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Land Suitability Analysis for Rice Cultivation Using a GIS-based Fuzzy Multi-criteria Decision Making Approach: Central Part of Amol District, Iran

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Abstract

Maddahi Z., Jalalian A., Kheirkhah Zarkesh M.M., Honarjo N. (2017): Land suitability analysis for rice cultivation using a GIS-based fuzzy multi-criteria decision making approach: central part of Amol District, Iran. Soil & Water Res., 12: 29–38.

Land suitability analysis and preparing land use maps is one of the most beneficial applications of the Geographic Information System (GIS) in planning and managing land recourses. The main objective of this study was to develop a fuzzy multi-criteria decision making technique integrated with the GIS to assess suitable areas for rice cultivation in Amol District, Iran. Several suitability factors including soil properties, climatic conditions, topography, and accessibility were selected based on the FAO framework and experts' opinions. A fuzzy analytical hierarchical process (FAHP) was used to determine the weights of the various criteria. The GIS was used to overlay and generate criteria maps and a land suitability map. The study area has been classified into four categories of rice cultivation suitability (highly suitable, suitable, moderately suitable, and unsuitable). The present study has attempted to introduce and use the FAHP method to land suitability analysis and to select lands in order to be used as best as possible. Areas that are classified as highly suitable and suitable for rice cultivation constitute about 59.8% of the total area of the region. The results of the present research indicate that the FAHP is an efficient strategy to increase the accuracy of the weight of the criteria affecting the analysis of land suitability.

Keywords: fuzzy analytical hierarchy process (FAHP); GIS; land suitability map; multiple criteria; rice growing; spatial analysis

The multi-criteria evaluation is nowadays used in some regional planning processes. The aim of these processes is mostly predicting the potential of the land for different applications. The agricultural application is the most important (Chen *et al*. 2008; Giri & Nejadhashemi 2014). This method may become crucial in the future of land-use planning (Yu *et al*. 2011). Selecting the best assessment method for the purposes of planning the use of lands in the future or in the present is therefore very important in countries like Iran. The land evaluation method is a systematic method which evaluates the potential of lands in order to find the best region for cultivating some special crops.

Theoretically, the potential of land suitability for agricultural use is estimated through an evaluation process which uses criteria such as climate, soil, water resources, topography, components of the environment, and understanding the local environment (Ceballos-Silva & Ľopez-Blanko 2003; Pourkhabbaz *et al*. 2014).

The analytic hierarchy process (AHP) is a multi-criteria method for assessing the land use suitability based on the Geographic Information System (GIS)

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(Satty 1980; Malczewski 2004; Hansen 2005). The AHP is one of the popular methods widely used to resolve multi-criteria decision-making (MCDM) problems (Chang *et al*. 2007). The multi-criteria land suitability evaluation based on the FAO (1976) framework has been applied in some areas (Baniya 2008; Mustafa *et al*. 2011). The main shortcoming of the AHP method is related to the judgements of an expert on the absolute values assigned to numbers 1–9 which is unable to manage uncertainty. The fuzzy set is used in AHP computations in order to compensate for this flaw (Chang *et al*. 2007; Rathia *et al*. 2015). The combination of the AHP and fuzzy sets makes the judgements and decisions more flexible. Fuzzy AHP (FAHP) reflects the human mind when making decisions based on approximate data and uncertainty. These methods have barely been used in developing countries like Iran. Many researches have been conducted so far on land suitability through the use of the GIS-based AHP method for the purposes of cultivating rice (Nyeko 2012; Kihoro *et al.* 2013; Getachew & Besufekad 2015; Konan-Waidhet *et al*. 2015). However, the FAHP has rarely been used in land suitability researches. This is the strongest motivation for carrying out this study, in which the GIS-based FAHP land suitability analysis method was used to classify the study region with regard to its potential for rice cultivation.

MATERIAL AND METHODS

Study area. The preset research was conducted in the central region of Amol District which is located in Haraz oasis in Mazandaran Province, Iran (Figure 1). This region covers an area of 304.83 km^2 and is situated in the northern part of Iran between 36°34'43'' and 36°22'16''N latitudes and 52°11'34'' and 52°26'54''E longitudes.

Multi-criteria decision making. The MCDM method presents a potential framework which reflects the opinions of the people involved in the decision-making process. This information framework combines a number of criteria and forms an assessment index unit (Yu *et al*. 2011). The combination of the MCDM method and the GIS method represents a powerful tool for spatial analysis (Yu *et al.* 2009).

With regard to the large number of factors which affect decision-making, land suitability analysis can be recognized as a multi-criteria evaluation method (Reshmidevi *et al.* 2009).

Fuzzy analytical hierarchy process. The FAHP is an AHP format which assesses different criteria through the use of fuzzy numbers. While AHP is based on using the Crisp numbers, FAHP has overcome the flaws of AHP. Since ambiguity is a common characteristic of many decision-making problems, the FAHP method has been developed to compensate for

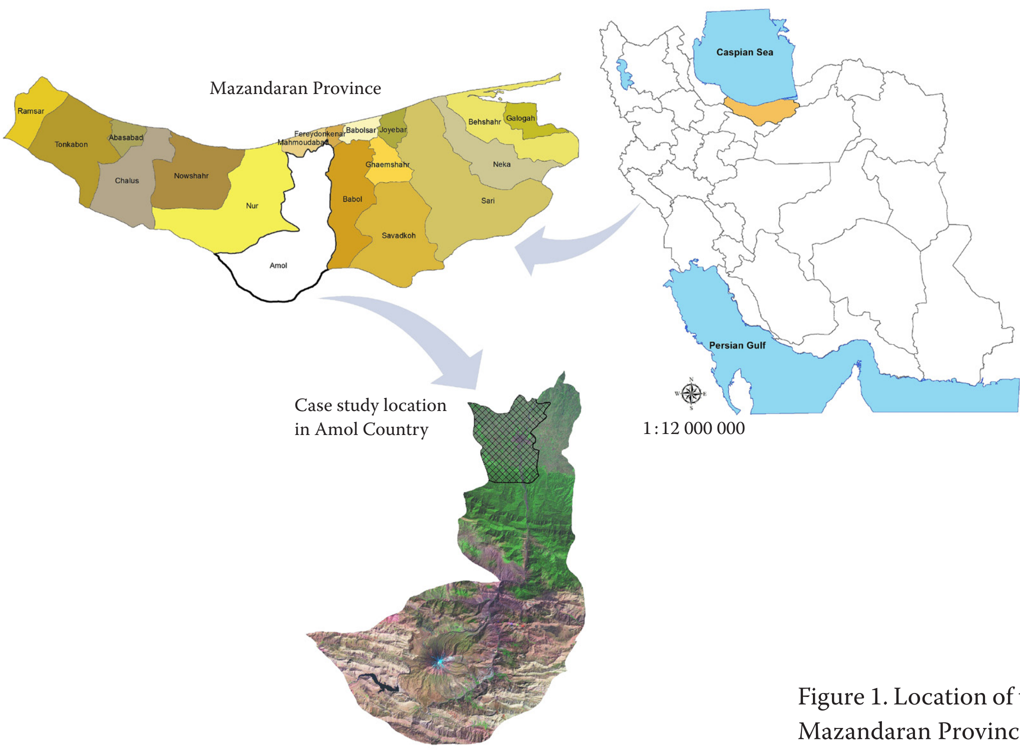

Figure 1. Location of the case study area in Mazandaran Province, Iran

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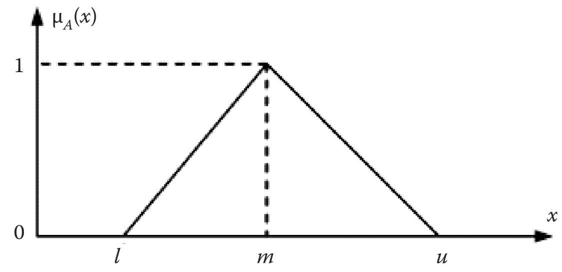

Figure 2. Fuzzy triangular number

that imperfection (Mikhailov & Tsvetinov 2004). Therefore FAHP is able to eliminate the ambiguity and doubt from the assessment when it comes to complicated and multi-index problems (Erensal *et al*. 2006).

A triangular fuzzy number (TFN) expresses the relative strength of each pair of elements in the same hierarchy and can be denoted as $M = (l, m, u)$, where $l \leq m \leq u$. The parameters l, m, u indicate the smallest possible value, the most promising value, and the largest possible value, respectively, in a fuzzy event. A triangular type membership function of M fuzzy number can be described as in Eq. (1) (Chang 1996) (Figure 2). When $l = m = u$, it is a non fuzzy number by convention.

$$f(x) = \begin{cases} \dfrac{x-l}{m-l}, & l \leq x \leq m \\ \dfrac{u-x}{u-m}, & m \leq x \leq u \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

Different methods have been presented in literature and the fuzzy analysis is one of the methods suggested by Chang (1996). In the present research the fuzzy analysis is applied because it is a simpler calculation method in comparison with other FAHP methods. Triangular fuzzy numbers are used in A pair-wise comparison matrix $\tilde{A}$ (a_{ij}) which could be mathematically expressed as follows:

$$\tilde{A} = (\tilde{a}_{ij})_{n\times n} = \begin{bmatrix} (1,1,1)(l_{12},m_{12},u_{12})\ldots(l_{1n},m_{1n},u_{1n}) \\ (l_{21},m_{21},u_{21})(1,1,1)\ldots(l_{2n},m_{2n},n_{2n}) \\ \vdots \quad\quad \vdots \quad\quad \vdots \\ (l_{n1},m_{n1},n_{n1})(l_{n2},m_{n2},n_{n2})\ldots(1,1,1) \end{bmatrix} \tag{2}$$

where:

$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$

$\tilde{a}_{ij}^{-1} = (1/u_{ij}, 1/m_{ij}, l_{ij})$

$i, j = 1, \ldots, n$ and $i \neq j$

The steps of fuzzy Chang's extent analysis could be explained as follows:

First step: Sum each row of the fuzzy comparison matrix $\tilde{A}$. Then normalize the row sums (obtaining their fuzzy synthetic extent) by the fuzzy arithmetic operation:

$$\tilde{S}_i = \sum_{j=1}^{n} a_{ij} \otimes \Big[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\Big]^{-1} \tag{3}$$

where:

$\tilde{S}_i$ – value of fuzzy synthetic extent with respect to the i^{th} object

$\otimes$ – extended multiplication of two fuzzy numbers

Second step: calculate the degree of possibility for $\tilde{S}_i \geq \tilde{S}_j$ by the following equation:

$$V(\tilde{S}_i \geq \tilde{S}_j) = \sup_{y\geq x}\,[\min(\tilde{S}_j(x), \tilde{S}_i(y))] \tag{4}$$

This formula can be equivalently expressed as:

$$V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1, & m_i \geq m_j \\ \dfrac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, & m \leq x \leq u \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

where $\tilde{S}_i = (l_i, m_i, u_i)$ and $\tilde{S}_j = (l_j, m_j, u_j)$ (6)

Figure 3 illustrates this degree of possibility for two fuzzy numbers.

Third step: Estimate the priority vector $W = (w_1, \ldots, w_n)^T$ of the fuzzy comparison matrix $\tilde{A}$ as follows:

$$W_i = \frac{l_i + u_i + m_i}{3}, \; i = 1, \ldots, n \tag{7}$$

In order to rank the criteria, the TFN should be defuzzified, so we use a simple centroid method.

Fourth step: normalize the calculated weights of each criterion as follows:

$$NW_i = \frac{w_i}{\sum_{j=1}^{n} w_j}, \; j = 1, \ldots, n \tag{8}$$

where $\sum_{i=1}^{n} NW_i = 1$, $i = 1, \ldots, n$

In order to perform a pairwise comparison among fuzzy parameters, linguistic variables have been defined for several levels of preference (Table 1).

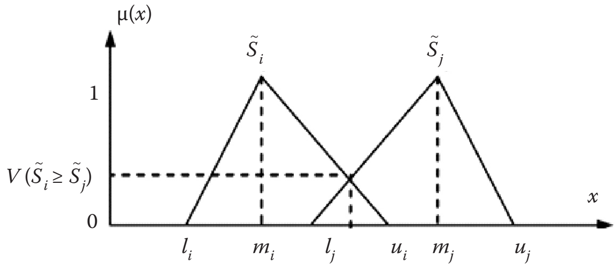

Figure 3. The degree of possibility $V(\tilde{S}_i \geq \tilde{S}_j)$

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Table 1. Triangular fuzzy number of linguistic variables used in the study

Linguistic variables for importance	Crisp pair-wise number	Triangular fuzzy numbers	Reciprocal triangular fuzzy numbers
Extreme importance	9	(9, 9, 9)	(1/9, 1/9, 1/9)
Very strong importance	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Strong or essential importance	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Moderate importance	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Equal importance	1	(1, 1, 1)	(1, 1, 1)
Intermediate values	2, 4, 6, 8	(7, 8, 9), (5, 6, 7), (3, 4, 5), (1, 2, 3)	(1/9, 1/8, 1/7), (1/7, 1/6, 1/5), (1/5, 1/4, 1/3), (1/3, 1/2, 1)

To determine if the comparisons are consistent or not, a consistency ratio (CR) is calculated by the Eq. (9):

$$CR = \frac{CI}{RI} \tag{9}$$

$$CR = \frac{\lambda_{max} - n}{n - 1} \tag{10}$$

where:

CI – consistency index

λ – average value of consistency vector

n – number of criteria

RI – random index, the consistency index of a randomly generated pair-wise comparison matrix, simply obtained from the table of Random Inconsistency Indices (Table 2)

The CR is designed in such a way that if $CR < 0.10$, the ratio indicates a reasonable level of consistency. However, $CR > 0.10$ indicates inconsistent judgements (Shariff & Wan 2008).

The ability of FAHP in combining different types of input data and the uncertainty method of pair-wise comparisons were used to simultaneously compare two parameters for the purposes of classifying land suitability for rice cultivation in the study regions in northern Iran.

The overall flow of the methodology we have followed herein is presented in Figure 4.

Selection of evaluation criteria. The set of the selected criteria must sufficiently reveal the decision-making space and must act as a guide to the final goal (Prakash 2003; Kihoro *et al.* 2013). Evaluation of land suitability is a multi-criteria assessment process and its criteria have been derived from spatial and non-spatial and qualitative and quantitative data and under different conditions (Chen *et al.* 2010). Based on the opinion of experts and the view of decision-makers and FAO framework in 1976 for irrigated rice cultivation, the influential factors have been classified into four main categories including soil properties, climate conditions, topography, and accessibility. Main categories and categories/factors used in the study are shown in Figure 4.

Data collection and preparation using the GIS. Data preparation is the first fundamental step in the land suitability analysis. The following data set was prepared to that end:

- Digital topographical maps 1 : 25 000 (National Cartographic Centre organization) were used to create triangulated irregular network (TINs), digital elevation map (DEM), and derivate layers such as slope and aspect.
- Available information on wells, springs, streams, and river were obtained from the Mazandaran water organization and were mapped in a GIS domain. The exact locations of residential areas were obtained from the related national agency and were mapped using the GIS software.
- Meteorological data for a 10-year period (Iranian Meteorology Organization) were used to create climate maps
- Field operations using GPS for soil sampling were performed and various physico-chemical experiments were done on samples for the purpose of soil mapping.
- Landsat thematic mapper (TM) satellite images were used to derive land use through image classification techniques and Google Earth images with high spatial resolution to correct the land use map.

Table 2. Random consistency index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.24	1.41	1.45	1.49

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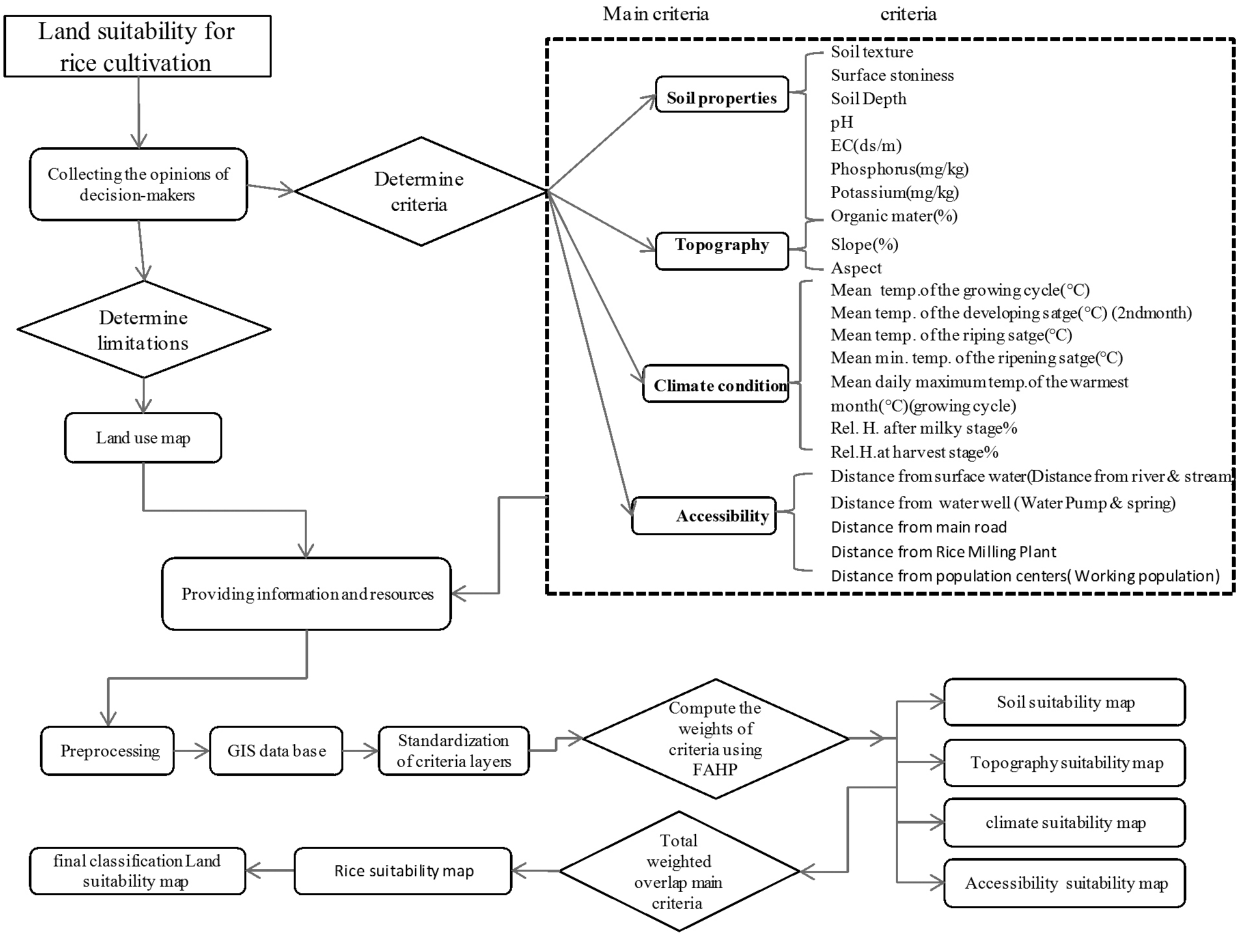

Figure 4. Flowchart of the methodology used in the study

After preparing the spatial database including all the essential thematical and geometrical modifications, topology was also created. All vector layers were then converted into raster format with a 30 m resolution and the spatial datasets were processed in ArcGIS software, Version 10.1.

Based on the land use map obtained from satellite images taken from the region, 14.4% of the area is used for residential purposes (not suitable for crops cultivating) and it was deleted from all maps. The spatial distributions of some import datasets are shown in Figure 5.

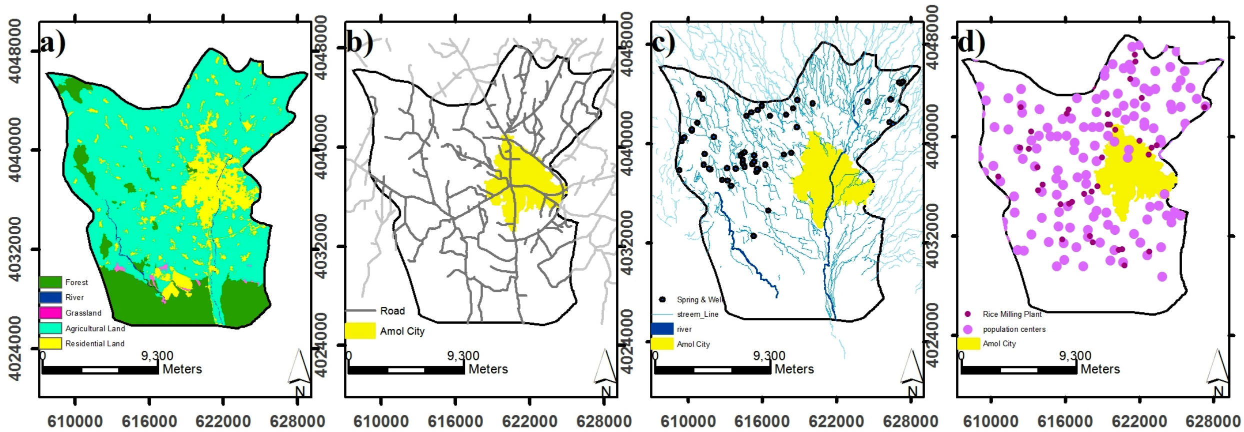

Figure 5. Land use of the study area (a), main roads (b), rivers and streams (c), residential areas (d)

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Table 3. Fuzzified pair-wise comparison matrix of the main criteria (fuzzy judgement matrix)

Criteria	Soil properties	Topography	Climate	Accessibility
Soil properties	(1, 1, 1)	(5, 6, 7)	(6, 7, 8)	(3, 4, 5)
Topography	(1/7, 1/6, 1/5)	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)
Climate	(1/8, 1/7, 1/6)	(1/5, 1/4, 1/3)	(1, 1, 1)	(5, 6, 7)
Accessibility	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1/7, 1/6, 1/5)	(1, 1, 1)

Standardization of criteria. After preparation, the maps had to be standardized. The values in different input maps may have different meanings and they may include different measurement units (e.g. the slope map in terms of percentage, temperature in terms of degree, etc.). In order to make the values mutually comparable, it is necessary to standardize them by turning into similar measurement units (0–1). This is called making the values without scale. Two standardization methods were applied in this research: Spatial AHP, which was used for standardization of all the applied criteria but for the distance criteria, for the standardization of which the Cost-benefit analysis was used. For example, in the population centre criterion the Cost-benefit analysis assigns the highest score (suitability degree = 1) to the area nearest to the population centres and the lowest one (suitability degree = 0) allocates to the farthest.

RESULTS AND DISCUSSION

Calculating criteria weighting. The criteria weights are weights which are allocated to target in relation to the map (Meng *et al*. 2011). The FAHP method and Chang's (1996) method, which is a very simple method for generalizing the hierarchical analysis process to the fuzzy space, was used in order to assign weight to the criteria through. This method is based on computational mean of the experts' opinion and the time normalization method and the use of triangular fuzzy numbers.

A pair-wise comparison matrix has been made fuzzy based on the experts' opinion and using the triangular fuzzy numbers (Table 3). The act of turning the matrixes into fuzzy matrixes through Eqs (3–8) aimed at reaching the normal weights (Table 4). The weights resulting from the FAHP were computed likewise for each category (Table 5).

Overlaying map layers and analysis. After calculating the weights of the criteria in the present research through the FAHP method, the entire criteria maps were overlaid through the use of the GIS function and the suitability maps were prepared for the main criteria. The main suitability maps went through weight overlaying eventually and the final map of suitability for rice cultivation was produced. The result of integrating the weights of the criteria obtained from the FAHP with the criteria maps with the raster calculator function in 10.1 ArcGIS software.

Land suitability maps of the study area according to different aspect of topography, soil properties, climatic conditions, and accessibility are demonstrated in Figure 6. The final land suitability map, resulting from finally weighted overlay, is shown in Figure 7.

The final classification land suitability map of readiness of the study area for rice cultivation was obtained by weighted overlay of the four suitability maps which were obtained from the extracted main criteria (Figure 7).

As mentioned previously, the standard weights of the criteria and the sub-criteria were obtained from

Table 4. Fuzzy evaluation of the main criteria (performance fuzzy analytical hierarchical process)

Criteria	Fuzzy number			Normalized weights
	lower	middle	upper	
Soil properties	0.359425	0.509778	0.722625	0.526079
Topography	0.147193	0.231288	0.244409	0.205857
Climate	0.151558	0.209373	0.292491	0.215947
Accessibility	0.038168	0.049562	0.069968	0.052117

λ_{max} = 4.27; *CI* = 0.09; *CR* = 0.1; λ – average value of consistency vector; *CI* – consistency index; *CR* – random index

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the FAHP process. Based on the final map, the study region was classified into four groups, namely: highly suitable, suitable, moderately suitable, and unsuitable. The classified map indicates that 15% (45.72 ha) of the study region is highly suitable, 44.8% (136.56 ha) of the region is suitable, 41.15% (125.43 ha) is moderately suitable, and 13.89% (42.34 ha) is unsuitable for rice cultivation.

Of the entire region, 59.8% is either highly suitable or suitable for rice cultivation. With regard to the results, seemingly a wide area of the region has a great potential for rice cultivation and production. Based on the annual rice cultivation in the region and the comparison made between that and the land suitability map, most of the rice is currently cultivated in this region in Iran. Therefore it is advisable to cultivate

Table 5. Weights derived from performance fuzzy analytical hierarchical process for all criteria

	Fuzzy number			Normalized weights
	lower	middle	upper	
Soil properties criteria				
Soil texture	0.103109	0.208943	0.394564	0.208694
Surface stoniness	0.128886	0.233285	0.226047	0.229980
Soil depth	0.091212	0.174049	0.321496	0.173314
pH	0.060755	0.103009	0.179015	0.101256
Electrical conductivity	0.061072	0.113978	0.209411	0.113567
Phosphorus	0.033709	0.059026	0.109601	0.059805
Potassium	0.033709	0.059026	0.109601	0.059805
Organic matter	0.030298	0.048684	0.102294	0.053579
Consistency ratio				0.06
Topography criteria				
Slope	0.333333	0.666667	1.200012	0.65563
Aspect	0.222217	0.333333	0.600006	0.34437
Consistency ratio				0.01
Climate condition criteria				
Mean temperature of the growing cycle (°C)	0.098592	0.236364	0.448826	0.239437
Mean temperature of the developing stage (°C)	0.089201	0.136364	0.212602	0.133856
Mean temperature of the ripping stage (°C)	0.089201	0.136364	0.212602	0.133856
Mean minimal temperature of the ripening stage (°C)	0.089201	0.136364	0.212602	0.133856
Mean daily maximum temperature of the warmest month (°C)	0.089201	0.136364	0.212602	0.133856
Relative humidity after milky stage (%)	0.089201	0.136364	0.212602	0.133856
Relative humidity at harvest stage (%)	0.051637	0.081818	0.165357	0.091284
Consistency ratio				0.06
Accessibility criteria				
Distance from surface water (distance from river and stream)	0.255164	0.403891	0.629301	0.401782
Distance from water well	0.061837	0.100970	0.163046	0.101619
Distance from main road	0.205043	0.321616	0.500580	0.320351
Distance from rice milling plant	0.067436	0.111070	0.188313	0.114394
Distance from residential areas with work opportunities	0.047691	0.062453	0.088197	0.061854
Consistency ratio				0.1

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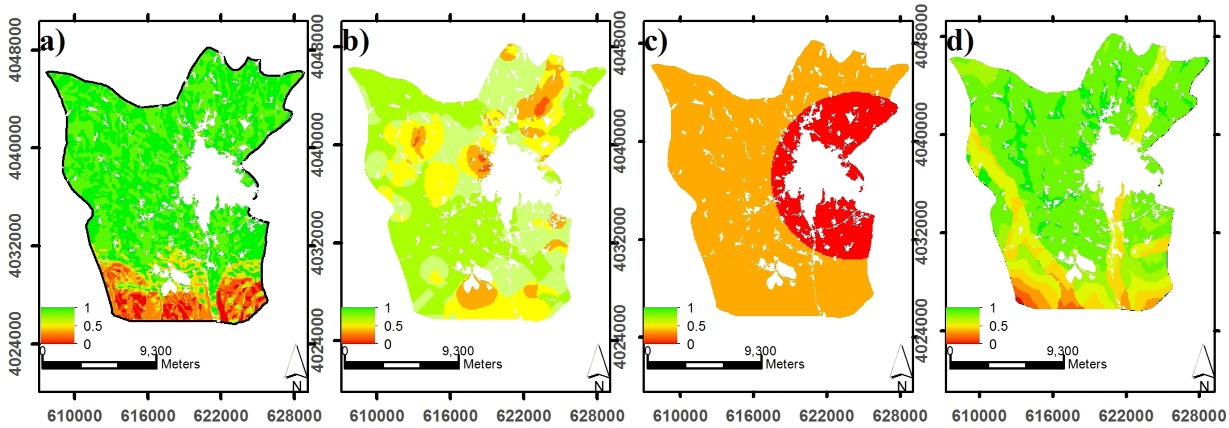

Figure 6. Suitability maps of topography (a), soil properties (b), climatic conditions (c), and accessibility factor (d)

rice in the regions which are highly suitable or suitable for rice cultivation and the other crops should be planted in areas less suitable for rice cultivation.

Comparison of the obtained land suitability map and the land use map indicates that the geographical levels suitable for rice cultivation overlap with a vast area of the region which includes agricultural lands. These lands are made up of rice fields and gardens.

With regard to the previous studies, one of the disadvantages of using multi-criteria decision-making methods through the use of classic AHP is the uncertainty in selecting the value of the criteria in relation to one another in pair-wise comparison (a number between 1 and 9) (Sehra *et al*. 2012; Velasquez & Hester 2013; Konan-Waidhet *et al*. 2015).

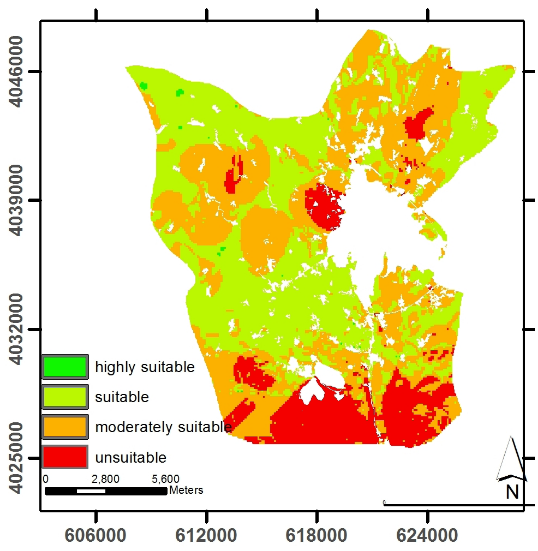

Figure 7. The classified final map of the study area for rice cultivation

Factors such as lack of knowledge and information, natural uncertainty and complexity of the decision-making spaces, and lack of proper measurement instrument and criterion cause uncertainty in the decisions made on assigning the priorities.

The most important reasons behind using the FAHP rather than the classic hierarchical analysis process is that the values are compared in pairs in the classic hierarchical analysis process through absolute numbers (Saaty 1980), while with regard to the conditions, the experts' opinions cannot always be certain and accurate. This uncertainty can be shown with fuzzy logic (Jiang & Eastman 2000).

CONCLUSIONS

The suitability map for rice cultivation was prepared in the present research through the GIS-based FAHP method. The properties of the soil, topography, climate, and accessibility were determined as the main criteria for determining the suitability with regard to the expert opinion and the previous literature. This map was then compared with the existing land use map of the study region. The results show that the regions entitled highly suitable and suitable have already largely been under cultivation.

The results of this study and matching them with the current conditions of the region show that the fuzzy hierarchical analysis process (FAHP) is an efficient strategy to increase the accuracy of assigning weight to the criteria which influence the land suitability analysis.

The inability of the common decision-making methods to consider the uncertainty paves the way for the use of fuzzy decision-making methods. One

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of the flaws of the analytic hierarchy process (AHP) is its inability to consider uncertainty of judgements in pair-wise comparison matrixes. This shortcoming has been compensated for by the FAHP method. Instead of considering a specific number in pair-wise comparison, a range of values are considered in FAHP for the uncertainty in the opinion of the decision-makers.

The methodology of the present research can be beneficial to prioritizing the lands for rice cultivation and it can also improve exploitation and protect the resources and sustainable management. The results of this study can provide useful information on selecting a proper cultivation pattern in the region since it considers the main criteria for rice cultivation in the study area and the opinion of the local experts.

It is advisable to use different AHP fuzzy methods and also to compare the results of different AHP fuzzy methods in future researches.

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