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Developing a new model for ecological capability evaluation of irrigated lands in Firouzabad Township, Iran

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Abstract. Agricultural planning is a very complex task, since there are numerous goals, which should be achieved simultaneously, and various components and elements, which must be considered at the same time. The process of agricultural suitability evaluation for crop production requires specialized geo-environmental information and the expertise of a computer scientist to analyze and interpret the information. The main objective of this paper is to test a new model (based on Iranian ecological and FAO models) for ecological capability evaluation with geometric mean evaluation for better planning management of irrigated lands. Next, the proposed method was verified and compared with other well-known methods such as the Iranian ecological model with Boolean logic, arithmetic mean, and WLC. To test the models, we used the normalized difference vegetation index (NDVI). The test results indicated that the method revised by geometric mean evaluation (overall accuracy %=95 and Kappa coefficient =0.91) was the best among the used methods, and the arithmetic mean method (overall accuracy %=46 and Kappa coefficient =0) had the lowest accuracy. Thus, this method (Geometric mean evaluation) has high flexibility in locating agricultural lands. Overall, this study can be used as a basic method to evaluate ecological suitability for other regions with similar conditions owing to its simplicity and high precision.

Keywords: Ecological Capability, Irrigated Farming, Boolean, Geo-Mean, GIS.
JEL codes: Q01, Q15.

1. INTRODUCTION

The increase of food production in line with growing population is the major challenge for the coming decades, especially in countries with limited water and land resources. Iran is one of those countries, as it suffers from limited renewable water resources due to low rainfall, high evaporation, and excessive withdrawal of ground water. The increasing and competitive demand for land, for both agricultural production and other purposes, requires that decisions be made on the most beneficial use of the limited land resources (Ayalew, 2015; Lahmian, 2016). Failure to achieve a perfect match between land capability and use can be particularly problematic for agricultural production, since cultivating wrong crops on wrong soils can result in poor yields and its associated financial and other losses (Froja, 2013; Jokar, 2015; Masoudi, 2014; Mokarram and Zarei, 2021).

Agriculture in Iran is an important activity, and agricultural economy is a significant part of the country's economy. Iran is one of the first lands, where agriculture appeared. Some ancient migrations to this country were also due to finding better lands for agriculture. According to official statistics in 2016 (Jalali, 2020), 17.6% of the Iranian workforce is engaged in the agricultural sector. Accordingly, the share of the added value of the agricultural sector at constant prices in Iran is 6%, including 71% of cultivation and horticulture, 24% of animal husbandry, 4% of the aquatic sector, and 1% of forestry. Nearly one-third of Iran's lands are suitable for agriculture; however, due to the poor quality soil and inappropriate water distribution in most areas, only 12% of Iran's land is used for agriculture. Nevertheless, less than a third of the agricultural land is irrigated, and in other cases, it is rainfed. The alluvial plain of the Sefidroud River in the north and the Mughan plain in the northwest and the plain of Karun, Dez and Karkhe rivers in Khuzestan have more fertile soil than other agricultural areas in Iran. According to the FAO statistics, Iran is among the top 7 countries in agricultural production of 22 important products. Iran ranks first in pistachio, saffron and barberry production in the world. It also ranks second in date production and fourth in apple production. The most important agricultural products of our country are wheat, rice, cereals, sugar beet, fruit, nuts, cotton, and tobacco (Jalali, 2020).

The Food and Agriculture Organization (FAO) (1983) defined land evaluation as the process of assessment of land performance when used for specified purposes. Hence, land evaluation can be useful for predicting the potential use of land based on its attributes (Jahantigh et al., 2019; Jokar, 2015; Lee and Yeh, 2009; Martin and Saha, 2009; Masoudi and Sonneveld et al., 2010; Rossiter, 1996; Zonneveld, 1989). Land suitability evaluation is considered one of the most effective methods for proper agricultural land use planning regarding decisions on specific crops (He et al., 2011; Masoudi and Zare, 2019; Mu, 2006; Nwer, 2006; Pan and Pan, 2012; Prakash, 2003).

Since the study by McHarg (1969), land suitability assessment has become a standard method in land use planning. Furthermore, land is regarded as a complex system resulting from the interaction of physical, biological, and anthropological phenomena operating over different scales of time and space. Therefore, the choice of the proper method of evaluation for planning is crucial (Hosseini, 2018; Masoudi et al., 2017; Pan et al., 2021).

Recently, most studies have combined physical parameters affecting the yield agricultural crops and socio-economic factors in the process of land suitability assessment (Elsheik et al., 2010; Keshavarzi, et al., 2010; Yohannes and Soromessa, 2018). Nowadays, technological advancements in the geo-spatial domain have brought ease for decision-makers to utilize land resources at maximum (Alavi Panah et al., 2001; Mapedza et al., 2003; Nazari Viand et al., 2019). Mitra and Ilangova (2004) have reported that Geographical Information Systems (GIS) play a very strong role in site selection. GIS is typically used to store and analyze extensive information in the map-based format (Amarsaikhan et al., 2004). Fallah Miri et al. (2008) investigated agricultural suitability in the Kasilian watershed by GIS. The results revealed that approximately 30% of lands were appropriate for agriculture. In another paper, Pourkhabbaz et al. (2014) investigated the suitability of agriculture using multi-criteria evaluation (MCE) methods such as analytic hierarchical process (AHP) and (Serbian name) VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and Simple Additive Weighting (SAW) in the Takestan-Qazvin plain. Their results indicated that the application of MCE could be useful in agricultural evaluation (Safaripour and Naseri, 2019). Feng et al. (2014) utilized AHP and FUZZY methods for the land suitability evaluation of China's coastal improvement. The outputs demonstrated that the FUZZY method had high flexibility in land capability evaluation. Other scientists in other regions of the world mentioned the usefulness of MCE methods in evaluating the ecological potential of different uses (Amici et al., 2010; Ananda and Herath, 2009; Liao and Wu, 2013; Perveen et al., 2013).

Contrary to the above methodologies, Iranian ecological model (Makhdoum, 2006), Boolean logic and geometric mean models have been utilized for agricultural capability assessment with an ecological perspective. Although Boolean logic is a simple method, it can be qualitative and strict enough to locate suitable regions for each land-use (Jokar and Masoudi, 2016; Jokar et al., 2021). The geometric mean method for ecological capability evaluation is proposed as a new MCE method, which has a quantitative and easier evaluation approach than other MCE methods (such as WLC and genetic algorithm) that are usually difficult for users. Thus, the present study was conducted to develop a new method newer than Boolean logic, and average-based methods. This proposed method may assess the irrigated land capability more simply, systematically, and accurately.

2. MATERIALS AND METHODS

2.1 Study area

Firouzabad Township (Fig. 1) is located in Fars Province, southern Iran. Firouzabad is in the southwestern part of Fars Province. This township has an area of 3559 km^2. This city is placed in the range of 53 degrees 31 minutes east longitude and 29 degrees 15 minutes north latitude. The average height is approximately 1600 m. The climate is wet and moderate. According to the 2015 census, the population of this city is 121,417 people, being the eighth most populated city in Fars Province. Currently, the cultivation of plants such as wheat, barley, rice, rapeseed and corn is carried out to manage water resources and optimally use agricultural lands in Firouzabad county. According to the surveys and experts, products such as grapes, walnuts, pomegranates, peaches, pistachios, figs and citrus fruits are the most important garden products of the city, and the production of more of these products enjoys an advantage owing to its compatibility with the climatic conditions of the region and its better sales market.

2.2 Method

This paper was conducted based on 2 overall sections: A. Models Description and Reclassification of Parameters (Section 2.2.1); and B. Evaluation and Formulation of the Proposed Model Based on Boolean Logic, Arithmetic Mean and Geometric Mean, and WLC (Section 2.2.2). Figure 2 depicts the platform structure of the designed model.

2.2.1 Models description and reclassification of parameters

The Iranian evaluation model of ecological capability for agricultural use (Makhdoum, 2006) consists of 7 classes. The Food and Agriculture Organization (FAO) ecological model (6 classes) is also a classical model. We used both mentioned models to define a proposed model. Both models have many similarities; however, there are differences such as the lack of climate indicators in the FAO model and the drought index, and the lack of a series of indicators related to water criteria in both models. By examining classes 1 and 2 of the indicators of both models, as well as classes 3 and 4, contributed to the determination of classes 1 and 2 of the indicators of the new model, respectively. Additionally, the examination of classes 5 and 6 of the Iranian ecological model indicators, along with class 5 of the FAO model indicators, helped in determining class 3 of the new model indicators. Finally, the examination of class 7 of the Iranian model indicators and class 6 of the FAO model indicators, helped in determining class 4 of the new model indicators (Masoudi, 2018). Hence, the proposed model and its indicators were reclassified as four classes,

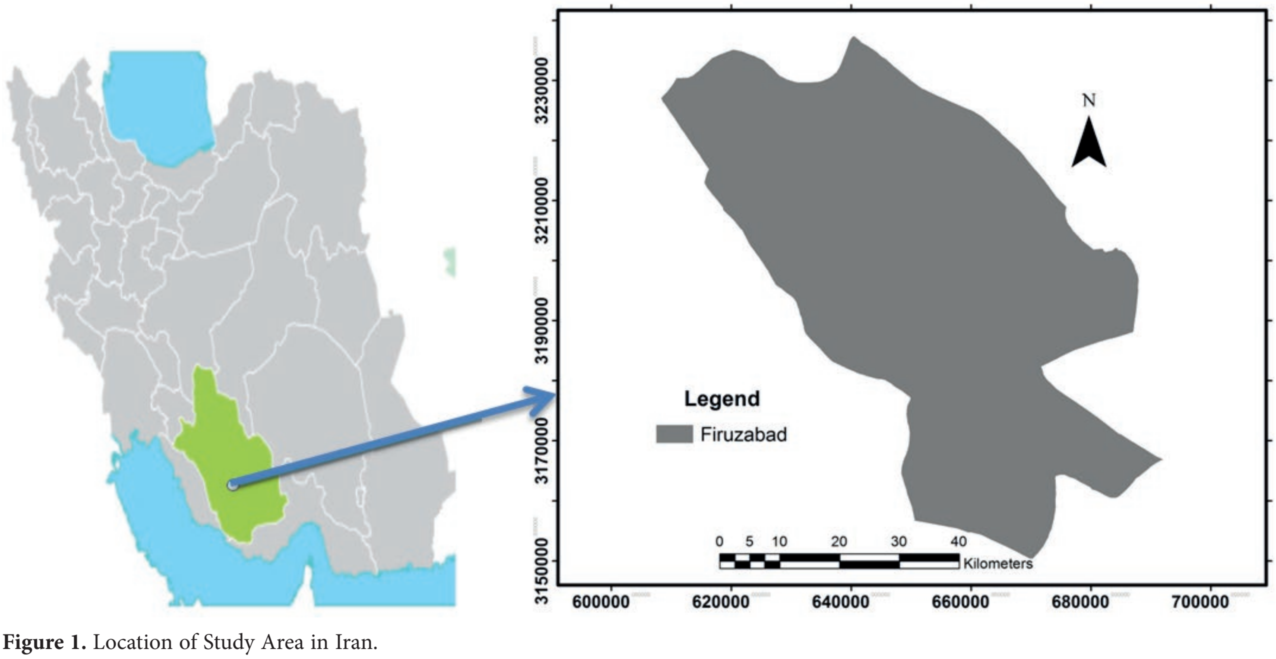

Figure 1. Location of Study Area in Iran.

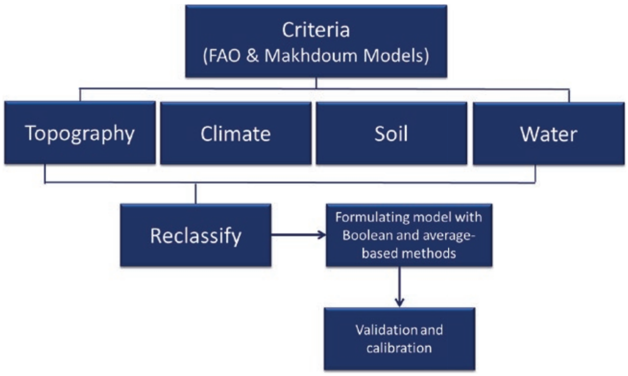

Figure 2. Flowchart showing the methodology adopted for ecological capability evaluation in this study.

including suitable (good), moderate, poor and unsuitable (Tables 1 and 2).

It should be noted that the parameters included in the revised proposed model of Iranian ecological and FAO models are based on geographical and environmental conditions of the study area (such as drought and degradation of water resources). Another reason for using two models was based on the selection of the suitable order in their parameters and range of classes (Masoudi, 2018). Therefore, the proposed model was adjusted based on the integration of Iranian ecological and FAO models (Table 2).

2.2.2 Evaluation and formulation of the proposed model based on boolean logic, arithmetic mean, and geometric mean

The ecological capability models of irrigated agriculture were based on climate, physiographic, water and soil criteria and according to different evaluation methods. The prepared maps include methods of the Iranian ecological model with Boolean algebra with 7 classes, its reclassified model of evaluation with the maximum limitation way in 4 classes, different MCE and WLC methods, and the proposed method of geometric mean.

Boolean algebra: Boolean logic has three basic operators: Intersection (logical term AND), Union (logical term OR), and Inverse (logical term NOT) (McHarg, 1969; Malczewski, 2004).

Arithmetic mean: In the Arithmetic mean method, the scores related to the parameters were averaged.

Weighted Linear Combination (WLC): The WLC method was used for the weighted overlay of the input data layers. In the weighted linear combination, first, indicators (or factors) are combined by applying weights to each indicator to determine the score of each criterion (Equation 1). The criteria are then combined by applying weights to each criterion to obtain the final score for the suitability map classification (Equation 2). In each equation, constraint factors (C_i) were also considered. Calculation of weightings was performed in the Expert Choice software. The results of the study showed the weights of indicators and criteria with the compatibility ratio or CR<0.1.

$$\textit{Criterion score}=[(W_1\times \textit{indicator}_1)+(W_2\times \textit{indicator}_2)+\cdots+(W_n\times \textit{indicator}_n)]\times C_i \quad (1)$$

$$\textit{Suitability score}=[(W_1\times \textit{Criterion}_1)+(W_2\times \textit{Criterion}_2)+\cdots+(W_n\times \textit{Criterion}_n)]\times C_i \quad (2)$$

Geometric Mean: To each indicator listed in Table 2, a weight from 0 to 3 is given based on its ecological (quantitative or qualitative) range (0 shows the ecological condition of unsuitable and 3 indicates the ecological condition of suitable for irrigated use). For example, score 2 is given to the coarse granulation of soil. Next, every criterion is calculated according to the geometric mean of the parameters in Equation 3:

$$\textit{Criterion}=(\textit{indicator}_1\times \textit{indicator}_2\times\cdots\times \textit{indicator}_n)^{1/n} \quad (3)$$

Table 1. Suitability classes of agriculture use in different models (Masoudi, 2018).

Iranian Ecological Model Classes	Suitability Description	FAO Classes	Suitability Description	Proposed Model (Reclassified)	Suitability Description
1	High Suitable	1	High Suitable	1	Suitable
2	Suitable	2	Suitable		
3	Moderate	3	Moderate	2	Moderate
4	Somewhat Moderate	4	Moderate to low		
5	Low to Moderate	5	Low	3	Low or Poor
6	Low				
7	Non-Suitable	6	Non-Suitable	4	Non-Suitable

Table 2. The parameters classes for ecological capability assessment of irrigated farming (Jokar and Masoudi, 2022; Masoudi, 2018).

Criteria	Indicators	Class limits and their ratings score			
		Highly Suitable (3)	Moderately Suitable (2)	Poorly Suitable (1)	Not Suitable (0)
Topography	Land type	Plain	-	Hill	Mountain
	Slope (%)	0-8	8-15	15-30	>30
Climate	Current state of climate	Semi-arid to wet	Arid	Super arid	-
	Drought	Slight	Moderate	Severe and very severe	-
Soil	Texture	Heavy, moderate, light	Coarse	Very Coarse	-
	pH	6.1-8.5	4.2-6,8.5-9	9-9.5	>9.5
	Depth	Deep	Semi deep	Shallow	Very Shallow to None
	Gravel percent	0-35	35-75	>75	-
	Drainage	Good to moderate	Poor	-	-
	Erosion	None, slight	Moderate	Severe	Very Severe
	Granulation	Fine to Moderate	Coarse	-	-
	Evolution	Perfect	Moderate	Low	None
	EC(mmhos/cm)	<8	8-16	16-32	>32
	ESP	<15	15-30	30-50	>50
	Fertility	Good	Moderate	Low to Very Low	-
Water	Quantity of water(m^3/year)	>3000	1500-3000	<1500	None
	Lowering of water table(cm/y)	None, 0-20	20-30	>30	-
	EC(μmhos/cm)	0-750	750-2250	>2250	-
	SAR	0-18	18-26	>26	-

Where *Criterion* is a criterion like soil and climate, indicator is a parameter of a criterion like the slope for topography, and n is the number of indicators for a criterion, such as 2 for climate and topography criteria and 4 for the water criterion. Next, all criteria are multiplied using the geometric mean to define the final score of the ecological capability for the irrigated agriculture in each polygon (Equation 4):

$$\text{Final score of land capability for irrigated agriculture} = (\text{Topography} \times \text{Soil} \times \text{Climate} \times \text{water})^{1/4} \quad (4)$$

Then, the final scores of polygons help us to prepare quantitative classes of the final ecological capability map for the irrigated agriculture in GIS based on Table 3.

Table 3. Suitability classes for Irrigated planning based on scores of polygons (Jokar and Masoudi, 2022; Masoudi, 2018).

Suitability classes	Good (1)	Moderate (2)	Poor (3)	Non-suitable (4)
Quantitative classes	> 2.5	1.5 – 2.5	0.5 – 1.5	< 0.5

2.3 Calibration and validation

To evaluate the accuracy of the obtained map quantitatively, it is compared pixel by pixel to ground reality (Makhdoum et al., 2009). In the current research, first the maximum production was calculated by the normalized difference vegetation index (NDVI) images of the MODIS satellite data for the year 2014 with the pixel size of 250 m (Holben, 1986). To evaluate the maximum production with the NDVI index in agricultural lands, the images should be from the spring season, when the maximum greenery can be observed in the region, and be selected from a year when there is neither drought nor high precipitation, which have a negative effect on the evaluation of the region's production. Therefore, the spring images of 2014 were selected, since during this year, the precipitation was normal compared with the recent years of study. To prepare this image ($NDVI_{max}$), the image having the maximum production (maximum NDVI per year) among the three spring images was selected. Then, the average and standard deviation of production in current irrigated lands were calculated by $NDVI_{max}$ images. In general, NDVI data should be normal (statistically) to calculate the parameters. Next, samples of irrigated lands (Table 4) and non-irrigated

Table 4. Error Matrix for irrigated use in Study Area.

Model		Ground reality	
Classify	Class	Agricultural land with production more than or equal to the average (NDVI value ≥ μNDVI)	Agricultural lands with poor production (NDVI value < $\mu_{NDVI} - SD_{NDVI}$), and natural resource lands in mountains and hills, desert lands
	1,2	*	
	3,4		*
Number of points		964	1097

lands were systematic randomly gathered by the "Create Fishnet" algorithm in the ArcGIS 9.3 software. Then, these points were overlaid on the land capability maps. The result is observed in a table namely, "Error Matrix" or agreement matrix (Table 4), and quantitative indices such as overall accuracy and Kappa coefficient were calculated (Congalton, 1991). Overall accuracy is used to measure the correct classification of all reference or test samples. The overall accuracy is usually expressed as a percent. The Kappa coefficient is generated from a statistical test to evaluate the accuracy of a classification. The Kappa coefficient essentially evaluates how well the classification is performed as compared with just randomly assigning values, i.e. did the classification do better than random. The Kappa coefficient ranges from -1 to 1.

To calibrate the model, omission and commission errors from the Error Matrix of the geometric mean map were used to increase the level of accuracy. Hence, according to the omission and commission error and maps of parameters in the geometric mean method, the quantitative ranges of suitability classes (Table 3) were changed slightly. This kind of calibration was performed in other classifications like Mediterranean Desertification and Land Use (MEDALUS) Method (Sepehr et al., 2007; Zakerinejad and Masoudi, 2019).

3. RESULTS

Figure 3 depicts the final map of ecological capability with the best accuracy (geometric mean). Table 5 also shows accuracy assessment indices in the different used models.

The results demonstrated that the proposed method (4 classes) using the geometric mean was better than the Iranian ecological model (Table 5). Moreover, the calibrated proposed method (4 classes) using geometric mean evaluation (with overall accuracy %=95 and Kappa coefficient =0.91) is the best among the different used models (Table 5). It should be noted that the arithmetic mean method (with overall accuracy %=46 and Kappa coefficient =0) has the lowest accuracy. Additionally, WLC method with considering constrains (with overall accuracy %=95 and Kappa coefficient =0.91) has higher accuracy than those without constrains. These results are close to the geometric mean (Geomean); however, the geometric mean model is simpler than WLC with considering constrains (Masoudi, 2018).

Figure 4 shows the percent area for different classes in four different models. In the maximum limitation method, the whole area is under poor and unsuitable classes, and the study area does not have the suitable capability in classes 1 and 2. In the arithmetic mean method, much of the study area is under the moderate class with approximately 90%. Poor and unsuitable capability classes are not observed in this method. In the geometric mean method, much of the study area with almost 76% is under the class of unsuitable, and the other ratios are 18% (moderate), 6% (suitable), and 0 % (poor). In the WLC method with considering constrains, the percentage of each class is almost similar to that of the geometric mean method. Indeed, in the range of 0 to 1 (grade of fuzzy members) and in sum-based methods like the arithmetic mean, the prepared map tends to be 1 or good. Therefore, this method has low sensitivity in location. On the contrary, the map prepared based on the Boolean method tends toward 0 or the unsuitable class. Thus, this method has high sensitivity in location. The proposed method of the geometric mean is placed from 0 to 1 (Fig. 4). Therefore, this method has high flexibility in differentiating classes and locating them. These results indicate that the geometric mean (with 4 classes) can be a useful model for finding the potential area for agriculture. It should be noted that the geometric mean evaluation with higher accuracy is simpler than WLC methods, since it does not need the weighting process.

4. DISCUSSION

The Iranian ecological land use models introduced by Makhdoom (Makhdoum, 2006) and the FAO model

Table 5. Amount of overall accuracy, Kappa coefficients in the different used models.

A) Iranian Ecological Model, Boolean logic (Maximum limitation method), Arithmetic mean methods and Geometric mean

Model Type	Iranian Ecological Model	Revised method (4 classes)			
		Boolean logic	Averaged based		
			Arithmetic mean (indicators)	Arithmetic mean (criteria)	Geometric mean
Overall Accuracy (%)	82	53	46	81	95
Kappa Coefficient	0.64	0.01	0	0.60	0.91

B) WLC Method (with and without consideration of constrains)

Accuracy indicators	Revised method (4 classes)			
	Averaged based			
	WLC indicators analysis without constrains	WLC indicators analysis with constrains	WLC criteria analysis without constrains	WLC criteria analysis with constrains
Overall Accuracy (%)	46	95	82	95
Kappa Coefficient	0	0.91	0.65	0.91

Note: In Table 5B are presented results of Equation 1 (WLC indicators analysis without constrains and WLC indicators analysis with constrains) and results of Equation 2 (WLC criteria analysis without constrains and WLC criteria analysis with constrains).

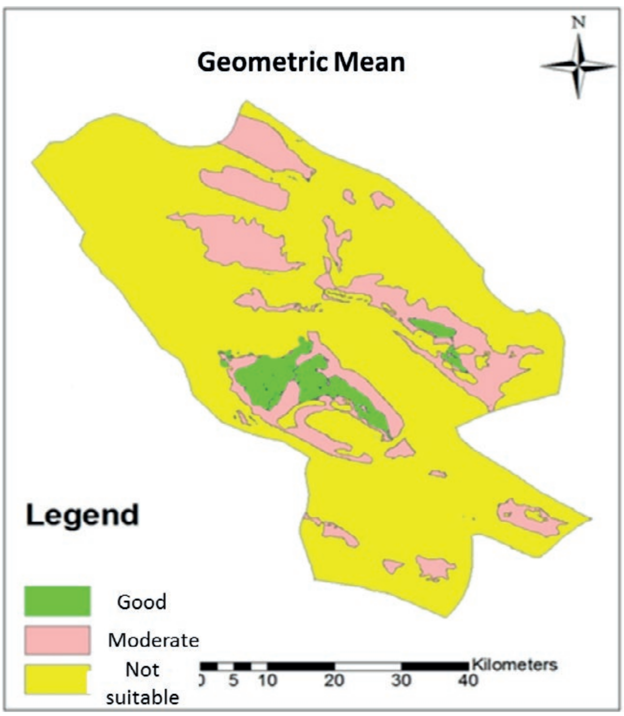

Figure 3. Ecological capability map prepared with the best accuracy.

(FAO, 1976) should be revised based on the areas under evaluation. Hence, it is essential to revise these models

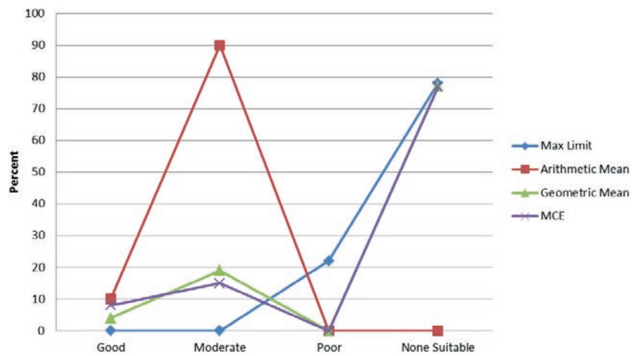

Figure 4. Percent of land under different capability classes for different methods of irrigation use.

for different topographic and climatic conditions. In this research, firstly, the ecological capability models of land uses were studied by different methods (Boolean and mean-based methods) and with a general view of the environmental conditions of Firouzabad County. In this work, each irrigated agriculture model was evaluated by the criteria affecting it as follows:

Based on the current results acquired in the different attitudes of irrigated agricultural models with efficient criteria, it was defined that by considering important indices such as drought and degradation of groundwater resources, especially in arid and semi-arid zones, which have unsuitable conditions for these parameters, the model accuracy was improved. In one study assessing desertification in arid and semi-arid regions based on the MEDALUS model, Sepehr et al. (2007) found that since the MEDALUS model was prepared for the Mediterranean area, it needed to be revised for use in arid and semi-arid areas, groundwater conditions.

As the results in Table 5 reveal, to evaluate the ecological capability for irrigated agricultural use (using the drought index and water resources degradation), the geometric mean method has the highest accuracy compared with other methods. The results show that Boolean methods tend to provide unsuitable classes, while arithmetic mean methods tend to provide suitable and moderate classes, and the geometric mean method is among the mentioned methods.

In addition, in the suggested model by the geometric mean, the average of ecological situations has been studied, and socioeconomic situations have been investigated indirectly, as agricultural use is a kind of use related to socioeconomic situations. The offered method by geometric mean evaluation is a simple system of ecological-socioeconomic status indicating restrictions and true potential of land together. In terms of irrigated farming modeling, the results of this study match well with those obtained by Jahantigh et al. (2019) and Masoudi et al. (2017). Their quantitative results confirm well with the current research.

In Boolean methods (like FAO, 1976), the classification process is difficult. However, the suggested model is more flexible than the Boolean model. This criticism of the Boolean method can also be observed in studies by Elaalem (2012), Jokar and Masoudi (2016), and Asadifard et al. (2019). Furthermore, Amiri et al. (2010) utilized two models, namely Boolean and AHP-Fuzzy (Analytic Hierarchy Process and Fuzzy) methods, to evaluate the ecological capability of forestry in Mazandaran Province, northern Iran. Their results confirm the improvement of the AHP-Fuzzy method versus the common assessment of Boolean for the ecological capability of forests in the northern part of Iran. The results of the current study confirm the same findings. Moreover, contrary to the above studies, Amici et al. (2010) employed the Boolean method to evaluate the rank of classification uncertainty in the Tuscany area of Italy and found that it was a helpful method for the comer ecological investigation of the vegetation area.

The other benefit of the new offered method of the geometric mean is lowering the wider effects of some parameters like soil criteria with many indicators against topography criteria using only two indicators.

Additionally, there are areas with ecological specifications of unsuitable conditions (e.g. very severe salinity). Determination of these lands as the zero number in equations 3 and 4 causes these lands to be evaluated as unsuitable. This evaluation method supports the strict view of the Boolean logic (Jokar et al., 2021). Obviously, in the WLC method, the number 0 is also used as a constrain factor, so that the presence of only one indicator or factor that is unsuitable makes that polygon or pixel unsuitable; however, other ecological indicators are suitable or partly-suitable.

5. CONCLUSION

Land use planning should be carried out with a unified attitude of development and nature conservation. Attaining this important aim in the point of sustainable development is possible with the attitude of capability evaluation and land management. Different criteria are required in the land evaluation procedure. The main aim of this research was to evolve a new method in comparison with various methods for land capability assessment. This research evaluated a type of modeling with Boolean logic and MCE (WLC) models by GIS. Then, the land capability maps for irrigated agriculture were prepared. Next, the best model was produced based on the geometric mean method. Indeed, the major evolution was the combination of the FAO model with the Iranian ecological model via the geometric mean method in GIS. The current research outcome can be used in land use planning in other areas with same situations. Therefore, the results of the study can be employed by numerous managers in natural resources and environmental field for suitable land management.

Generally, the results of this research demonstrated that in any study and field survey, it cannot be stated which method is the best one to evaluate land capability and land use planning. Obviously, in this case, the evaluator must investigate the ecological, social and economic conditions of each region in the process of ecological capability evaluation. The outcomes of this study led to a remarkable success in the land evaluation procure and will be regarded as beginning and reference points for further studies and assessments. Since land capability evaluation subjects are multi-criteria and have one aim, it is recommended that in further researches this model should be planned for each land use and that all land uses be evaluated using land use planning methods like MOLA (multi-objective land allocation).

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