LAND SUITABILITY EVALUATION FOR WHEAT CULTIVATION BY FUZZY THEORY APPROACHE AS COMPARED WITH PARAMETRIC METHOD

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ABSTRACT:
Nowadays infinity examples of irreparable damaging to natural resources have been occurred due to lack of attention and improper uses of soil and water. Land evaluation is a process of assessment of land performance when used for specified purposes. In other words, Land Evaluation is the estimation of the possible behaviour of the land when used for a particular purpose. The main purpose of this study is to prepare land suitability evaluation maps for Wheat using Fuzzy classification in Shavur area, Khuzestan province. In the model non-physical factors is included. The results are compared to a Crisp classification using the standard FAO framework (parametric) for land evaluation which, include non-physical parameters as well. In the present study, eight soil parameters, such as soil Texture, Wetness (ground water depth and hydromorphy), Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP), Gypsum (%), $CaCO_3$ (%),Topography, Soil depth and pH values, are chosen for crop-land suitability analysis and thematic maps are developed for each of the parameters with IDW model. Different Fuzzy membership functions obtained from the literature (Con function) were employed and the weights for each parameter were calculated according to an Analytic Hierarchy Process (AHP) that relies on pair wise comparisons. Climatic requirements, landscape and soil requirements for selected crop was determined based on parametric method. Finally classes of land suitability provided for each Land unit. The coefficient of Kappa is used for comparing these two methods and choosing the better one. The results with the parametric method showed 26% of the area as moderately suitable, 25% as marginally suitable and 49% as unsuitable. The results with the Fuzzy theory showed 31% of the study area as highly suitable for wheat 29 % as moderately suitable, 19% as marginally suitable and 21% as unsuitable. Based on the results it has been concluded that Fuzzy method allows obtaining results that seems to be corresponded with the current conditions in the area.

1. INTRODUCTION

Agriculture is important as a source of food and income, but How, Where and When to cultivate are the main issues that farmers and land managers have to face day to day. Land evaluation is carried out to estimate the suitability of land for a specific use such as arable farming or irrigated agriculture. Land evaluation can be carried out on the basis of biophysical parameters and/or socio-economic conditions of an area (FAO 1976). Planning and management of the land use suitability mapping and analysis is done by application of GIS (Geographic Information System) (McHarg, 1969; Brail and Klosterman, 2001; Collins et al., 2001). The GIS-based land use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitant for animal and plant species (Store and Kangas, 2001), geological favourability (Bonham-Carter, 1994), suitability of land for agricultural activities (Cambell et al., 1992; Kalogirou, 2002), landscape evaluation and planning (Miller et al., 1998), environmental impact assessment (Moreno and Seigel, 1988), selecting the best site for the public and private sector facilities (Church, 2002) are also other examples. The GIS-based approaches to this problem have their roots in the applications of hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early 20th century (Collins et al., 2001). Several studies have been focused on this subject, including evaluation of many factors and aggregation of these factors in many different ways (Lukasheh et al. 2001; Kontos et al. 2003; Sener et al. 2006). The overlay procedures play a central role in many GIS applications (O'Sullivan and Unwin, 2003) including techniques that are in the forefront of the advances in the land use suitability analysis such as: multi-criteria decision analysis (MCDA) (Malczewski, 1999), artificial intelligence (AI) ingeo-computation methods (Ligtenberg et al., 2001; Xiao et al., 2002) and visualization methods (Jankowski et al., 2001). Over the last forty years or so GIS-based land use suitability techniques have increasingly become integral components of urban, regional and environmental planning activities (Collins et al., 2001). GIS are used for geographic data acquisition and processing. The analytical hierarchy process (AHP) developed by Saaty (1977) is the multi-criteria evaluation technique used, enhanced with Fuzzy factor standardization. Besides assigning weights to factors through the AHP, control over the level of risk and trade off in the siting process is achieved through a second set of weights, i.e., order weights, applied to factors in each factor group, on a pixel-by-pixel basis, thus taking into account the local site characteristics. The AHP has been incorporated in the GIS technology producing a flexible way of combining various criteria.
The main purpose of this study is to prepare land suitability evaluation maps for Wheat using Fuzzy classification and compare it with FAO method for Shavur area in Khuzestan in GIS.

2. METHODS

2.1 Fuzzy method

Fuzzy logic was initially developed by Lotfi Zadeh in 1965 as a generalization of classic logic. Zadeh (1965) defined a Fuzzy set as "a class of objects with a continuum of grades of memberships"; being the membership a function that assigns to each object a grade ranging between zero and one, the higher the grade of membership the closest the class value to one. Traditionally thematic maps are represented with discrete attributes based on Boolean memberships, such as polygons, lines and points. These types of entities have a value or do not have it; an intermediate option is not possible. With Fuzzy theory, the spatial entities are associated with membership grades that indicate to which extent the entities belong to a class (Hall et al, 1992). Mathematically, a fuzzy set can be defined as (Mc Bratney A. B. and Odeh I. O. A. 1997):

$$A = \{x, \mu_A(x)\} \quad \text{For each } x \varepsilon X \qquad \text{Eq.1}$$

Where μ_A is the function (membership function MF) that defines the grade of membership of x in **A**. The MF $\mu_A(x)$ takes values between and including 1 and 0 for all **A**. If $X = \{x_1, x_2, ..., x_n\}$ the previous equation can be written as:

$$A = \{[x_1, \mu_A(x_1)] + [x_2, \mu_A(x_2)] + ... + [x_n, \mu_A(x_n)]\} \qquad \text{Eq.2}$$

In plain words equations 1 and 2 mean that for every x that belongs to the set **X**, there is a membership μ_A function that describes how the degree of ownership of x in **A** is.

Mc Bratney and Odeh (1997) expressed the fuzzy membership function μ_A as (X)→[0,1] with each element x belonging to **X** with a grade of membership μ_A (X) ε [0,1] this way μ_A=0 represents that the value of x does not belong to **A** and μ_A=1 means that the value belongs completely to **A**. Alternatively 0< μ_A (X)<1 implies that x belongs in a certain degree to **A**.

The membership function can take any shape and can be symmetrical or asymmetrical. The simplest function is of triangular form but Trapezoidal, Gaussian, Parabolic among others are also possible. Given the non-discrete characteristics of soils and land use, fuzzy theory suits well to the analysis of land suitability. With fuzzy representation the boundaries between suitability classes are not so strict and map units that are more or less suitable that is in an intermediate condition can be described properly. The development of GIS has contributed to facilitate the mapping of land evaluation results, both Boolean and fuzzy, but the topological rules imbibed in GIS software are based on Crisp theory.

Interpolation using of 64 sampling point are developed for each of the parameters with IDW (Inverse Distance Weighted) for production map for each one of parameters model. The calculation of the fuzzy memberships for the Soil depth and Wetness (water depth and hydromorphy) was evaluated using a linear function as given in Eq.7 (Moreno, 2007).

$$\mu_A(X) = f(x) = \begin{Bmatrix} 0 & x \le a \\ x - a / b - a & a \prec x \prec b \\ 1 & x \ge b \end{Bmatrix} \qquad \text{Eq.7}$$

Where x is the input data and a and b are the limit values according to Sys tables.

For Texture soil, Cation Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP), Gypsium (%), CaCO3 (%) ,Topography, and pH values, using a linear function as given in Eq.8 (Moreno, 2007).

$$\mu_A(X) = f(x) = \begin{Bmatrix} 1 & x \le a \\ b - x / b - a & a \prec x \prec b \\ 0 & x \ge b \end{Bmatrix} \qquad \text{Eq. 8}$$

For land suitability it is required to calculate the convex combination of the raster values containing the different fuzzy parameters. The convex combination means that "if $A_1, \dots A_k$ are fuzzy subclasses of the defined universe of objects **X** and $w_1, \dots w_k$ are non-negative weights summing up to unity, then the convex combination of $A_1, \dots A_k$ is a fuzzy class **A** whose membership function is the weighted sum" (Burrough, 1989), where the weights $w_1, \dots w_k$ were calculated using APH as described in the previous section and the fuzzy parameters μ_A have been calculated with the membership functions described in the previous sections and using conditional statements in ArcGIS. Equations 3 to 5 present the convex combination.

$$\mu_A = w_1 \cdot \mu_{A1} + \dots\dots\dots \; w_k \cdot \mu_{Ak} \qquad \text{Eq.3}$$

$$\mu_A = \sum_{j=1}^{k} w_j \cdot \mu_{Aj(x)} \qquad x \in X \qquad \text{Eq.4}$$

$$\sum_{j=1}^{k} w_j = 1 \qquad w_j > 0 \qquad \text{Eq.5}$$

AHP relies on Pairwise Comparison Matrices which are matrices relating different components and assigning values according to their relative importance. These values are given by a scale from 1 to 9, where 1 means that the two elements being compared have the same importance and 9 indicates that from the two elements one is extremely more important than the other

2.2. FAO Framework method

In this study the FAO Framework for Land Evaluation (1976) has been employed to classify the potential land use. According to this framework, the structure for suitability classification is composed of four categories:

I. Land Suitability Orders: reflecting kinds of suitability. S: suitable, N: non suitable.

II. Land Suitability Classes: reflecting degrees of suitability within orders such as S1(highly suitable), S2(moderately suitable), S3 (marginally suitable) and N (not suitable).

III. Land Suitability Subclasses: reflecting kinds of limitation or main kinds of improvement measures required, within classes (e.g. S2m, S2e, etc.).

IV. Land Suitability Units: reflecting minor differences in required management within Subclasses such as S2e-1, S2e-2.

In evaluating of the qualitative land suitability, land properties were compared with the corresponding plant requirements. In this stage, in order to classify the lands, the Sys *et al.* (1991) parametric method was used. In parametric method land and climate characteristics are defined using different ratings. In this method impressive features in land suitability is ranked between a minimum and maximum value (usually between 0 and 100) according to Sys table. If a feature is so effective 100 and if it isn't effective zero will be assigned to that feature. These rankings are shown with A, B, C …..

To determine different characteristics and land indexes the following equation is used.

$$I = R\min \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \dots} \qquad \text{Eq. 6}$$

Where, $R_{\min}$ is a parameter with a minimum rank

And A, B, C …are parameters rank influencing the land suitability.

3. STUDY AREA

The study area, Shavur plain, lies in the Northern of Khuzestan province, Iran. It is located within coordinate of latitude 31˚37'30'' and 32˚30'00'' North and longitude 48˚15'00'' and 48˚40'40'' East with the area of 774 km^2 (Fig.1). Data used for the case study were consisting of: Topography, Wetness, Soil fertility, salinity and alkalinity and soil physical characteristics (Texture, Soil depth, CaCO3 and Gypsum in percent) which are extracted from the report of the land classification study (Ministry of Energy, 2006).

Fig.1. Location of the study area in Iran.

Climate data and those related to the stages of the plant growth were taken from Khuzestan Soil and Water Research Institute (2009) collected data and physiological requirements of the wheat plant were extracted from tables prepared specifically for Iran (Givi, 1997).

4. Results and Discussion

Fuzzy maps were prepared for each of the parameters are shown in Fig.5. AHP relies on Pair wise Comparison Matrices which are matrices relating different components and assigning values according to their relative importance. These values are given by a scale from 1 to 9, where 1 means that the two elements being compared have the same importance and 9 indicates that from the two elements one is extremely more important than the other. The table with the scale for Pair wise Comparison is shown in Table 1 (Saaty and Vargas 2001). As an example, pH has been considered more important than Slope and received a value of 5 when compared to it, while Slope when compared to pH received its reciprocal, 1/5. The final weight is the result of dividing each record value by the sum of the respective column and then calculating the average for the corresponding row. The results of Pair wise Comparison Matrix in the AHP method for preparation of the weights used for the overly of the Fuzzy maps are given in Table 2.

The classified land suitability evaluation based on the Fuzzy logic is shown in Fig. 2.

Table .1 Pair wise Comparison Matrix for Wheat Suitability according to Saaty

Parameters	CEC and ESP	Soil wetness	CaCO3	Gypsum	pH	Texture	Soil depth	Topography	Weight
CEC and ESP	1	2	3	4	5	6	7	8	0.3290
Soil wetness	1/2	1	2	3	4	5	6	7	0.2243
CaCO3	1/3	1/2	1	2	3	4	5	6	0.1526
Gypsum	1/4	1/3	1/2	1	2	3	4	5	0.1053
pH	1/5	1/4	1/3	1/2	1	2	3	4	0.0750
Texture	1/6	1/5	1/4	1/3	1/2	1	2	3	0.0525
Soil depth	1/7	1/6	1/5	1/4	1/3	1/2	1	2	0.0359
Topography	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.0254

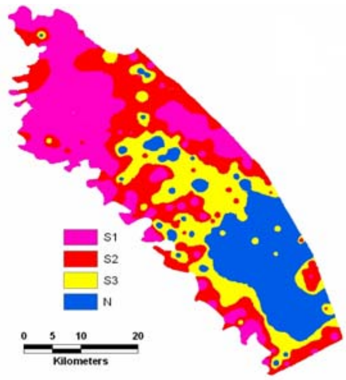

Fig.2. Classified land suitability map for wheat (Fuzzy method)

The results of the qualitative land suitability classes by using the guidelines given by Sys et al. (1993) in Eq.6 for wheat plant were determined and is given in Table 2 (the first 10 units are presented and the rest of the units are omitted from the Table) and the land suitability maps base on the parametric (FAO) method is shown in Fig.4.

Table 2. Samples results of the qualitative suitability evaluation of different land series for wheat using parametric method

Land units	Land index	Suitability classes
1	57.3	S2
2	38.6	S2
3	41.2	S2
4	56.8	S3
5	35.3	S3
6	14.1	S3
7	8.2	S2
8	52.2	S2
9	37	S3
10	21	N

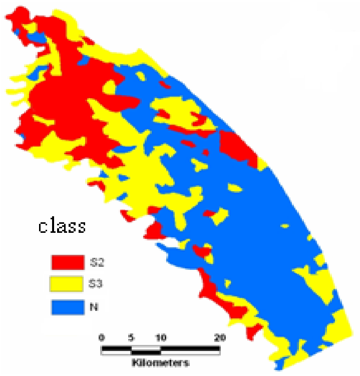

Fig.3. Land suitability map for wheat (FAO method)

As it is shown in fig3. The region is classified in to 3 classes: N,S2 and S3. There is no any instance of Class S1 because the features are discrete and higher weights which assigned to the limiting features in land suitability evaluation.To assess the agreement between the Fuzzy and the FAO methods, the Kappa statistic developed by Cohen (1960) was calculated. The Kappa coefficient is a measurement of the degree of agreement between two observations(maps) and its calculation is based on the difference between the tow maps. A Kappa value of 0 indicates that there is a poor agreement between the maps and a value of 1 indicates an almost perfect agreement. The value of Kappa coefficient for this study is calculated to be 0.28 between two maps (Fuzzy map and FAO) which shows a poor agreement between the two methods (maps) for the land suitability evaluation of Shavur plain. Fig. 4 shows the results of this comparison as a map.

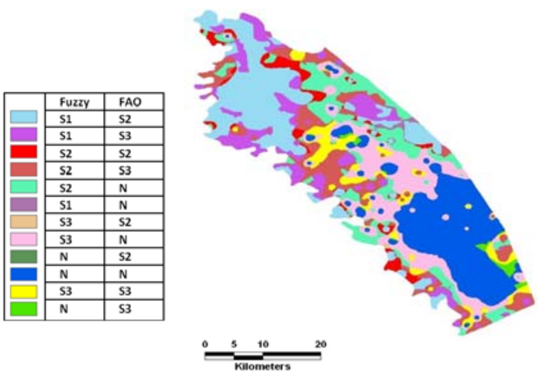

Fig.4. Comparison map showing correspondence between Fuzzy and FAO results.

The results of the FAO method show 26% of the land to be moderately suitable (S2 class), 25% as marginally suitable (S3 class) and 49% as not suitable (class N). In comparison, the results of the Fuzzy method show 31% of the land as highly suitable (S1 class) which the FAO method does not evaluate. Furthermore, the moderately suitable class for Fuzzy is 29% which is almost equivalent to the result of the FAO method. The class S3 (marginally suitable) is 19% and for class N (not suitable) is 21% for Fuzzy which they are quite different in compare with the FAO method results.

In order to evaluate and present the better method between these methods, five different cultivation fields were randomly chosen and the yields per hectare of the irrigated wheat were measured. The points are plotted on the prepared comparison map and are shown in Fig.6 and their information is given in Table 3. This Table shows the corresponding classes of the locations for different methods together with the production yield measured in the field. According to the Jihade Keshavarzi organization of the Khuzestan Province (The organization responsible for the agricultural affairs), the maximum, average and minimum yield for the wheat production in the Shavur plain are about less than 2, 3.5 and more than 5 tons/ha respectively.

The differences of the yield are due to the suitability of the soil and the categories of the land (Jihade Keshavarzi organization, 2009). Considering these figures we can consider the fields having yield of more than 4 tons/ha having soil class of suitability S1, between 3 and 4 tons/ha, S2, between 2 and 3 tons/ha, S3 and less than 2 tons/ha having class of N. Base on this consideration and the result of the measured yield of the field locations in the Fig.6 Fuzzy method is considered to be better than the FAO method.

Table.3 Information of the sampling points for comparison of the results of Fuzzy and FAO methods.

Location	X	Y	Class of Fuzzy	Class of FAO	yield tons/ha
1	249476	3539574	S1	S2	4.82
2	255364	3527325	S2	S3	3.93
3	256693	3538530	S2	N	3.47
4	260017	3535966	S1	S3	4.86
5	263245	3524476	S3	N	2.12

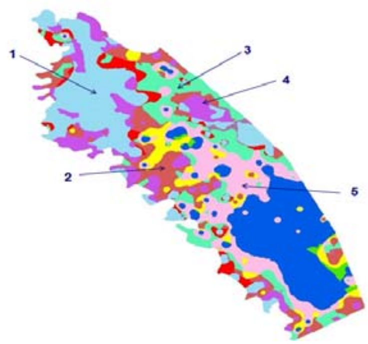

Fig.6. Sampeling locations for comparison of the Fuzzy and FAO methods (Table 3, shows the information of the points).

CONCLUSION

Since the soil properties have contineouse spatial change, Fuzzy method which is based on the continouse ahanges of the parameters used in the evaluation of the soil sutability can classify the soil better than FAO methd. This is proved by the field observation and the agreement with the work of Sanchez Moreno (2007).

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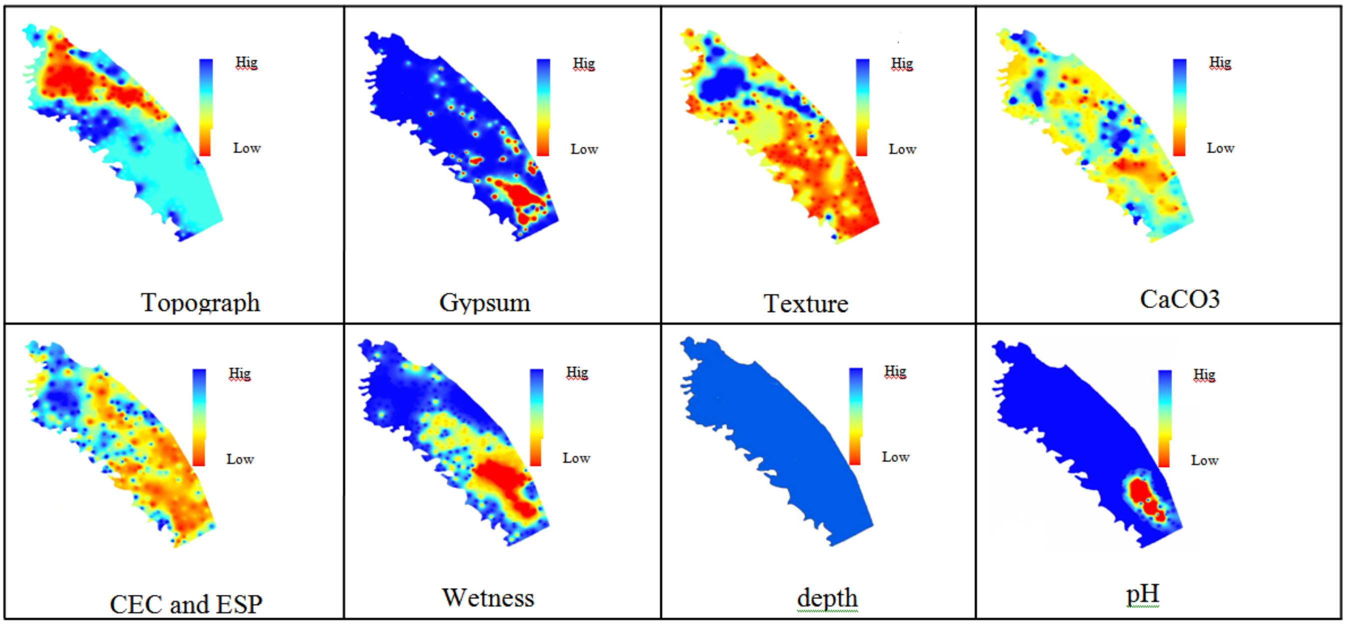

Fig.5. Fuzzy maps for each of parametrs

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