Application of MCDM method in Fuzzy Modeling of Land Suitability Evaluation

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Abstract
Classical and conventional (traditional) land suitability methods are based on Boolean's Two-valued Logic that defines different land suitability classes completely distinctive. These methods have many disadvantageous in description of capabilities and land suitability for different applications, therefore fuzzy modeling based on fuzzy sets theory is the best method in land suitability assessment. In this theory, membership is not two-valued; instead it could be a range of values from 0 to 1. The function that states the degree of membership in a set is named "membership function". In this research, Pairwise Comparison Method in the form of Analytical Hierarchy Process(AHP) used for weighting different assessed criteria for land suitability of an irrigated wheat field in Takestan and results from fuzzy methods compared with those from conventional methods, for example Parametric method. The correlation coefficient between land index and observed yield in the study area were 0.91 and 0.85 for the fuzzy approach with AHP method and parametric approach respectively.

Key Words
Two-value logic(classic logic); Fuzzy sets theory; Irrigated wheat; Analytical Hierarchy Process(AHP); Takestan.

Introduction

In general, land suitability describes "the fitness of a given parcel of land for specific uses" (FAO 1976).Appropriate land use decisions are vital to achieve optimum productivity of the land and to ensure environmental sustainability. This requires an effective management of land information on which such decisions should be based. Land suitability evaluation is one of the effective tools for such purposes.(baja *et al*. 2001). There are generally two kinds of land suitability assessment approaches. First, the qualitative approach is used to assess land potential at a broad scale or is employed as a preliminary method for more detailed investigation (Baja *et al*. 2002; Dent and Young 1981). The results of qualitative classification are given in qualitative terms, such as highly suitable, moderately suitable, and not suitable. The qualitative factors could not use the numerical score to present. Second, the quantitative approach is using parametric techniques involving more detailed land attributes which allow various statistic analyses to be performed (Baja *et al*. 2002; 2001). Quantitative methods such as modeling in land evaluation are necessary for a land use planning (Van Diepen *et al*. 1991). Recently, most studies combined the qualitative and quantitative approaches in the process of land suitability assessment.One of the most recently used models in land evaluation is fuzzy model. In the real world, some objects are quite differentiated from others and their boundaries are quire evident: a river crossing through a valley is quite distinguishable from its surroundings when in full discharge, an area covered by a lake is distinct from the land areas surrounding it; but soil and vegetation and other patterns in nature change transitionally: the limit between two types of soil or vegetation is, in most of the cases, not so clearly defined. Fuzzy modeling appears as an alternative to deal with these continuous or uncertain environments. While in Boolean logic a value is true of false, with fuzzy logic the value could be partially false of partially true which allows for a representation more according to the reality. Hierarchy Process (AHP) as proposed by Thomas Saaty in the early 1980s.AHP can be used as a consensus building tool in situations involving a committee or group decision-making (Saaty 1980). AHP uses a hierarchy of factors where each general factor is subdivided or composed of several contributing subfactors.The objective of this study is to apply fuzzy set technique for land suitability evaluation and relate it to irrigared wheat yield in Takestan area. Yield information is of interest to users (farmers) and policy makers (government officials) who are responsible for rural development

Methods

The Study Area

The land investigated in research located in Takestan(Qazvin province) and has the area of 40000 hectares;

between latitudes of 36°3′33′′ and 36°14′14′′ N and between longitudes of 49°32′45′′ and 49°53′51′′ E at north of Takestan city. The average, minimum and maximum heights are 1668, 1216 and 2119 meters from sea level respectively. Figure1, shows the study area in Qazvin province and Iran.

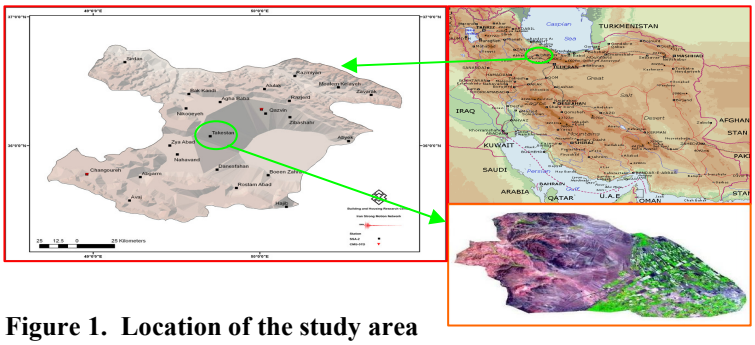

Figure 1. Location of the study area

In this study, the 1:25000 scale topographic lines were studies to prepare elevation model and the soil map of region was generated via digital elevation model, slope map, geological map and field and experimental studies(Figure 2). The studied region has two soil temperature regimes, Thermic and Mesic which the Thermic regime mainly covers eastern sections and Mesic regime includes western section. Furthermore, the studied area has two soil moisture regimes including Aridic and Xeric regimes.

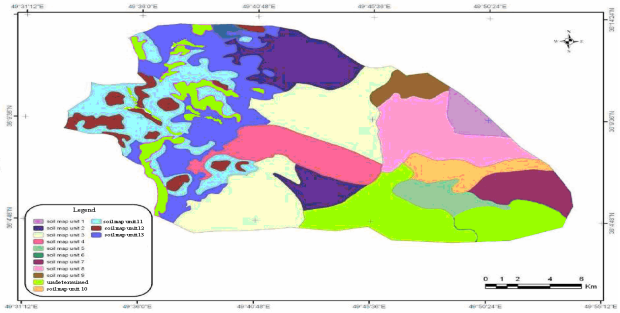

Figure 2. soil map units of the study area

Based on Soil Taxonomy(2006), this region has soils in Entisols,Aridisols and Inceptisols orders. Using GPS device and base map, profiles location defined and profiles excavated and described using presented methods in "Field Book Describing and Sampling Soils"(1998).

Application of fuzzy set theory in land suitability evaluation

The studied area was divided into 13 land units and 8 land characteristics that are effective in irrigated wheat selected including slope (%), soil depth (cm) cation exchange capacity (Cmol+/kg), electrical conductivity (dSm^{-1}) Sodium adsorption Ratio, volumetric content of gravel (%), organic carbon content in soil (%) and Calcium carbonate content (%). The irrigated wheat requirements were determined using FAO frame work for land evaluation (Sys 1985). In the studied region plain lands has gentle slope and mountain land has steep slope. To determine the land suitability classes for irrigated wheat via land biophysical characteristics, the Fuzzy and Classic methods used. In classic method (parametric), first a degree designated to each limitation levels, then based on intensity limitation relevant degree determined for each land characteristic and via Storie method, land index in each land unit obtained and finally land suitability class determined. In fuzzy method based on irrigated wheat requirements the Sigmoidal(Tang *et al*. 1992) and Kendel membership functions were used to determine degree of membership for each land characteristic to land suitability classes and the results were set in a matrix named characteristic matrix(R). Then, via Analytic Hierarchy Process the weight of each effective land characteristic in irrigated wheat cultivation was calculated and put in weights matrix (W). The Analytic Hierarchy Process is based on pair-wise comparisons for generation of relative matrix. In this method, pair-wise comparisons considered as input and relative weights are as outputs. The Saaty scale (1980) was used for generation of pair-wise comparison matrixes which relatively rates priorities for two criteria. The criteria priorities are defined according to expert's comments and experience. After generation of pair-wise comparisons matrix, the criteria weights are calculated that includes sum of each column of pair-wise comparison matrix and division of each component by the result of each relevant column sum. The resulted matrix is knows as normalized pair-wise comparison matrix. The average of each row of the pair-wise comparison matrix is calculated and these average values indicate relative weights of compared criteria.To determine the final land suitability class in each land unit, a

multiple operator (combination) used and characteristic matrix in each land unit (R) multiplied by weights matrix (W) and resulted final matrix of land suitability (E). Components of land suitability matrix indicate degree of membership of relevant land unit to land suitability classes. This matrix is calculated as: $E = W \circ R$. in order to calculate land index, the sum of components of land suitability matrix (E) is set to one (standardized) and the new components of matrix are multiplied by average of indexes of land suitability classes respectively.

Results

As indicated in Table1, land suitability evaluation via fuzzy method increased land indices in some land units and improved some land suitability classes.The calculated regression between land index and region production (Figure 3), was 0.91 and 0.85 for fuzzy sets theory and parametric method respectively.A comparison between results of this research and other investigators as well as (Tang *et al*. 1992; Van Ranst *et al*. 1996) indicates that the fuzzy method with higher correlation factor, has more accuracy and capability of predicting production, since fuzzy set method considers continual land changes and is more efficient in reflecting spatial variability of soil characteristic rather than Bool's two-valued logic that overlooks a considerable section of useful information during land evaluation processing. Nonetheless, accuracy of results is mainly dependant on designated weights to different land characteristics.Although in land suitability evaluation, nowadays the emphasis is on quantitative (numerical) methods, but of fuzzy sets theory's problem in land suitability evaluation is the high volume of calculations. On the other hand, increase in the number of land characteristic increases the number of pair-wise comparisons in comparison matrix and decision making on spatial variability of different characteristics in each land unit becomes difficult because different characteristics has different weights and weight designation to characteristics needs more experience and criteria precedence.

Table1 .Observed irrigated wheat yield , land suitability classes and land indices obtained by different methods for the different land units in Takestan area

Land unit No.	Observed yield (kg/ha)	Land suitability evaluation for irrigated wheat by different methods	
		parametric approach class (index)	fuzzy approach class (index)
1	4799.5	***S1*** (86)	***S1*** (90)
2	3569.4	***S2*** (81)	***S2*** (84)
3	3381.6	***S2*** (67)	***S2*** (82)
4	2642.5	***S2*** (65)	***S2*** (77)
5	3406.4	***S2*** (70)	***S2*** (76)
6	2382.8	***S3*** (59)	***S2*** (73)
7	2220.0	***S3*** (57)	***S2*** (72)
8	4778.9	***S1*** (86)	***S1*** (90)
9	3823.1	***S2*** (82)	***S2*** (80)
10	2222.7	***S3*** (57)	***S2*** (73)
11	2358.7	***S3*** (58)	***S2*** (65)
12	4801.1	***S1*** (86)	***S1*** (87)
13	3168.7	***S3*** (46)	***S2*** (80)

Conclusion

Fuzzy logic is an attempt to extend the concept of continuous variation of soil properties from the geographic space to the attribute space (Burrough *et al*. 1997). Boolean logic works on the principle that a site can belong to one and only one suitability class (e.g., suitable or not suitable). In reality however, there is usually

an overlap of classes in the attribute space. The admission of the idea of partial overlap of classes is expressed in terms of membership functions using fuzzy logic.

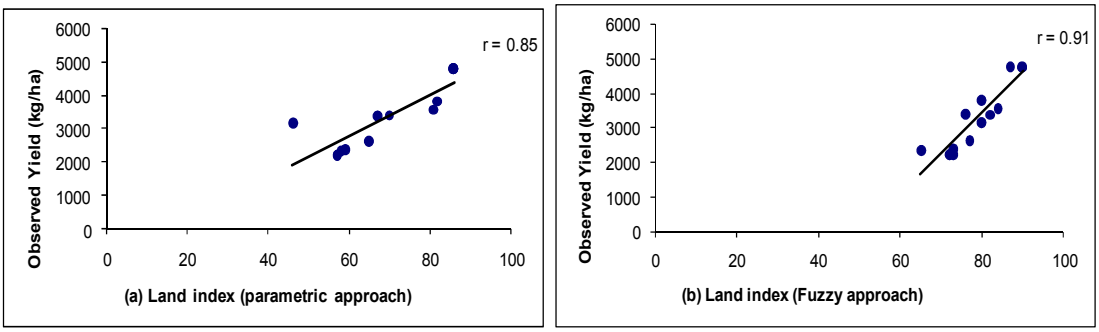

Figure 3. Linear regression between land suitability indices obtained with :(a) parametric approach and (b) fuzzy approach , and observed irrigated wheat yield in Takestan area

This approach was used by Lark and Bolam (1997) to address both uncertainty in prediction and uncertainty in interpretation of soil data for sugar beet production.The approach we present in this study does not incorporate management decision. Use of the land for wheat or any other crop remains a management decision. Similarly, the fact that an area has a relatively high suitability index does not automatically imply that high yields would be obtained if, for instance, the timing of planting or fertilizer application was wrong (braimoh *et al*. 2004). A major advantage of dynamic simulation models over the approach presented here is that dynamic simulation models can incorporate management decisions such as fertilizer application, time of planting, water application, and so forth in predicting crop yields. However, a major problem in utilizing such models in land evaluation is the requirement for large amounts of data. The use of fuzzy technique in this study produced land suitability for irrigated wheat in a continuous scale. Land suitability indices, reflecting inherent fertility of the soils(braimoh *et al*. 2004). High correlation between wheat yield and land suitability offers an explanation for the upward trend in wheat yields in the study area. Our approach is well applicable for applications in which subtle differences in soil quality are of a major interest. Using the SI model, we were able to evaluate the limitations of land characteristics to wheat in the study area. Major constraints to the use of fuzzy technique for land suitability evaluation thus proved valuable for identifying major constraints to crop production and strategies for overcoming them.

References

Baja S, Chapman MD, Dragonvich D (2001) Fuzzy modeling of environmental suitability index for rural land use systems: an assessment using a GIS. http://www.geocomputation.org/2001 (2006-1-16).

Baja S, Chapman MD, Dragonvich D (2002) A conceptual model for defining and assessing land management units using a fuzzy modeling approach in GIS environment. *Environmental Management* **29,** 647-661.

Braimoh AK, Stein A (2004) Land Evaluation for Maize Based on Fuzzy Set and Interpolation. *Journal of Environmental Management* **33,** 226–238.

Burrough PA, van Gaans PFM, Hootsmans R (1997) Continuous classification in soil survey: spatial correlation, confusion and boundaries. *Geoderma* **77,** 115–135.

Dent D, Young A (1981) Soil survey and land evaluation. George Allen and Uniwin, Boston.

FAO (1976) A framework for land evaluation. FAO Soils Bulletin 32, Rome.

Lark RM, Bolam HC (1997) Uncertainty in prediction and interpretation of spatially variable data on soils. *Geoderma* **77,** 263–282.

Saaty TL (1980) The analytic hierarchy process. MCGraw-Hill, NY.

Sys C (1985) Land evaluation, part I, И, Ш . ITC, University of Ghent, Belgium, 343 PP.

Tang H, Van Ranst E, SYS C (1992) An approach to predict land production potential for irrigated and rainfed winter wheat in Pinan County, China. *Soil Technology* 5, 213-224.

USDA, Soil Survey Staff (2006) keys to Soil Taxonomy. 10 th edition.

Van Diepen CA, Van keulen H, Wolf J, Berkhout JA (1991) Land evaluation: from intuition to quantification . In Advances in Soil Science Stewart, BA (Eds.) New York, spring. 139-204.

Van Ranst E, Tang H, Groenemans R, Sinthurahat (1996) Application of Fuzzy logic to land suitability for rubber production in Peninsular Thailand. *Geoderma* 70, 1-19.