

## Soil suitability evaluation for crop selection using fuzzy sets methodology

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Received October 17, 2015; accepted February 22, 2016.  
Delo je prispelo 17. oktobra 2015, sprejeto 22. februarja 2016.

### ABSTRACT

In this study appraisal of four different agricultural land evaluation methods including the so-called Storie method, square root method, maximum limitation method and fuzzy sets method, was done. The study was performed in Bastam region, located in Semnan province at the north east of Iran. Three crops including tomato, wheat and potato were assessed for the purpose of this research. Soil characteristics assessed were rooting depth, CaCO<sub>3</sub>, organic carbon content, clay content, pH and slope gradient. Statistical analyses were done at significance levels of  $\alpha = 0.1$  and  $\alpha = 0.05$ . Results of regression between land indices, calculated through the four methods, with observed yields of the crops, showed that the regression were significant in fuzzy sets method for all of the assessed crops at  $p = 0.05$  but not significant in maximum limitation method for any of the crops. The Storie and square root methods also showed a significant correlation with wheat yield at  $p = 0.1$ . This study was a demonstrative test of fuzzy sets theory in land suitability evaluation for agricultural uses, which revealed that this methodology is the most correct method in given circumstances.

**Key words:** fuzzy sets, land evaluation, land use, soil classification, crop growth conditions, soil suitability, crop selection

### IZVLEČEK

#### UPORABA METODOLOGIJE MEHKIH MNOŽIC PRI OCENI PRIMERNOSTI TAL ZA RAZLIČNE POLJŠČINE

V raziskavi so bile ocenjene štiri metode vrednotenja kmetijskih zemljišč vključujoč Storijevo metodo, metodo kvadratnega korena, metodo maksimalne omejitve in metodo mehkih množic. Raziskava je potekala na območju Bastama, v provinci Semnan, v severovzhodnem delu Irana. Primernost omenjenih metodah je pokazala, da je statistično značilna samo odvisnost pridelka od indeksa primernosti zemljišč dobljenega z metodo mehkih množic. Storijeva metoda in metoda kvadratnega korena sta pokazali značilno odvisnost pridelka pšenice od indeksa primernosti zemljišč pri  $\alpha = 0,1$ . Raziskava je bila demonstracijski preskus primernosti uporabe metode mehkih množic pri vrednotenju zemljišč v kmetijski rabi. Ugotovljeno je bilo, da je bila ta metodologija v danih okoliščinah najprimernejša.

**Ključne besede:** mehke množice, vrednotenje zemljišč, raba tal, klasifikacija tal, razmere za rast poljščin, primernost tal, izbira poljščin

## 1 INTRODUCTION

Classification of rural lands with regard to their suitability for a specific crop production is important, since different land units have different

advantages and limitations. To allocate each land unit for optimal and sustainable production of a crop, land use planning should be implemented in

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every area. A reasonable land use plan is obtained through a precise and confident land evaluation method. The land evaluation results should present a pragmatic description of land units capabilities and restrictions. As every land unit has its own restrictions and advantages and each crop has its own requirements for growth, a precise land evaluation method is required for rational decision making on agricultural land use management and allocation of crops to different land units.

The soundness of the evaluation method should be investigated before using its results for decision making on land utilization. There are several methods of land evaluation such as parametric methods, maximum limitation method and fuzzy sets method. There are two methods called Storie (Storie, 1976) and square root (Khiddir, 1986) that both can be subsumed under the group of parametric methods. The core idea of parametric methods is based on combining (multiplying) numerical rates of several factors (soil characteristics) to obtain a total land index/rate in a given land unit for a given crop. Here, the soil characteristics are given a rate between 0 to 100 depending on their influence on a considered land use, then, they are combined in a few different ways to obtain a total rate for a specific land unit for a given crop/land use. A land unit with a higher land index/rate is more suitable for optimal utilization for a certain crop. In maximum limitation method relations among different soil characteristics is ignored and no combination of different characteristics is considered, instead the lowest rate among characteristics rates is considered as an index for a land unit for a specific utilization type.

In all of these classical methods, land suitability rating (classification) is implemented based on discretely defined classes of suitability and variability of characteristics values and their influence on crop growth. This is called Boolean logic, which states that membership to a set is only expressed by member (1) or non-member (0) and there is no values or degrees between this two categories. For example, if rooting depth is over 150 cm (which is suitable for a crop growth) is given the value of 1 (member to the suitable class) and if it is below 100 cm (which is not optimal for a crop growth) is considered as non-member and would be declared as unsuitable. This logic does

not consider relative suitability for other values out of these rigid limits. However, gradual and continuous variability in characteristics values and their influence on crop growth has been clearly observed in soils. Therefore, applying this approach causes losing some information when reflexing the values within or out of the rigid limits, since variability in soil qualities and characteristics is rather continuous or fuzzy and not discrete.

Fuzzy mathematics was first presented by Zadeh (1965). In the fuzzy sets theory, elements membership to a set is defined by a degree of membership and variabilities are considered continuously. This would take into account a range of values between 0 to 1 as well. This can reflect the real situation in the nature by presenting the relative values within the rigid borders defined in the Boolean logic makes our understanding and surveys closer to the true conditions in the real world.

Fuzzy sets methodology in land evaluation has raised a lot of interest among researchers, since this method gives a more realistic output in comparison with the Boolean approach (Burrough, 1989; Tang et al., 1991; Burrough et al., 1992; Van Ranst et al., 1996 and Nisar Ahmed et al., 2000). McBratney and Odeh (1997) discussed the application of fuzzy sets in soil science. Torbert et al. (2008) discussed fuzzy modelling for soil quality assessment. Some recent studies on land evaluation by fuzzy methodology have been done by Rodrigo et al. (2005), Vliet (2013), Elaalem (2013) and Chang and Ko (2014). Fuzzy logic approach has also been used in different areas of soil science through different techniques (Malczewski, 2006; Jian-Hua et al., 2009; Reshmidevi et al., 2009; Yue-Ju et al., 2010; Gruijter et al., 2011; Kong et al., 2011 and Liu et al., 2013). Kalogirou (2002) has criticized fuzzy sets methodology; He concluded that further research is needed to confirm the prominence of fuzzy methodology in comparison with Boolean methods for land evaluation. Holistically, it seems to be a sound and useful methodology. No other significant studies have been done on assessing the different methods of agricultural land suitability evaluation. Comparative studies are rare among the recent decade publications and a confirmative research on land suitability evaluation frameworks

with special stress on soil significance in crop cultivation conditions is missing. Although the fuzzy methodology has been used in land evaluation studies with different purposes and different points of view, but testing the accuracy of this methodology and its comparison with other frameworks is needed.

The present research explores to find out the best methodology for soil suitability evaluation by

comparing results of different methods and then classify agricultural lands of Bastam area based on intrinsic soil chemical and physical characteristics. Three crops including tomato (*Solanum lycopersicum* L. (*Lycopersicon esculentum* Mill.)), common (bread) wheat (*Triticum aestivum* L.) and potato (*Solanum tuberosum* L.), which have been cultivated in the study area, were studied to test the methodologies overly.

## 2 MATERIALS AND METHODS

### 2.1 Study area description

This study was performed in Bastam region in Semnan province located on the north east of Iran. The study sites were located between coordinates 54° 39' to 55° 20' of east longitude and 36° 26' to 36° 45' of north latitude. The altitude was about 1600 m above the sea level. The area surface was about 53500 ha. Slope gradient varied from flat to 8 %. The physiography of studied land units is comprised of Gravelly Alluvio-Colluvial Fans, Piedmont Plateaux and Alluvial Plains. According to the bioclimatic map of the region (FAO and UNESCO, 1988), the study area climate is attenuated sub-desert climate. Mean annual precipitation is 154 mm and mean annual temperature is 14.6 °C, according to the 55-year mean data of Shahrood meteorological station located in the study area. Dominant crops of the area are wheat, maize, barley and potato. Some parts of the region are used as pasture and some of them are under fallow or set aside lands.

### 2.2 Soil sampling and analysis

In total, 104 soil profiles were investigated and among those, eleven representative profiles were selected. Therefore, 11 representative land mapping units, taxonomically classified to the family level, were separated (Fig 1). The procedure of taxonomic land classification was according to soil taxonomy manual of the United States Department of Agriculture (USDA, 2010). This classification is based on field surveys including morphological descriptions of soil profiles like leaching evidences, soil horizons positions and their depth, and chemical and physical analysis such as electrical conductivity, organic carbon, exchangeable sodium percentage, cation exchange

capacity, carbonate content, texture, structure, etc. The geological and topographical base maps and aerial photos were used for eliciting basic information of the geology and geography of the study region and for help in delineation of land units. Some yearly and monthly climatic data for a 50 year period between 1955-2005 including temperature and precipitation rates were also used in taxonomic land classification when determining the soil moisture and thermal regimes according to the USDA Soil Taxonomy (2010). The taxonomic classification revealed that aridisols and entisols are dominant soil orders in the region. Soil moisture regimes were aridic and torric, and thermal regime was mesic. Geographical position of land mapping units (soil families) of the study area is shown in Fig. 1 and the measured site characteristics are presented in Table 1.

Samples were gathered from each horizon of the representative soil profiles independently and the laboratorial analyses were performed for each horizon separately. At last, one value is reported for each parameter in each soil profile as obtained from mean calculations of all horizons of a profile according to the procedure presented in Sys et al. (1993) which considers higher significance of surface layers for crop growth. The chemical and physical analyses were performed according to internationally accepted methods in the literature such as Carter and Gregorich (2008).

### 2.3 Physical land suitability evaluation

The physical land evaluation is regarded as a specific case of land evaluation. It is the assessment of land characteristics with regard to possible utilization types, which is important for maintaining long-term productivity of lands

through optimal utilization (Sharififar et al., 2013). In agricultural land suitability assessments, each measured land characteristic value is compared with reference threshold limits of crop requirements in every land unit e.g. the reference tables presented by Sys et al. (1993). Then each characteristic is assigned a rate ranging from 0 to 100 through linear interpolation in reference intervals of each suitability class for each crop. Rates of the considered characteristics are then combined (through the four methods assessed in this research) to obtain a total rating, called land index, in every land unit for a given crop. The land index of a land unit is a score ranging from 0 to 100. A land unit is defined as an area of the soil surface, which has characteristics different from other areas and is separated from other areas with regard to soil taxonomic classification. In other words, a land unit is a taxonomically separated soil class and its bounds are determined according to the level of the soil taxonomic classification (Soil Survey Division Staff, 1993; USDA, 2010).

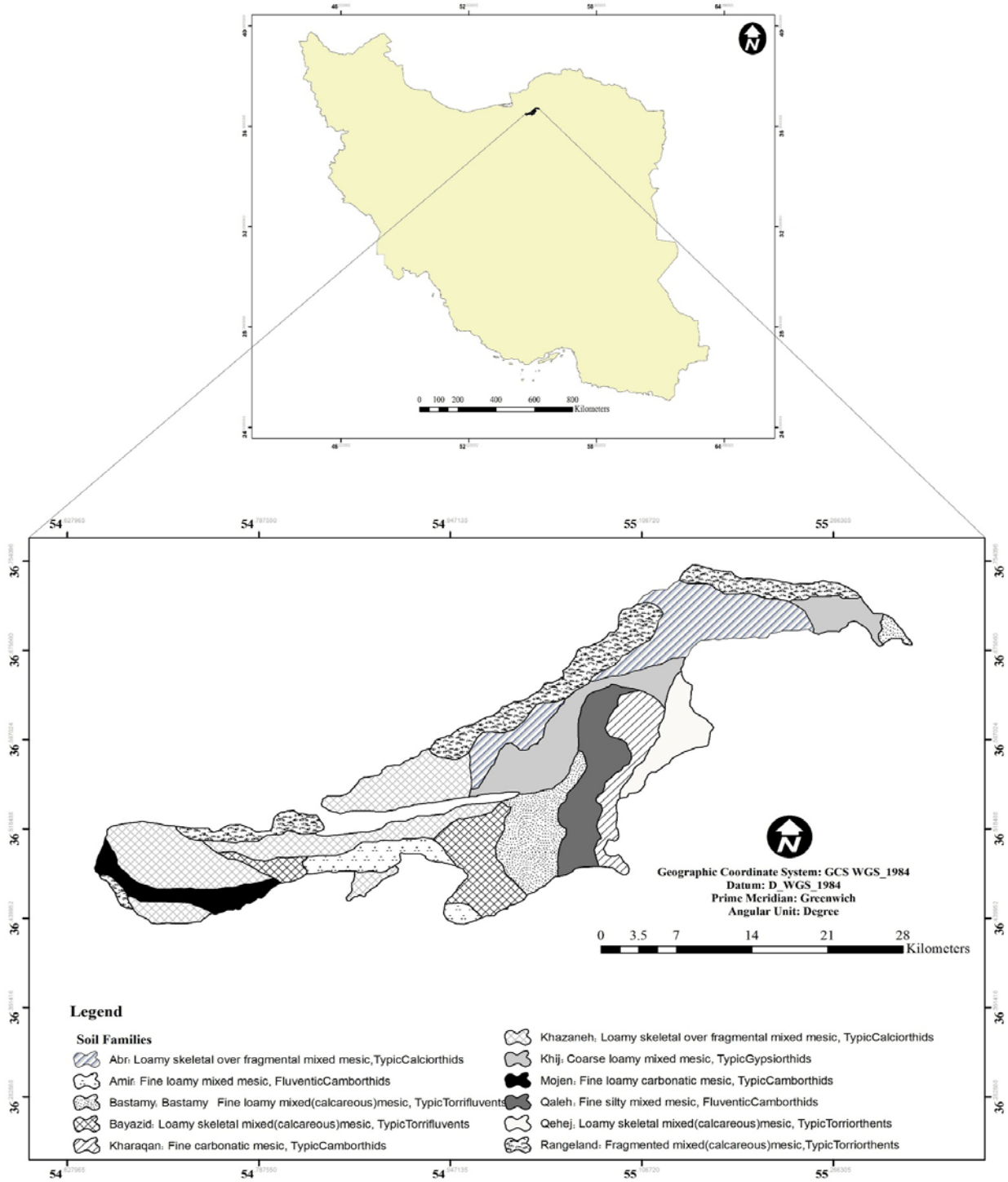
The characteristics considered for land suitability evaluation in this study are; rooting depth, soil clay content, CaCO<sub>3</sub> content, slope gradient of land units, pH and organic carbon content. These

characteristics have significant influence on crop growth which have been confirmed by FAO (1976) and have been used and confirmed by other researchers such as Biox and Zinck (2008), Mendas and Delali (2012) and Sharififar et al. (2013). These characteristics have also been chosen for important soil suitability assessing and predictive crop yield models such as Almagra and Albero (De la Rosa et al, 1992, 2004, 2009; Shahbazi et al., 2008; Jafarzadeh et al., 2009; Shahbazi and Jafarzadeh, 2010; Sharififar, 2012). Some characteristics such as drainage class, salinity and climatic characteristics were not considered for the evaluation, since they have negligible differences among land units. The climatic parameters have not been considered for the evaluation, since they do not vary within land units significantly and their influences are approximately identical for all of the studied land units and therefore they are not applicable for land classification. All the studied crops are irrigated via underground water supplies. The criteria for land suitability evaluation have been discussed deeply by Messing et al. (2003). They have also confirmed the significant influence of some of the criteria used in this study for crop growth.

**Table 1:** Mean values of land characteristics of the study area

Land units	Clay content(% <sup>a</sup> )	Carbonate content%	Rooting depth (cm)	pH	Slope%	Organic carbon%	Surface area (ha)
<b>Abr</b>	16.40	31.0	95	7.8	0-5	0.40	8125
<b>Amir</b>	29.75	23.7	145	7.9	0-2	0.33	1525
<b>Bagh</b>	5.00	5.5	22	7.9	5-8	0.24	7250
<b>Bastamy</b>	22.22	28.5	160	7.8	0-2	0.44	3975
<b>Bayazid</b>	7.11	14.7	95	8.0	2-5	0.38	3525
<b>Kharaqan</b>	42.40	55.8	125	7.8	0-2	0.60	3550
<b>Khazaneh</b>	18.00	24.0	40	7.9	5-8	0.35	9450
<b>Khij</b>	9.00	36.0	86	7.8	2-5	0.35	7225
<b>Mojen</b>	22.80	41.5	150	8.0	0-2	0.30	1725
<b>Qaleh</b>	36.18	30.2	150	8.0	0-2	0.80	4350
<b>Qehaj</b>	11.00	20.0	140	8.0	2-5	0.09	2800

a) clay content as well as all other parameters values are mean values of the soil profile horizons (except slope and rooting depth),



according to the instructions in Sys et al. (1993).

**Figure 1:** Soils taxonomic classification and positions of the study area land units (by ArcGIS Software® ; Sharififar et al. (Sharififar@ut.ac.ir)).

## 2.4 Maximum limitation method

In this method, crop requirements are matched with soil characteristics and then suitability of a land unit for a specific crop is determined by the rate of the characteristic that has the lowest rate among all of the characteristics. This approach is based on the Liebig's Law of the Minimum (Brown, 1942), which in its generalized form states that growth is controlled not by the total amount of resources available, but by the scarcest resource (limiting factor). In other words, Liebig's law states that growth only occurs at the rate permitted by the most limiting, whichever factor it may be. In maximum limitation method, lowest rate of characteristics rates (the most limiting one) is reported as the land index in every land unit for each of the crops. The advantage of this method is that it does not consider the interactions and/or any relations among characteristics and ignores any proportionality between characteristics and no combination is carried out. Interactions among the characteristics is a fairly complicated issue and needs precise survey and expertise, thus, it can affect the total land index (rating) wrongly or correctly. When such interactions are omitted, a significant source of error is removed. Therefore, this method is simple and easily applied, as it does not need high expertise. It is simple and easy to use, but seems to have low precision, since it only takes one characteristic into account. For example, there may be only one characteristic with the rate of suitability (index) of e.g. 55 which does not show whether all other soil characteristics are also 55 in rating or higher than this rate. It has been discussed by Bion and Zinck (2008).

## 2.5 Square root method

The so-called square root method was presented by Khiddir (1986), which takes into account all the characteristics, but a higher impact is considered for the most limiting one (the least scored one) on crop growth. The following equation shows how the land index is calculated in the square root method.

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

Where:

I: index of the square root method

$R_{\min}$ : the minimum rated characteristic

A, B, ...: criteria other than minimum rated criterion

A, B, etc. are the characteristics considered for assessment (rooting depth, organic carbon content, etc.) mentioned earlier. This method could also have inspired from the logic of Liebig's Law, but here all of the considered characteristics are taken into account and they are all combined by multiplication. In the equation, the most limiting characteristic (the one with the lowest rate) influences the final obtained land index (total rate for a land unit) more than others. When multiplied by other characteristics, the limiting factor that has the lowest rate, may affect the total land rating irrationally. Thus, it is square rooted in order to decrease its irrational influence on total land index and make it more balanced mathematically. The limiting factor may have a much lower rate and the outcome of the multiplication may be an abnormal number for decision making when compared to the reality in the nature.

## 2.6 Storie method

The Storie method was presented by Storie (1976). In this method, all the characteristics rates are multiplied by each other. There is no difference among their effectiveness on crop growth. The land index is calculated through the following equation:

$$SI = (A) \times (B/100) \times (C/100) \times \dots \quad (2)$$

SI: Storie index

A, B, C: rates of the considered characteristics.

In this method, what is noticeable is the type of the equation, in other words, the in which characteristics are combined. That is the core idea for considering this method for evaluation, as it has been used by some researchers somewhat successfully and by some researchers it was reported as dissatisfactory and problematic in revealing real land capability or suitability (Tang, 1993; Van Ranst et al., 1999; Bazgir, 2000)

More explanations on the maximum limitation and parametric methods of land evaluation can be found in Sys et al. (1991a,b).

## 2.7 Fuzzy sets method

In this study, three fuzzy membership functions including S shaped, Z shaped and Kandel (a type of Gaussian) functions were used to give each of the land characteristics a degree of membership to each suitability classes ranging from 0 to 1. Zero is the least and one is the highest degree of membership of the measured characteristics to a reference suitability class. Four reference suitability classes including: S1: highly suitable (75-100), S2: suitable (50-75), S3: moderately suitable (25-50) and N: non-suitable (0-25), were defined for each of the land characteristics and for each crop separately. Separate functions are defined and modulated for each of the reference suitability classes of each characteristic. This three mathematical functions show the relation between a dependent variable (y) with an independent variable (x), in which the vertical axis (y) presents the relative degree of membership of a soil characteristic to a suitability class. For example, the less the land slope gradient, the better the ground is for cultivation operations, therefore, we use z-shaped function to assess that the less the x-axis value, the higher the membership degree for this characteristic in a given land unit for a given crop. S-shaped membership function was used for soil depth (rooting depth) and organic carbon content and Z-shaped function was used for  $\text{CaCO}_3$  and slope gradient. Kandel function was used for clay content and pH. The nature of variability of these characteristics determines the type of function to be applied. Clay content and pH values do not vary in one way, in other words, we can not say that the higher the better or the lesser the better, but it depends on the type of the considered crop requirement for optimal growth. In some cases, a medium value or a range of values is suitable, which is best fitted and adapted with the type of variation/dependence in the Kandel function. The applied functions including S-shaped, Z-shaped and Kandel are as follows respectively:

Equation (3):

$$mf(x) = \begin{cases} 0, & x \in [-\infty, \alpha) \\ 2 \left( \frac{x-\beta}{\gamma-\alpha} \right)^2, & x \in [\alpha, \beta) \\ 1 - 2 \left( \frac{x-\beta}{\gamma-\alpha} \right)^2, & x \in [\beta, \gamma) \\ 1, & x \in [\gamma, +\infty) \end{cases}$$

Equation (4):

$$mf(x) = \begin{cases} 1, & x \in [-\infty, \alpha) \\ 1 - 2 \left( \frac{x-\beta}{\gamma-\alpha} \right)^2, & x \in [\alpha, \beta) \\ 2 \left( \frac{x-\beta}{\gamma-\alpha} \right)^2, & x \in [\beta, \gamma) \\ 0, & x \in [\gamma, +\infty) \end{cases}$$

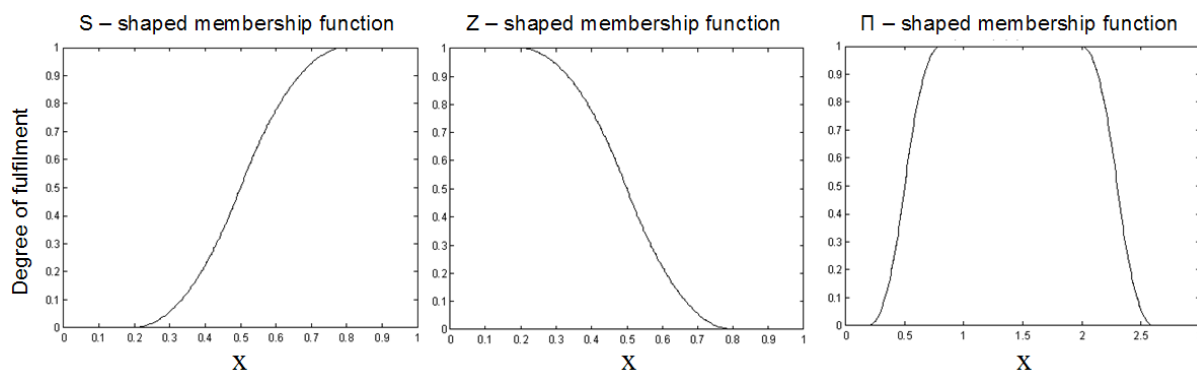
Equations (3) and (4) represent increasing and decreasing fuzzy membership functions for land characteristic  $x$  respectively (e.g. rooting depth for increasing and slope gradient for decreasing). Where  $\alpha$  and  $\gamma$  are lower and upper limits of reference threshold values (reference suitability classes which are determined based on specific crops requirements, (Sys et al. 1991)) of  $x$  characteristic and  $\beta$  is  $(\alpha+\gamma)/2$ .

Equation (5):

$$mf(x) = \begin{cases} \frac{1}{1 + \left[ \frac{(x-b_1)}{d} \right]^2}, & x < b_1 \\ 1, & b_1 \leq x \leq b_2 \\ \frac{1}{1 + \left[ \frac{(x-b_2)}{d} \right]^2}, & x > b_2 \end{cases}$$

In the Eq. (5),  $x$  is the value of measured characteristics, varying on a bilateral basis (e.g. soil pH having two poles of acidity and alkalinity),  $b_1$  and  $b_2$  are lower and upper limits of reference thresholds for characteristic  $x$ ,  $m$  is  $(b_1+b_2)/2$  and  $d$  is  $(m-b_1)$ . Figures 2 shows the graphs of functions S-shaped, Z-shaped and Kandel. The Kandel function is used to determine the membership degree of characteristics for S2 and S3 classes and the S-shaped and Z-shaped functions both are used for S1 and N classes depending on how the threshold values vary (increasingly or decreasingly).





**Figure 2:** Fuzzy membership functions

S membership function for rooting depth and organic carbon content.

Z membership function for CaCO<sub>3</sub> and slope gradient.

Kandel membership function for clay content and pH.

In all three functions, x-axis is variability of a given soil characteristic and y-axis is degree of membership, which is defined in every suitability class separately.

After calculating the membership degree of all the characteristics to the four reference suitability classes (in every land unit for every crop), a so-called characteristics matrix is established for each land unit. Then, this matrix is combined with a so-called weights matrix. The weights matrix is comprised of relative weights of land characteristics with regard to their influences on crop growth. These weights are determined through expertise pairwise comparison of the characteristics by using analytical hierarchy process technique (Saaty, 1980, 2001). The rationale in which the weights were determined is the comparison of relative significance of intrinsic soil parameters influence on crop growth. The weights were not determined with regard to each crop condition, but with regard to the soil parameters relative importance through expert judgments. In the judgments, variations of the parameters within the study region and level of restriction they induce on crop growth with reference to the threshold values are also considered. For example, soil texture not only has a major influence on crop growth by controlling several other parameters like plant available water, nutrient retention, ventilation, etc., but also has a tangible variation and sample analyses revealed that it restricts several crops growth when compared with reference threshold limits. Therefore, this parameter was assigned the highest relative weight. The weights matrix is the same for assessment of all of the land units, but the characteristics matrix varies within different land

units and different crop. The weight matrices calculated in this study are shown at the appendix of this paper. The following is an example of weights matrix and characteristics matrix in the land unit of Kharaqan for potato cultivation.

Characteristics matrix:

Weights matrix:

[Clay% Slope% O.C% Depth pH CaCO<sub>3</sub>%]  
 [0.235 0.155 0.105 0.175 0.135 0.195]

	S1	S2	S3	N
Clay	0.14	0.81	0.09	0
Slope	1	0.31	0.2	0
O.C	0	0.5	1	0
Depth	1	0.02	0.01	0
PH	0.15	1	0.31	0
CaCO <sub>3</sub>	0	0.01	0.08	1

The weights matrix and characteristics matrix are combined using a fuzzy operator as follows:

$$E = W \circ R \tag{6}$$

Where, E is the suitability matrix (with one row and four columns), W and R are weights and characteristics matrices respectively and (°) is the



fuzzy operator that combines the two matrices via the following formula:

$$e_j = \min (a_1 + a_2 + \dots + a_n, 1) \quad (7)$$

Where:

$$a_i = \max (0, w_i + r_{ij} - 1), i = 1, 2, \dots, n. \quad (7-1)$$

$e_j$  is the value of  $j$ th element in the suitability matrix,  $w_i$  and  $r_{ij}$  are given correspondent elements of weights and characteristics matrices respectively, and "min" and "max" signify the minimum and maximum value of the range inside the parenthesis respectively.

Afterwards, the matrix  $E$  is standardized in such a way that the summation of its elements is equal to one (e.g., dividing each element to the summation of all the elements). Then, the final land index is calculated through the following formula:

$$L_i = \sum (d_j \times A_j) \quad (8)$$

Where,  $L_i$  is land index in a specific land unit,  $d_j$  is standardized value of the  $j$ th element of the matrix  $E$  and  $A_j$  is mean value of the upper and lower limits of the  $j$ th reference suitability class. The

reference suitability classes are divided to four classes including S1, S2, S3 and N, as defined for parameters previously. These total suitability classes determine a land unit suitability class with regard to cultivation of a specific crop. Detailed information on fuzzy mathematics can be found in the literature such as Wang (1997), and fuzzy functions can be searched through MATLAB<sup>®</sup> software.

To test the accuracy of each of these methods, the land indices obtained through each method are compared with observed yield of each land unit for each crop through a linear regression and a subsequent statistical significance t-student test. The observed yield data of the crops were mean values of several-year (about 5 years) cultivation, recorded in different land units at the Agriculture Organization of Bastam. The yield values were obtained by doing some corrections locally in different land units by direct interviews with some farmers of the region. They are usually recorded after each harvest event in different land units of the region at farm levels and are registered at the Bastam Agricultural Organization.

### 3 RESULTS

Chemical and physical analysis of soil samples shows that the major limitations of the region for agriculture are unsuitable soil texture (coarse and in some cases gravelly texture) for the determined crops and high amounts of carbonate content which is a restricting factor for growth of many crops. Results of land indices obtained by four evaluation methods for tomato, wheat and potato cultivation in each land unit are shown in Table 2, 3 and 4 respectively. Results of each evaluation method (land indices) were compared with observed yield in every land unit for the three crops mentioned. In The dependence of yield on four different land use indices is presented on Fig.

3, 4 and 5 for potato, tomato and wheat respectively. The Table 5 presents the statistical significance of this dependencis. The fuzzy sets indices explain the highest amount of yield variability for all three crops, so it was recognize as the best method among all. The yield data for the land units Bayazid and Khazaneh were missing, so the evaluation results for these land units are not presented in the paper. The land unit Bagh (named as rangeland in the maps) is used as a low return pasture and does not have capability of cultivation because of its very shallow rooting depth.

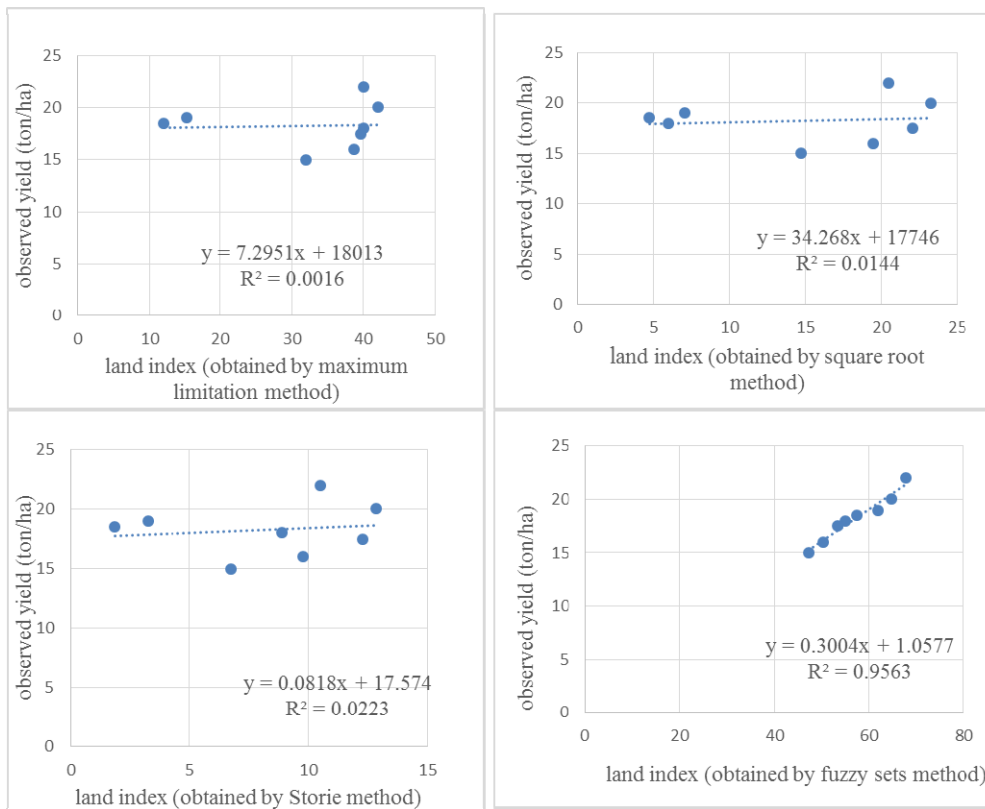


Figure 3: Regression results for land suitability evaluation of potato.

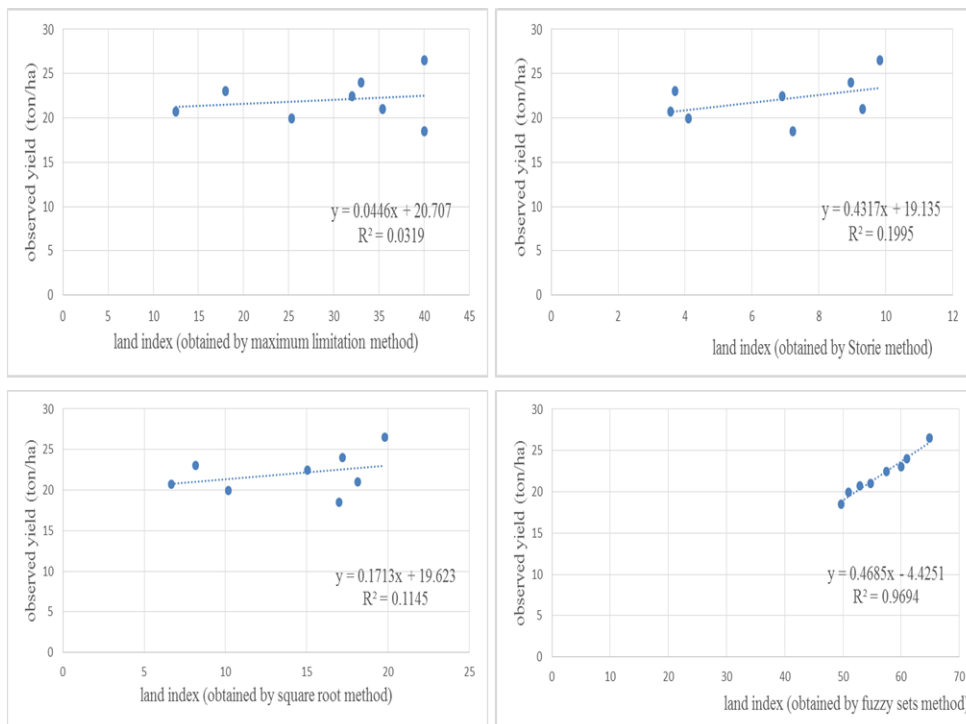


Figure 4: Regression results for land suitability evaluation of tomato.

**Table 2:** Land indices calculated by different methods and observed yields of potato

Land units	Maximum limitation	Storie	Square root	Fuzzy sets	Observed yield (ton/ha)
Abr	38.66	9.79	19.46	50.27	16.0
Amir	40.00	10.48	20.48	67.87	22.0
Bastamy	42.05	12.82	23.22	64.80	20.0
kharagan	12.00	1.84	4.70	57.43	18.5
Khij	32.00	6.75	14.70	47.27	15.0
Mojen	15.33	3.25	7.06	61.89	19.0
Qaleh	39.66	12.28	22.07	53.30	17.5
Qehej	40.00	8.87	5.96	55.01	18.0

**Table 3:** Land indices calculated by different methods and observed yields of tomato

Land units	Maximum limitation	Storie	Square root	Fuzzy sets	Observed yield (ton/ha)
Abr	32.00	6.90	15.04	57.51	22.5
Amir	40.00	9.82	19.82	64.89	26.5
Bastamy	35.39	9.30	18.14	54.73	21.0
kharagan	12.50	3.56	6.67	52.94	20.7
Khij	25.33	4.09	10.18	50.93	20.0
Mojen	18.00	3.70	8.16	59.99	23.0
Qaleh	33.00	8.96	17.20	60.97	24.0
Qehej	40.00	7.22	17.00	49.72	18.5

**Table 4:** Land indices calculated by different methods and observed yields of wheat

Land units	Maximum limitation	Storie	Square root	Fuzzy sets	Observed yield (ton/ha)
Abr	60.00	35.40	46.08	61.25	2.5
Amir	40.00	30.60	34.99	74.15	3.0
Bastamy	50.00	34.00	40.23	63.35	2.7
kharagan	12.50	6.86	9.26	63.31	2.7
Khij	50.00	15.18	19.48	69.72	2.8
Mojen	40.00	14.02	23.68	59.74	2.0
Qaleh	75.00	45.12	58.17	78.25	4.0
Qehej	40.00	12.77	14.30	60.87	2.2

#### 4 DISCUSSION

Although the crops yields are influenced by many factors other than soil, such as diseases and managerial measures, but they are used only as an indicator of each land unit potentiality, in order to compare capabilities of different land units. Moreover, the differences of farm management levels among land units of the study area, which could influence the yields, is negligible, as interviews were done with some farmers. Therefore, if we some scan approximations, we can be confident that the differences between

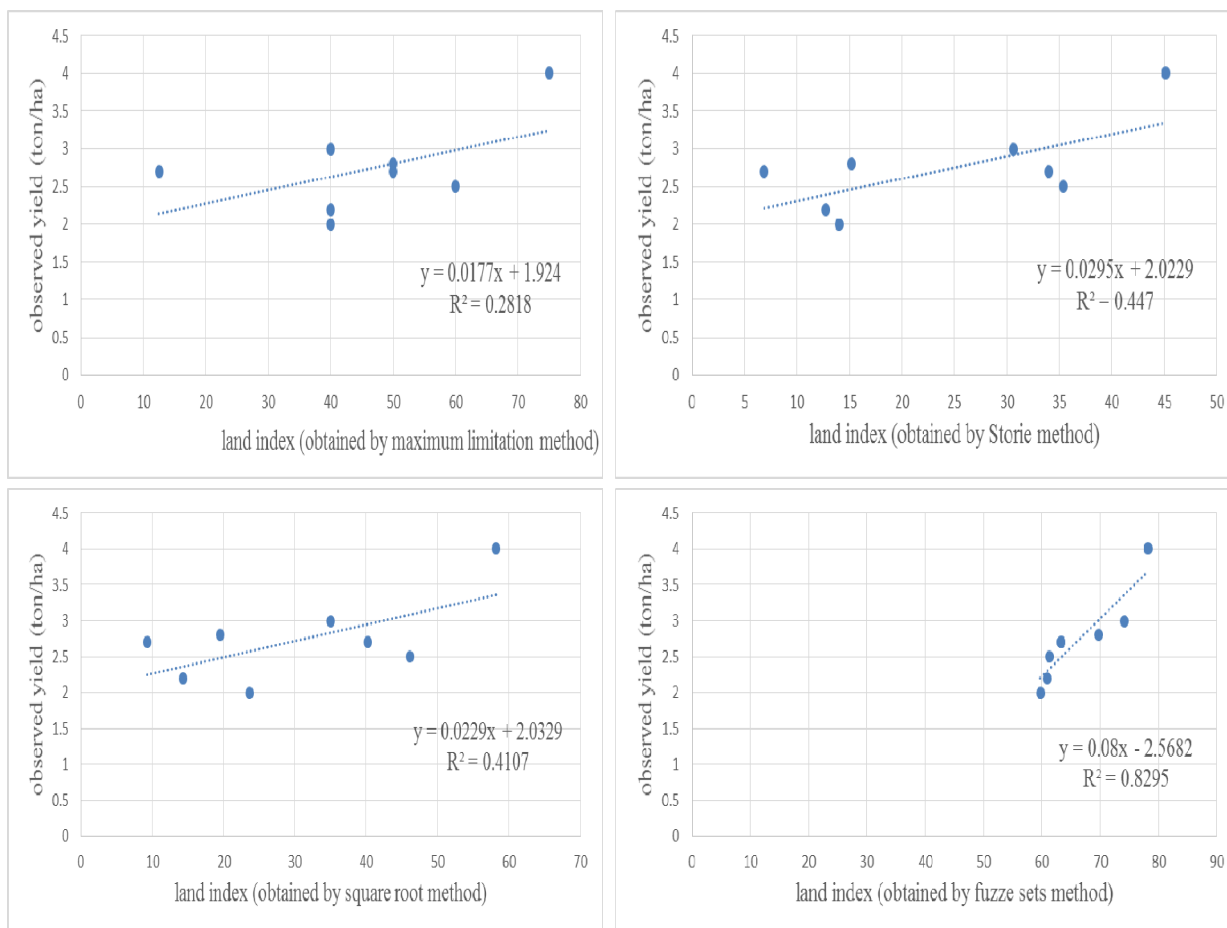
different land units crop yields are purely due to different soil capabilities only.

The most suitable crop amongst the three crops, obtained by fuzzy sets method, was determined for cultivation in each land unit. Figure 6 shows the highest suitable crop for each land unit. The whole region is mainly suitable for wheat cultivation in comparison with the other two crops and the land unit Qaleh shows the highest suitability for wheat production. Tomato is not recommendable for

cultivation in the study area due to low suitability of soils of the region for production of this crop.

Other researchers have come to similar results such as Tang et al. (1992) that investigated the fuzzy method in comparison with other methods

(maximum limitation and parametric methods) in China, and found that the fuzzy method has the highest correlation coefficient (0.96) when compared with observed yield, meanwhile this coefficient was lower for parametric and maximum limitation methods.



**Figure 5:** Regression results for land suitability evaluation of wheat

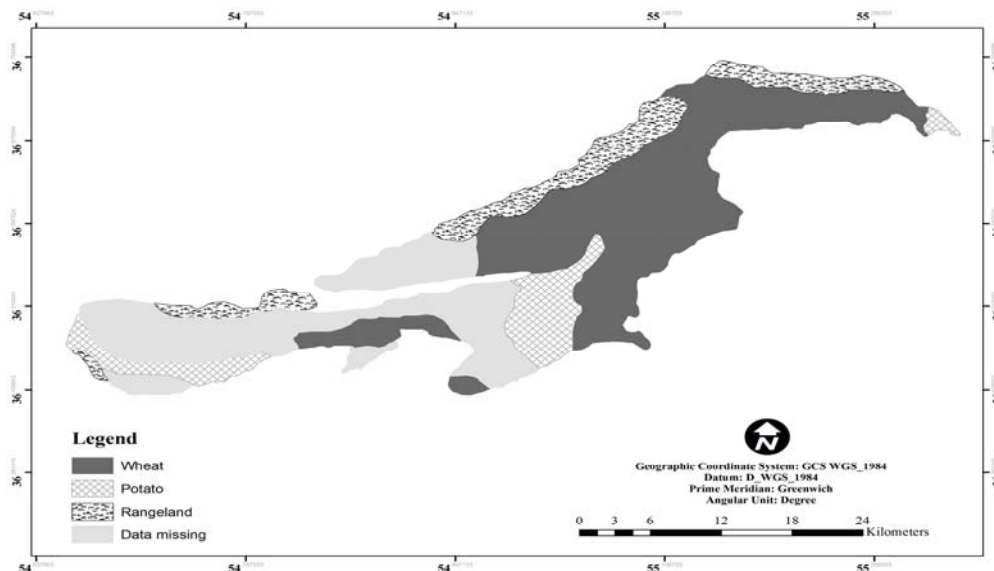
In Thailand, a similar study on rubber was done by Van Ranst et al. (1996). They also found the fuzzy sets method as the best method for land suitability classification. Likewise, the advantageous application of fuzzy methodology has been confirmed by Tang et al. (1997). They reported higher accuracy of fuzzy method in comparison with Boolean methods for land suitability evaluation of different crops. In another study, Van Ranst and Tang (1999) performed land suitability evaluation for corn cultivation using fuzzy and Boolean approaches. They compared land indices, calculated through different methods, with observed yield, and obtained correlation coefficient

of 0.97 for the fuzzy approach and thereby reported the higher accuracy of fuzzy method compared with Boolean methods. Another study to compare parametric method with fuzzy method on irrigated wheat was done by Mohammadi and Givi (2002) in Iran. They compared the land indices with observed yield of the crop and obtained a correlation coefficient of 0.14 and 0.35 for parametric and fuzzy methods respectively. Corona et al. (2008) explained some benefits of fuzzy set application in land suitability assessment and performed a case study on land suitability by using fuzzy sets. They concluded that this methodology is quite useful in such projects. In a study in the

country where the study area is located, Keshavarzi et al. (2010) applied the fuzzy sets method for classification of lands for irrigated wheat production. They compared the wheat yield with land indices and obtained a correlation coefficient of 0.91, but they did not compare this method with any other methods. There are no other recent studies on comparing or testing the methods of land evaluation.

Despite the preeminence of the fuzzy method, it needs high amounts of calculations that makes it a demanding task. The typical difference between fuzzy method and other conventional methods is the procedure of combining the criteria (land characteristics) and allocation of different weights to the criteria in the fuzzy method. It is evident in soil specialists' point of view that different soil/land characteristics have different impacts on crop growth, for example, soil texture does not have identical influence on crop growth as pH, since the soil texture type controls several other soil qualities like amount of total soil water retention, plant available water, ventilation, water infiltration, etc. Therefore, assigning proportionate weights for different characteristics is necessary. Nevertheless, in the other three methods mentioned, all the characteristics influences on crop growth are considered evenly. That is a reason why their results are less reliable than fuzzy

methods. Results of the Storie and square root methods regression were not significant for tomato and potato. The results of maximum limitation method regression with the crops yields were not significant for any of the crops in all of the land units. This could be because of not taking into account all of the characteristics that affect land capability/suitability for crop production. A conclusion can be elicited here that considering the effective characteristics and the way of combining them is important and affects the final calculation results significantly. The fuzzy sets methodology application in land evaluation is based on the assumption that the changes in soil properties and suitability classes of land units are not crisp but gradually changing within space. When we define the reference suitability classes limits as precise and crisp but not vague or fuzzy, we lose parts of the obtainable information in our analyses. Because soil parameters values vary continuously and naturally are not precisely separated. Therefore, using fuzzy approach in such analyses, which can reveal the intrinsic continuity and vagueness in land evaluation, seems to be a significantly more efficient methodology than traditional classical methods. This methodology has a high efficiency in showing slight but highly important differences in parameters variations, which greatly influences the results of land evaluation process.



**Figure 6:** The most suitable crop in each land unit (land indices calculated through fuzzy sets method); [Sharififar et al., (Sharififar@ut.ac.ir)]

## 5 CONCLUSION

In the study area:

Fuzzy sets method regression results are significant at  $p = 0.05$  and had the highest reliability in comparison with the other three methods.

Results of the Storie and square root methods correlations were only significant for wheat production at  $p = 0.1$ .

Regression analysis results of maximum limitation method with the crops yields were not significant.

This study was a demonstrative test of fuzzy sets theory in land suitability evaluation. Different

techniques of land evaluation are used by researchers around the world, but among the basic frameworks of land evaluation, fuzzy methodology results are the nearest one to the real qualities of lands undoubtedly.

However, application of this methodology, in comparison with other classic methods, is rather a demanding task but it is sound and precise enough.

We suggest building a computerized model of the fuzzy procedure for easier implementation of land suitability assessments.

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