Research Article

Assessment of Agricultural Land Suitability using Fuzzy Set Method

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Abstract | Agriculture is the basic source of national income and food of all developing countries of the world, but land manager and farmers face the main problem when and where to cultivate. The present study was aims to analyze the efficiency of the parametric and fuzzy set methods in the land assessment for wheat production of Tando Allahyar district of Sindh Province. The present study able to provide grade performance suitability of lands for agricultural purposes; it could be more helpful for farmers of the research area. Fuzzy AHP methods could be beneficial for future studies for land suitability. The study finding have capabilities of different methods combined with fuzzy analytic hierarchy process (AHP) and the potential time and cost saving methods can assess the suitability of land. Finding shows that the fuzzy set method is different from parametric method. The influence of explicit weight on land characteristics is combined with the evaluation of land characteristics. The correlation coefficient is high for both indices, but results obtained with fuzzy set method (r=0.97) showed a higher accuracy with yields than those obtained with the parametric method (r=0.86). Furthermore, finally formed the suitability grade or suitability index. Besides a dominant suitability class, the fuzzy set method equally provides information on the degree of belonging of the land unit to each of the suitability classes discerned. The good results obtained by using the fuzzy set method are helpful further development and application of the land evaluation field.

Received | December 25, 2018; **Accepted** | February 16, 2019; **Published** | February 28, 2019
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Citation | Abbasi, N.A., M.N.H.A. Ali, B. Abbasi, S.A. Soomro, N.A.K. Nangraj, J.G.M. Sahto and S.A. Morio. 2019. Assessment of agricultural land suitability using fuzzy set method. *Pakistan Journal of Agricultural Research,* 32(2): 252-259.
DOI | http://dx.doi.org/10.17582/journal.pjar/2019/32.2.252.259
Keywords | Land suitability, Limitation method, Parametric method, Fuzzy set method, Wheat

Introduction

To increase food production in line with growing population is the greatest challenge for the coming decades especially in countries with limited water and land resources. The continuing deterioration of land and water resources occurring in several regions of the world is partly as a result of the mismatch between land suitability or capability and land use. The suitability of agricultural land is an important technology to decide the cropping pattern, planning and activities of agricultural planting in the future at least environmental and economic costs. Agriculture is main stay of the economy of Pakistan employing 42.3 percent of labor force. This sector directly contributes around 19.5 percent to the Gross Domestic Product (GDP) of the country. Wheat is currently ranked first among all cereal crops in Pakistan and it is the most important food crop in ancient times and as a source of human food. Wheat accounts for 9.6% of the added value of agriculture and 1.9% in GDP of Pakistan (GoP, 2017). The land

suitability analysis is to examine an area to determine the specific location of land use, such as planting crop varieties. Land suitability tools have been widely used to identify better management practices in agricultural areas (Singha and Swain, 2016). Land suitability evaluation is essentially the calculation of land attributes, and compares it with crop demand, and develops the suitability index of land crop production in a clear spatial way (Wang et al., 2006). Consequently, the suitability assessment of the land includes soil analysis, topography and vegetation data to compare land characteristics and crop needs of the study area. The analysis allows the determination of the major limiting factors for the production of specific crops, so that policy-makers can develop a crop management to improve land productivity. The suitability of land can be carried out according to the biophysical parameters and socioeconomic conditions of the area (FAO, 1976). FAO proposed a general classification of land suitability, in which two suitability orders were discussed as: Suitable (S) and unsuitable (N). The orders were subdivided into the following description:

Order	Class	Description
S	S1	very suitable
	S2	moderately suitable
	S3	marginally suitable
N	N1	Unsuitable
	N2	permanent unsuitable class

In the recent years, land suitability for the agriculture based on preference infrastructural under FAO framework developed and number of methodologies have been developed (Sys, 1985, 1991; Satty 1977, 1980; Brossier, 1990). The limitation method refers to the crop requirement tables for each type of land use. For each characteristic, the table defines the class levels criteria. The land class is determined according to the most limiting characteristics, the advantage of this approach is simplicity and no overlap and interaction, and so many features can be used to evaluate (Sys et al., 1991). In the parametric method, different land characteristics are used to define differing rating of the different limitation levels of land features for land suitability are ranked between a minimum and maximum value (normally 0 to 100) (Sys et al., 1991). Therefore, appropriate land units can only choose one of the pre-defined land suitability classes. Another method of determining the stability classes by using the fuzzy set theory is proposed by Zadeh (1965). The definition and determination of certain classes, such as "very important", are expressed ambiguously. In fuzzy pertaining, the determination of specific boundaries is difficult, and the attribution of various factors to various concepts and problems is relative. Saaty, 1980 developed analytic hierarchy process (AHP), and the multi criteria evaluation technique was improved by the standardization of fuzzy factors. In order to analyze the efficiency of the new methodology, the limitation, parametric and fuzzy set methods was applied in the land assessment for wheat production of Tando Allahyar district of Sindh Province.

Materials and Methods

Study area

District Tando Allahyar, is located in Sindh province, Pakistan (Figure 1). It is one of the nine districts of Hyderabad Division which is located between Longitude 680 34' 23" and 68057' 35" East and Latitude 250 12' 24" and 25045' 17" North at a mean elevation of about 21 m above mean sea level (MSL). The Administrative Units include 03 Talukas, 19 Union Councils, 87 Mauzas and 01 Municipal Committee. The climate of Tando Allah Yar is mild and pleasant. Summer is neither hot nor cold in winter. The hottest months in summer are June and July, and the coldest months in winter are December and January. The hot winds from May to August blow from the south to the north, and the cold winds blow from the north to the south in November, December and January. It is pleasant Tando Allahyar at night. Due to climatic conditions and adequate irrigation water supply, different types of crops were planted in the area, especially cotton, wheat, sugar cane and fruits and vegetables. This area is made up of flat and fertile land. It has an effective canal system that guarantees agricultural productivity (Craig, 2013).

Data source

A total of sixteen soil locations of the study are considered in district Tando Allahyar. Soils samples was selected randomly. The soil samples were transported to Laboratories of the Soil Chemistry (S.F), ARI Tandojam. The actual yield data for wheat from different locations was obtained by interview with farmer. The collection of data sets is shown in Table 1.

Crop suitability requirement

The crop suitability requirement table for wheat

Figure 1: *Graphical map of study area.*

Table 1: *Summary of the selected characteristics wheat in the study area.*

	Soil depth (cm)	pH	EC (dS/m)	$CaCO_3$ (%)	Soluble & Exch. Na (meq/L)	Soluble Ca + Mg (meq/L)	Sodium Adsorption Ratio (SAR)
Minimum	50	7.7	1.0	15.6	2.6	10	0.95
Maximum	150	8.5	4.6	29.75	22.2	27	5.73
Mean	100	8.02	1.75	20.59	6.54	18.50	2.06

cropping was established the structure of FAO framework, literature data and previously established requirement tables (Sys, 1985). The land suitability requirements are presented in Table 2.

Classification of land suitability methods

Limitation method: The limitation method adopted by the Sys et al. (1991). Each land characteristics are evaluated by a relative scale of limitation, i.e. no limitation=0,slightlimitation=1,moderatelimitation=2, severe limitation= 3 and very severe limitation= 4. The limitation level determined as comparison of each land characteristics with requirement of crop.

Parametric method: The parametric method was suggested by (Sys et al., 1991), in this method land and climatic characteristics were using differing scale level of 0 to 1. The land characteristics calculated as the product of individual values of all characteristics and multiplied by 100. After the determined the land

Table 2: *The crop requirements in terms of land characteristics.*

Soil Characteristics	Suitability classes and rating scale					
	SI		S2	S3	NI	N2
	0	1	2	3	4	5
Rainfall (growing cycle)	>600	570	500	350	<250	-
Actual soil depth (cm)	>100	90	80	50	-	<20
Drainage condition (coarse / fine texture)	Imperfect/ good	Moderate	Good /imperfect	Poor aeric	Poor drain-able	Very poor non drain
Surface Texture	SiC, Co, Si, SiL,Sicl	SC, C>60s, L	C>60v, SCL	SL, LfS	-	Cm, SiCm, LcS,Fs, cS
pH	7.0-6.5 7.0-7.5	6.5-6.0 7.5-8.2	6.0-5.6 8.2-8.3	5.6-5.2 8.3-8.5	<5.2 -	- >8.5
Organic Carbon (%)	>1.5	1.5-1.0	1.0-0.5	<0.5	-	-

index: S1: very suitable land (75-100), S2: moderately suitable land (50-75), S3: marginally suitable land (25-50), N1 unsuitable land (12-25) and N2: No suitable land (0-12).

Fuzzy set method: Initially developed fuzzy set theory by Zadeh's (1965) dealing with classes that define fuzzy sets e.g. moderately suitable land and marginally suitable land classes. Zadeh proposed the membership in a set be measured not as a 0 or a 1 as in the traditional set theory. The function that describes the degree of belonging to a set is called membership function. The suitability classes S1 to N2 membership functions have to establish. The evaluation of a land characteristic consists of the determination of degree membership characteristics to each of the suitability classes. Finally, the land suitability is obtained by using the product weight matrix and the membership matrix.

Determination of memberships function: Determination of membership functions and evaluation matrix: A membership function is established for each suitable class. They show that the value of land characteristics belongs to the level of suitability. If the value of the land characteristics is complete or is not absolute in the class considered, the value of the member is 1 or 0, respectively. If value of the land characteristics to a certain extent belongs to the determination of the value of the intermediate membership and the general form function, the S-membership function obtained from the smooth two interpolations (Ruan, 1990). The S-membership function defined as:

$$S(\chi;\alpha,\beta,\gamma)=\begin{cases}0; & \chi\varepsilon[-\infty,\alpha]\\ 2\left[{}^{(\chi-\alpha)}/_{(\gamma-\alpha)}\right]^2; & \chi\varepsilon[\alpha,\beta]\\ 1-2\left[{}^{(\chi-\gamma)}/_{(\gamma-\alpha)}\right]^2; & \chi\varepsilon[\beta,\gamma]\\ 1; & \chi\varepsilon]\lambda,+\infty]\end{cases}$$

Where;
$\beta = (\alpha + \gamma) / 2$

To determine organic carbon by membership functions as:

$$S1(x;0.5,0.8,1.1)=\begin{cases}0; & x\varepsilon[0,0.5]\\ 2[(x-0.5/0.6]^2; & x\varepsilon[0.5,0.8]\\ 1-2[(x-1.1)/0.6]^2; & x\varepsilon[0.8,1.1\\ 1; & x\varepsilon[1.1,m]]\end{cases}$$

$$S2(x;0,0.5,1)=\begin{cases}0; & x\varepsilon[0,0.5]\\ 2(x)^2; & x\varepsilon[0,0.5]\\ 1-2[(x-1)^2; & x\varepsilon[0.5,1\end{cases}$$

$$S2(x;1,(1+m)/2,m=\begin{cases}1-2[(x-1)/(m-1]^2; & x\varepsilon[1,(1+m)/2]\\ 2[(x-m)/(m-1\_]^2; & x\varepsilon[(1+m)/2,m]\\ 0; & x\varepsilon[m,+\infty[\end{cases}$$

$$S3(x;0.5,(0.5+m)/2,m=\begin{cases}1; & x\varepsilon[0,0.5]\\ 1-2[(x-0.5)/(m-0.5]^2; & x\varepsilon[0.5,(0.5+m)/2]\\ 2[(x-m)/(m-0.5\_]^2; & x\varepsilon[(0.5+m)/2,m]\\ 0; & x\varepsilon[-\infty,+\infty[\end{cases}$$

$$N1(x)=N2(x) \quad = \quad 0; \qquad x\varepsilon]-\infty,+\infty[$$

Where;
x: Organic carbon content (%); m: Organic carbon content (%) possible maximum value; $x\varepsilon[0,0.5]$: x can takes any value between 0 and 0.5.

For S1 Equation, if x takes a value between 0 and 0.5, its membership value in class S1 is equal to 0. If x take 0.5 and 1.1, its membership value will be calculated according to S-function. If x equals 1.1 or more the membership value in S1 class is unity.

A similar membership function is established for other land characteristics considered in the evaluation. An exception is made to the characteristic "drainage" that is treated as in traditional set theory.

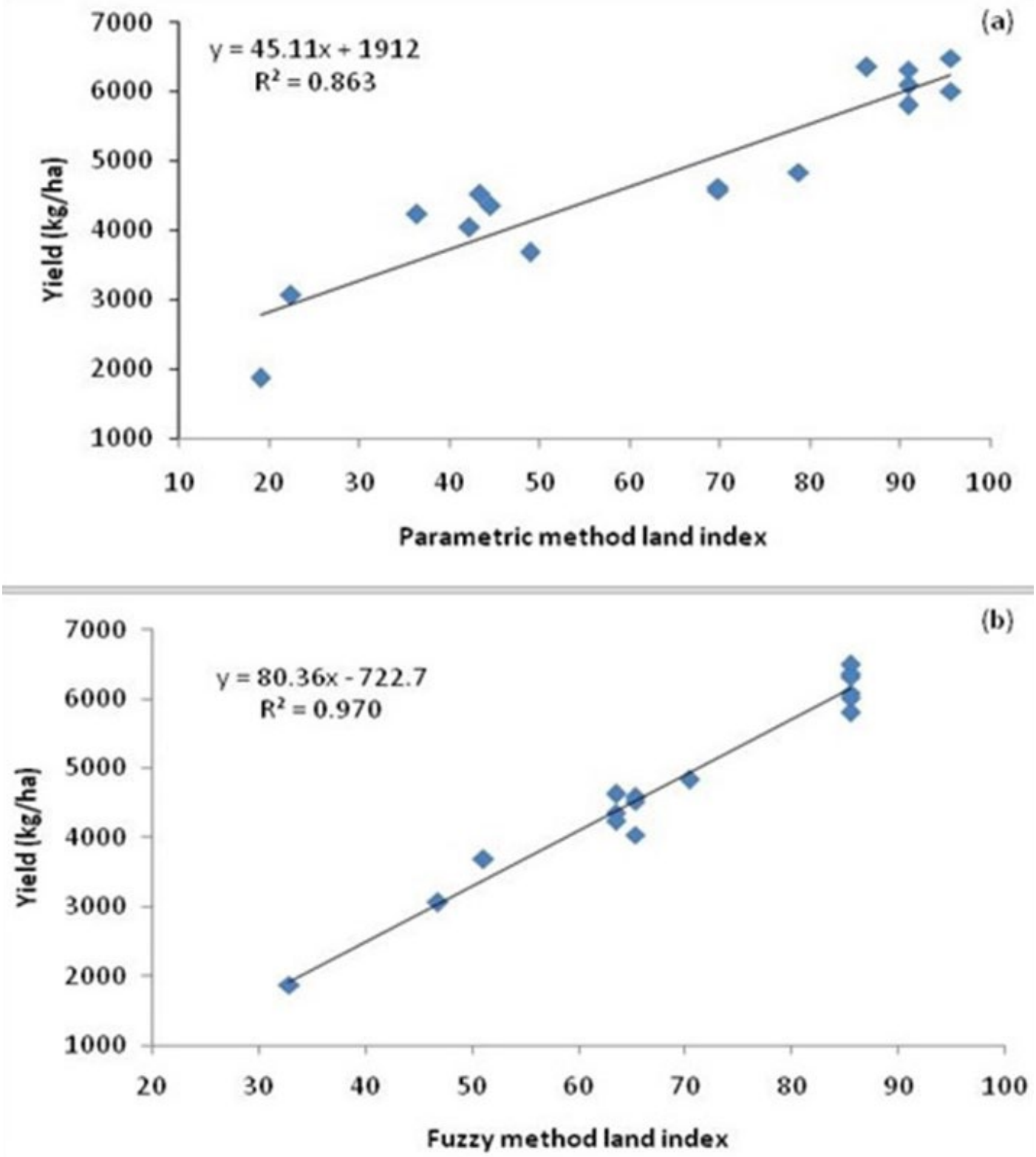

Figure 2: *A linear regression with (a) the parametric method and (b) Fuzzy set method of land suitability indices*

Determination of weight factors: Land characteristics have different effects on crop production. Their relative importance in crop yield can be expressed by weight factor. The weight is attributable to the characteristics of each land, based on the value and value of the partial regression coefficient. The weight value of a significant land feature can be written as the weight matrix (W), that is:

$$W = [\ RF \quad DR \quad TX \quad DP \quad OC\ ]$$
$$= [\ 0.67 \quad 0.99 \quad 0.83 \quad 0.50 \quad 0.33\ ]$$

The final suitability matrix (E) or final evaluation is obtained by multiply the two fuzzy matrix (W and R) established in previous phases. That is, if the sum of the elements of the evaluation matrix (E) is equal to 1, the exponent can be calculated as evaluation of the

Table 3: *Matrix of land suitability for wheat by pairwise comparison.*

	Soil depth	pH	EC (dS/m)	$CaCO_3$ (%)	Soluble & Exch. Na (meq/L)	Soluble Ca + Mg (meq/L)	Sodium Adsorption Ratio (SAR)	Weight
Soil depth	1	2	3	4	5	6	7	0.329
pH	1/2	1	2	3	4	5	6	0.224
EC (dS/m)	1/3	1/2	1	2	3	4	5	0.152
$CaCO_3$ (%)	1/4	1/3	1/2	1	2	3	4	0.105
Soluble & Exch. Na (meq/L)	1/5	1/4	1/3	1/2	1	2	3	0.075
Soluble Ca + Mg (meq/L)	1/6	1/5	1/4	1/3	1/2	1	2	0.052
SAR	1/7	1/6	1/5	1/4	1/3	1/2	1	0.035

product of matrix elements (member weight factors) and the average applicable rank grades. The result is a weighted index.

Analytical hierarchy process: The weights matrix (W) was calculated with each land characteristics, this method has the ability to incorporate different types of data and compare the two parameters is the same, known as a pair comparison. This input and relative weights considered as outputs in pairwise comparison method. The Saaty Scale (Saaty, 1980) used to prepare the pairwise comparison for each parameters.

Results and Discussion

The pairwise comparison was applied for each parameter by the AHP method as given in Table 3. The Sys (1993) table for each soil field corresponding was compared with the Limitation, Parametric, Fuzzy set and FAO method.

The land evaluation procedure by FAO for soil site suitability conducted by Das and Sudhakar (2014) in East Khasi Hills District of Meghalaya. Land suitability for various agricultural crops has been carried out at different methods i.e. remote sensing, multi criteria decision making etc. The land suitability classifications for wheat cropping on 16 soil sites are summarized in Table 4. This comparison indicates a quite good agreement amongst the 3 applied methods; the different only found where land sites have a degree of suitability somewhat near class limits as in Sample No. 10, 11 and 15. In this comparison method, the results equally demonstrate that the fuzzy set method is less severe than the other applied methods. Land suitability tools have been extensively applied to identify better management Practices in agricultural areas. Singha and Swain (2016) reported that Fuzzy-logic integrated with Multi-Criteria Evaluation in GIS environment found most suitable for agricultural crops.

Table 4: *Different land suitability classification evaluation results.*

Sample No.	Observed (kg/ha)	Limitation Class	Parametric class	Parametric land index	Fuzzy class	Fuzzy index
1	6490	SI	SI	95.7	SI	85.5
2	6360	SI	SI	86.3	SI	85.5
3	6320	SI	SI	90.9	SI	85.5
4	6090	SI	SI	90.9	SI	85.5
5	6010	SI	SI	95.7	SI	85.5
6	5800	SI	SI	90.9	SI	85.5
7	4840	SI	SI	78.8	S2	70.4
8	4630	S2	S2	69.8	S2	63.5
9	4580	S2	S2	69.8	S2	65.3
10	4520	S2	S3	43.5	S2	65.3
11	4360	S2	S3	44.6	S2	63.5
12	4240	S3	S3	36.4	S2	63.5
13	4040	S3	S3	42.3	S2	65.3
14	3680	S3	S3	49.0	S2	51.1
15	3060	S3	NI	22.5	S3	46.8
16	1870	NI	NI	19.1	S3	32.9

In order to judge the efficiency of the methods, the classification results are compared with the observed wheat grain yield. The linear regression between land suitability indices obtained with the parametric method with fuzzy set method. The results represented in Figure 1 is showed the correlation coefficients between methods, the correlation coefficient is high for both indices, but results obtained with fuzzy set method (r=0.97) showed a higher accuracy with yields than those obtained with the parametric method (r=0.86). As comparison between other researches with this result (Sanchez, 2007, Mohammad Rezaei et al., 2014; Van Ranst et al., 1996; Hamzeh et al., 2014) proved that the fuzzy method with higher correlation coefficient has higher ability to predict the output and precision. Fuzzy AHP for land suitability was carried

out and compared with standard method of the FAO framework (Hamzeh et al., 2014). Results shows that the fuzzy AHP method has a higher accuracy than the standard FAO method.

Conclusions and Recommendations

The study provides grade of performsance of suitability of lands for agricultural purposes; it could be more help for farmers of the research area. Fuzzy AHP methods could be beneficial for future studies for land suitability. The study will have capabilities of different methods combine with fuzzy analytic hierarchy process (AHP) and the potential time and cost saving methods can assess the suitability of land. The limitation method permits to determine suitability classes without further specifications. Land units that have a degree of suitability intermediate between classes are either strongly favored or downgraded by attributing a single suitability class. Compared to the limitation method, parameter method and fuzzy set method are able to describe the degree of suitability independent of class limits. Fuzzy set method is different from parameter method. The influence of explicit weight on land characteristics is combined with the evaluation of land characteristics. Finally, suitability grade or suitability index is finally formed. Besides a dominant suitability class, the fuzzy set method equally provides information on the degree of belonging of the land unit to each of the suitability classes discerned. A disadvantage of the fuzzy set method is the extensive calculation procedure. Land suitability classification is, for now, treated in an empirical way. We do not escape from this approach in using the theory of fuzzy sets. The good results obtained by using the fuzzy set method are helpful to the further development and application of the land evaluation field.

Author's Contribution

Abbasi, N.A. conceived of the presented idea, write-up the manuscript, and data analysis; N.A.K. Nangraj contributed data collection; B. Abbasi and J.G.M helped to develop the methodology section; Soomro S.A. and S.A. Morio helped to analyzed and the data; and M.N.H.A. Ali reviewed the final manuscript and act as a corresponding author.

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