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Comparison of parametric and fuzzy analytic hierarchy process in land evaluation (Case study: Varamin region)

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Abstract
In last decades, the skillful planning of land resources has become a major issue for rural development. The development of cultivated areas becomes gradually impossible due to ever increasing population growth and urban development. Fuzzy logic is preferred to Boolean logic for land evaluation, because fuzzy techniques lead to estimate for land use suitability on a continuous scale and can therefore, be more informative than the Boolean technique. The objective of this study is to apply fuzzy set methodology in the context of a decision making process known as the Analytic Hierarchy Process (AHP) to land evaluation for irrigated wheat. The results revealed that the results obtained with fuzzy AHP method are in better agreement (R^2=0.911) with the observed yield as compared to those obtained with parametric method (R^2=0.804). Although, the fuzzy AHP provided more efficient and accurate results than parametric method, the choice of membership functions, width of the transition zones and weight values are determinant to achieve its realistic results in land suitability assessment.

Key words: *Multi-criteria decision making, Fuzzy set theory, Land suitability evaluation, parametric method*

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Introduction

In the present modern world, the development of cultivated areas becomes gradually impossible due to ever increasing population growth and urban development, particularly in countries with restricted water and other natural resources (Orhan et al., 2003). Therefore, it is very important to prevent land degradation and to conserve soil resources. This is possible by proper land use planning (LUP). In this regard, monitoring of land use change and sustainable use of existing land resources are noteworthy.

Land suitability evaluation (LSE) is a prerequisite for land use planning and development (Niekerk, 2010). Land suitability assessment is defined as the classification of lands in terms of their suitability for a defined use. De La Rosa and van Diepen (2002) believe that the main object of the land evaluation is the prediction of the land unit inherent capacity for a given use without deterioration. Land evaluation is carried out to predict land performance, both in terms of the expected benefits from and constraints to productive land use, as well as the expected environmental degradation due to these uses (Rossiter, 1996). Land evaluation procedures focus increasingly on the use of quantitative procedures to enhance the qualitative interpretation of land resource surveys (Braimoh and Vlek, 2004). Land evaluation is a decision making procedure that relies on hard sciences of chemistry and physics but still requires knowledge of social and institutional factors so as to be able to evaluate the consequences of decisions (Waterstone, 1994).

Fuzzy set theory has been widely used in soil sciences for land evaluation, soil classification and soil quality indices (Zhu et al., 2010). According to it, observations are grouped into continuous classes, instead of classifying them into hard classes (Burrough et al., 1992; McBratney and Odeh, 1997). Fuzzy land evaluations define continuous suitability classes rather than “true” or “false” categories as in the Boolean model (Keshavarzi, 2010).

In multi-criteria decision making (MCDM), which is used for determination of the optimum land utilization type for an area, unequal importance of different land criteria is taken into account. The investigation of a number of alternatives taking into account multiple criteria and conflicting objectives is the main goal of multi-criteria evaluation (MCE) techniques. In these techniques, it is necessary to select alternatives and rank them according to their degree of attractiveness (Ceballos-Silva and López-Blanco, 2003).

Mokhtar (2010) reported that the Fuzzy AHP method presents land suitability classes as continuous values, while the use of the Boolean method results in neat crisp sets, which are less realistic in nature. Braimoh and Vlek (2004) applied the fuzzy set and interpolation techniques for land suitability evaluation for maize in Northern Ghana. They concluded that the use of the fuzzy technique is helpful for land suitability evaluation, especially in applications in which subtle differences in soil quality are of a major interest. Ceballos-Silva and López-Blanco (2003) delineated the suitable areas for production of maize and potato crops in central Mexico through the multi-criteria evaluation approach. They concluded that the integration of GIS and multi-criteria decision making process can be used as an unbiased method. According to Nisar Ahamed et al. (2000) and Prakash (2003), the AHP approach failed to address the uncertainty through the pairwise comparison analysis and this was the path for the integration of fuzzy set models in the AHP approach. Servati et al. (2013) reported that the fuzzy approach provided better results than the parametric square root method to evaluate the suitability of alfalfa for lands in Khajeh region located in East Azerbaijan province, Iran. Qiu et al. (2014) concluded that the fuzzy models achieve better predictive accuracies than their classic counterparts for land suitability/capability evaluation. The results showed that by incorporating fuzzy suitability membership of environment factors in the modeling process, these fuzzy models also produce more informative fuzzy suitability maps.

According to the literature review, land suitability assessment is an interdisciplinary approach and is a multi-criteria decision making on one hand and modelings soil system without fuzzification do not realistically describe it on the other hand. Therefore, it is necessary to use both of the multi-criteria decision making and fuzzy system for real description of land potentiality for different land uses. Therefore, further research is needed into using the fuzzy set methodology in the context of a decision making process known as the analytical hierarchy process (AHP) to land evaluation. The aim of this research is to explore the role of fuzzy logic in multi-criteria of land evaluation for wheat in some part of Varamin region and compare the results with those of Boolean technique (parametric method).

Materials and methods

Study area and data compilation

The study area with an approximate area of 2000 hectares is located between latitude 35° 20' and 35° 24' N and longitude 54° 38' and 54° 42' E in the Varamin area, Tehran province, Iran. The mean annual rainfall in the area is 170 mm and its mean annual temperature is 17.4 °C with a mean altitude of 972 m a.s.l. The ground water table depth is more than 10 m. Required climatic data was obtained from a nearby meteorological station for a 20 years period (1994–2014). Based on U.S. Soil Taxonomy (Soil Survey Staff, 2014b), the soil moisture and temperature regimes of the area are acidic and thermic, respectively. The landscape is piedmont plain with gently sloping. Irrigated wheat, barley and maize are the most important crops cultivated in the area.

56 soil profiles were described with regular grid sampling method based on semi-detailed soil survey. Soil samples were collected from different horizons of the profiles. Prepared samples were subsequently analyzed for required soil properties in land suitability evaluation (Sys et al., 1993) using standard methods (Soil Survey Staff, 2014a). The studied soils were classified in Entisols and Aridisols. 14 soil profiles were selected as representative pedons. 12 representative pedons were located in wheat cultivated farms. In order to validation of land suitability results, wheat yields in three plots 1*1 m were randomly measured in each cultivated farm.

Land suitability evaluation with parametric method

In this method, a numerical rating with a scale of 0 to 1 is allocated to different suitability classes according to Sys et al. (1991). The land characteristics, i.e., climatic data and soil properties, with wheat requirement tables presented by Sys et al. (1993), were matched. Consequently, the square root formula was used to calculate the land index (LI). The relevant equation is as follow:

$$LI = R_{min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \ldots} \quad (1)$$

where LI is the specified land index, A, B, etc., are different ratings for each land characteristic, and R_{min} is the minimum rank or value (Sys et al., 1991).

Land suitability evaluation with fuzzy analytic hierarchy process (Fuzzy AHP)

In fuzzy technique, asymmetrical and symmetrical semantic import (SI) models were used to generate membership values for land characteristics (McBratney and Odeh, 1997). Asymmetrical models (Figures 1 a and b) have been employed where the land quality improves with increase and decrease of characteristic values, while, symmetrical models (Figure 1c) were used for characteristics that have two ideal point values (Burrough and McDonnell, 2000)

The membership values of the different land characteristics (soil and climate) were

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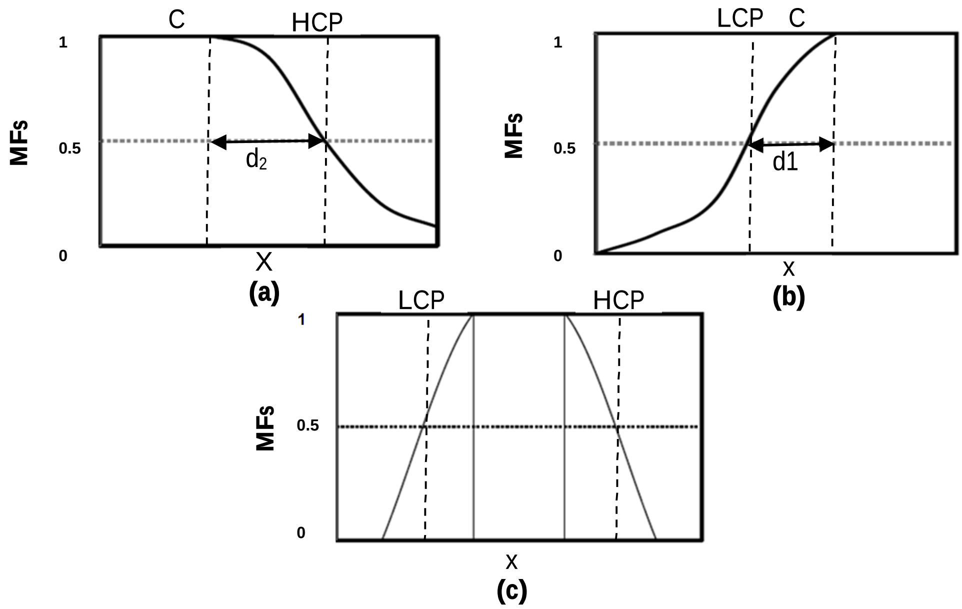

▲Figure 1. Fuzzy membership functions. (a) and (b) Asymmetrical models, (c) Symmetrical model. LCP and HCP are the lower and upper crossover points, respectively, d1 and d2 are the width of transition zones

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subsequently arranged in a characteristic matrix (R). The relative effects of each land characteristic on wheat yield can be demonstrated the weight factor. The weight values for all land characteristics were shown in weight matrix (W). In this study, the weight for each land characteristic was determined by pairwise comparisons in the context of a decision making process known as the AHP. The AHP was introduced by Saaty (1994) and is an effective mean of dealing in the context of decision making process. In this approach, land characteristics were organized in a hierarchical structure. Figure 2 shows the hierarchical structure used in this study. To make pairwise comparisons at each level of the hierarchy, decision makers can develop relative weights, called priorities to differentiate the importance of each land characteristic. The scale recommended by Saaty (1994) is from 1/9 to 9. The 9 and 1/9 indicate that one criterion is significantly the most and the least important, compared with the others, respectively. Thus, if two criteria are of equal importance, they would receive the same rating (Table 1).

In order to obtain an evaluation matrix (E), weight matrix (W) was combined with the characteristic matrix (R) using a fuzzy set operator (Van Ranst et al., 1996).

"$E = W^{o}R$" (2)

where "o" is the fuzzy set operator. The triangular norm T and triangular conorm T were used instead of minimum and maximum in this operator, respectively (Ruan, 1990). The evaluation matrix (E) was calculated as follow:

$$e_j = \min(a_1 + \ldots + a_n, 1) \text{ with } a_i = \max(0, w_i + r_{ij} - 1) \quad (3)$$

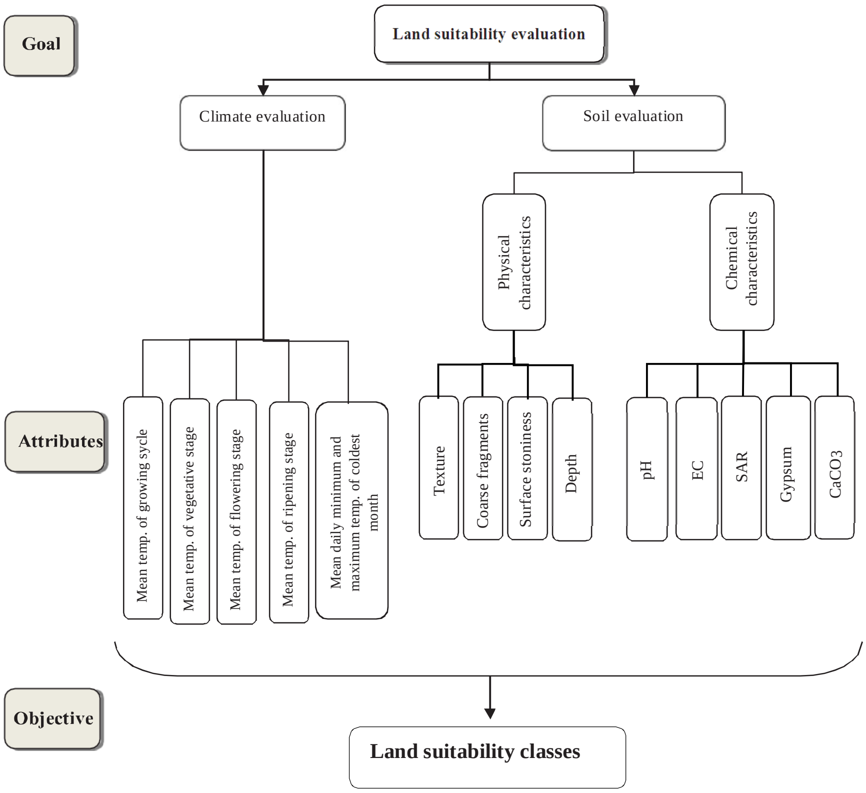
where W_i is the weight value for the i^{th} characteristic, r_{ij} denotes an element of the matrix R for the i^{th} characteristic under j^{th} suitability class and e_j represents the element of matrix E for suitability classes of S1 to N.

In order to calculate a land index, the sum of the evaluation matrix (E) elements has to be set equal to 1 (standardization) and the new values are multiplied by the average indices of the different suitability classes, respectively (Van Ranst et al., 1996):

$$LI = \sum [d(E_j) * A_j] \quad (4)$$

Where LI is the land index, d is the normalized values of matrix E and A_j is the average of the minimum and maximum index of j^{th} suitability class.

The pairwise comparisons matrix and programming were done using IDRISI and MATLAB software, respectively.



▲ Figure 2. Hierarchical organization of the land criteria for wheat production

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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 Very	6
strong importance	7
Very to extremely strong	8
Extreme importance	9

▲ Table 1. The nine-point scale used in pairwise comparison (Saaty, 1994)

Results

Table 2 presents the weighted average of each land characteristic, which was calculated by depth weighting factor (Sys et al., 1991). Soil criteria were averaged over the rooting system depth (100 cm) with the exception of pH, for which only the upper 25 cm was considered.

The relative effect of land characteristics on yield can be shown by weighting factors. Since in this study, pairwise comparisons approach in the context of AHP was used to weights estimation, one of the basic assumptions of this approach is that judgments in decision making about the impact of evaluation criteria

Land unit	pH	EC (dSm^{-1})	SAR	$CaCO_3$ (%)	Gypsum (%)	Soil texture	Coarse fragments (%)	Depth (cm)	Climate index
1	8.7	12.9	20.5	14.0	1.8	SL	0.8	200	89.9
2	8.5	4.5	5.4	5.6	4.5	SL	22.4	160	89.9
3	8.3	3.1	3.5	4.1	1.3	LS	15.3	60	89.9
4	8.6	1.2	2.1	5.8	1.1	S	33.8	180	89.9
5	8.0	3.5	4.2	7.4	1.3	LS	35.3	180	89.9
6	8.6	1.1	1.2	9.0	1.1	LS	37.3	200	89.9
7	8.1	5.5	7.3	7.3	1.7	SL	8.5	170	89.9
8	8.0	6.5	7.5	9.2	1.4	SL	2.7	180	89.9
9	8.2	1.8	4.4	8.0	1.0	LS	26.2	80	89.9
10	8.8	1.2	3.7	6.7	1.0	LS	42.6	110	89.9
11	8.7	0.9	1.3	9.5	0.9	S	41.2	140	89.9
12	8.6	0.4	0.5	7.8	1.0	LS	43.0	180	89.9

▲ Table 2. Land characteristics affecting wheat production

on production does not match with reality. Therefore, it is necessary that the decision makers have knowledge about the decision issue. The consistency ratio calculation leads to overcome this problem. The consistency ratios show any inconsistencies that may have arisen through the pairwise comparisons analysis. This value indicates the probability of randomly assignment of the ratings. A consistency ratio of 0.1 or less is considered acceptable (Malczewski, 1999). Table 3 shows the pairwise matrices were made over hierarchy levels for wheat cultivation. The obtained consistency ratio less than 0.1 shows that the comparisons of criteria were perfectly consistent, and the relative weights are appropriate for application in land suitability models.

The overall weights in hierarchical organization of land characteristics for wheat production were shown in Table 4. These weights were obtained by multiplying the relative weights (Table 3) at each level of the hierarchy. The overall weights revealed that the coarse fragment is the main constraint for wheat production. Soil pH was the least important criterion due to having the lowest weight. Landscape characteristics such as slope, drainage and flooding were not considered in the land evaluation, because these characteristics did not show any limitation limitation for the wheat production.

The land suitability class for each land unit was obtained based on land index (Table 5). Table 5 represents that land suitability evaluation with Fuzzy AHP increases the land index in all land units and land suitability class have been improved in some land units. In the other words, the results of Fuzzy AHP approach expressed more suitability (the higher land index) of study area for wheat production as compared to parametric method.

For validation, the correlations between the land indices obtained by parametric and Fuzzy AHP methods and the observed yield are shown in Figure 3. The results obtained by the fuzzy AHP method are in better confirmation (R^2=0.911) with the observed yield as compared to those obtained with parametric method (R^2=0.804). Although, the fuzzy models achieve better predictive accuracies than parametric method for land suitability evaluation, the choice of membership functions, width of the transition zones and weight values are very important in fuzzy set approach application to land suitability assessment.

Chemical soil characteristics	pH	EC	SAR	$CaCO_3$	Gypsum	Weights
pH	1	0.2	0.25	0.5	1	0.078
EC	5	1	2	3	4	0.421
SAR	4	0.5	1	2	3	0.246
$CaCO_3$	2	0.33	0.5	1	2	0.149
Gypsum	1	0.25	0.33	0.5	1	0.086
Consistency ratio						0.01
Physical soil characteristics	**Texture**	**Surface stoniness**	**Coarse fragments**	**Depth**		**Weights**
Texture	1	0.5	0.33	5		0.190
Surface stoniness	2	1	0.33	4		0.241
Coarse fragments	3	3	1	6		0.509
Depth	0.2	0.25	0.167	1		0.060
Consistency ratio						0.03
Soil characteristics	**Physical soil characteristics**	**Chemical soil characteristics**				**Weights**
Physical soil characteristics	1	2				0.667
Chemical soil characteristics	0.5	1				0.333
Climatic characteristics	**MTGC[a]**	**MTVS[b]**	**MTFS[c]**	**MTRS[d]**	**MMMTC[e]**	**Weights**
MTGC[a]	1	0.2	0.5	0.5	1	0.147
MTVS[b]	5	1	0.33	0.33	1	0.105
MTFS[c]	2	3	1	1	3	0.316
MTRS[d]	2	3	1	1	3	0.316
MMMTC[e]	1	1	0.33	0.33	1	0.115
Crop growth requirements	**Soil characteristics**	**Climatic characteristics**				**Weights**
Soil characteristics	1	3				0.7500
Climatic characteristics	0.33	1				0.2500

▲ Table 3. Pairwise comparison matrix

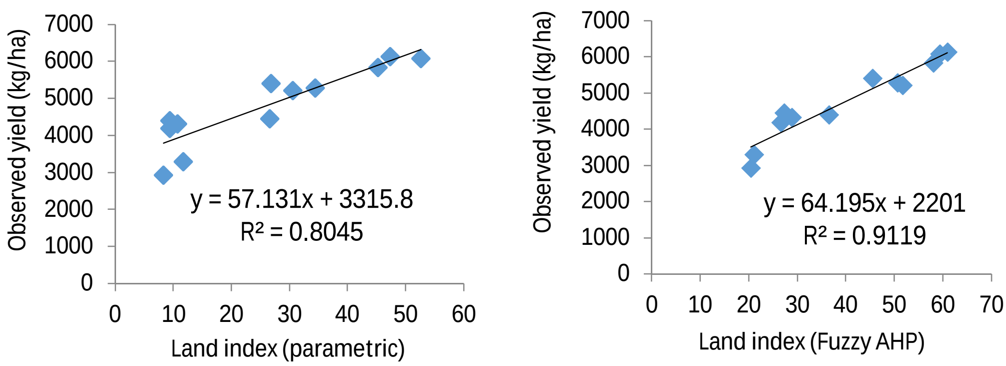
[a] Mean temperature of growing sycle, [b] Mean temperature of vegetative stage, [c] Mean temperature of flowering stage, [d] Mean temperature of ripening stage, [e] Mean daily minimum and maximum temperature of coldest month.

Soil and climate characteristics	Weights
pH	0.019
Ec (dSm^{-1})	0.105
SAR	0.066
$CaCO_3$ (%)	0.037
Gypsum (%)	0.021
Soil texture	0.095
Surface stoniness	0.121
Coarse fragments (%)	0.225
Depth (cm)	0.030
Mean temp. of growing sycle (°c)	0.037
Mean temp. of vegetative stage (°c)	0.026
Mean temp. of flowering stage (°c)	0.079
Mean temp. of ripening stage (°c)	0.079
Mean daily minimum and maximum temp. of coldest month (°c)	0.029

▲ Table 4. Overall weights in hierarchical organization of land characteristics for wheat production

Land unit	Parametric method		Fuzzy AHP method	
	Land suitability class	Land index	Land suitability class	Land index
1	N2	8.31	N1	20.43
2	N2	11.73	N1	21.13
3	N2	9.36	S3	26.58
4	N2	10.69	S3	28.85
5	N2	9.40	S3	36.58
6	S3	26.56	S3	27.30
7	S3	26.87	S3	45.55
8	S3	30.61	S2	51.75
9	S3	34.46	S2	50.65
10	S3	45.25	S2	58.02
11	S2	52.67	S2	59.34
12	S3	47.32	S2	60.97

▲ Table 5. Land indices and land suitability classes obtained by parametric and Fuzzy AHP methods



▲ Figure3. Relationships between observed yields and land suitability indices obtained by parametric and Fuzzy AHP methods

Conclusions

Van Ranst et al., (1996), Tang et al., (1997), Van Ranst and Tang (1999), Monero (2007) and Keshavarzi et al., (2010) have proven more ability of fuzzy set techniques as compared to Boolean methods for land suitability assessment. Prakash (2003) and Mokhrat (2010) reported that the AHP approaches have the capacity for addressing and exploring the uncertainties associated with land resources, especially if it is integrated with fuzzy set models. The results of this study, which are in agreement with mentioned studies, represent superiority and more reliability Fuzzy AHP method as compared to parametric method; because Boolean technique ignores the continuous variation of soil and landscape properties and uncertainties associated with predicted land suitability indices. In Fuzzy AHP method, the choice of membership functions, width of the transition zones and weight values are most critical issue in its application to land suitability assessment. Keshavarzi et al., (2010), Mokhtar (2010), Monero (2007) and Braimoh and Vlek (2004) have confirmed that knowing the relative effect of land characteristics whit regard to yield and the choice of membership functions are needed to achieve the realistic results in land evaluation.

The fuzzy multi-criteria approach differs from the conventional land evaluation methods in its use of calculated weights and its organization of criteria in the hierarchy levels to fit the suitability problems into the framework of decision-making. This research also confirmed that the fuzzy AHP method as a credible and accurate approach could be applied for the integration of data from various domains and sources and to delineate an area in diverse suitability classes for specific crops through the MCE technique.

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