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New application of fuzzy logic algorithm in GIS for land classification

Seyyed Hadi SADEGHI[1,*], Alireza EILDOROMI[1], Mohammad FARAMARZI[2]

[1] University of Malayer, Hamadan, Iran, Department of Watershed Management
[2] University of Malayer, Hamadan, Iran
* *Corresponding author*: Hadi.watershed@gmail.com

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Abstract

Population growth and disorganization of urban planning have led to unsuitable city development in the center of Iran. Suitable region recognition for urban land development is an important step towards future planning. In the present study, fuzzy logic algorithms (*OR, And, Sum, Product* and *Gamma*) were used within GIS in order to identify valuable land for appropriate residential development. Moreover, effective factors of urban land development (elevation, slope, aspect, geology, land use, drainage network, main and bypass roads, distribution of urban and rural areas, and fault line layer) were examined on fuzzy analyses to find the most effective ones. The results showed that, by considering the regional priorities and constraints, the best operator was Gamma, with a power of 0.9. According to this, 74 percent of the total regions are located between less and the least valuable lands and the remaining surfaces (i.e. 26% of the region) were classified from valuable to the most valuable lands. The sensitivity measurement of the layers used in the study showed that fault and distribution of urban and rural layers were the most and the least effective layers on region recognition (i.e. by 25.83% and 3.29%, respectively).

Keywords: *land classification, fuzzy logic, GIS*

Rezumat. O nouă aplicație SIG a algoritmului ce folosește logica fuzzy pentru clasificarea terenurilor

Creșterea populației și carențele planificării urbane au dus la o extindere inadecvată a orașelor în centrul Iranului. Recunoașterea regiunii adecvate pentru dezvoltarea arealelor urbane este un pas important în planificarea. În studiul de față au fost studiați algoritmi de logică fuzzy (*SAU, Și, Sumă, Produs* și *Gamma*) în SIG pentru a identifica terenuri valoroase pentru dezvoltarea rezidențială adecvată. Mai mult, au fost examinați factori efectivi ai dezvoltării terenurilor urbane (altitudine, pantă, aspect, geologie, utilizarea terenului, rețeaua de drenaj, drumurile principale și ocolitoare, distribuția zonelor urbane și rurale și faliile), folosind logica fuzzy, pentru a-i identifica pe cei mai importanți. Rezultatele au arătat că, luând în considerare prioritățile și constrângerile regionale, cel mai bun operator a fost Gamma, cu o putere de 0,9. Conform acestuia, 74% din totalul terenurilor sunt puțin și foarte puțin valoroase, iar suprafețele rămase (adică 26% din regiune) au fost clasificate de la cele valoroase la cele foarte valoroase. Măsurarea sensibilității straturilor utilizate în studiu a arătat că cele ce cuprind faliile și distribuția zonelor urbane și rurale au fost cele mai eficiente, respectiv cele mai puțin eficiente pentru recunoașterea regiunii (cu 25,83%, respectiv cu 3,29%).

Cuvinte-cheie: *clasificarea terenurilor, fuzzy logic, SIG*

Introduction

The purpose of this study is site selection for the appropriate development of urban settlements and identification of effective layers on region recognition (RR) using fuzzy analyses, in GIS. Recently, new urban centers have increased in order to balance the growth of large cities in Iran. During recent years, numerous cities, especially the large ones, have seen a city or new cities in their neighborhoods (Zaraby, 2009). In some cases, some geomorphologic factors (elevation, slope, etc.) have created obstacles to urban development, which caused several problems.

One of the most important questions regarding the manner of attracting population in these cities concerns the site selection techniques and development of cities over the time. In addition, the principles of urbanism should be known in order to determine the best location of urban development and population growth (Liu et al. 2014).

In recent years, urban planning has taken into account environmental hazards and natural processes. Different priorities such as topography, land use, land slope, climate, earthquakes, and distance from urban areas and main roads should also be considered for site selection (Dursun et al. 2011).

Geographical Information Systems (GIS) is a computer-based tool that can be used for different study purposes such as entry, storage, manipulation, analysis and display of geographical data. As GIS can manage a large amount of spatial data, it can serve as an ideal tool in the site selection studies (Isalou et al. 2013; Shahabi et al. 2014).

The fuzzy method helped the researchers to make better use of incomplete, inaccurate and ambiguous data (Salaski, 2002; Jamshidi-Zanjani & Rezaei, 2017). Numerous researches were conducted around the world in order to introduce physical development patterns of cities; for instance, in Nalos (west Azarbaijan province, Iran) affective factors of city development, including environmental and physical factors, were classified. These factors were overlapped in Arc GIS and the results showed that according to city conditions, environmental factors had the most important impact on city development (Naghibi & Shirmohammadi, 2008).

Bahram (2011) introduced natural factors, such as spatial and living limitation, as the main problems of Sanandaj city development based on constraints and environmental factors.

Gharakhlou et al. (2011) found two options for physical development of Babolsar city. The first concerned the inward development of the city, which was possible by allocating higher building and the second concerned the outward development of city, southwest of Babolsar, which was determined in GIS for future development according to city's limitation.

Rezaee and Melek Rudy (2010) investigated on physical development of Rudbar city. They found that numerous limiting factors induce effects on the development of the city; among them slope, landslides, faults, and the seismicity risk had the most important impact on RR.

Zoghi et al (2017) used fuzzy logic, weighted linear combination (WLC) and Multiple Criteria Decision Making (MCDM) in order to optimize site selection; they concluded that the combination of fuzzy logic, WLC and MCDM has a high accuracy and positioning in locating optimal solar sites.

In a different study, RR was done using fuzzy logic in GIS to determine appropriate areas for physical development in Divandareh, Iran. Hereby, ten layers were used based on priorities and restriction of the city and prone areas using the best-known fuzzy operator (Gamma) for city development (Hosseini et al. 2011).

The usefulness of fuzzy logic in GIS modelling for urban land evaluation was confirmed in different studies as well (Daniel, 1992; Chang Ni-Bin, 2008; Davidson et al. 1994; Khorram et al. 2015; Jamshidi-Zanjani & Rezaei, 2017).

The present study concerns a very extensive area located in the center of Iran. No study has been done in this regard and there is no development program for residential regions. Therefore, RR for urban land development is considered as one of the main objectives. Furthermore, the effects of layers are examined based on fuzzy analyses in GIS, in order to find their roles in RR.

Material and Methods

The region under study covers an area of 31,022 km², its coordinates being marked by 54°2' and 55°33' long. E and 31°25' and 33°56' lat. N.

From north and south, the area is connected to Isfahan, Semnan and Yazd, individually. The maximum altitude of the region is 3128 m above sea level (Figure 1).

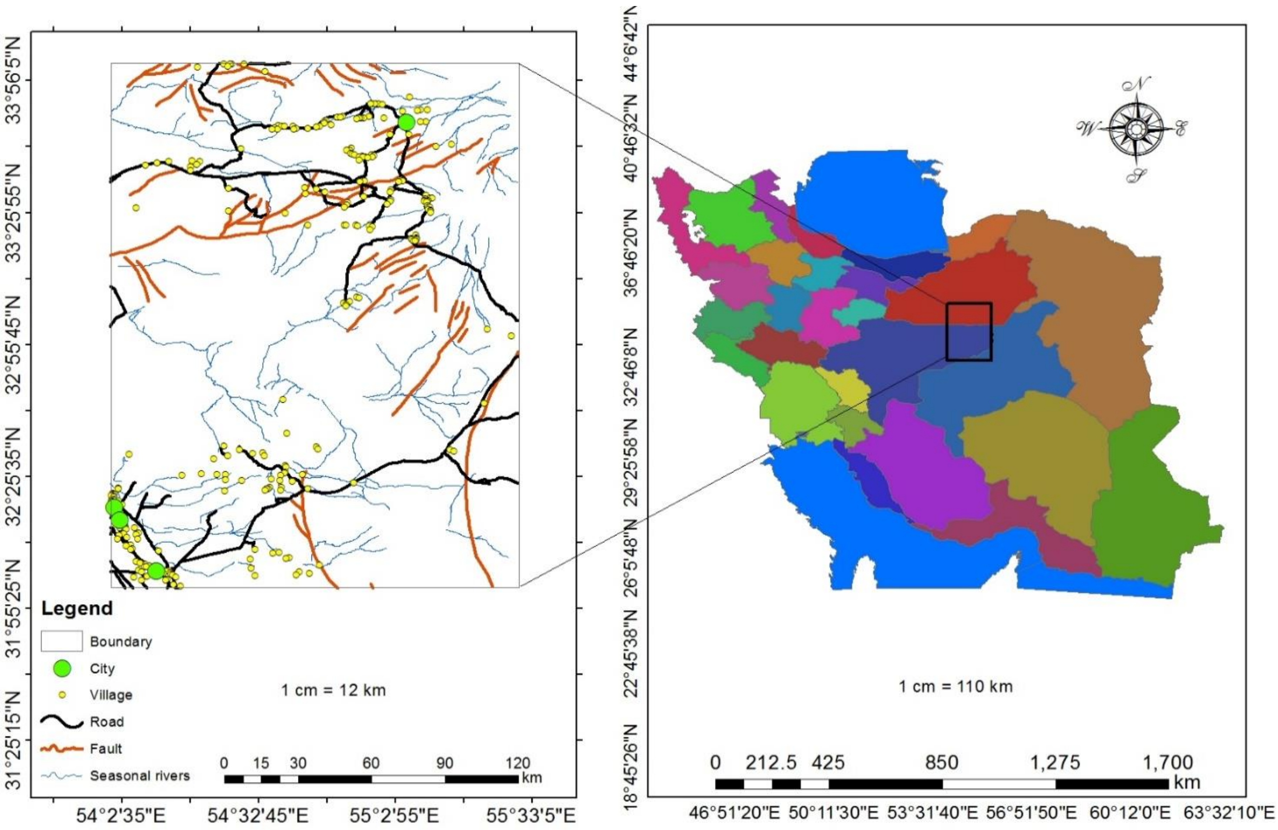

Fig. 1: Location of study area in Iran

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Fuzzy logic

Fuzzy membership values range between 0 and 1; however, there are no practical constraints on the choice of fuzzy membership values. Values are simply chosen to reflect the degree of membership of a set, based on subjective judgment. The fuzzy membership values must reflect the relative importance of each map, as well as the relative importance of each class of a single map (Hosseini, 2011).

Model inputs

Based on studies conducted on RR, many factors are involved in this regard. According to the view of experts and to the environmental and human characteristics, the most important factors that affect the region in terms of RR and physical development include elevation, slope, aspect, geology, distance from drainage network, land use, distance from the main and bypass roads, distribution of urban and rural areas, and distance from fault lines.

The data for these nine criteria for RR were obtained from governmental organizations and the information was examined by using the fuzzy method in GIS. At first, all layers were scaled, and their raster were prepared to implement fuzzy model in Arc GIS. The layers were weighted based on responses from groups of producers and researchers in Arc GIS (Pradhan et al. 2009).

Lesser height and slope, north and northwest direction (these directions receive the highest sun shine in the area), closeness to the main and bypass roads, closeness to urban services, resistance to erosion, significant distance from rivers and fault lines, and dense pasture lands received the highest weight. Each layer got the same total weight (0.111), to recognize their roles on RR by using fuzzy algorithm in GIS. Membership function for the layers was linear, which is derived from the deficiencies of the Boolean logic-based evaluation method (Daniel, 1992). For instance, in relation to the fault lines, any point located within a distance of less than 1 km was rated as the least valuable, 1 to 2 km was less valuable, 2 to 3 km was valuable, 3 to 4 km was very valuable, and above 4 km was the most valuable land. The sub-criteria was determined and weighted based on GIS classification for each criteria and the view of experts and environmental characteristics of Isfahan, Semnan and Yazd province (Table 1).

Table 1 Evaluation Criteria, Membership and Weights based on responses from groups of producers and researchers

Criteria	Sub-criteria	Weight	Total weight	Fuzzy Membership
Elevation	698-959m	0.81-1	0.111	Linear
	959-1287m	0.66-0.81		
	1287-1618m	0.47-0.66		
	1618-2000m	0.47-0.25		
	2000-3057m	0-0.25		
Slope	0-6 %	0.94-1	0.111	Linear
	6-11%	0.70-0.94		
	11-20%	0.50-0.70		
	20-40%	0.38-0.50		
	40-73%	0-0.38		
Aspect	South	0-0.25	0.111	Linear
	South-East	0.25-0.40		
	South-West	0.40-0.50		
	East	0.50-0.60		
	West	0.60-70		
	North-East	0.70-0.80		
	North-West	0.80-0.90		
	North	0.90-1		
Geology	Higher sensitivity to erosion	0-0.05	0.111	Linear
	Medium sensitivity to erosion	0.05-0.49		
	Low sensitivity to erosion	0.49-1		
Land use	Residential areas	0-0.02	0.111	Linear
	Bare and rock land	0.02-0.07		
	Saline land	0.07-0.15		
	Desert	0.15-0.49		
	Denser pasture lands	0.49-0.88		
	Dense pasture lands	0.88-1		
Drainage network	Distance to river	0-1	0.111	Linear
Main and bypass roads	Distance to road	0-1	0.111	Linear
Distribution of urban and rural areas	Distance to urban and rural area	0-1	0.111	Linear
Fault	Distance to fault line	0-1	0.111	Linear

The layers were named and the final estimation was conducted on them to determine whether the urban land is most valuable, very valuable, valuable, less valuable or least valuable using fuzzy operators including *And, OR, Product, Sum,* and *Gamma* (with different powers).

Fuzzy *AND*

This operator sets values of 0 and 1. It is defined as (eq. 1):

$$\mu_{combinatin} = MIN(\mu_A, \mu_B, \mu_C, \ldots) \quad (1)$$

where μ_A is the membership value for map A at a particular location, μ_B is the value for map B, and so on.

"Fuzzy AND results in a conservative estimation of set membership, which tend to produce small values".

Fuzzy *OR*

The output membership values are controlled by the maximum values of any of the input maps, for any particular location. The fuzzy OR is defined as:

$$\mu_{combinatin} = MAX(\mu_A, \mu_B, \mu_C, \ldots) \quad (2)$$

Fuzzy *Algebraic Product*

The product membership function is defined as:

$$\mu_{combinatin} = \prod_{i=1}^{n} \mu_i \quad (3)$$

where μ_i is the fuzzy membership function (i=1, 2... n).

"The Product fuzzy membership values tend to be very small with this operator due to the effect of multiplying several numbers less than 1".

Fuzzy *Algebraic Sum*

This operator is complementary to the fuzzy algebraic Product. "The result is always larger or equal to the largest contributing fuzzy membership value", being defined as:

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

where μ_i is the fuzzy membership function for the i-th map and i=1, 2... n maps are to be combined.

Fuzzy *Gamma*

"This is defined in terms of the fuzzy algebraic Product and the fuzzy algebraic Sum by eq. 5":

$$\mu_{combinatin} = (\text{Fuzzy Algebraic Sum})^{\gamma} * (\text{Fuzzy Algebraic Product})^{1-\gamma} \quad (5)$$

where γ is a parameter between 0 and 1 (Zimmermann and Zysno, 1980). When γ is 1, the combination is the same as the fuzzy algebraic Sum and when γ is 0, the combination equals the fuzzy algebraic Product. This operator was applied with 0.7, 0.8 and 0.9 powers.

Sensitivity measurement of layers

In order to understand the effective layers on fuzzy analyses, one of nine layers is removed at each step, and eight remaining layers are used for RR. Each layer is evaluated based on its impact on RR.

Results and Discussion

It was specified in evaluation of the fuzzy operators including And, OR, Product, and Sum that none of these operators were appropriate for physical development feasibility, because their results were far away from realistic (Mirnazari et al, 2015; Motevalli and Esmaili, 2013; Hosseini et al, 2011). Although these operators were confirmed as unsuitable methods for classification in different researches, testing these operators in relation to urban development would give a better understanding of the fuzzy logic technique.

The *Gamma* operator (with 0.7, 0.8, and 0.9 powers) was also tested in order to identify the best power applied, which depended on whether the identified areas are the regions with restriction or not. If the identified areas fall in the restricted regions, the operator would not be found as appropriate for RR.

Figure 2 illustrates the classification of RR using all operators. Five classes were categorized from the most to the least valuable land, based on priorities and restrictions in the study region. Findings indicated that fuzzy *OR* and *Sum* operators covered the highest valuable land for physical development, and the fuzzy *Product* and *And* operator expressed more different conditions of the region. They cover the least valuable lands for physical development of city. These operators including fuzzy *OR, Sum, Product* and *And* selected either all or none of region for city development which their selection were not suitable for our purposes. It means that these operators did not consider the criteria and limitation of the regions that were defined in Table 1. However, the *Gamma* operator, with different powers, indicated a sensible balance of RR (Pradhan et al. 2009).

Table 2 shows the proportion of RR using the operators. According to this table it can be concluded that fuzzy *OR* and *Sum* operators identify more than 99% of the study region as the most valuable land. This conclusion was opposed to fuzzy And and Product operators. These operators identified the highest region between less and least valuable land. This conclusion was different in the case of fuzzy *Gamma* with power of 0.7, 0.8 and 0.9 which more reasonable results based on priorities and limitations achieved for RR. Among the different powers (0.7, 0.8 and 0.9) of the Gamma operator, fuzzy Gamma with 0.9 power

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had better recognition of the region (Hosseiny et al. 2011; Yalcin, 2008; Lee, 2007).

Estimations of Gamma with power of 0.7 and 0.8 showed that these two operators did not include some of suitable areas for city development while their locations based on priorities and limitations (Table 1) are appropriate for new city development. This importance was grasped by examination of the constraints and priorities in the subject area, which were provided by used layers. Hereby, by means of Gamma operator (0.9) most valuable, very valuable, valuable, less valuable and least valuable lands included 2.26%, 7.5%, 16.22%, 29.30% and 44.70%, respectively.

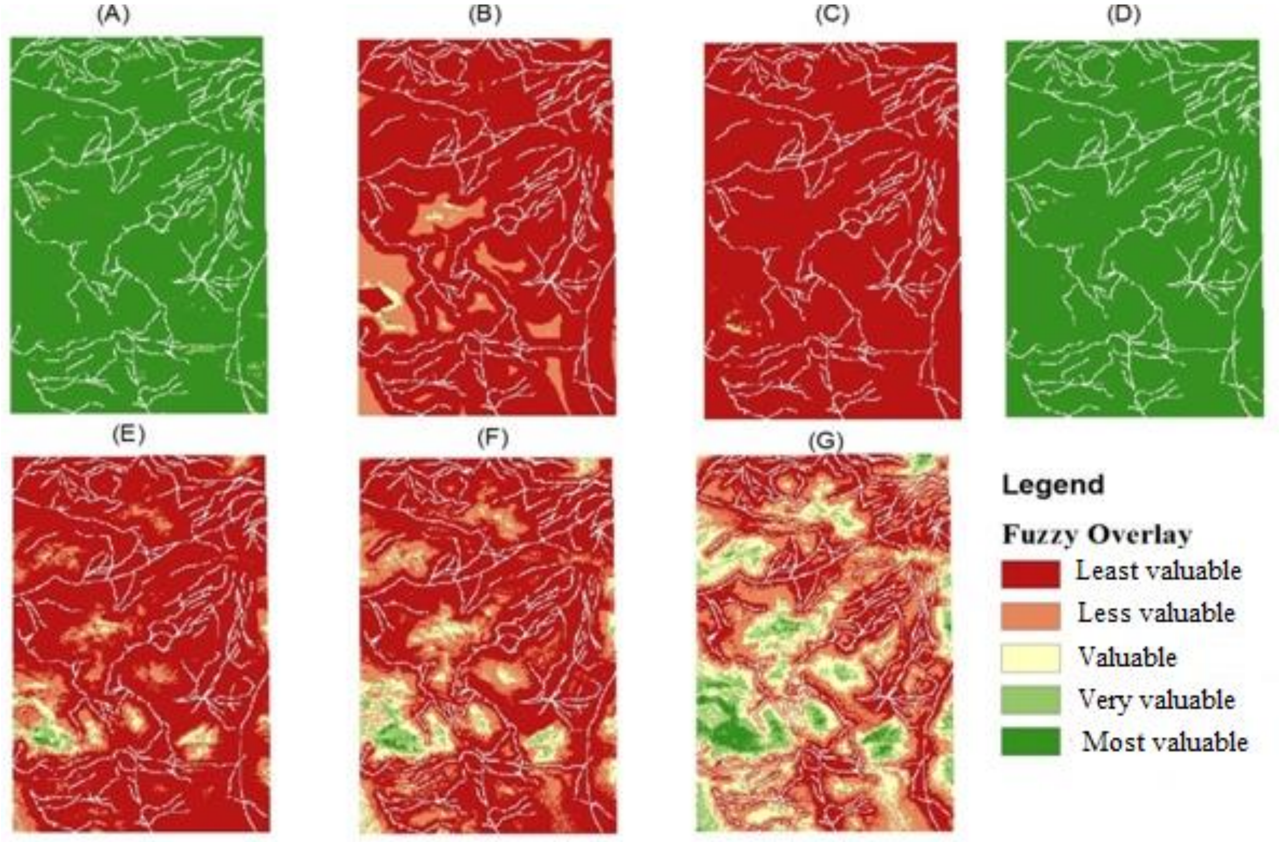

Fig. 2: Classification of RR with all operators including A: OR; B: And; C: Product; D: Sum; E: Gamma 0.7; F: Gamma 0.8; G: Gamma 0.9

Table 2 RR of subject area by all operators

	Gamma 0.9	Gamma 0.8	Gamma 0.7	Sum	Product	And	OR
Most valuable	2.26	0.28	0.1	99.9	0.0008	0.002	99.37
Very valuable	7.5	1.77	0.66	0.0004	0.003	0.006	0.47
Valuable	16.22	5.6	2.07	0.0002	0.003	0.7	0.009
Less valuable	29.30	17.62	9.37	0.00009	0.17	8.41	0.006
Least valuable	44.70	74.69	87.78	0.0001	99.74	90.79	0.0002

Figures 3-11 show the effect of layers on RR when using fuzzy analyses. The restrictions and the priorities of applied factors were used for RR verification (Meshginni et al. 2013; Shamsipour & Shikhi, 2010). Thus, the elevation factor was examined in the entire area and it was found that sections which were chosen as the most valuable and very valuable lands had no height restriction. This means that they are at an altitude lower than 2000 m, which are valuable for physical development. Figure 3 illustrates that elevation layer affect RR by 4.98%.

In the examination of slope restriction, it is founded that 90% of the total region are located between the slopes of 0 and 11 percent which is the most appropriate slope for residential development (Cowan, 2005). Out of the regions selected for development from valuable to the most valuable lands, none is out of this slope range. Figure 4 shows that slope layer affects RR by 5.23%.

With respect to the aspect, important areas were identified from valuable to the most valuable lands. In this regard, northern and north-eastern aspects were determined as the most appropriate directions for development because areas with these aspects receive the highest sun radiation in the region. Two suitable sections identified in the center of the region have south-eastern and south-western aspects. Figure 5 indicates that aspect layer affects RR by 3.82%.

The geology investigation of the region showed that more than half of the area under study combine marl, chalk, and sandstone, which have average resistance to erosion (Tavfigh, 1991, Zoghi et al., 2017). Valuable lands located in the southern part of the study region have soils that are more resistant to erosion; this area mainly comprises sandstone and conglomerates. Figure 6 shows that geology layer affects RR by 5.05%.

The low-density vegetation within the areas suitable for development represents an important part of the regions' cover. The main part of the valuable lands is located in the southeast and southwest of the study region in desert. Figure 7 illustrates that land use layer affects RR by 7.63%.

The river element has always been an effective factor for RR. This element is considered a possible potential of dry and extreme dry region, which has the potential of flood. The total length of the rivers in the region is 2,542 km. None of the identified regions is in the flooded area (Shirzadi et al. 2011, Jamshidi-Zanjani and Rezaei, 2017). Figure 8 shows that river layer affected RR by 22.45%.

The most of suitable regions, ranging from valuable to the most valuable plots, are appropriate for development based on the evaluation of the main and bypass roads. The total length of main and bypass roads is 1,165 km. These circulation axes connect cities such as Khor Biabanak to Ardekan, Meibod, and Yazd. Moreover, being near or far from urban and rural areas is always considered as one of the determinant factors for RR due to they will provide better condition for other regions. Figure 9 indicates that the main and bypass roads layer affect RR by 17.27%.

The distribution of urban and rural areas indicates that the highest distribution is in the south, southwest, north, and northwest. Being near the city was the priority of evaluation the urban and rural areas distribution for RR (Mohammady et al. 2009). According to figure 10, urban and rural areas distribution layer affects RR by 3.29%.

The length of the faults in the region is 1,060 km. Despite this fact, the important element is that none of the areas suitable for urban development and identified from valuable to the most valuable are on the fault line (Ercanoglu and Candan, 2004; Jamshidi-Zanjani and Rezaei, 2017; Zoghi et al., 2017). Figure 11 shows that fault layer affects RR by 25.83%.

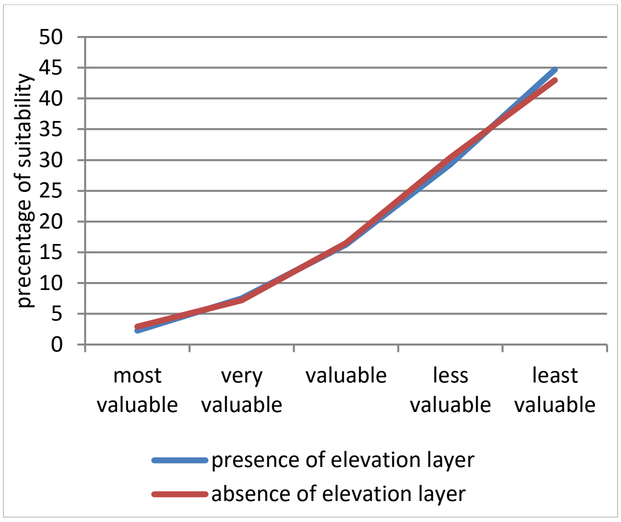

Fig. 3: RR in the presence and absence of elevation layer

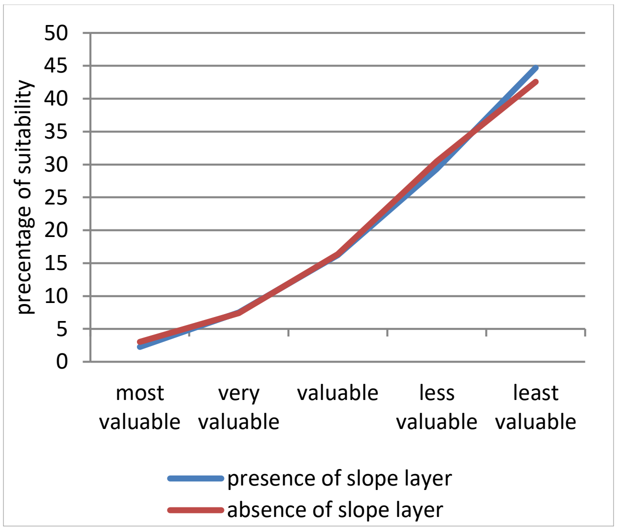

Fig. 4: RR in the presence and absence of slope layer

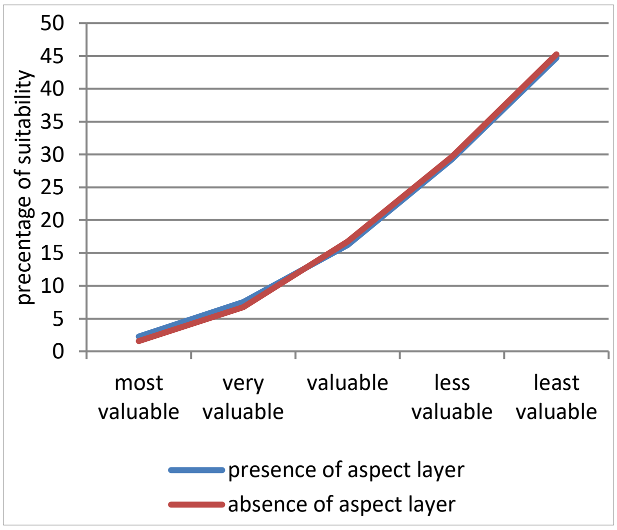

Fig. 5: RR in the presence and absence of aspect layer

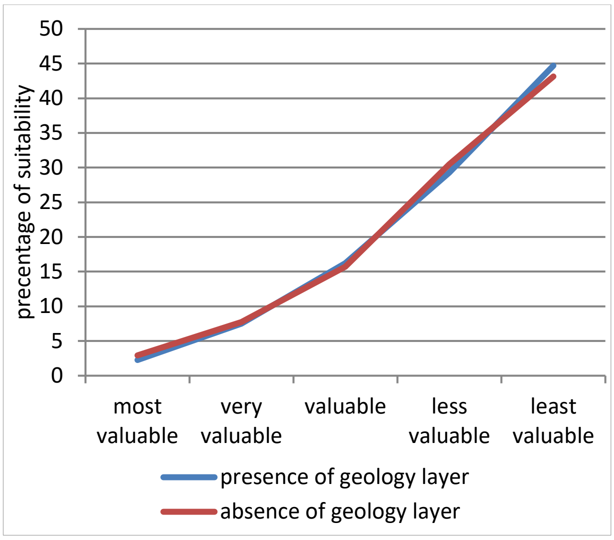

Fig. 6: RR in the presence and absence of geology layer

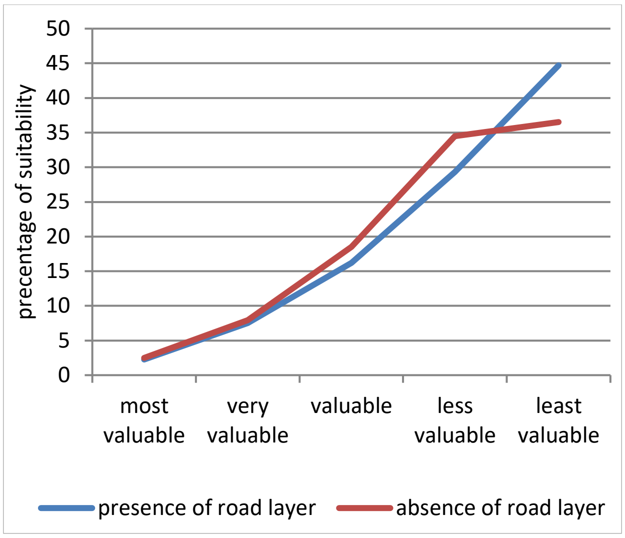

Fig. 9. RR in the presence and absence of main and bypass roads layer

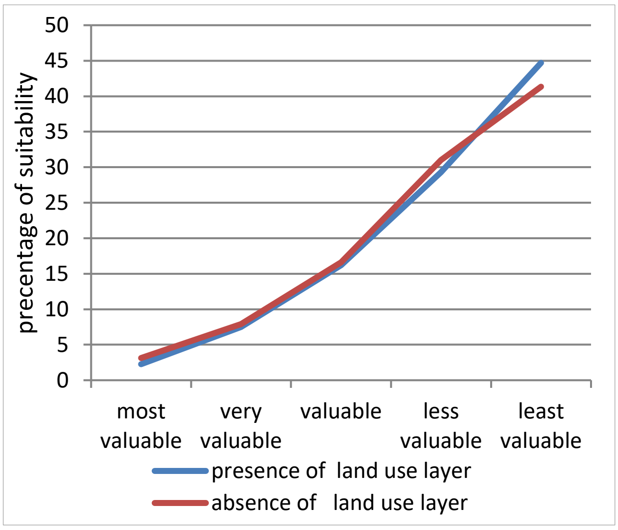

Fig. 7: RR in the presence and absence of land use layer

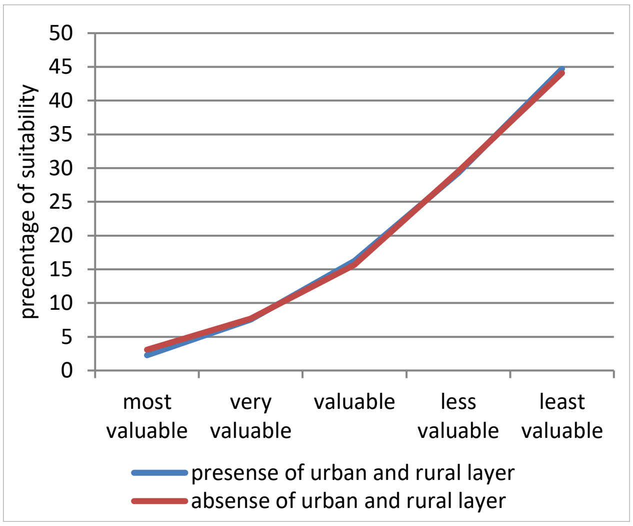

Fig. 10. RR in the presence and absence of urban and rural areas layer

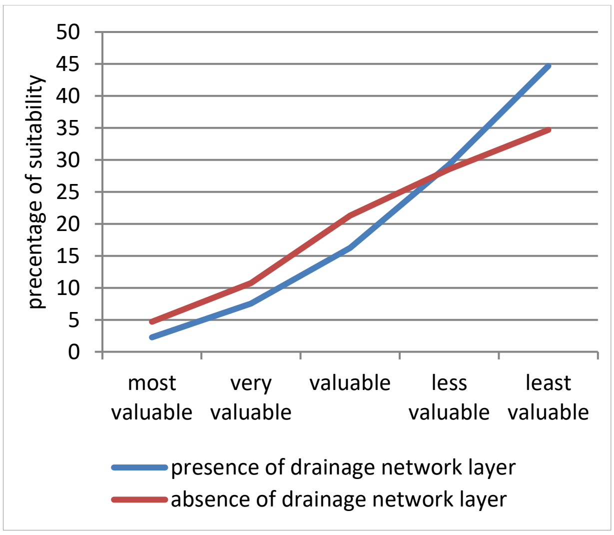

Fig. 8: RR in the presence and absence of river layer

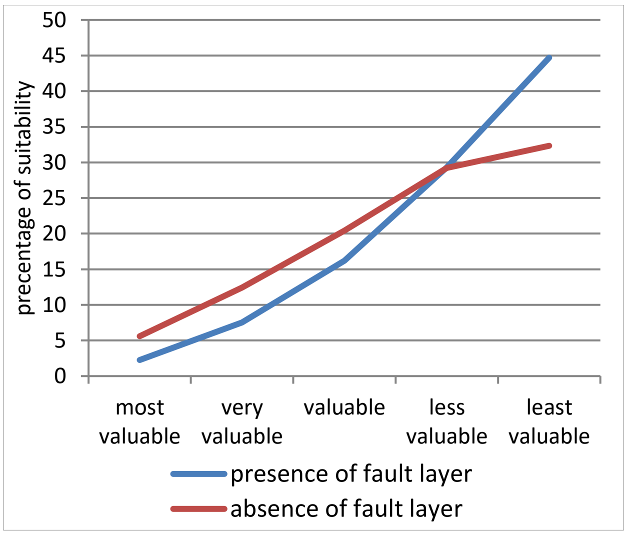

Fig. 11. RR in the presence and absence of fault layer

Conclusion

Site selection is an important strategy towards city planning. This importance is much sensible in areas where city development plans lack. This research was conducted in order to suggest prone areas for urban land development in the center of Iran. The effective layers that are important for determining RR were used and their impacts were examined to find the most influential layer on RR, by using fuzzy algorithm in GIS. According to the findings, *Gamma* (0.9) was the best operator among all operators that had either very less or a lot more RR based on priorities and restrictions. The most valuable, very valuable, valuable, less valuable, and least valuable lands were including 2.26, 7.5, 16.22, 29.30, and 44.70 percent, respectively. The analyses of the nine factors showed that the fault line layer (by 25.83 %) and the distribution of urban and rural layers (by 3.29 %) represented the most effective and, respectively, least effective layers on RR. Other effective layers on RR included the drainage network, the main and bypass roads, the land use, the slope, the geology, the elevation, and the aspect layer, individually.

It appears that one of the drawbacks of fuzzy algorithm is that this technique is much influenced by polyline feature (fault line, drainage network) when applying for site selection, rather than polygon (land use, geology) and point (distribution of urban and rural) features. By this, some effective factors such as land use, geology, elevation etc. were less considered, while they are highly important in residential area development. Overall, the *Gamma* operator is suggested for site selection, and the other fuzzy methods should not be tested for this kind of purposes. Moreover, other layers like groundwater level should be used for site selection study in order to find the best site for city development. Watershed operations on its seasonal rivers are suggested before any city development in the selected areas.

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