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## Research Article

# Evaluation of land suitability for irrigation using fuzzy analytic hierarchy process

Y. Hoseini\*

Moghan College of Agriculture and Natural Resources - Mohaghegh Ardabili University, Ardabil, I. R. Iran

\* Corresponding Author: yaser\_hoseini@ymail.com  
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**ABSTRACT-** Use of new techniques to evaluate irrigation areas can enhance water use efficiency in agriculture. In this study, the fuzzy analytic hierarchy Process (FAHP) was used to qualitative land suitability for sprinkler irrigation and was compared with the parametric method. Evaluation based on parametric method showed that an area of about 1597.83 hectares (31%) of the lands was highly suitable ( $S_1$ ) and an area of about 787.3 hectares (15%) was "moderately suitable" ( $S_2$ ). About 2242.9 hectares (43%) were marginally suitable ( $S_3$ ). Permanently inappropriate suitability included about 546.91 hectares (11%). Inappropriate in present condition suitability matched no land in the study zone. Based on the Fuzzy Analytic Hierarchical Process, there was not highly suitable ( $S_1$ ) area in the plain. The parts with  $S_2$  suitability also included an area of about 432.96 hectares (8.3%). Moreover, areas of about 3100.98 hectares (59.9%) were marginally suitable ( $S_3$ ). Some southwest and eastern parts of the plain were not currently suitable ( $N_1$ ) that included an area of about 1277.68 hectares (24.6%).  $N_2$  suitability was also observed in some southern in two parts including an area of about 363.38 hectares (7%). Since about 31% of the lands were included as "highly suitable" areas based on the parametric method, and in contrast, there was no "highly suitable" areas in FAHP method, so considering the area of "highly suitable" shown that there was a significant difference between the two methods in terms of "highly suitable" land evaluation. Considering the gradual changes in soil properties, FAHP evaluation has higher accuracy than the ordinary parametric method in evaluating land suitability.

### INTRODUCTION

Limited water and soil resources and growing population have led countries around the world towards raising agricultural production per unit area and optimal utilization of these resources. Due to population growth and rising living standards, the demand for food has increased. In this regard, identification and knowledge of the parameters that somehow affect food production are essential. Since water and soil are considered of the most important factors, so recognition of potentials and limitations of lands as well as needed water supplies are the most essential factors to increase the production. Due to these reasons, planners were encouraged to use fuzzy analytic hierarchy process tools in combination with GIS (Hoseini, 2018) for in integrating and handling multiple and different factors (Albaji et al., 2015; Turkish Statistical Institute, 2018). Those techniques provided structured and spatially explicit evaluation frameworks (Karimi et al., 2018) and facilitated evidence-based judgments for sustainable land-use management practices (Roy et al, 2018). Mihalilova and Dengis (2019) studied land and soil properties 972 ha of

Black Sea region in Turkey, and suitability maps were produced for surface and pressurized irrigation methods in the Çar amba Delta. Results showed that fuzzy based method was more flexible and sensitive and thus this method had better reflected real conditions in area, than the parametric method.

To determine land suitability for irrigation, soil properties and topography need to be assessed. Hence, to efficiently use water and soil resources, methods should be used that can specify land suitability for the desired irrigation method more accurately. In recent years, powerful systems called fuzzy inference systems have been used in various sciences. Using the language power of fuzzy systems, these systems were able to utilize the advantages of this model in order to analyze very powerful complex processes. fuzzy systems are one of the most efficient methods in the field of forecasting and modeling (Akbarzadeh et al, 2009). It was reported that a fuzzy system was able to use human language and human experiences and experts and connoisseurs (Karatalopoulos, 2000). Sys et al. (1991) proposed a parametric evaluation method to evaluate

lands based on soil properties. On the basis of that method land suitability measurable factors for irrigation were divided into four factors including texture, structure, depth and calcium carbonate that considered as physical soil properties related to water in the soil. Soil chemical properties which were related to salinity and alkalinity such as soluble salts and exchangeable sodium, drainage characteristics and environmental factors such as slope directly affected the assessment of soil in the region.

Fuzzy analytic hierarchy Process method was considered as the base method in land evaluation in many studies. Dengiz (2006) applied parametric evaluation to compare two drip and sprinkler irrigation methods on a research farm in the south of Ankara. In this research, in addition to use of geographical information system (GIS) to analyze the data and provide the relevant maps, physical features of the soil, topography, salinity, alkalinity and drainage capability were analyzed and the results showed that 31.1% of lands in the studied area was suitable for drip irrigation and 51.2% of the lands in the same area was suitable for sprinkler irrigation. So, sprinkler irrigation was more suitable than drip irrigation for more than half of the area. Also, the use of GIS in parametric evaluation is of special importance for irrigation methods and in addition to saving time of data analysis, it can easily be updated. Naseri et al. (2009) examined the parametric method in Lali Plain and considered six factors including soil texture, lime, soil depth, salinity, slope and drainage. The results of their study showed that 1732 hectares (48.5%) of the studied lands were suitable for all three types of irrigation (drip, sprinkler and surface). While 384 hectares (10.8%) of the lands were not suitable for drip irrigation and there was no unsuitable land for sprinkler and surface irrigation in this area. Calderon et al. (2005) investigated qualitative land suitability evaluation for surface and drip irrigations in Shuyang County, China. They provided land suitability maps for surface and drip irrigations using Sys et al. (1991) parametric method and GIS. Increasing the slope of lands along with a reduction of soil depth and increased gravels were the most important factors limiting irrigation in the area. Albaji et al. (2006) evaluated 77706 hectares of lands of Khuzestan's Shavoor Plain for surface and drip irrigations using Sys et al. (1991) parametric method. Through data analysis, they concluded that 14925 hectares of land in the area studies were well suited for drip irrigation and that soil salinity and drainage were the most important limiting factors in surface and drip irrigations. Finally, based on obtained results, they suggested that the drip irrigation method was more suitable than surface irrigation in lands of this area. Mirzaiie Takhtgahi et al. (2005) located pressurized irrigation systems in the central areas of Kermanshah province (approximately more than one-third of the area of Kermanshah). In this research, the potential and suitability of pressurized irrigation systems in the central areas of Kermanshah province were investigated based on climatic conditions, quality of extractable

groundwater resources, topographic conditions, features of the soil and product type and then recommendations required were presented according to the parameters studied. District of this study included Kuzaran Plains, Mahidasht, Miandarband, Baladarband, Razavar, Poshtdarband, Dinevar, Hasanabad (Eslamabad), Bisotun, Rawansar Plain, Dorudfaraman and Sarfiruzabad. In this study, feasibility and potential of central areas of Kermanshah province were examined in terms of implementation of pressurized irrigation systems using local visits, field experiments, studying reports available, topographic maps, analyzing the chemical tests of wells in the area, reviewing soil studies of the region and analysis of data obtained. Today, fuzzy sets with high ability to process input data have increased the accuracy of analyzes in many sciences. The ability of fuzzy sets is using the membership function. Membership function defines the membership degree of elements between zero and one (Koorehpazan, 2008). Unlike Boolean logic which was reported to be relied on zero-one logic (Binary) and basically has a two-valued attitude towards theorems (Mottakan et al., 2009), Lu et al. (2009) assessed ecosystem and environmental vulnerability in Don Giang Co reservoir by using Fuzzy Analytic Hierarchical Process (FAHP) method. Results showed that the environmental vulnerability of the region was at a moderate level. Zare Naghadehi et al. (2009) used FAHP method to select the optimal mine extraction method for Jajarm Bauxite Mine. They concluded that the FAHP method was able to rank the assessment problems that general Analytic Hierarchical Process (AHP) method was not able to rank them. Khashei Sivaki et al. (2014) examined FAHP method to determine the appropriate places for groundwater extraction in Neyshaboor plain. Results showed that the FAHP method could determine the appropriate places. Ramzi et al. (2014) studied the potential and possibility of using drip irrigation systems in southern Khorasan with regard to climate conditions, quality of groundwater, topographic status, and soil characteristics by using the FAHP method. Results showed that the drip irrigation system could be used in 50% of Southern Khorasan lands. Moreover, this system could be used for other 50% with taking some actions, except nine plains. Elaalem (2013) used a FAHP technique compared with the parametric method to evaluate the farmlands in Libya. He showed that the accuracy of FAHP was greater than that of the parametric method caused the integrative property of the factors in the fuzzy technique. Qureshi and Hasan (2018) stated that arable land assessment was necessary to diminish investment risk in agriculture and enhance agricultural productivity. Hamzeh et al. (2014) indicated that parametric assessment methods showed value and capability of lands less than reality compared to those of the fuzzy logic method. Since various parameters were involved in the land assessment process and different physical and chemical constraints of the soil were effective in the assessment, planners were interested in using tools such as geographical information system (GIS) and a multi-criteria decision-making processes in their assessments (Seyedmohammadi et al., 2018;

Houshyar et al., 2017; Torrieri & Batà, 2017). In a study conducted by Singha and Chandra Swain (2016), multi-criteria decision-making system was used to specify suitable agricultural areas and the results revealed the appropriate ability to combine the soil factors to achieve this goal. Feizizadeh and Blaschke (2013) applied land suitability assessment using GIS and multi-criteria decision-making process in Tabriz. In this study, they employed different suitability factors such as soil, climate, and available water properties, and used the shareholders' opinions for assessment at different levels. In the end, the hierarchical structure was used to map the proportion of dryland and irrigated lands. The results indicated that 65676 hectares of the studied area were suitable for irrigation and 120872 hectares for dryland cultivation. Today, fuzzy sets with a high ability to process the input data have enhanced the accuracy of analyses in many sciences. Hence, using the capabilities of the FAHP method, which has been shown to be able to identify the results of land assessment more accurately through the ability of fuzzy systems to evaluate effective parameters, formed the objectives of the present research. Thus, this study was conducted with the aim of using the FAHP method that is thought to be better than conventional fuzzy systems to evaluate land suitability of the lands based on the parametric system for sprinkler irrigation. Moreover, the goal of this study was to optimize the conventional parametric lands suitability evaluation system by using the analytic hierarchical fuzzy inference Process for sprinkler irrigation in the Fathali region of Moghan City, Iran.

## MATERIALS AND METHODS

The study area is a part of Fatih Ali Plain with a 5175-hectare area which is located 35 kilometers southwest of Parsabad and 230 kilometers northwest of Ardabil. The area can be accessed through Ardabil-Parsabad road. Geographical location of the area is 47° 35' 56" to 47° 21' 21" of eastern longitude and 39° 25' 12" to 39° 28' 28" of northern latitude. The soil moisture regime was Weak Aridic, a subcategory of Aridic, and its thermal regime was Thermic (Hoseini & Kamrani., 2018). Fig.1 shows the location of the Fath-Aali plain in the Mughan region. Twenty stations were used to determine the physical characteristics of the soil and studies were conducted by the county's Soil and Water Engineering Services Company. The initial tests including electrical conductivity on saturated paste extract (EC<sub>e</sub>), saturated paste reaction (pH) on samples, total neutralizing materials (T. N. V) and mechanical analysis were carried out on all soil samples in the laboratory. According to the soil characteristics of each unit and profile features, soil series were specified and chemical analyses of soil samples were done. To measure the physical parameters, undisturbed samples were provided from different depths of the soil and parameters required were determined in the lab. Summary of physical and chemical test results are represented in Table 1. Fig. 2 shows maps of land units in the studied area.

## Fuzzification of the Parameters Affecting Land Evaluation through the Parametric Method

It was reported that a fuzzy system was composed of three parts including fuzzy sets, membership functions, and fuzzy rules (Klein, 1999). In fuzzy sets, as can be seen in Fig. 3, changes of data among sets occur gradually like changes of variables in nature (Zadeh, 1965). Membership functions assign members of fuzzy sets range to a number in 0-1. Since the parametric assessment method presented by Sys et al. (1991) was used in current research to examine lands for different methods of irrigation, effecting parameters in this method should be made fuzzy by using different functions. In the parametric method, soil characteristics are classified and the possibility for irrigation index is calculated based on the soil properties.

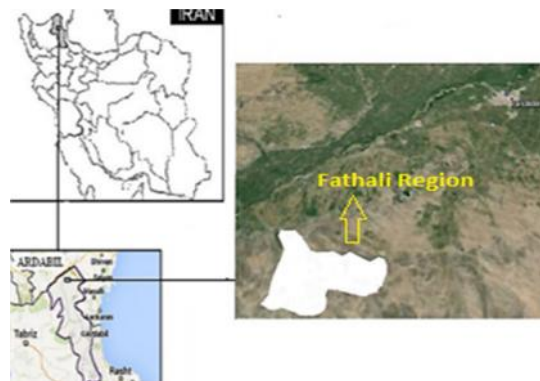


Fig. 1. Location of the studied area



Fig. 2. The map of land units in the studied area

In such a condition where linguistic terms (low, medium, high) are not precise enough to explain the variables, fuzzy sets create fuzzy rules that would increase the accuracy of explaining variables. It was reported that selection of the appropriate membership functions (linear, triangular, sine, bell) was very important for fuzzy sets (Burrough and McDonnell, 1998). The parametric evaluations presented by Sys et al. (1991), Laffan and Rees (2004) and Dengiz (2006) were applied in this study. Soil characteristics were graded and utilized in calculation of the capability index for irrigation systems. Furthermore, the effective parameters in this method were required to be fuzzified

using various functions. So, the following function was used for the parametric evaluation method.

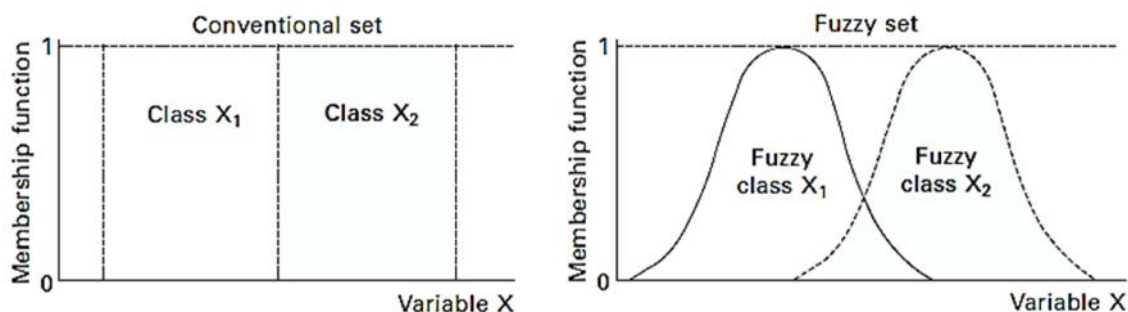
$$C_i = A * \frac{B}{100} * \frac{C}{100} * \frac{D}{100} * \frac{E}{100} * \frac{F}{100} \quad (1)$$

where  $C_i$  is the irrigation system capability index calculated; letters are respective ratings for A: soil texture, B: soil depth, C:  $CaCO_3$  content, D: electrical conductivity, E: drainage, F: slope. Some specified marks were used in the parametric method. These marks included  $S_1$  “highly suitable”  $S_2$  “moderately suitable”,  $S_3$  “marginally suitable”,  $N_1$  “currently not suitable” and  $N_2$  “permanently not suitable”. All parameters affecting the parametric land evaluation method were graded to the membership function values in the interval of 0 and 1 based on their range. To this end, the linear membership functions were used and the triangular

membership functions were used for the calcium carbonate percentage parameter. For example, membership degree "0" indicates that the fuzzy set (e.g "slope grade" in slope class) reduces the quality of the land chosen for sprinkler irrigations and the membership degree "1" in fuzzy set (e.g "degree of soil depth" in the soil depth class) shows the positive effect of this parameter on the evaluation for two irrigation method. Values given to each parameter based membership function of each parameter are shown in Table 2. As shown in Table 3, all the parameters affecting land evaluation were attributed to membership functions between 1 and 9 based on their importance. Finally, the weight of each parameter was calculated using analytical hierarchy process method.

**Table 1.** Physical and chemical properties of the soil samples

Statistical Indicators	Soil particles %			EC (dS/m)	PH	OC %	Caco3 (Meq/100gr Soil)	cation exchange capacity
	Clay	Silt	Sand					
Mean	30.2	36.1	33.7	4.3	7.8	0.3	4.3	17.7
Maximum	53.3	56.3	87.6	17.5	8.3	1.0	23.8	31.7
Minimum	5.6	4.1	11.0	0.5	7.1	0.0	0.4	7.3
Standard deviation	10.5	10.3	18.3	3.8	0.2	0.2	3.8	5.8
Median	32.1	38.6	29.8	2.6	7.7	0.3	3.0	16.8



**Fig. 3.** Membership functions of fuzzy and non-fuzzy (conventional) sets

**Table 2.** Fuzzification of parameters irrigation method selection and factors membership functions based on parametric system

Fuzzyfication {class x}= fuzzy value	Irrigation methods	Effective Factor
{0-3}=1, {3-16}=0.9, {16-30}=0.55, {>30}=0.35	Sprinkle	Slope (%)
{Well drained }=1, {Moderately drained}=0.9, {Imperfectly drained}=0.75, { Poorly drained }=0.65, {Very poorly drained}= 0.45	Sprinkle	Drainage Classes
{Clay Loam (CL) }=1, { Silty Loam (SiL) }=0.9, { Sandy Clay Loam (SCL) }=0.95, { Silty Clay (SC) }=0.85, { Clay (C) }= 0.85	Sprinkle	Textural Classes
{0.3>}=0.9, {0.3-10}=0.95, {10-25}=1, {25-50}=0.9, {>50}=0.8	Sprinkle	$CaCO_3$ Content (%)
{4>}=1, {4-8}=0.95, {8-16}=0.85, {16-30}=0.75, {>30}=0.65	Sprinkle	Soil salinity(ds/m)
{20>}=0.3, {20-50}=0.65, {50-80}=0.85, {80-100}=0.95, {>100}=1	Sprinkle	Soil Depth(cm)
{Highly suitable}: >0.8, { Moderately suitable }:0.6 – 0.8, { Marginally suitable }:0.45 – 0.59, { Currently not suitable }:0.3 – 0.44, {Permanently not suitable}: <0.29	Sprinkle	Suitability classes

This calculation was done in the FAHP extension in GIS software; All soil characteristics represented by a map in the GIS, were fuzzified and characterized by fuzzy systems, and expressed by a corresponding membership function within ArcSDM. Therefore, the fuzzy membership of all parameters indicated the importance of the soil parameters.

**Table 3.** Definition numbers of pairwise comparison matrix

Definition	Intensity of importance
Equal importance	1
Equal to moderate importance	2
Moderate importance	3
Moderate to strong importance	4
Strong importance	5
Strong to very strong importance	6
Very strong importance	7
Very to extremely strong	8
Extreme importance	9

A linear membership function was selected for factors and all values of the fuzzy set changed monotonically with the nine class numbers. In the hierarchical analysis method, to determine the weight of the effective factors, the comparison of effective parameters based on the expert opinion of researchers in the form of 10 questionnaires was used. A binary comparison matrix with (6×6) size and n(n-1) judgment was made in the AHP extension in GIS software and the final weight of the data was calculated. Next, the pairwise comparison matrix was determined. If the matrix was not consistent, the binary comparisons repeated again until the matrix was compatible. For this purpose,  $\bar{a}_{max}$  should be calculated from the following equation.

$$\bar{a}_{max} = \frac{1}{N} \sum_{i=1}^n \frac{\bar{a} \times W_{(i,j)}}{W_{(i,j)}} \tag{2}$$

$\bar{a}_{max}$ : Average compatibility vector,  $\bar{a}$ : Geometric mean of the matrix,  $W_{i,j}$ : Weight or priority of replacement, N: The number of alternatives compared.

Consistency index (CI) is calculated to verify the coefficients of the effective factors that is crucial for more accurately represented judgments and if there was any inconsistency, experts are asked to re-examine the importance of the parameters in the pairwise comparison matrix. CI index and consistency ratio (CR) can be calculated with Equations (3) and (4) where n is the size of pairwise comparison matrix and RI is the random index. When  $CR < 0.1$ , the consistency test is passed (Uyan,2013).

$$C I = \frac{\bar{a}_{max} - n}{(n - 1)} \tag{3}$$

$$C R = \frac{C I}{R I} \tag{4}$$

Equation 5 and the spatial data modeler (AHP) in the geographic information system were used to overlay factors affecting land evaluation. Using factor provided in equation 5 and by taking into consideration  $\alpha = 0$ , the effective factors were multiplied together and the final map was extracted.

$$\tilde{f}(x) = (1 - \prod_{i=1}^n \tilde{f}_i(x))^\alpha \times (\prod_{i=1}^n \tilde{f}_i(x))^{1-\alpha} \tag{5}$$

$\mu_i$  is the fuzzy membership function for parameter number i.  $\alpha$  is the appropriate power to obtain the best results which is equal to zero based on the parametric method. After the map of each factor is provided in accordance with Table 3, the land evaluation index of different points was extracted by overlaying all the weighted maps obtained.

## RESULTS AND DISCUSSION

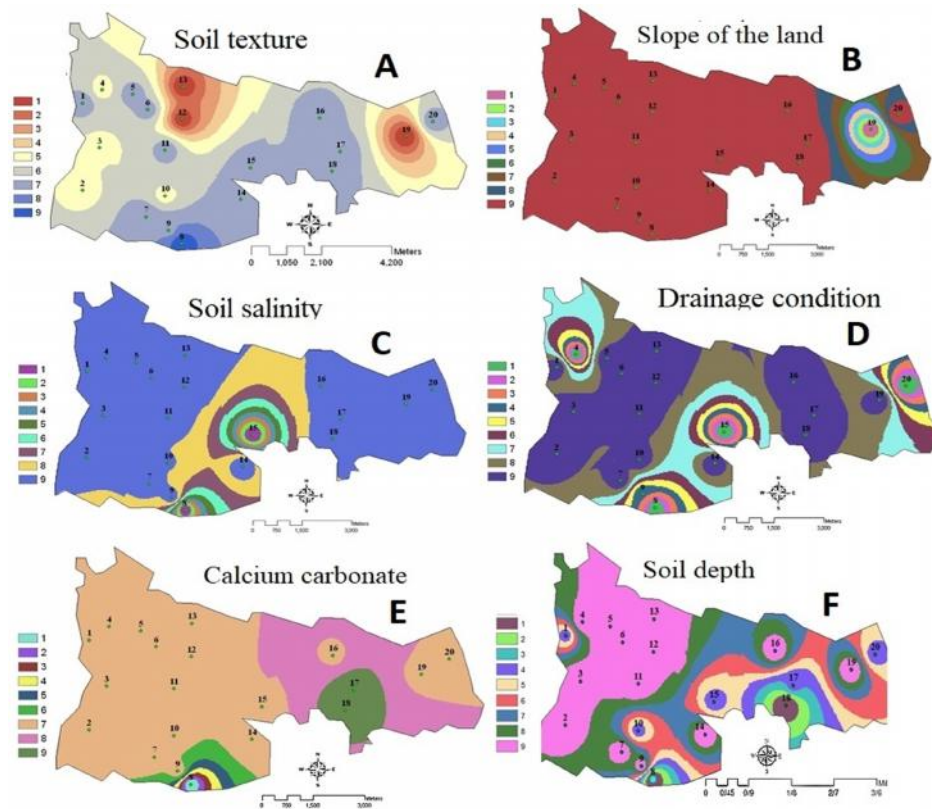
Table 4 presents the weight values of the effective soil layers for sprinkler irrigation in the studied area. Weights to particular soil properties were assigned based on a standardized eigenvector which was derived from each comparison matrix (6×6). Note that soil salinity had the highest Weights (0.34) for sprinkle irrigation system, which was inconsistent with the results of Miháliková and Dengiz (2019) but soil texture in both study had a high weight, while for CaCO<sub>3</sub> contents. the lowest values (0.09) were calculated in both studies. Furthermore, inconsistency rate in the study was 0.03 which was less than 0.1 and is acceptable and implies that all the pairwise comparisons that considered were consistent. This means that relative weights can be accepted for use in the analysis. Due to the low leaching yield of sprinkler irrigation to reduce soil salinity, the weight of this parameter was considered higher than other parameters. The membership function map of the parameters affecting the assessment of irrigation systems is presented in Fig. 4. Based on the fuzzy membership function, suitable locations for irrigation were classified between “1” (unsuitable locations) and “9” (very suitable locations). To compare the old and conventional methods of parametric assessment and their results with those of the fuzzy hierarchical method, Fig. 5 and Fig. 6 were prepared which show the difference between the two methods. Fig. 5 shows the results of the land assessment map for the sprinkler irrigation system based on the parametric method using the ordinary Thiessen Polygons. As shown in Fig. 6 after applying the weights of the layers and combining them, the land use map was extracted. The area of land classification is presented in Table 5. As shown in this Table, there is a major difference between the two methods in terms of completely suitable lands, so that in the fuzzy hierarchical analysis process, there was no “Completely appropriate” suitability, indicating a significant difference between the two methods in land assessment. Since the measured parameter’s value was assumed zero and one for the whole unit in the parametric method, considering the high area of land “Completely appropriate” for the area could be attributed to this. By

comparing the figures for Unit 16 scores with an area of approximately 500 hectares, it was determined that the scores based on the parametric system were high in all effective parameters except the soil salinity score. This has resulted in this unit being regarded to be a high-suitability unit in the final conclusion; while if the limits of this unit in the assessment of the fuzzy hierarchical analysis method in Fig. 6 were considered, it becomes clear that given the influence of adjacent units, part of

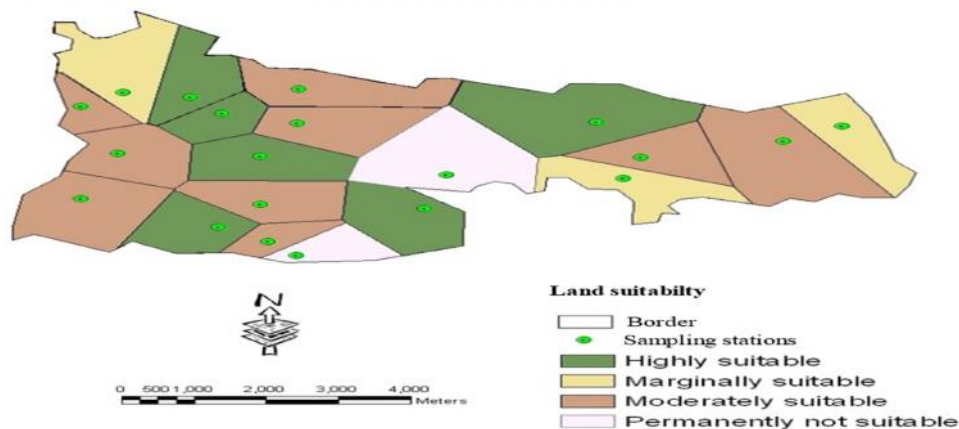
this unit obtained an average score and about half of its area was considered as “Partly appropriate” lands. This was also observed for units 5, 6, 7, 11, 14, and especially for units 7 and 14 that have obtained average scores in the assessment of soil salinity and calcium carbonate parameters as well as soil drainage capability by fuzzy hierarchical analysis.

**Table 4.** Weight values of effective indices in land evaluation for sprinkler irrigation

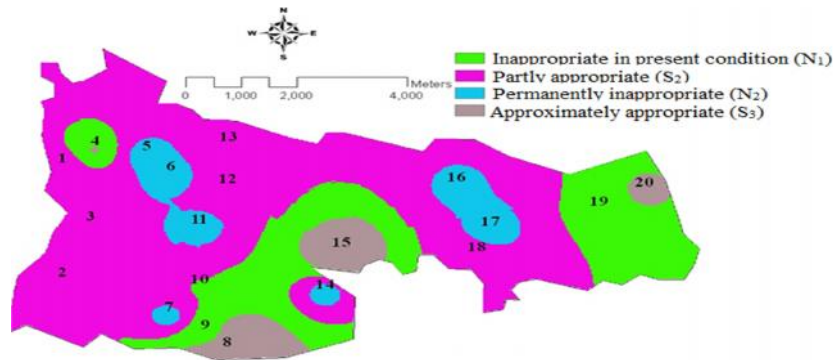
Effective indices	Textural Classes	Slope	Soil Salinity	CaCo3 Content	Drainage Classes	Soil Depth
Weight	0.2531	0.1628	0.3454	0.09624	0.1425	0.1536



**Fig. 4.** The membership function map of the parameters influencing irrigation system evaluation (a) soil texture, (b) slope of the land, (c) soil salinity, (d) calcium carbonate, (e) drainage condition, and (f) soil depth



**Fig. 5.** The land suitability map for sprinkler irrigation based on the parametric system



**Fig. 6.** The land suitability map for sprinkler irrigation based on the FAHP system

**Table 5.** The land suitability areas for FAHP and parametric methods

Sprinkle irrigation land suitability	Parametric method(ha)	FAHP method(ha)
Completely appropriate ( $S_1$ )	1597.83	---
Partly appropriate ( $S_2$ )	787.3	432.96
Approximately appropriate ( $S_3$ )	2242.96	3100.98
Inappropriate in present condition ( $N_1$ )	---	1277.68
Permanently inappropriate ( $N_2$ )	546.91	363.38
SUM	5175	5175

Concerning suitable lands, as shown in Table 5, the “Partly appropriate” area in the parametric assessment was approximately twice those in Fuzzy Hierarchical Analysis. “Approximately appropriate” lands in the fuzzy hierarchical analysis method have been located adjacent to the “Partly appropriate” lands. These lands were mainly adjacent to Units 5, 6, 7, 11, 14, 16 and 17; however, in parametric assessment, Units 20, 18 and 4 were classified as “Approximately appropriate” units for sprinkler irrigation. Assessment by fuzzy hierarchical analysis method seems to be closer to reality since the existence of “Approximately appropriate” land near the “Partly appropriate” land was reasonable. Since unit 17 has obtained relatively low scores in soil depth, given its high score in other parameters including soil salinity parameter, which had the highest weight in assessment, this was one of the “Approximately appropriate” units in the fuzzy hierarchical analysis assessment. Nevertheless, in the parametric method, it was classified as a low-capability area due to the same effect of the layers as well as not considering the weight of the layers and their membership function. Table 5 shows that the “Approximately appropriate” lands had the most areas in the assessment of the two methods and the zones considered for these areas were larger in the fuzzy hierarchical method than those in the parametric method. These lands included areas with the average scores in both methods and the most important factors in obtaining average scores for these areas in the fuzzy hierarchical method were the soil salinity and soil texture factors in the western part of the plain and in addition to the above factors, the calcium carbonate factor in the eastern areas of the plain, has gained an average score for these areas. It seems that the results of the two methods were close in terms of the average

score. As shown in Table 5, there was no parametric assessment of “Inappropriate in present condition” land; while, 1277.68 hectares of the studied area were included in these areas in the assessment of the fuzzy hierarchical analysis. In the fuzzy hierarchical analysis, these areas were located around “Permanently inappropriate” zones with low scores in all effective parameters except for slope and soil texture parameters. The reason that these areas were hidden in parametric assessment was gaining high scores in other parameters. Since in this method, the gradual changes in parameters were not observed, these areas were classified as “Partly appropriate” in parametric assessment. The effect of fuzzy hierarchical method and weighting the layers on the final assessment was well observed in the zone 19. As illustrated in Fig. 6, the area around the zone 19 had small value in terms of soil texture and slope parameters; however, it was able to be classified as areas with “Inappropriate in present condition” due to gaining high scores on influential parameters such as soil salinity, and not to be classified as “Permanently inappropriate” like areas 8 and 15. Concerning “Permanently inappropriate” areas, the assessment of the two methods was approximately the same, but the parametric method identified the area of these lands larger than those identified by the fuzzy method. In the study conducted by Elaalem (2013) on assessing northwestern Libyan agricultural lands by means of fuzzy inference system and parametric method, it was shown that the fuzzy method was able to assess the lands more accurately and the characteristic of integration of the effective indicators was better considered in the fuzzy method. This was in line with the results of the present study. In a study by Bagherzadeh and Paymard (2015) that addressed the

assessment of land suitability for selection of irrigation methods based on fuzzy and parametric methods in Mashhad plain, it was revealed that in land assessment using fuzzy logic, “suitable” lands for drip irrigation were about 6 times the surface irrigation. Hamzeh et al. (2014) indicated that compared to the fuzzy logic method, parametric assessment method showed the actual value and capability of lands less than fuzzy logic method and the accuracy of parametric assessment method was approximately one-quarter of that of the fuzzy method. This might be due to the cohesion properties of the parameters affecting the assessment process. In the fuzzy method, this cohesion is applied by membership functions in the effective parameters and the importance of the mentioned parameters in the fuzzy method is considered based on the membership function of the indices. In a study conducted by Bagherzadeh and Gholizadeh (2016) on the assessment of lands by parametric and fuzzy methods, it was also revealed that although the accuracy of the fuzzy method was higher than the parametric method, the parametric method was able to accurately determine the quality of the lands. This suggests that if the number of constraining and influencing factors is low, in case of classifying parameters with fuzzy membership functions, the effect of these factors on the results is reduced and the results of parametric method and fuzzy logic method are approximated. In addition, a number of researches performed in this field have revealed that parametric assessment can be as accurate as of the fuzzy method (Keshavarzi and Sarmadian, 2009; Bagherzadeh and Mansouri Daneshvar, 2011; Bagherzadeh et al, 2016), which is on in line with the results of the present study. In this study, since the studied area included different constraints such as soil texture, calcium carbonate content and soil depth, the results of the two methods were very different. It seems that in most of the agricultural soils with different limitations in Iran, it is better to use fuzzy methods for estimating the land capacity for different irrigation methods.

## CONCLUSIONS

Since Iran has an arid and semi-arid climate, and due to insufficient water in this climate, the optimal use of water resources is inevitable. The accurate specification of land classification in terms of irrigation capability

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may help optimize water use. Using the fuzzy hierarchical analysis process in the dissection of parametric land assessment methods can reinforce these methods to a stronger assessment tool; since due to considering the gradual change in soil properties and ignoring the old parametric methods, these methods are not sufficiently accurate. The differences between the two methods in determining the “Completely suitable” lands were clearly observed in the present research since because in the old parametric methods the obtained suitability was considered for the whole Thiessen Polygons, the amount of “Completely suitable” lands in this method was more than that in the fuzzy hierarchical method. It should be noted that with the ability to weigh the layers affecting land assessment in the fuzzy hierarchical method, this method was even more accurate than the fuzzy methods that merely determine the suitability of land based on the membership functions of the variables affecting the assessment. Generally, in the old parametric method, the lands have more capability than in the fuzzy hierarchical method. This can be due to one or two factors influencing the assessment process and since the effect of the factors is considered identical and the considered level is equal to the corresponding polygon, the land potential is shown more than reality. Whereas, considering the gradual change of the influential parameters and the variable membership function for each parameter, as well as the different weight of the parameters affecting the assessment, the abnormal effect of one or two factors in the final land assessment is reduced in the fuzzy hierarchy system and the assessment approaches its real values. Therefore, it seems that it is necessary to use methods that consider gradual changes in effective parameters, especially in areas with more restrictions. Furthermore, because geographic information system based methods provide management tools for selecting irrigation methods, the use of GIS can provide better management and increase irrigation system efficiency.

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## ارزیابی تناسب اراضی برای آبیاری با استفاده از فرآیند تحلیل سلسله مراتبی فازی

یاسر حسینی\*

دانشکده کشاورزی و منابع طبیعی مغان- دانشگاه محقق اردبیلی، اردبیل، ج. ا. ایران

\*نویسنده مسئول

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#### واژه‌های کلیدی:

روش تحلیل سلسله مراتب فازی\*

سیستم اطلاعات جغرافیایی (GIS)

ارزیابی اراضی

پارامتریک

آبیاری بارانی

**چکیده-** استفاده از روش‌های جدید برای تعیین ارزیابی اراضی می‌تواند باعث افزایش بهره‌وری آب در کشاورزی شود. در این تحقیق از فرآیند تحلیل سلسله مراتبی فازی (FAHP) برای بهینه‌سازی ارزیابی پارامتریک تناسب اراضی، در روش آبیاری بارانی استفاده شد و نتایج با روش پارامتریک مقایسه گردید، نتایج روش معمول پارامتریک مشخص نمود که مساحتی حدود ۱۵۹۷/۸۳ هکتار (۳۱ درصد) از اراضی دارای تناسب  $S_1$  (کاملاً مناسب) بوده و مساحتی حدود ۷۸۷/۳ هکتار (۱۵ درصد) دارای تناسب  $S_2$  (نسبتاً مناسب) بود و تناسب  $S_3$  (تاحدودی مناسب) مساحتی حدود ۲۲۴۲/۹ هکتار (۴۳ درصد) را شامل می‌شد. همچنین تناسب  $N_2$  (نامناسب دائمی) مساحتی حدود ۵۴۶/۹۱ هکتار (۱۱ درصد) را در بر گرفته و تناسب  $N_1$  (نامناسب در شرایط فعلی)، در منطقه مورد مطالعه وجود نداشت. ارزیابی براساس سیستم سلسله مراتب فازی، نشان داد که در منطقه تناسب  $S_1$  وجود نداشته و مناطقی که دارای تناسب  $S_2$  بودند، مساحتی حدود ۴۳۲/۹۶ هکتار (۸/۳ درصد) را شامل می‌شد. همچنین حدود ۳۱۰۰/۹۸ هکتار (۵۹/۹ درصد) دارای تناسب  $S_3$  بوده و اراضی با تناسب  $N_1$  مساحتی حدود ۱۲۷۷/۶۸ هکتار (۲۴/۶ درصد) را در قسمت جنوب غربی و شرق دشت، شامل شد و تناسب  $N_2$  نیز، مساحتی حدود ۳۶۳/۳۸ هکتار (۷ درصد) را در قسمت جنوبی و در دو ناحیه دشت، شامل شد. از آنجاکه حدود ۳۱ درصد از اراضی براساس روش پارامتریک جزو مناطق "کاملاً مناسب" قرار گرفتند و در مقابل در روش ارزیابی سلسله مراتب فازی مناطق "کاملاً مناسب" وجود نداشت، در نظر گرفتن مساحت اراضی "کاملاً مناسب" نشان داد که تفاوت عمده‌ای بین دو روش از لحاظ ارزیابی اراضی "کاملاً مناسب" وجود دارد که این موضوع اختلافی معنی‌دار دو روش را نشان می‌دهد. در نظر گرفتن تغییرات تدریجی در ارزیابی در روش سلسله مراتبی فازی، دقت بیش‌تر این روش را نسبت به روش معمول پارامتریک سبب می‌گردد.