Science Arena Publications
Specialty Journal of Geographical and Environmental Science
Available online at www.sciarena.com
2017, Vol, 1 (1):50-59

# Zonation of Superficial Karst Development Using Fuzzy Logic Method (Case Study: Shirez Karstic Masses)

**Masoomeh Rajabi[1], Asadollah Hejazi[2], Somayeh Almasi Ghobadian[3]***
[1]Professor, Faculty of Environmental planning and education, Tabriz University, Tabriz, IRAN.
[2]Associate Professor, Faculty of Environmental planning and education, Tabriz University, Tabriz, IRAN.
[3]PhD Student, Faculty of Environmental planning and education, Tabriz University, Tabriz, IRAN.
*Corresponding Author

***Abstract:*** *The karstic masses play key role in providing water for the settlements and agricultural land surrounding them. In Kermanshah Province, most of the altitudes consist of carbonate formations and the Shirez karstic masses are of them and located in the Zagros thrust zone (or High Zagros zone). This karstic mass has a potential to develop the karst due to the geological, hydrological and geomorphological conditions. In order to investigate the development of karst in the studied area, the layers of geology, elevation, slope, aspect, precipitation, temperature, distance from fault and vegetation were used. Moreover, in order to produce the fuzzy maps of the affecting factors, Arc GIS software and membership functions of Fuzzy large, Fuzzy small and Fuzzy linear were used. Finally, the fuzzy algebraic sum, product and gamma operator were used to produce the final map. The results of present study show that the gamma operator with a value of 8% has a higher accuracy than other operators and according to it, 0.24 of the zone studied is placed under the developed karstic category. The developed karstic zones have a great influence on the absorption of atmospheric precipitation and the feeding of aquifers; therefore, it is necessary to protect these areas in order to prevent the pollution of groundwater.*

***Keywords:*** *development of karst, zoning, fuzzy logic, Shirez karstic masses.*

## INTRODUCTION

Karst is a particular type of landscape formed by water in carbonate rocks (Gili E et al., 2011). Karstic regions have unique geomorphic and hydrological characteristics, such as developed underground drainage, and specific landforms formed by dissolution. Developed karstic areas are often characterized by landforms such as Devlin, Pullman, Cave, Uvala, Lapia, Dry Valley, and Springs, which separate it from non-karstic areas (Karimi H, 2012). Karst development and formation of water resources in carbonate formations is a result of various tectonic forces, erosion, climatic conditions and lithology. Karst water sources are the most important sources of drinking and agriculture water in karstic areas (Andreo B et al., 2006). About 20% to 25% the world's population' lives largely or completely depend on underground water from the karst (Afrasiabian A, 1998). In Iran, 11% of all rocks and 90% of the Zagros rocks are composed of carbonate rocks (Ford D et al., 1989). Economic and social development of the regions also depends on the availability of high quality water, and that is why, the demand for karst water sources has increased in the world in recent decades (Polemio Met al., 2009). On the one hand, the distribution of karstic masses in Iran has led to the formation of various geomorphologic landforms and, on the other hand, the presence of calcareous springs with high discharge is very important in supplying the water resources of villages and cities surrounding the karstic masses (Behniafar A et al., 2009). Given the increasing demand for water and the location of Iran in arid and semiarid regions of the world and the development of carbonate formations in vast areas in Iran, this water source is of great importance. Therefore, identification of the factors affecting the evolution of karst and the zoning of karst development has a special position and priority in hydrological studies of karst water sources. Also, exploitation and protection of underground water in karstic aquifers are of particular importance due to the rapid transfer of water Vias, J et al., 2010).

One of the most important measures to properly exploit the karst water sources is the karst development zoning, which is carried out using various methods. (Hyland E et al., 2006) has used regression methods to investigate the possibility of formation of sinkholes,( Lamlas M et al.,2008) have used a logistic regression model in order to investigate the probability of occurrence and formation of karstic sinkholes. (Maleki A et al., 2008) have used analytical hierarchy process, surface density, information value, weight of variables and experimental method for zoning karst development in Kermanshah Province. (Maghsoudi Met al., 2009) have studied the karst development in the Parav-Bistoun mass using recession coefficient, spring death time and chemical and isotope analysis. (Qorbani M et al., 2012) used a multivariate linear regression model to zone the evolution and contamination sensitivity of Karst in Shaho karstic masses. (Abbasi M et al., 2014) have zoned the karst evolution in the Noa Anticline in northwest Zagros using an entropy model. (Zarvash N et al., 2014) have investigated the potential of karst development in the KabirKouh Anticline, Ilam by combining fuzzy methods and analytical hierarchy process (AHP) and evaluated its efficiency desirable. (Maghsoudi M et al., 2015) have zoned the intensity of carbonaceous rocks in the Seif Abad-e-Laghar Basin using the fuzzy gamma operator and considered the fuzzy gamma coefficient of 0.4 to be suitable for zoning the dissolution. The Shirz karstic mass has proper conditions in terms of karst water sources due to its geological location, climatic conditions and geomorphological characteristics. The present study aimed to investigate and identify the factors affecting the development of karst geomorphology and to zone the karst development in the Shirz karstic masses using fuzzy logic model.

**Location of case study**

Shirez karstic mass with a total area of 178 km$^2$ is located in the east of Kermanshah Province and the north of Harsin City and between 34˚14′ and 34˚22′ N◦ and 46º 26′ and 47˚ 45′ E◦ (Fig. 1). Its maximum and minimum elevations are 2680 and 1345 meters above sea level. The surface waters of the area are spilled into Gamasiab and Badavar rivers which are of the sub-basins of the Karkheh River. The studied area has a Mediterranean climate (moderate) and according to Alijani's classification (Alijani B, 1997)], it is considered as a part of the Kurdistan precipitation zone.

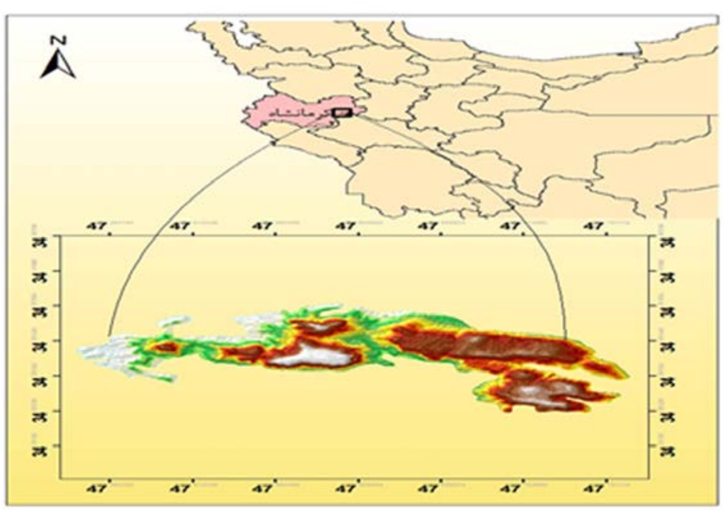

Figure 1. Location of the studied study

Geologically, Shirez Mountain is a thick limestone mass belonging to the second period of geology. The characteristic of this lime is its mass state in which layering is rarely observed. The aspect of faults is northwest-southeast, which often stretches along the Shirez lime mass, so that the margin of this mountainous mass can be seen as steep walls in many of its slopes (Fig. 2).

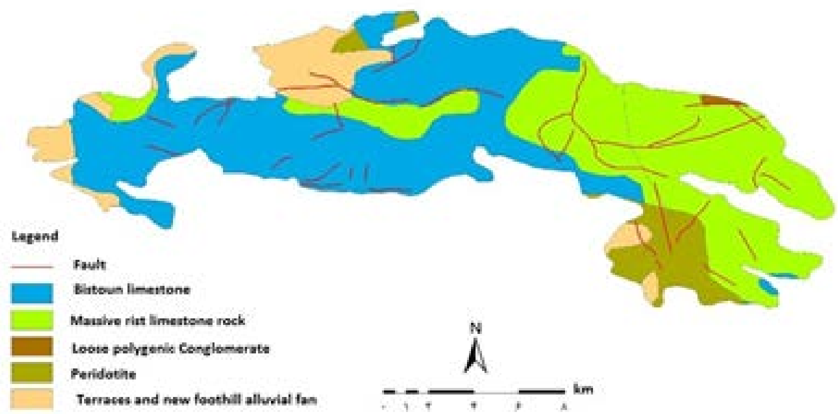


Figure 2. Geology map of the studied area

**Method**

The formation and development of karst in a region is a result of various factors and the impact of these factors are different. In present research, eight factors of lithology, distance from faults, elevation, slope, aspect, precipitation, temperature and vegetation were used for zoning the development of karst surface forms. The map of each effective factor was produced in GIS software and ENVI using topography map 1: 50000, geology map 1: 100000, soil and land use maps 1: 250000, Landsat satellite imagery, digital elevation model, and temperature and precipitation statistics obtained from the meteorological stations of the studied area. The maps were made fuzzy using membership functions and then combined using fuzzy operators. The sinkholes of the region were firstly extracted using the Fillsink method and satellite imagery, and then, the accuracy of results was evaluated using the field studies.

**The factors affecting the karst development**

**Lithology:**Bistoun limestone and massive rift limestone, which form 45 and 37 percent of the area of the Shirz karstic masses, respectively and play a key role in the karst development. Conglomerate, peridotite and the deposits of current age placed on the margin of this karstic mass are less importance in the formation and development of karst.

**Fault, seam and fracture:** Faults and fractures lead to the formation and development of karst by creating penetration pores and transferring water into carbonate rocks. The Shirez karstic masses have many faults, seams and gaps that are effective in the karst development.

**Elevation:** The height factor has a secondary effect on karst development, and it directly affects the parameters such as participation, temperature and vegetation. Therefore, with the increase in elevation, the karst development increases.

**Slope:** The slope in the karstic zones has a potential to impact on the karst development due to its effect of the movement and flow of water, long-lasting snow event, vegetation and water penetration. In general, at mild slopes, water moves more slowly and snow remains for a longer time and consequently, water penetration and vegetation will increase.

**Aspect:** the northern and the southern slopes have the greatest and least impact on the karst development. North-facing slopes provide a ground for karst development due to less evaporation and longer-lasting snow event.

**Precipitation:** Precipitation supplies water needed for the process of dissolution and transfer of water. The maximum precipitation is consistent with the elevations and mountaintops of the studied area.

**Temperature:** The temperature factor greatly influences the karst development by affecting the snowmelt coefficient, lasting snow event and evaporation. Lowering the temperature in the highlands results in an increase in precipitation and longer lasting of snow as well as a reduction in evaporation.

**Vegetation:** Vegetation can accelerate the karst development by reducing the water flow velocity and increasing the amount of carbon dioxide in the soil, thereby leading to an increase in water-soluble carbon dioxide. In the studied area, dense pastures have the greatest impact on the karst development.

## Fuzzification of layers

In present study, fuzzy logic method was used to zone the karst development. Fuzzy Logic was firstly introduced to act and make decision under uncertain conditions by Professor LotfiZadeh. Fuzzy logic is logical, which replaces the simpler machineries with the various concluding methods in the human brain. Classic logic shows anything based on a binary system (true or false, zero or one), but the fuzzy logic shows the correctness of anything with a number between zero and one(RaeoufFard F, 2007). A fuzzy set is defined in a range of {1-0} by a function. A membership degree is assigned to each member of a fuzzy set and one member can belong to more than one set with different membership degrees.

Fuzzy Logic is able to present many of the vague and inaccurate concepts, variables, and systems in a mathematical formulas and to provide a ground for making decisions under uncertain conditions. Since the phenomena, like karst, are formed by a variety of different factors and conditions which are not definite, so it is better to use fuzzy logic in studying them (Momeni M, 2008). The maps of effective factors were produced in the Arc GIS 10.2 software and made fuzzy using membership functions of Fuzzy small, large and Fuzzy linear in the Fuzzy membership tool.

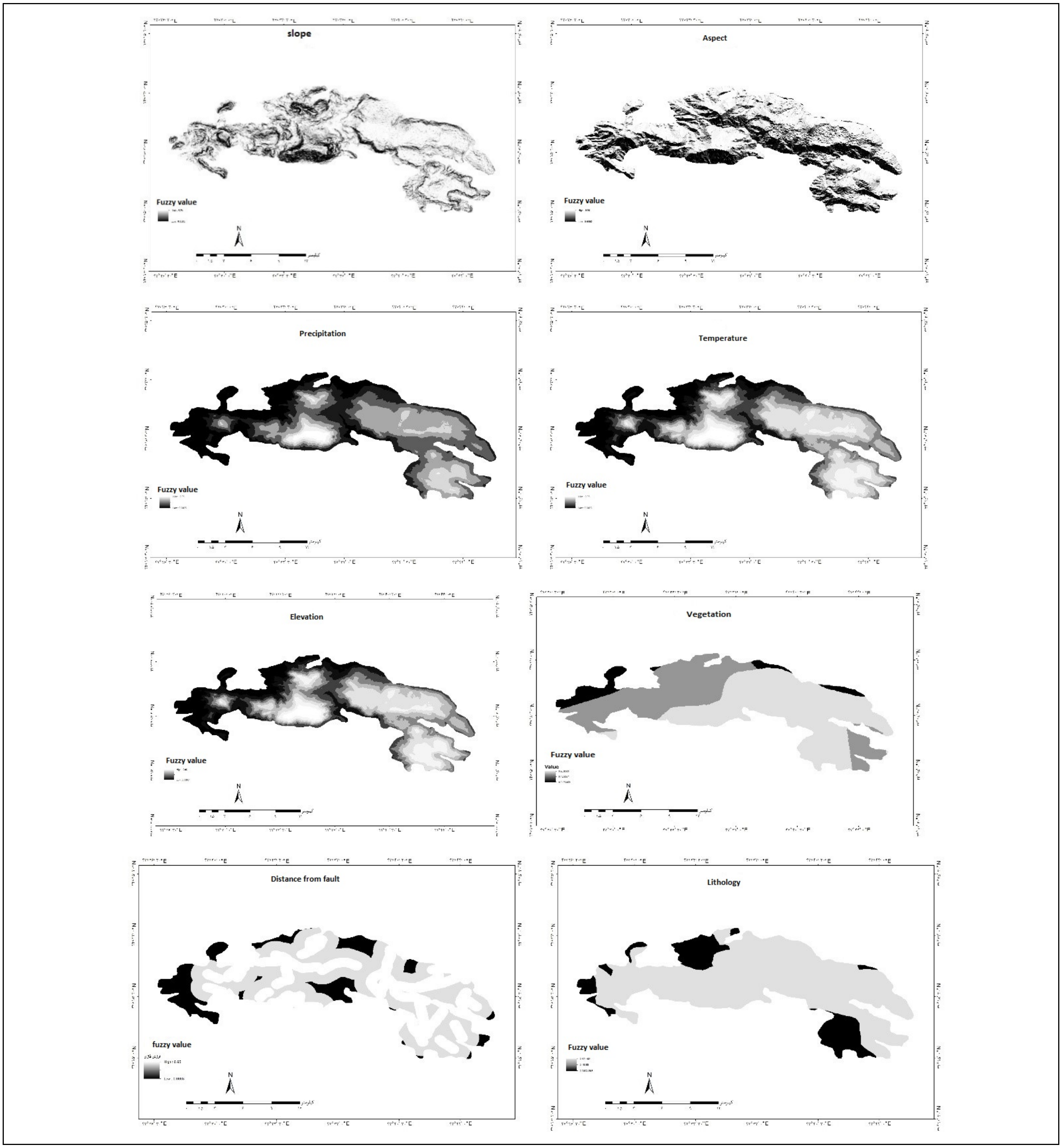


Fig. 3: Fuzzy maps of factors affecting the karst development

## Combination of fuzzy layers and zonation of karst development

In the fuzzy logic model, various operators can be used to zone the karst development. In present research, fuzzy algebraic sum, product and gamma operators were used to overlap the fuzzy maps of effective factors and to produce the final karst development zoning map. Finally, these maps were classified into four undeveloped, less, medium and high developed karstic zone classes.

Fuzzy product operator: in this operator, all information layers are multiplied by each other and is defined by the following equation.

$\mu Combination (x) = \prod n_i = 1\ \mu(x)$

Fuzzy algebraic sum operator complements the fuzzy product operator and is defined as:

$\mu\ Combination(x) = 1\Pi\ ^{n}{}_{i=1}\ (1\text{-}\mu)$

The fuzzy gamma operator is based on the fuzzy product and algebraic sum and is defined as follows:

$\mu Combination = (Fuzzy\ Alg.Sum)^{\ y} \times (FuzzyAlg.Product)^{\ 1\text{-}y}$

where y is the parameter specified in the range of zero and one. When y is equal to 1, the combination is the same as the product of the fuzzy algebraic sum, and when y is zero, the combination is equal to the product of the fuzzy algebraic multiplication. Correct selection of its value produces some values at the output that are consistent with the increasing effects of sum and decreasing effects of product (Suri S, 2013).

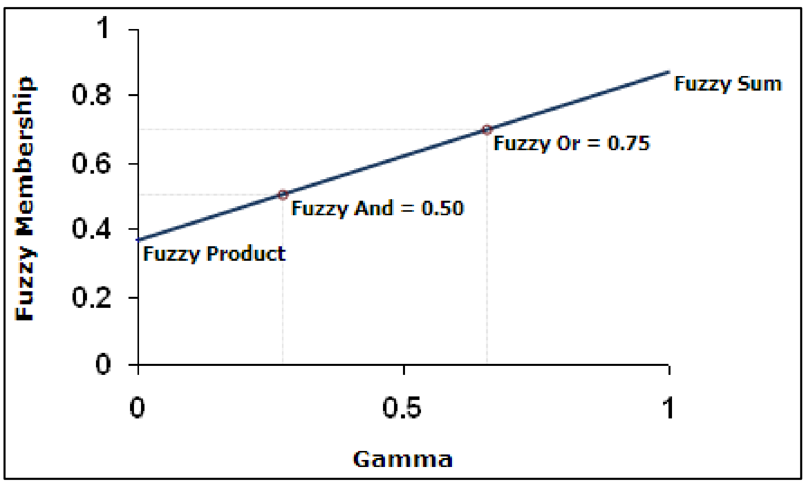


Figure 4. Relationships between fuzzy gamma and other types of fuzzy functions

**Results and discussion**

Investigating the maps produced using different operators indicates that with the use of fuzzy product operator, the numbers approached zero in the output map, resulting in a small number of pixels in the developed karst class. In the map produced by this operator, 76% of the studied was placed in the undeveloped karstic zone category, and the developed karst covered only 1% of the area (Figure 5).

In the fuzzy algebraic sum operator, since it complements the fuzzy product operator, the pixels approached one, and thus, the great number of pixels were placed in the developed karst class, so that 95% of the region forms a developed karst (Fig. 6).

The result obtained using fuzzy gamma operator is closer to reality because this operator has moderating role in comparison with fuzzy sum and product operators, which is why the operator has a higher accuracy in the output map. In present study, a gamma of 0.8 was used to produce the karst development zoning map. In the map obtained from this operator, 29%, 27%, 20% and 20% of the area were placed in the undeveloped, less and medium developed and high developed karst categories, respectively (Figure 7).

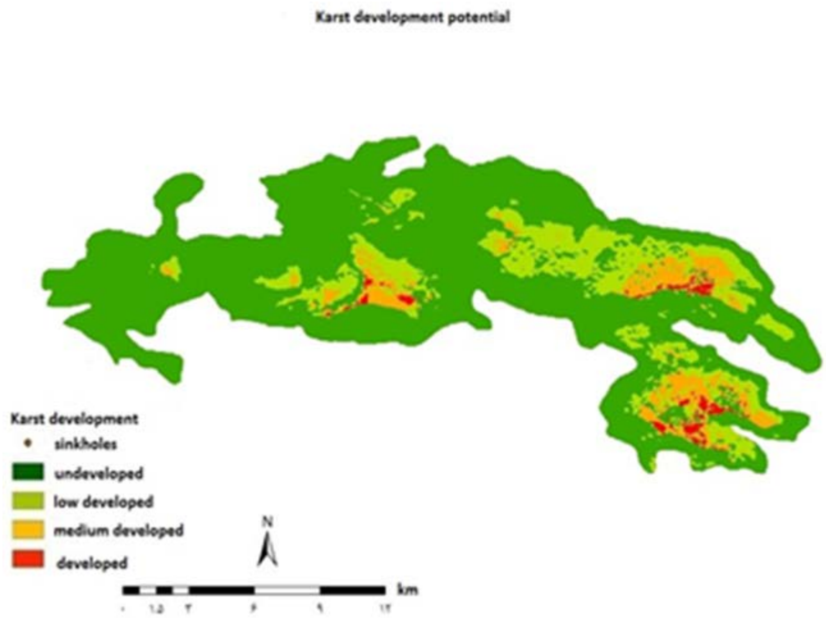


Figure (5). Karst development zoning map using the product operator

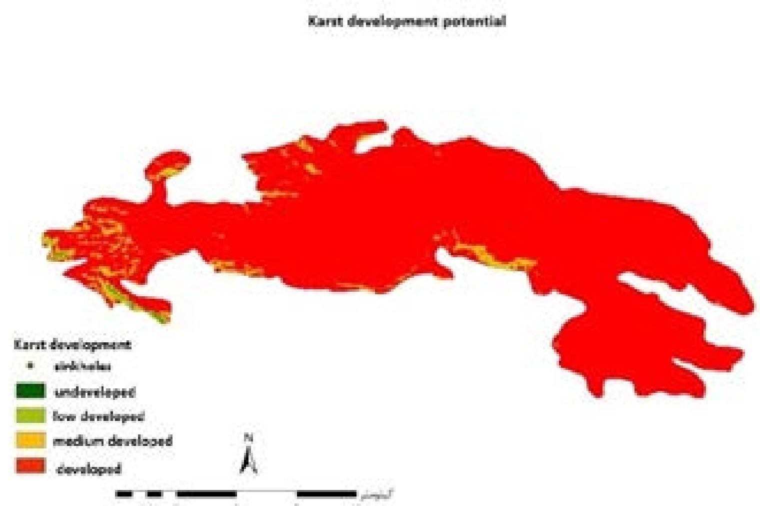


Figure (6). Karst development zoning map using sum operator

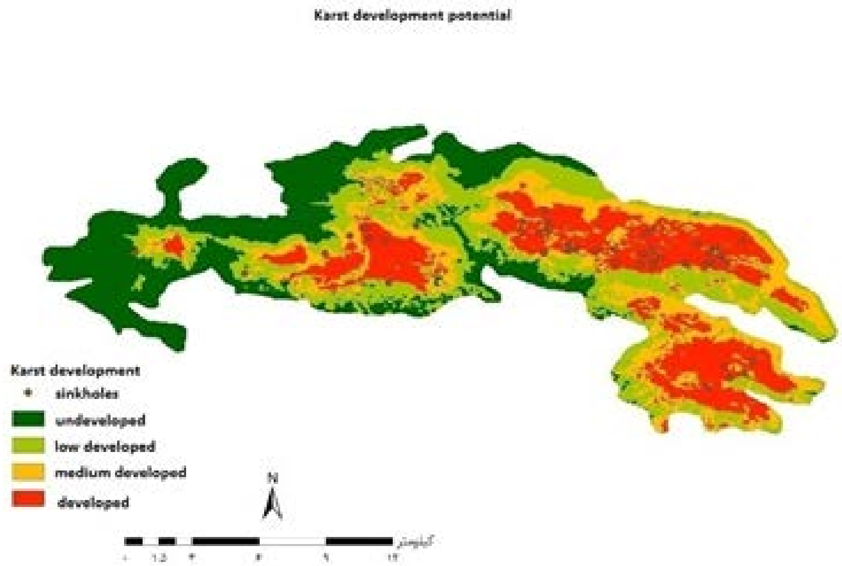


Figure 7. Karst development zoning map using gamma 0.8 operator

Table (1). Karstic zones (in percent)

| | Undeveloped karstic zone | Less developed karstic zone | Medium developed karstic zone | High developed karstic zone |
|---|---|---|---|---|
| Fuzzy product operator | 76% | 17% | 6% | 1% |
| Fuzzy sum operator | 1% | 1% | 3% | 95% |
| Fuzzy gamma operator (its value is 0.8) | 29% | 27% | 20% | 24% |

In order to investigate the accuracy of the used methods, sinkholes layer and karst zoning map were overlapped. sinkholes are specific landforms of karstic topography and represent one of the most important karst geomorphologic processes. By overlapping the sinkholes and the karst zoning maps, it was found the gamma value is 0.8. Moreover, it was found that 79%, 13% and 8% of the sinkholes were placed in the high, medium and less developed karstic zone categories.

Undeveloped karstic zone is located on the edge of mountainous masses, which are at the elevation below 1900m and has lower precipitation and a higher temperature than other areas. In terms of lithology, this area is located on non-karstic formations. The developed karstic region is expanded in the region containing Bistoun limestone and massive rift limestone, and there are faults and fractures also within this area. This zone is formed at the elevation above 2000 m, which is characterized by higher precipitation and lower temperatures than other areas and often has mild slope and pastures.

## Conclusion

Karst development zoning of Shirez karst mass was carried out using fuzzy logic method and fuzzy sum, product and gamma operators and the map produced using fuzzy gamma operator is more consistent with the real karst development zoning. According to this map, the developed karstic zone includes 24% of the studied area, that is, an area of 42.3 $km^2$. The expansion of karstic landforms in this area is enormous and 79% of the sinkholes are placed in the high developed karstic zone. The factors affecting the karst development of this zone are including faults, mild slopes (0 to 5 degrees), low temperatures and high precipitation, mostly in the form of snow. The zone with low karst development, which includes 29% of the studied area, is located at low altitudes, which has lower precipitation and higher temperatures, and there is a greater distance between it and the faults and fractures. The accuracy of the zoning map was specified by overlapping the two maps of karst development zoning and karstic sinkholes. It was found that fuzzy gamma has a desirable efficiency, so that 92% sinkholes were placed in two classes of developed and medium developed karstic zone.

The developed karstic zones have had a great influence on the absorption of atmospheric precipitation and feeding of aquifers in the studied area, and these aquifers play an important role in the formation and development of settlements in the studied area. Overall, the developed karstic areas are highly vulnerable. Therefore, in order to manage water sources as well as prevent groundwater contamination, it is necessary to take some measures such as preventing the degradation of pastures, preventing the introduction of contaminants from relevant organizations in this area.

## References


1. Gili, E., Fandel, C., (2011). Karstology: Karst, Caves and Springs, CRC Press.
2. Karimi, H., (2012). Hydrogeology of karstic area, Hydrogeology- a global perspective, www.intechopen.com/books/ Hydrogeology- a global perspective/ Hydrogeology of karstic area.
3. Andreo, B., Goldscheider, N., Vadillo, I., Vias, J., Neukum, C., Sinreich, M., Jimenes, P., Brechenmacher, J., Carrasco, F., Hotzl, H., Perles, M., Zwahlen, F., (2006). Karst groundwater protection: First application of a Pan-European approach to vulnerability, hazard and risk mapping in the Sierra de Libar (Southern Spain), Science of the total Environment, No 357, PP. 54-73.
4. Afrasiabian, A., (1998), "The importance of water resources studies and research in Iran", Proceedings of the Second World Water Conference in Karst Formations, Tehran-Kermanshah, 126-137.
5. Ford, D., Williams, P., (1989). karstHidrology and Geomorphology.
6. Polemio, M., Casarano, D., Limoni, P., (2009). Karstic aquifer vulnerability assessment methods and results at a test site (Apulia, southern Italy), Natural hazards and earth system sciences, No 9, PP. 1461-1470.
7. Behniafar, A., Ghanbarzadeh, H., Abbasali, F. (2009), "Geomorphic characteristics of Akhmalad karstic masses in the northern slopes of Binalood Highlands", Journal of Geography and Development, Issue. 14, pp. 121-140.
8. Vias, J., Andreo, B., Ravbar, N., Hotzl, H., (2010). Mapping the vulnerability of groundwater to the contamination of four carbonate aquifers in Europe, Journal of Environmental Management, No 91, PP. 1500-1510.
9. Hyland, E. S, Kennedy, M.L., Younos, T. and Parson, S., (2006). Analyses of Sinkholes Susceptibility and Karst Distribution in the Northern Shenandoah Valley, Virginia: Implications for Low Impact Development (LID) Site Suitability Models, Virginia Polytechnic Institute and State University Blacksburg, Virginia.
10. Lamelas, M. T., Marinoni, O, Hoppe, A., Riva, J., (2008). Doline Probability Map Using Logistic Regression and GIS Technology in the Central Ebro Basin (Spain), Environmental Geology, Vol. 54, No 5, PP. 963-977.
11. Maleki, A., Shohani, D., AlaeiTaleghani, M. (2009), "Karst zonation and evolution in Kermanshah Province", Journal of Humanities, Issue.13, No.1, pp. 271-295.

12. Maghsoudi, M., Karimi, H., Safari, F., Charaei, D, (2009), "Investigation of the karst development in the Parav-Bistoun mass using recession coefficient, spring death time and chemical and isotop analysis ", Journal of Natural Geography Researches, Issue. 69, pp. 51-65.
13. Qorbani, M., Onagh, M., (2012), "Zonation of evolution and contamination sensitivity of karst using multivariable linear regression model, Case study: Shaho karstic region", Journal of Quantitative Geomorphology Research, Issue. 1, p. 19-33
14. Abbasi M., Bagheri S., JafariAghdam, M. (2014), "Karst evolution zonation using the entropy model, Case Study: Noa Anticline in Northwest Zagros", Journal of Geosciences, Issue. 94, pp. 161-168.
15. Zarvash, N., Vaezi, A., Karimi, H., (2014), "Evaluation of Karst development potential in Kabirkouq anticline in Ilam province using fuzzy combination and Analytical Hierarchy Process (AHP) and remote sensing and GIS", Journal of Quantitative geomorphology, Issue. 3, pp. 144-157
16. Maghsoudi, M., Akhavan, H., Mehdiyan, M., Ashoornezhad, Gh., (2015), "Zonation of the intensity of carbonaceous rocks in the southern Zagros (Case study: Seif Abad-e-Laghar Basin)", Journal of Natural Geography Studies, Issue. 47, No.1, pp. 105-124.
17. Alijani, B. (1997), "Determination of natural seasons in Iran", Journal of Geographical Research, 29 (35): 21-33.
18. RaeoufFard, F. (2007), "The M coefficient for solving fuzzy problems, the first fuzzy international conference.
19. Momeni, M. (2008), "New issues in operation research", Second Edition, Tehran, p.360.
20. Suri, S., Baharvand S., Farhadinejad, T. (2013), "Landslide hazard zonation using fuzzy logic (Case study: Cham Sangar Basin)", Journal of Remote sensing and GIS in natural resources, Issue. 4, pp. 47-60.

- Iran Geology Organization, Geology map with a scale 1: 100000, Kermanshah and Mianrahan Sheets.
- Geographic organization of the Armed Forces, topography map with a scale 1: 50000, Bistoun, Konduleh, Kermanshah, Mianrahan and Shah Khani Castle Sheets.