https://doi.org/10.17221/59/2018-RAE

Using a fuzzy control system to optimise the parametric method for selecting the appropriate irrigation system

Yaser Hoseini, Manochehr Shiri Janaghard*

Department of Irrigation and Drainage, Faculty of Agriculture, Moghan College of Agriculture and Natural Resource, University of Mohaghegh Ardabili, Ardabil, Iran

**Corresponding author: y_hoseini@uma.ac.ir*

Citation: Hoseini Y., Shiri Janaghard M. (2019): Using a fuzzy control system to optimise the parametric method for selecting the appropriate irrigation system. Res. Agr. Eng., 65: 70–75.

Abstract: In this study, a fuzzy logic system was used to optimise a parametric evaluation system in surface and sprinkler irrigation systems. This study was performed on a surface area of 5,175 ha in the Fath-Ali region located in the Ardabil province of Iran. It was indicated that for the sprinkler and surface irrigation system, an area of about 385.06 ha (7.4%) and 159.81 ha (3%) of land is "highly suitable" and an area of about 286.1 ha (5.5%) and 312.69 ha (6%) is "moderately suitable", respectively. About 2,810.08 ha (54.3%) and 2,744.17 ha (53.02%) were respectively "marginally suitable" for the sprinkler and surface irrigation systems. The "currently not suitable" suitability included about 1,322.88 ha (25.5%) and 1,746.05 ha (33.7%) and the "permanently not suitable" suitability included about 370.91 ha (7.1%) and 212.28 ha (4.1%) in the zone under study. According to the results, there is a major difference between the "highly suitable" land obtained through the two methods and the area of the "highly suitable" land using the sprinkler irrigation method is about two times the area of the "highly suitable" obtained through the surface irrigation method.

Keywords: surface irrigation; evaluation of lands; sprinkler irrigation; optimisation

Selecting a proper irrigation method in irrigated agriculture in order to achieve a high efficiency and maximum water use and soil and water conservation are as important as pest control and adding fertilizers in a crop's production. The agricultural land suitability for the irrigation assessment is defined as the process of the land performance assessment when the land is used for alternative kinds of irrigation (Ahmed 2016; Diallo et al. 2016). The principle purpose of the agricultural land suitability for the irrigation evaluation is to predict the potential land and its limitation for kinds of irrigation methods (Abdel Rahman et al. 2016). In Iran, evaluating the land suitability for selecting the irrigation methods is vital for agricultural development. A GIS-based land suitability analysis is essential to assess the potential and constraints of a given land parcel for irrigation purposes. Sys et al. (1991) proposed a parametric evaluation system to select the irrigation methods based on the physical and chemical properties of soil. This technique was considered as the base method in the land evaluation and many studies have been undertaken in this field. Naseri et al. (2009) examined the soil quality for different irrigation methods in the Lali plain and considered 6 factors including soil texture, soil depth, lime, salinity, drainage and slope. The results showed that 1,732 ha (48.5%) of the lands studied was suitable for all three types of irrigation (surface, sprinkler and trickle). Albaji et al. (2006) evaluated 77,706 ha of lands of the Khuzestan's Shavoor plain for trickle and surface irrigation using the Sys parametric method. The results obtained suggested that the trickle irrigation method is more suitable than the surface irrigation method in the lands of this area. An irrigation land suitability analysis is dependent on the physical and chemical properties of soil in relation to methods of irrigation considered (Kebede, Ademe 2016;

https://doi.org/10.17221/59/2018-RAE

Valdivia-Cea et al. 2017). But all of these studies ignore the continuous changes of the soil properties and, thus, it causes their evaluation results to be not accurate enough. This problem is solved by considering a fuzzy system and its membership functions. Fuzzy systems are, today, one of the most efficient methods in the field of forecasting and modelling (Akbarzadeh et al. 2009). Using fuzzy logic capabilities which stem from the ability of a continuous membership function of input variables and by a combination of parameters affecting the irrigation methods evaluation in the parametric system. Thus, this study aimed to utilise the functionalities of the fuzzy logic method to evaluate the land suitability of the studied area based on the parametric system for sprinkler and surface irrigation. Moreover, the purpose of this study was to optimise the parametric lands suitability evaluation system uses of the fuzzy logic system.

MATERIAL AND METHODS

The region studied covers an area of 5,175 ha of part of the Fath-Ali plain land at a distance of approximately 35 km southwest from the city of Pars Abad and 230 km northwest from the city of Ardabil. The geographical coordinates of the lands are 47°35'56''E to 47°43'21''E and 39°25'12''N to 39°28'28''N. The soil moisture regime is weak aridic, a subcategory of aridic, and its thermal regime is thermic. Fig. 1 shows the location of pressurised irrigation network of Moghan Fath-Ali. In this paper, data from 20 stations was used which was derived from reports on detailed soil studies and the classification of the Fath-Ali Plain lands in Pars Abad. The project employer was the Agricultural Organization of Ardabil province and the studies were conducted

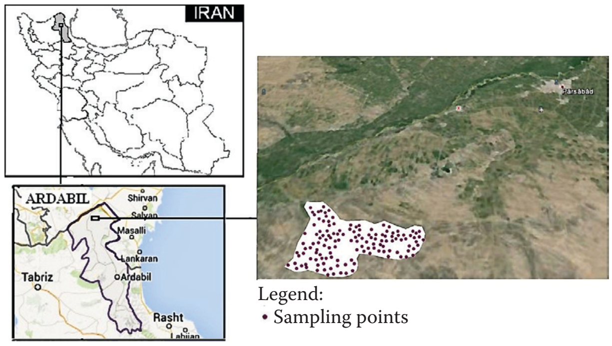

Fig. 1. Schematic of the study area

by the country's Soil and Water Engineering Services Company. The summary of physical and chemical test results are represented in Table 1. Fig. 2 shows maps of the land units in the studied area.

Fuzzification of the parameters affecting the land evaluation through the parametric method. Fuzzy systems are composed of three parts: (*i*) fuzzy sets, (*ii*) membership functions, (*iii*) fuzzy rules (Fig. 3).

In the parametric technique, soil properties are graded and used to calculate the irrigation suitability index (C_i) by the following function (Eq. 1):

$$C_i = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100} \quad (1)$$

where: A, B, C, D, E, F – are the gradation values of the soil texture, depth, lime, electrical conductivity, drainage, slope, respectively

Some specified signs are used in the parametric evaluation of the land suitability. These signs include S_1 (highly suitable), S_2 (moderately suitable), S_3 (marginally suitable), N_1 (currently not suitable) and N_2 (permanently not suitable). Depending on the type of irrigation, the values given to each factor based on the membership function of each factor are shown in Table 2. Eq. 2 and the spatial data modeller (SDM) in the GIS extension were used to

Table 1. The physical and chemical properties of the soil samples

Statistical indicator	Soluble cation (meq·l^{-1})					Soluble anion (meq·l^{-1})					Field capacity (vol%)	Soil density (g·cm^{-3})	
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	sum	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	sum		bulk	particle
Mean	12.2	9.4	29.2	0.6	51.4	0.0	3.1	230	26	522	21.3	1.6	2.6
Maximum	38.8	40.4	169.0	8.1	227.7	0.4	6.1	109	109	222.2	30.2	1.8	2.7
Minimum	2	0.4	1.4	0.0	6.8	0.0	1.1	0.9	3.1	7.3	12.9	1.4	2.4
SD	10.9	7.7	31.9	1.1	44.4	0.1	1.1	263	21.4	445	3.7	0.1	0.3
Median	6.8	6.4	14.3	0.3	31.8	0.0	3.2	9.4	17.8	33	22.2	1.6	2.6

SD – standard deviation

https://doi.org/10.17221/59/2018-RAE

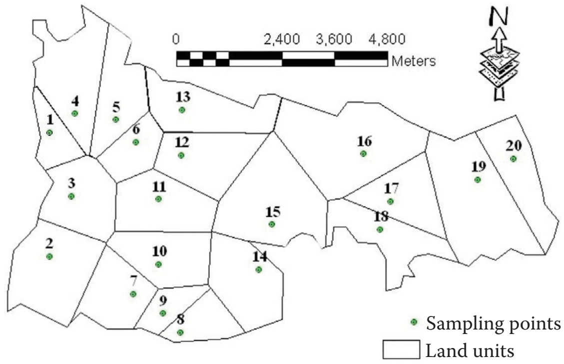

Fig. 2. Map of the land units

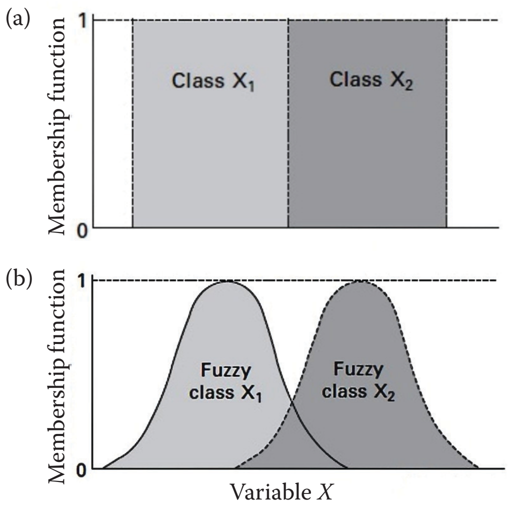

Fig. 3. Membership functions of the non-fuzzy (a) and fuzzy (b) sets; X – effective parameter

integrate the factors affecting the land evaluation. Using the factor provided in Eq. 2 and by taking γ = 0 into consideration, the effective factors were multiplied together and the final map was extracted:

$$\mu(x) = \left(\prod_{i=1}^{n} \mu_{i(x)}\right)^{\lambda} \times \left(\prod_{i=1}^{n} \mu_{i(x)}\right)^{1-\lambda} \tag{2}$$

where: x – effective parameter; μ_i – is the fuzzy membership function for factor i; λ – is the proper power to obtain the best results, which is equal to 0 based on the parametric method in this study

After the map of each factor is provided based on the values specified in the Table 2, the land evaluation index of the different points was extracted by overlaying all the obtained maps. Fig. 4 represents the diagram of the method steps.

RESULTS AND DISCUSSION

The membership function map of the parameters influencing the assessment of the irrigation systems is represented in Fig. 5. According to the fuzzy membership function, the suitable places for surface and sprinkler irrigation systems are classified between 0 (not suitable lands) and 1 (very suitable lands) which are illustrated in Figs 6a, b for the surface and sprinkler methods.

Table 2. Fuzzification of the selection parameters of the irrigation method and the factor's membership functions based on a parametric system

Effective factor	Irrigation method	Fuzzification {class x}: fuzzy value
Slope (%)	surface	{0, 3}: 0.95, {3, 6}: 0.9, {6, 16}: 0.8, {16, 30}: 0.6, {> 30}: 0.4
	sprinkler	{0, 3}: 1, {3, 16}: 0.9, {16, 30}: 0.55, {> 30}: 0.35
Drainage class	surface	{well drained}: 1, {moderately drained}: 0.8, {imperfectly drained}: 0.7, {poorly drained}: 0.6, {very poorly drained}: 0.4
	sprinkler	{well drained}: 1, {moderately drained}: 0.9, {imperfectly drained}: 0.75, {poorly drained}: 0.65, {very poorly drained}: 0.45
Textural class	surface	{clay loam}: 0.9, {silty loam}: 0.8, {sandy clay loam}: 0.85, {silty clay}: 0.9, {clay}: 0.95
	sprinkler	{clay loam}: 1, {silty loam}: 0.9, {sandy clay loam}: 0.95, {silty clay}: 0.85, {clay}: 0.85
$CaCO_3$ content (%)	surface	{< 0.3}: 0.9, {0.3, 10}: 0.95, {10, 25}: 1, {25, 50}: 0.9, {> 50}: 0.8
	sprinkler	{< 0.3}: 0.9, {0.3, 10}: 0.95, {10, 25}: 1, {25, 50}: 0.9, {> 50}: 0.8
Soil salinity ($dS \cdot m^{-1}$)	surface	{< 4}: 1, {4, 8}: 0.9, {8, 16}: 0.8, {16, 30}: 0.7, {> 30}: 0.6
	sprinkler	{< 4}: 1, {4, 8}: 0.95, {8, 16}: 0.85, {16, 30}: 0.75, {> 30}: 0.65
Soil depth (cm)	surface	{< 20}: 0.25, {20, 50}: 0.6, {50, 80}: 0.8, {80, 100}: 0.9, {> 100}: 1
	sprinkler	{< 20}: 0.3, {20, 50}: 0.65, {50, 80}: 0.85, {80, 100}: 0.95, {> 100}: 1
Suitability class	surface, sprinkler	{highly suitable}: > 0.8, {moderately suitable}: 0.6–0.8, {marginally suitable}: 0.45–0.59, {currently not suitable}: 0.3–0.44, {permanently not suitable}: < 0.29

https://doi.org/10.17221/59/2018-RAE

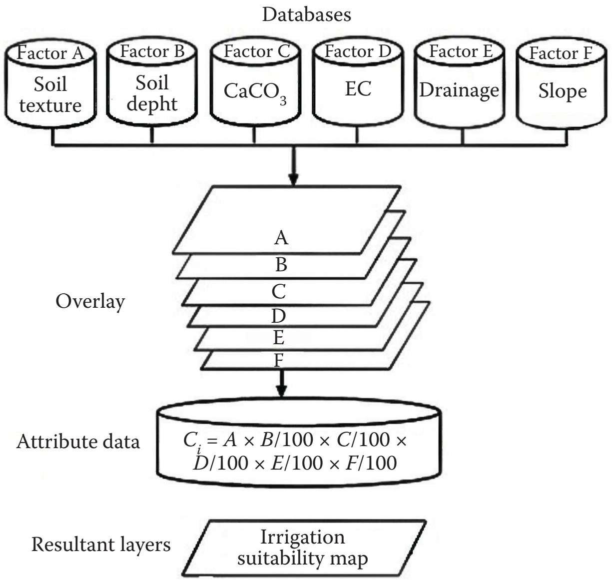

Fig. 4. Diagram of the parametric evaluation method using GIS

EC – electrical conductivity; *A*, *B*, *C*, *D*, *E*, *F* – gradation values of the soil texture, depth, lime, electrical conductivity, drainage, slope, respectively; C_i – irrigation suitability index

As specified in Figs 6a, b, in the evaluation of the land suitability for the sprinkler irrigation based on the fuzzy system, the western areas of the plain have the proper potential for implementation of the sprinkler irrigation system (Table 3), so they have S_1 suitability which is composed of an area of about 385.06 ha (7.4%). Lands with S_2 suitability consist of an area of 286.1 ha (5.5%). Moreover, the majority of the lands have S_3 suitability in an area of 2,810.08 ha (54.3%). Also, parts of the central and eastern areas of the plain have N_1 suitability consisting of an area of 1,322.88 ha (25.5%). And the central and eastern lands of the plain have N_2 suitability with an area about 370.91 ha (7.2%). Besides, based on the fuzzy evaluation for the surface method, the eastern lands of the plain are less suitable for this type of irrigation. Accordingly, lands with S_1 suitability comprise an area of 159.81 ha (3%) and lands with S_2 suitability consist of an area about 312.69 ha (6%). In addition, the northern and north-eastern lands of the plain have S_3 suitability with an area about 2,744.17 ha (53%). Some parts of the south-western and eastern lands have N_1 suitability consisting of an area of 1,746.05 ha (33.7%). In parts of the central and eastern lands of the plain, N_2 suitability can be seen which encompasses an area of 212.28 ha (4.1%). According to Figs 6a, b, the best land units for the

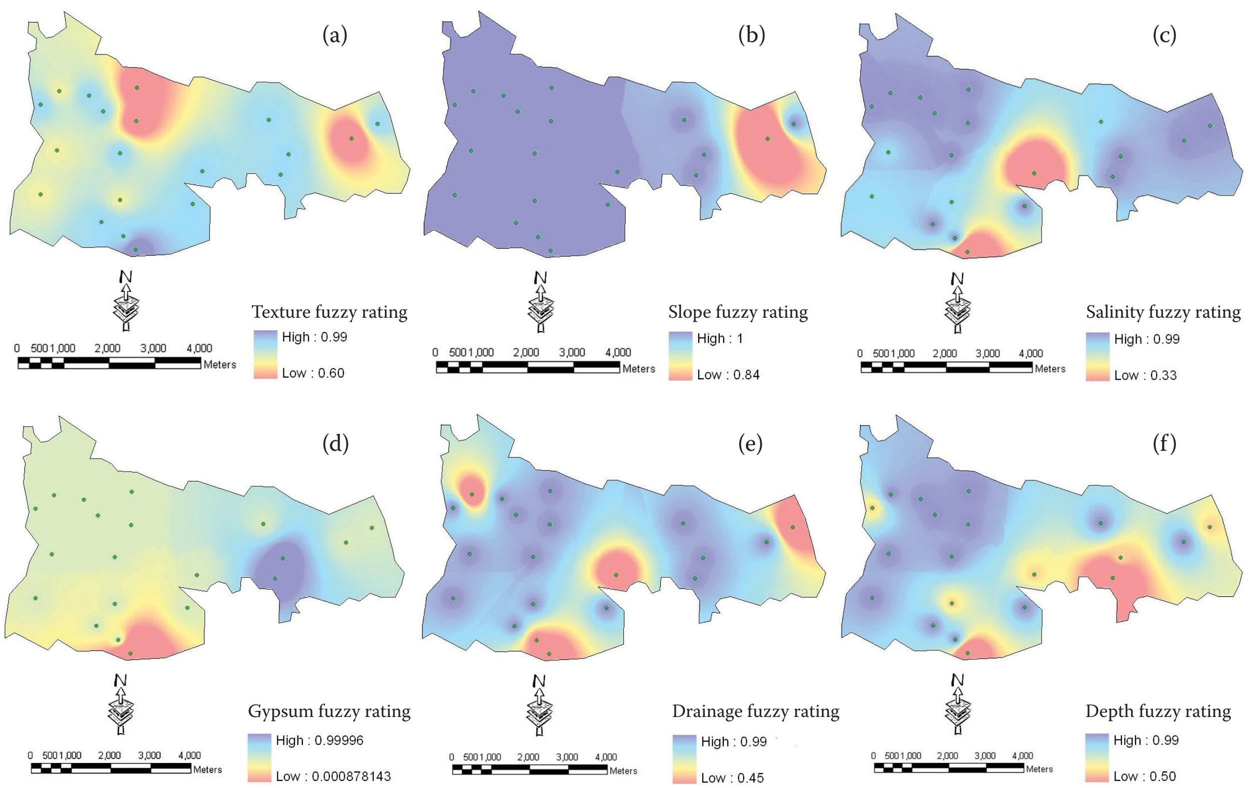

Fig. 5. Membership function map of the parameters influencing the irrigation system evaluation: soil texture (a), slope of the land (b), soil salinity (c), calcium carbonate (d), drainage condition (e), soil depth (f)

https://doi.org/10.17221/59/2018-RAE

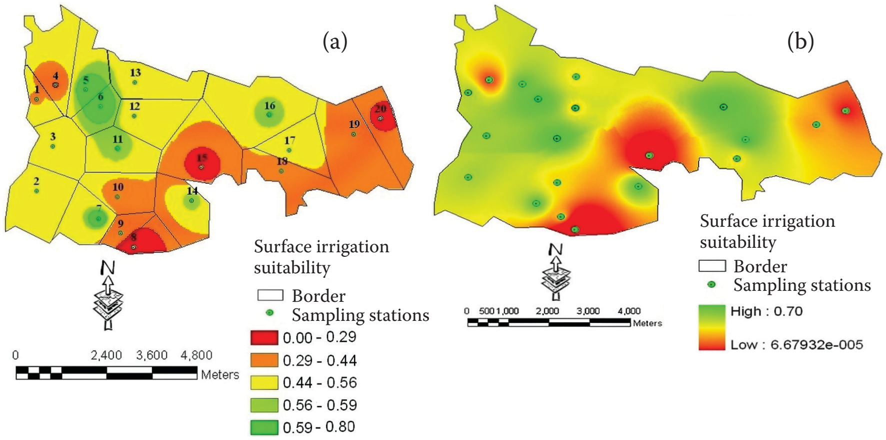

Fig. 6. Land suitability map for the surface (a), sprinkler (b) irrigation

surface and sprinkler irrigation systems based on the fuzzy system include units 5, 6and 11, in which a majority of them are located on the west side of the Fath-Ali plain. Also, parts of units 16 and 17 are considered as areas suitable for the sprinkler irrigation method. Since soil salinity, slope and drainage capability cause fewer restrictions in sprinkler irrigation systems, as illustrated in Figs 6a, b, the proportion of lands suitable for the sprinkler irrigation method based on the fuzzy system is more than 2 times greater than for the surface method. The results showed that there is a major difference between the two methods in terms of highly suitable lands, in which the area of lands highly suited for the sprinkler irrigation method is almost 2 times the size of the lands suited for the surface method, which reflects the significant difference between the land levels suited for the irrigation using the two methods. By comparing the figures related to the scores of unit 16 which is about 500 ha, it turned out that the values considered based on the parametric system have been high in all the effective parameters except for the scores related to the soil salinity and that is why this unit was considered as the highly suitable unit in the final conclusion. While, if we regard the amount of this

Table 3. The area of land suitability in the fuzzy logic evaluation method

Irrigation land suitability	Irrigation area (ha)	
	surface	sprinkle
Highly suitable (S_1)	159.81	385.03
Moderately suitable (S_2)	312.69	286.1
Marginally suitable (S_3)	2,744.17	2,810.08
Currently not suitable (N_1)	1,746.05	1,322.88
Permanently not suitable (N_2)	212.28	370.91
Sum	5,175	5,175

unit obtained from the fuzzy evaluation in Figs 6a, b, it becomes obvious that given the influence of the neighbouring units, a part of this unit acquires an average score, thus, a part of this unit area consists of marginally suitable lands. This applies to units 5, 6, 11, 14 and 7, in addition, units 7 and 14 which have especially earned average scores in the fuzzy evaluation in relation to the parameters of soil salinity and calcium carbonate. Also, the area of moderately suitable lands with the surface irrigation method is almost equal to the area of moderately suitable lands with the sprinkler method. The moderately suitable lands in the fuzzy approach are located in the vicinity of the highly suitable lands. These lands are mainly located in the vicinity of units 6, 11 and 16 and as it is clear, it seems that the fuzzy evaluation used for determining the moderately suitable lands is closer to reality. Because of this point, it seems reasonable that the moderately suitable lands are located adjacent to the highly suitable lands. Considering the gradual changes of the soil parameters in the fuzzy evaluation makes this method more accurate than the parametric technique. A number of studies conducted in this relation indicated that an evaluation using parametric methods could be as accurate as those employing fuzzy techniques (Sanchez Moreno 2007; Keshavarzi, Sarmadian 2009; Bagherzadeh, Mansouri Daneshvar 2011). These results contradict those findings in the present research. Moreover, Bagherzadeh and Gholizadeh (2016) used parametric and fuzzy methods to evaluate the lands. They showed that, although the fuzzy method was more accurate than the parametric method, the parametric method was still able to determine the land quality with suitable accuracy. This indicates that if there is a small number of limiting and influential factors, under the conditions of classifying the parameters

https://doi.org/10.17221/59/2018-RAE

by the fuzzy membership functions, the influence of these factors on the results will decrease and the results of the parametric method will become close to those of the fuzzy logic technique. In the present research, the results of the two methods were very different because there were various limiting factors in the region such as soil texture, calcium carbonate content, and soil depth. Apparently, it is better to use fuzzy techniques to estimate the capability of the lands for various irrigation practices because most agricultural soils in Iran face different limitations.

CONCLUSION

Determining the land suitability grade for various irrigation methods can improve the crop per drop in these areas. Moreover, using a fuzzy logic system to evaluate the land suitability for the irrigation can increase the accuracy of the parametric evaluation system. According to the results, there was a major difference between the highly suitable lands obtained through the fuzzy and conventional parametric methods. This showed that the fuzzy approach differed from the conventional land suitability evaluation methods such as the parametric method in its use of the calculated eigenvalues and the organisation of the criteria in the membership functions to fit the suitability problems into the framework of the decision-making. By considering the gradual changes in the soil parameters, it was shown that the fuzzy evaluation led to more accurate results compared to the parametric method. This paper also confirmed that the fuzzy approach, as a perfect method, could be useful to evaluate areas suitable for various irrigation methods, especially in areas with more restrictions.

References

Abdel Rahman M.A.E., Natarajan A., Hegde R. (2016): Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India. The Egyptian Journal of Remote Sensing and Space Sciences, 19: 125–141.

Ahmed M.A.E. (2016): Land evaluation of Gharb El-Mawhob area, El Dakhla oasis, New Valley, Egypt. [MSc Thesis.] Assiut, Assiut University.

Akbarzadeh A., Mehrjardi R.T., Rouhipour H., Gorji M., Rahimi H.G. (2009): Estimating of soil erosion covered with rolled erosion control systems using rainfall simulator (neuro-fuzzy and artificial neural network approaches). Journal of Applied Science Research, 5: 505–514.

Albaji M., Land A., Mravvej K., Broomand Nasab S. (2006): Land evaluation for irrigated agriculture for surface and sprinkle irrigation methods for the base production of Shavoor plain of Khuzestan. [MSc Thesis.] Ahvaz, Shahid Chamran University of Ahvaz. (in Persian)

Bagherzadeh A., Gholizadeh A. (2016): Modeling land suitability evaluation for wheat production by parametric and TOPSIS approaches using GIS, northeast of Iran. Modeling Earth Systems and Environment, 2: 126. doi: 10.1007/s40808-016-0177-8

Bagherzadeh A., Mansouri Daneshvar M.R. (2011): Physical land suitability evaluation for specific cereal crops using GIS at Mashhad plain, northeast of Iran. Frontiers of Agriculture in China, 5: 504–513.

Diallo M.D., Wood S.A., Diallo A., Mahatma-Saleh M., Ndiaye O., Tine A.K., Ngamb T., Guisse M., Seck S., Diop A., Guisse A. (2016): Soil suitability for the production of rice, groundnut, and cassava in the peri-urban Niayes zone, Senegal. Soil and Tillage Research, 155: 412–420.

Kebede T., Ademe Y. (2016): Evaluating land suitability for irrigation purpose in Abaya district, Borena zone, Ethiopia. African Journal of Agricultural Research, 11: 4754–4761.

Keshavarzi A., Sarmadian F. (2009): Investigation of fuzzy set theory's efficiency in land suitability assessment for irrigated wheat in Qazvin province using analytic hierarchy process (AHP) and multivariate regression methods. In: Minasny B.: Proceedings of the "Pedometrics 2009" Conference, Beijing, Aug 26–28, 2009: 38–46.

Naseri A.A., Rezania A.R., Albaji M. (2009): Investigation of soil quality for different irrigation systems in Lali plain, Iran. Journal of Food, Agriculture & Environment, 7: 955–960.

Sanchez Moreno J.F. (2007): Applicability of knowledge-based and fuzzy theory-oriented approaches to land suitability for upland rice and rubber, as compared to the farmers' perception. A case study of Lao PDR. [MSc Thesis.] Enschede, International Institute for Geo-information Science and Earth Observation.

Sys C., Van Ranst E., Debaveye J. (1991): Land Evaluation. Part I: Principles in Land Evaluation and Crop Production Calculations. Brussels, General Administration for Development Cooperation.

Valdivia-Cea W., Holzapfel E., Rivera D., Paredes G. (2017): Assessment of methods to determine soil characteristics for management and design of irrigation systems. Journal of Soil Science and Plant Nutrition, 17: 735–750.

Received for publication May 30, 2018
Accepted after corrections September 17, 2018