with the water they need. But, at present, there is no executive and codified program for the management of the karst masses in the country (Behniyafar, 2009, 122). Karst regions are generally considered as more sensitive environments as compared to the other rock lands.

The aquifers in the karst regions are vulnerable to pollution for such features of them as thin soil, spot water feeding in dolines, potholes and wells that bring about a reduction in the protective cover effect and rapid transferring of water (Cost, 2003, 9). Therefore, in order to make a principled use of the karst water, protection of the ground water in karst aquifers is of a vital significance (Vias, 2010, 1500 and Kovacs, 2003, 8). On the other hand, karst environments feature complex hydrogeological traits and this same feature renders the management of the water in these regions difficult and therefore a type of management based on comprehensive multidisciplinary research is required.

One of the most important measures that can be taken in line with managing and protecting the Karst water resources is the preparation of zoning maps for Karst development and aquifer susceptibility. This is carried out via making use of various methods and models. Hyland et al (2006) made use of regression methods for investigating the formation potential of sinkholes; Lamelas et al (2007) used logistic regression to evaluate the occurrence and formation likelihood of karst sinkholes; Maleki et al (2009) used analytical hierarchy process (expert analysis), surface density, information value, variables' weights and experimental methods to determine the zoning characteristics of karst alternations in Kermanshah Province and concluded that the information value method displays the best matching with the selected indices (closed

holes) in the region; Maghsoudy *et al* (2009) used the recession coefficients, springs' death time and isotope and chemistry results analyses to investigate the karst development in Parav-Bistoun massif; Ja'afar Bayglou *et al* (2011) made use of DEM to perform a morphotectonic analysis of the karst sinkholes of the Parav-Bistoun massif and concluded that the sinkholes are stretched along the tensile gaps and faults of the district; Ghorbani and Onagh (2012) applied the multivariate regression model to determine the zoning characteristics of karst development and karst sensitivity to pollution in Shahu Karst massif and, also, made use of regional sinkholes' information layer as the dependent variable and the high rate of compliance between the maps and the obtained results with the reality of the study region was indicative of the model's reliability and efficiency; Abbasi *et al* (2014) performed the zoning of Karst development in Nova anticline in northwestern Zagros by making use of entropy model; Zarvash *et al* (2014) investigated the karst development potential in Ilam's Kabirkouh anticline based on a blending of fuzzy methods and analytical hierarchy process and reported an optimal efficiency thereof; Maghsoudy *et al* (2015) utilized the carbonated rock dissolution intensity fuzzy gamma and drew a zoning map for Sayf Abad-e-Laghar area and also they realized a 0.4 Gamma rate as appropriate for the dissolution intensity. There are also numerous studies performed regarding the vulnerability of the karst aquifers amongst which the following works can be pointed out. Polemio *et al* (2009) made use of quantitative methods to evaluate the vulnerability of Apolia karst aquifer in southern Italy. Vias *et al* (2010) dealt with the investigation of the vulnerability of four karst aquifers in Europe based on COP method. Kattaa *et al* (2010) utilized risk model to determine the zoning properties of the karst aquifers' vulnerability in the western Syria and their results indicated that the use of the model along with GIS technique provides for an optimal efficiency in evaluating the aquifers' susceptibility. Soltani *et al* (2014) dealt with the evaluation of Marab Karst aquifers' pollution susceptibility through making use of RISKE model and autocorrelation function. Abbasi *et al* (2013) applied RISKE model to evaluate Manesht Karst aquifers' pollution vulnerability and knew it an optimal model for the evaluation of the karst aquifers' susceptibility.

Kermanshah Province is spread over some 24953.286 square-kilometer area in the western side of the country and the vast part of it is situated in overthrust and folded Zagros zones. The highest elevations in the province are made of carbonate formations (Maleki, 2009: 271). The geological, geomorphologic and climatic properties of the study area are indicative auspicious conditions for the development of karst and karstic aquifers. The current research paper aims at zoning the surface karst development in Hejr Karst massif through making use of fuzzy logic as well as evaluating the aquifers vulnerability via taking advantage of RISKE model.

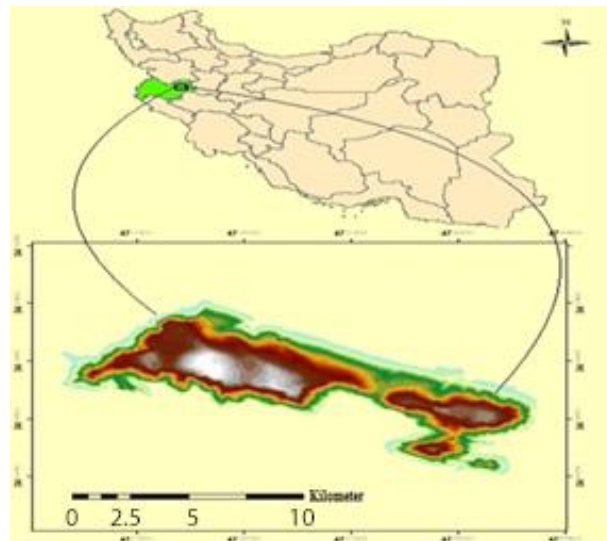
#### The study Region Position:

Hejr Karst massif is situated in the east of Kermanshah Province and west of Sahneh County and it comprises part of overthrust Zagros. The study region is about 129 km<sup>2</sup> in its area and it is positioned between 34°27' and 34°34' northern latitudes and between 47°22' to 47°35' eastern longitudes. It is 2556 meter above sea level in maximum.

The region features temperate Mediterranean climate and it is considered as a part of Kurdistan Precipitation region based on a precipitation classification proposed by Alijani (1997). Geologically, Hejr Mountain is consisted of a thick carbonate mass belonging to the second geological era. One prominent characteristic of this limestone is its massive form which rarely exhibits the existence of strata. The faults are northwest-

southeastward and they are stretched along Hejr limestone mass in such a manner that this mountainous mass is observable as steep and sharp walls in its connection point to the peripheral plains.

Figure (1): the study region position



#### MATERIALS AND METHODS

The present study makes use of fuzzy logic method to perform Karst development zoning operation and uses RISKE method to evaluate Hejr Karst aquifer vulnerability. There are numerous factors involved in the karst formation and development in a region and their impact size also differs. Therefore, according to the studies performed so far on the study region of interest to the current research paper and via making use of the study background, the effective indices influencing the karst development and susceptibility were identified. Eight factors, i.e. lithology, elevated strata, slope, slope orientation, precipitation, temperature, distance from the fault and vegetative cover were applied in the current study to perform zoning of the karst surficial shapes; moreover, the fivefold scale, including aquifer rock (r), infiltration (i), soil (s), karst development (k) and epikarst (e), were utilized to prepare a vulnerability map of karst aquifer pollution. The topography maps (1:50000), geology (1:100000), soil and land use (1:250000), Landsat images, digital elevation model and temperature and precipitation statistics provided by the meteorology stations located in the region were utilized as the study data. To analyze the data and prepare the required maps, there was made use of Envi and geographical information system software types. The regional sinkholes were first extracted by the use of Fillsink method and satellite images and then the model precision results were assessed via making use of field studies.

#### DISCUSSION AND RESULTS

##### Factors Influencing the Karst Development Zoning:

The effective factors on the formation and expansion of karst system in Hejr Massif can be divided to four sets, namely geological (lithology and fault), topographical (elevation, slope, dip direction), climatic (precipitation and temperature) and

vegetative cover, each of which has been investigated in the following sections:

**Geology:** the vast part of the study region's area is composed of Bistoun limestone that plays a considerable role in the karst development and account for the highest weight of the effects. The other rocks visible in the margins of the karst mass are of a lower importance. Fault and fractures in the limestone cause the development of karst through the creation of water infiltration and transferring cracks. There are small faults on the crown of the karst mass in the regions and there are some others in the margins of the mass.

**Topography:** elevation plays a secondary role in karst development in such a way that the elevation index is directly effective on such parameters as precipitation, temperature and vegetative cover. Therefore, karst development potential increases with the increase in elevation. The less steep slopes cause an increase in karst development potential due to the effect that they exert on the movement and flowing of water, longer maintaining of snow, increasing the vegetative cover and providing for a more intensified infiltration of water. The less steep slope of Hejr Karst massif has a great influence on the karst development. The dip directions are influential on the evaporation and transpiration and snow holding capacity. Generally, the northern slopes have the greatest effect and the southern foothills have the lowest effect on karst development.

**Climate:** precipitations supply the water required for the

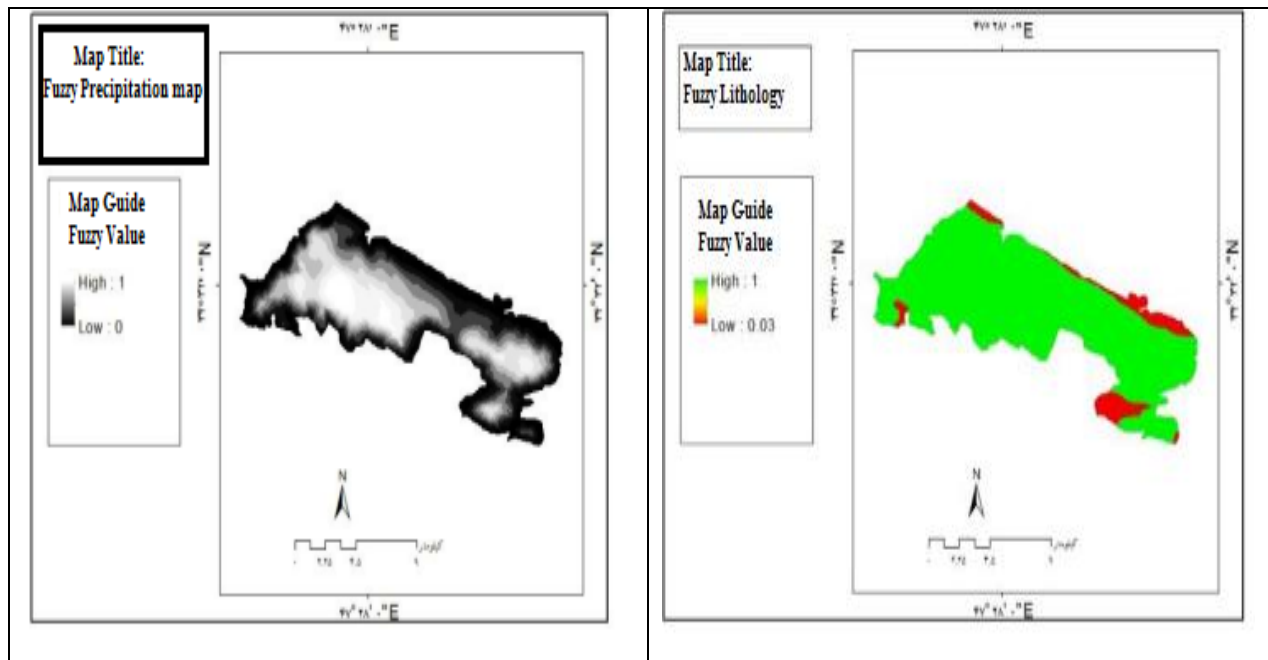
acceleration of dissolution process. The region's maximum precipitation occurs in the elevations and peaks. The temperature is factor that plays a considerable role in karst development via the effect it exerts on the snow melt coefficient, snow holding capacity and evaporation reduction.

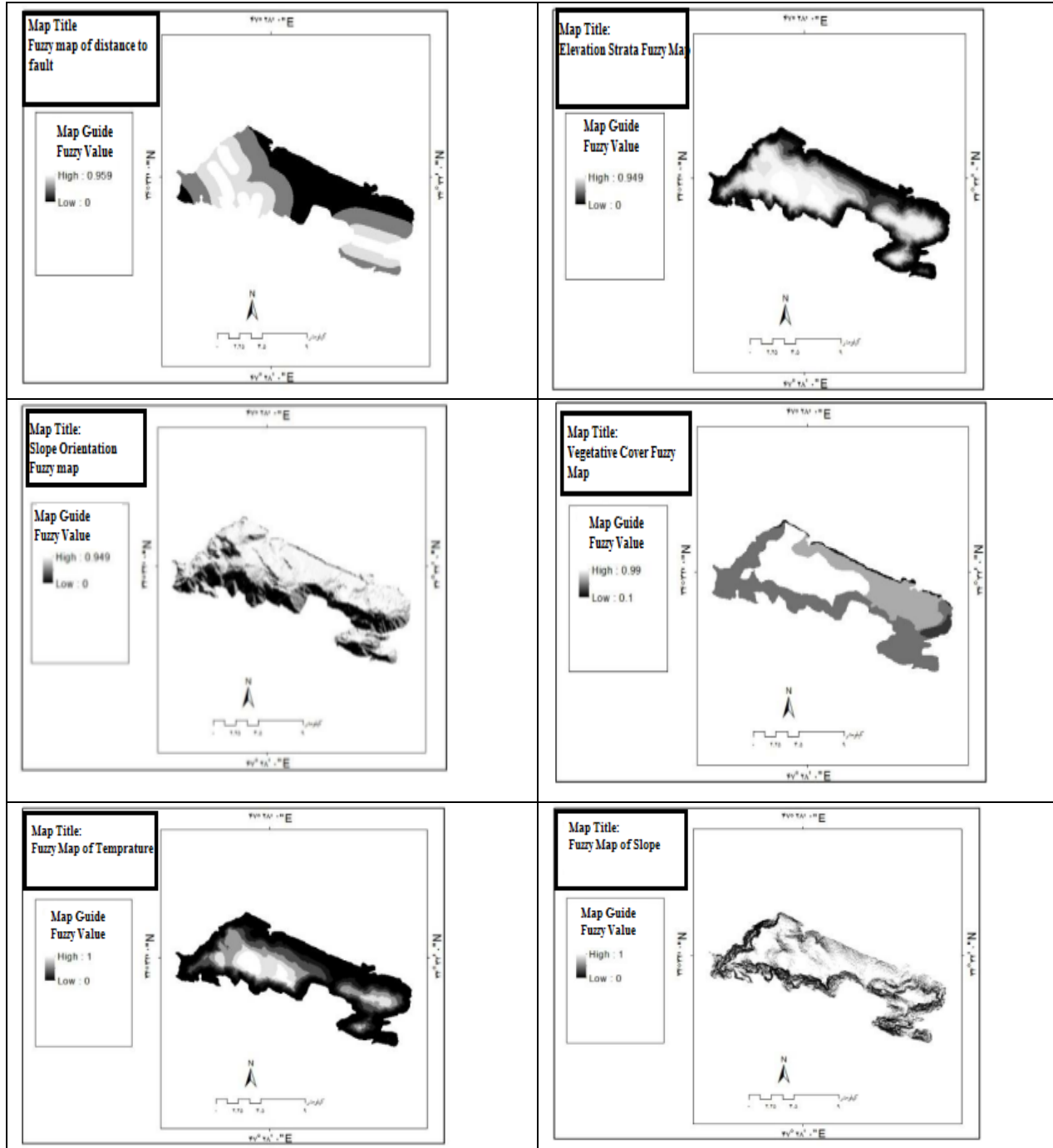
**Vegetative Cover:** Reducing the velocity of runoffs as well as increasing the amount of the carbon dioxide in the soil, the vegetative cover eventually leads to the increase in the dissolved carbon dioxide in the infiltrated water and accelerates the karstification process. The superfine pastures of the region account for the greatest weights.

**Layers Fuzzification:**

Fuzzy logic method was applied in the present study to perform karst development zoning operation. Fuzzy logic is capable of mathematical configuration of a great many of ambiguous and inaccurate concepts, variables and system and provide for the controlling and decision-making under uncertain conditions. According to the fact that such phenomena like karst develop under numerous and diverse factors and conditions and these factors are indefinite, therefore it is better to use fuzzy logic in studying them (Mo'meni, 2008, 187). To apply the layers in fuzzy logic model, firstly they should be fuzzified by taking advantage of membership function. The present study has made use of such membership functions as Fuzzy Large, Fuzzy Small and Fuzzy Linear in Arc GIS 10.2 environment to fuzzify the effective factors.

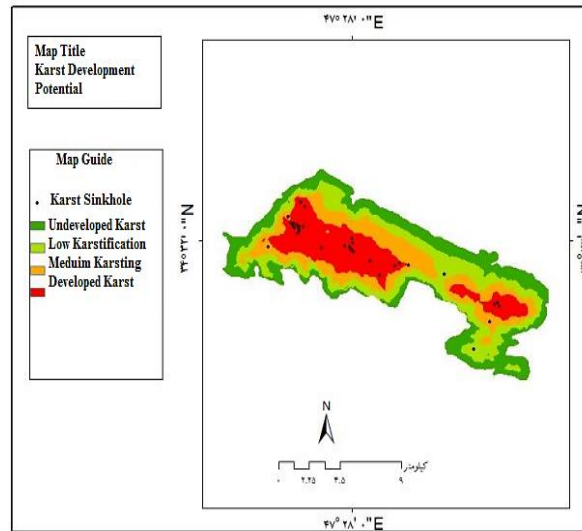
Figure (2): fuzzy maps of the factors influencing karst development





**Karst Development Zoning:**

Fuzzy 0.8 Gamma Operator has been used for determining the fuzzified maps' overlay and preparation of karst development zoning maps of the region. The fuzzy gamma operator is based on fuzzy algebraic multiplication sum and fuzzy algebraic total sum. Then the map is categorized in four sets of undeveloped karst, underdeveloped karst, intermediately developed karst and highly developed karst (figure 3). The use of gamma operator has been due to its moderating role in contrast to fuzzy summation and multiplication operators and also because it yields results a lot closer to reality in respect to the other operators.

**Figure (3):** karst development zoning map using 0.8 gamma operators

To evaluate the fuzzy gamma method's efficiency, there was made use of karstic sinkhole overlay on the karst development zoning map. It was made clear via the positive overlay of the sinkhole layers on the karst development zoning map that out of 33 sinkhole existing in the region 27 sinkholes are situated in the zone featuring very high development, 4 sinkholes were located in the zone featuring a high development rate and 2 sinkholes were positioned in the zone featuring intermediate development level (figure 3).

The undeveloped karst zone accounted for the vastest area of the mountainous mass and the developed karst zone accounted for the lowest area of the mountainous mass. The zone with little development was found situated in the mountainous mass margins and matched with elevation strata ranging from 1500 m to 1800 m. Lithologically, the region is replete with oolitic limestone, Bistoune limestone and quaternary sediments occurrences. The temperature ranged from 10°C to 13°C and the precipitation was in a range from 440 mm to 668mm. The land was either pasture or barren. The karst zone with high rate of development was located in elevation strata of over 1900 m within the limits of regional faults and the boundaries of Bistoun limestone. The temperature in this part was between 7°C and 10°C and precipitation was 680mm. The slope was below 5° and the dip direction was predominantly northward and the land was substantially used as pasture.

**Strata Areas:** the first stratum was 69 km<sup>2</sup>, accounting for 51% of the region; the second stratum was 25 km<sup>2</sup>, that accounts for 19% of the region; the third stratum was 31 km<sup>2</sup> in area that accounts for 23% of the region and the fourth stratum was 9 km<sup>2</sup> that accounts for 7% of the region and in total the whole land area was 134km<sup>2</sup>.

#### Karst Aquifer Vulnerability:

RISKE method was applied to evaluate Hejr Karst aquifer vulnerability in the current research paper.

There are numerous factors influencing the vulnerability of the karst aquifers. The risk model utilized herein considered the five following scales, aquifer rock (r), infiltration (i), soil (s),

karst development (k) and epikarst (e), for the preparation of karst aquifer pollution vulnerability. The topographic maps (1:50000), geology (1:100000), soil and land use (1:250000), Landsat images, digital elevation model and the statistics pertaining to temperature and precipitation obtained from the regional meteorological stations were utilized as the study data. To perform data analyses and prepare the required maps, there was made use of Envi software and geographical information system.

Risk model was applied to evaluate the karst aquifer's vulnerability. The risk index model proposed for the study of karst water resources vulnerability combines several topical layers (Kattaa, 2010, 1106). In this method, the evaluation of karst resource sensitivity to pollution was carried out by making use of five scales: aquifer rock (r), infiltration (i), soil (s), karst development (k) and epikarst (e). Each of these parameters is attributed a rank from one to four. The final vulnerability is calculated by making use of Ig index as the sum of the five layers' overlay weights.

$$I_g = \alpha R_i + \beta I_j + \delta S_k + \gamma K_l + \epsilon E_m \quad (\text{Relation 1})$$

In the above relation,  $I_g$  is the total vulnerability index and  $\alpha, \beta, \delta, \gamma$  and  $\epsilon$  denote the weight rate of each of the scales and their amounts are acquired from the scales' importance ratio to one another. The weight value of each of the coefficients can be obtained based on pairwise comparison model. In the relation (1), the relative importance of each of the scales in respect to one another is obtained via the relation (2).

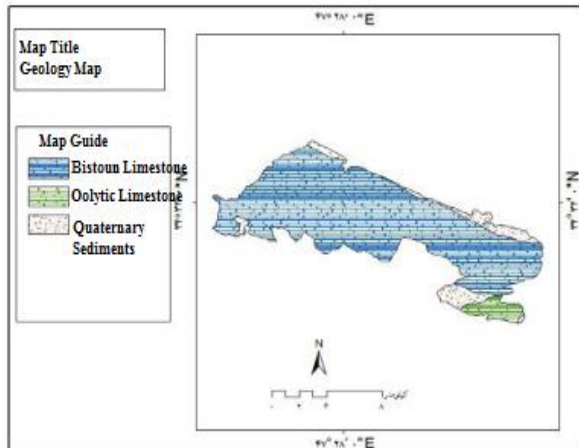
$$I > E = K > R = S \quad (\text{Relation 2})$$

#### Factors Influencing the Karst Aquifer Vulnerability:

Factors influencing the karst aquifer vulnerability incorporate five factors, lithology (aquifer rock), infiltration, soil, and karst and epikarst development.

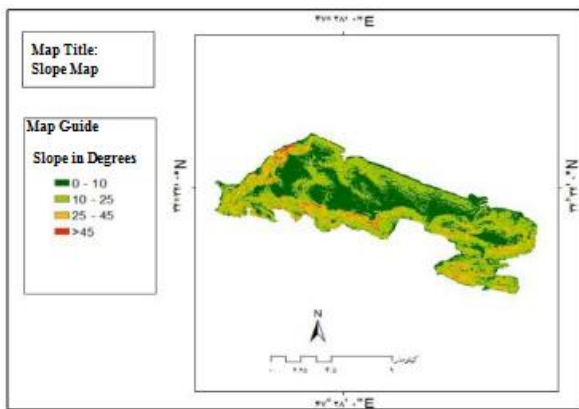
**Lithology:** the vast part of the regional area is constituted of Bistoun limestone and it has also been found that such a rock type's penetrance has played a large part in karst development so it accounts for the highest weight of the karst development. The other rock types that are predominantly seen in the margins of this karst massif are of a lower importance.

**Figure (4):** lithology map of the region



**Penetrance:** slope and development of karst are two most important factors influencing the penetrance. The slope in the karst regions is effective on the karst development potential due to the effect it exerts on the movement and flow of water, snow holding capacity, vegetative cover and water penetration. Generally, the water flows more slowly in lower slopes and the snow is retained for a longer period of time as a result of which the water can infiltrate deeper into the soil. Also, the water infiltration rate increases with the increase in karst development. To investigate and assess the factor “penetrance”, there was made use of slope layer and karst development layer overlay and the scoring was conducted based on the slope rate and the existence of sinkholes. The highest score belonged to the less steep regions on the crown of the karst development that are prone to the formation of sinkholes.

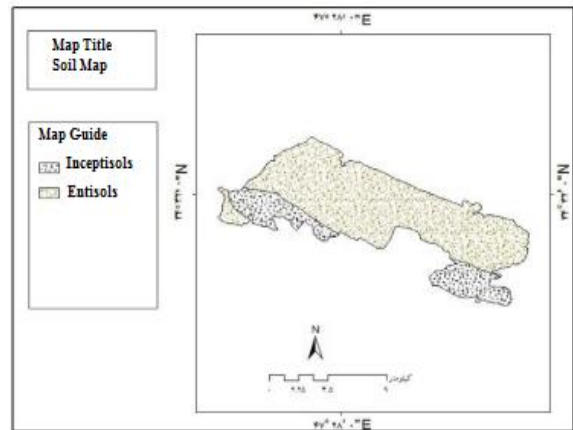
**Figure (5):** regional slope map



**Soil:** the soil map of the study region was extracted from Kermanshah Province Map (1:250000). The soil strata play their role in feeding the karst aquifer via covering the mountain surface and especially epikarst and resultantly the creation of barrier to the water infiltration and reducing the water permeation. The regional soil is comprised of inceptisols and entisols and they were found in their preliminary stages of formation and possess gross and stony textures. The assigning of scores to the soil strata is conducted based on the soil’s

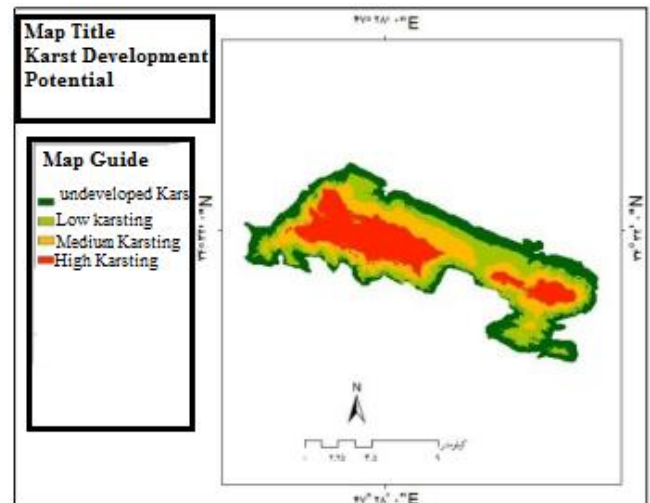
physical characteristics and its thickness. The present study results indicated the highest score belonging to inceptisols.

**Figure (6):** the regional soil map



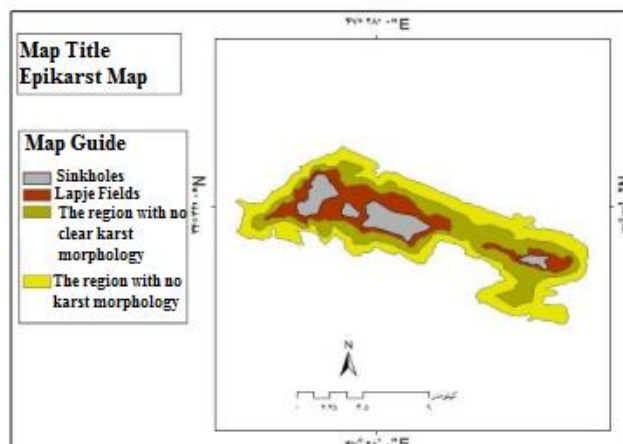
**Karst Development:** in regions featuring developed karst, the velocity and the amount of water infiltration increases and the water-rock contact is reduced also due to the existence of cavities and pores, so there is a higher likelihood of pollution penetration. To determine the score of this factor, there was made use of karst development and it was figured out that the regions of karst development on the crown of the karst massif have acquired the highest scores.

**Figure (7):** regional karst development map



**Epikarst:** the area on the karst rock is called epikarst the thickness of which ranges from some centimeters to ten meters. To identify and score the factor “epikarst”, karst development map and the sinkhole map were applied. The highest score belonged to the karst development region over which the sinkholes are spread.

Figure (8): regional epikarst map



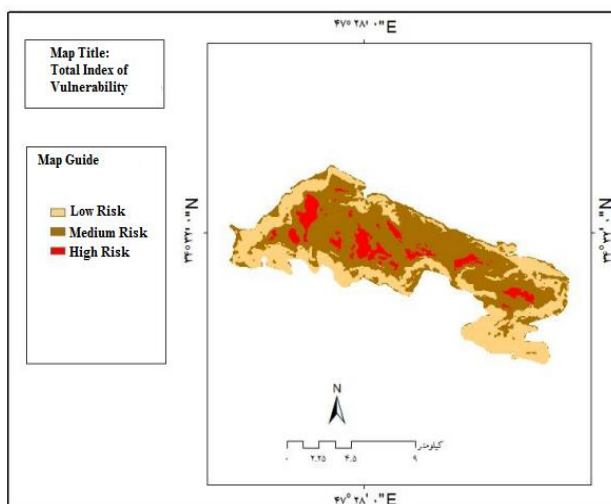
**Total Vulnerability Index Calculation:**

In this section, after assigning the scores to the five factors influencing the karst vulnerability and classifying them, the information layers were turned into raster data statistics in order to have them combined and blended. The coefficients of each of the scales were computed based on their relative importance and according to the relation (2) and the protection index, F, was calculated as below:

$$F = 0.09R + 0.5I + 0.08S + 0.16K + 0.18E \quad (\text{Relation 3})$$

The final map of the karst aquifer vulnerability has been drawn with the calculation of the foresaid index and summing the information layers in raster calculator in GIS software and then categorized to three categories of low sensitivity, intermediate sensitivity and high sensitivity (figure 9).

Figure (9):



**CONCLUSION**

The map of Hejr karst massif development zoning obtained via the use of fuzzy gamma demonstrates much of correspondence to the regions' karstic reality. Based on the zoning map

obtained herein, the regions with high karst development account for 14% of the total region, i.e. an area equal to 122.6 km<sup>2</sup>. There was observed much expansion of karst landforms in the region and 79% of the regional sinkholes were found situated in the zone featuring high karst development. Inter alia the factors influencing the karst development in this zone, the lithology, the low slope rate ranging from 0 to 5 degrees, low temperature and high precipitation more frequently seen as snow can be pointed out. The zone with low karst development, accounting for some 30% of the regional area has been found located in the lower elevations that feature lower precipitation and higher temperatures. The precision evaluation of the zoning map of the region via overlaying the karst sinkholes over it was reflective of the fuzzy gamma's optimal efficiency in such a manner that 94% of the region's sinkholes were found positioned in two strata featuring very high and high karst development.

The developed karst zones have a considerable effect on the absorption of the precipitations and feeding the regional aquifers and also they play significant roles in the formation and expansion of residential areas in the study region. According to the map of Hejr karst aquifer vulnerability, 76% of the region is classified in the category featuring a high vulnerability rate and this is suggestive of the high vulnerability of this aquifer to pollution. The category with high vulnerability was somewhat matching with the developed karst districts and these two are directly associated with one another. Therefore, in order to manage the water resources and also in order to prevent the ground water losses and pollution, the corresponding organizations are required to take such measures as preventing the destruction of pastures and preventing the pollutants from entering the ground water.

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