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Assessment of Land Capability for Different Irrigation Systems by Parametric and Fuzzy Approaches in the Mashhad Plain, Northeast Iran

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Abstract

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Water quality and quantity in agricultural systems of arid and semi- arid regions of the world are of great importance. In this regard the trend to pressurized irrigation systems compared to surface irrigation, elevating water use efficiency, has drastically increased in the agriculture sector. The present study aimed to assess land capability for different types of irrigation systems including surface, drip, and sprinkler practices by parametric and fuzzy approaches to evaluate the capability of cultivated lands on 6131 km^2 of the Mashhad Plain, Khorasan Razavi Province, northeast Iran. In this regard land qualities (drainage and slope), soil physical and chemical properties (texture, depth, salinity, drainage, calcium carbonate and gypsum percentage) and climate conditions (wind velocity) were evaluated by using the Geographic Information System (GIS). Based on parametric approach, some 1116.5 ha of the study area were classified as highly suitable (S1 class) for surface irrigation, while the corresponding values by fuzzy approach accounted for 6099.7 ha of the region. The moderately suitable class of S2, assessed by parametric and fuzzy approaches, included 5014.5 and 31.3 ha of the plain, respectively. It was revealed that the land capability indices were in higher classes (S1 to S2) by drip and sprinkler irrigation compared to the surface irrigation system and the soil texture was detected as the most limiting factor for using the surface irrigation system. With respect to current soil and climate conditions in the study area, the most efficient irrigation systems are drip and sprinkler practices.

Keywords: drip; fuzzy approach; GIS; irrigation; land capability; parametric; sprinkler; surface

Nowadays, the water crisis has made lots of problems in preparation of sufficient amounts of water for human societies all around the world. Global food security and stability strongly depend on the management of the natural resources. Today, some 40% of all world food is obtained from irrigated agricultural lands. However, food production via irrigated agriculture does not correspond to the current rapid population growth. The available water sources may not be able to meet various demands that inevitably result in the irrigation of additional lands in order to achieve a sustainable global food security. Since Iran is located in the semi-arid region of the world, the kind of the irrigation system which brings the highest crop yield is inevitable. On this basis, great capital investments over the recent years have been done to extend the new irrigation technologies such as sprinkler and drip irrigation on agricultural lands to increase water use efficiency and crop yield potential. Also, compared with the traditional surface irrigation, application of these new irrigation methods makes it possible to increase the surface area under cultivation with the same amount of water. To achieve this aim, first the resources of the land including land qualities/characteristics have to be identified and its capabilities for different kinds of irrigation methods should be determined. Land suitability, by definition, is the natural capability of a given land to support a defined use. The process of land suitability classification is the appraisal and

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grouping of specific areas of land in terms of their suitability for a defined use. According to FAO methodology (1976) land suitability is strongly related to "land qualities/characteristics" including erosion resistance, water availability, and flood hazards that are not measurable. As these qualities derive from "land characteristics" such as slope angle and length, rainfall, and soil texture, which are measurable, it is advantageous to use the latter indicators in the land suitability studies. Thus, the land parameters are used to obtain the land suitability for irrigation purposes. Sys *et al.* (1991) suggested a parametric evaluation approach for irrigation methods which was primarily based upon physical and chemical soil properties. In their proposed system, the factors affecting soil suitability for irrigation purposes can be subdivided into four groups:

– Physical properties determining the soil-water relationship including soil texture, gravel percentage, and soil depth;
– Chemical properties interfering with the salinity/alkalinity status such as soluble salts and exchangeable sodium percentage as well as calcium carbonate and gypsum content of the soil;
– Land terrain factors such as slope and drainage properties;
– Climate characteristics including wind velocity affecting sprinkler irrigation.

With respect to Sys's parametric evaluation approach, many researchers have studied land suitability evaluation for different types of irrigation all around the world. Among them, Briza *et al.* (2001) evaluating land suitability for surface and drip irrigation in the Ben Slimane Province, Morocco, found that the most limiting factors are soil physical parameters, which results in marginal suitability for both irrigation systems. Bazzani and Incerti (2002) provided a land suitability evaluation for surface and drip irrigation systems in the province of Larche, Morocco. Their results showed a large difference between applying the two irrigation systems. Bienvenue *et al.* (2003) evaluated land suitability for surface and drip irrigation in Thies, Senegal. It was shown that the most limiting factors were soil drainage and texture which resulted in S2 to N2 classes regarding the type of the irrigation system. Mbodj *et al.* (2004) performed a land suitability evaluation for two types of irrigation, i.e. surface irrigation and drip irrigation, in the Tunisian Oued Rmel Catchment. According to their results, the drip irrigation showed more suitability compared to the surface irrigation practice due to the topographic, soil, and drainage limitations encountered with in the surface irrigation. Dengize (2006) also compared different irrigation methods including surface and drip irrigation in the pilot fields of the Central Research Institute, south of Ankara, Turkey. He concluded that the drip irrigation method increased land suitability by 38% compared to the surface irrigation method. The most important limiting factors for surface irrigation in the study area were soil salinity, drainage, and soil texture, whereas the major limiting factors for drip or localized irrigation were soil salinity and drainage. Liu *et al.* (2006) evaluated land suitability for surface and drip irrigation in the Danling County, Sichuan Province, China. They found that in the study area drip irrigation was more suitable than surface irrigation due to minor environmental impacts. Albaji *et al.* (2008) carried out a land suitability evaluation for surface and drip irrigation in the Shavoor Plain, Khuzestan Province, southwest of Iran. They showed that the study area was not suitable for either irrigation system due to high soil salinity and weak drainage. Albaji *et al.* (2010) investigated different irrigation methods based on parametric approach in the Abbas Plain, Ilam Province, west of Iran. Comparisons of different types of irrigation systems revealed that sprinkler and drip irrigation were more effective and efficient than surface irrigation for improving land productivity, however the main limiting factors by using sprinkler/drip and surface irrigation in the study area were soil calcium carbonate content and drainage. The aim of the present study is to evaluate land capability for different types of irrigation systems in order to verify the possible effects of different management practices by parametric and fuzzy logic approaches and compare the performances of the two models by using GIS in the Mashhad Plain, Khorasan Razavi Province, northeast of Iran.

MATERIAL AND METHODS

General characteristics of the study area. The present study was conducted in the Mashhad Plain with an area of 6131 km^2, Khorasan Razavi Province, northeast Iran (Figure 1). The study area stretches between latitude 35°59'N to 37°04'N and longitude 58°22'E to 60°07'E including lands less than 1500 m a.s.l. The general physiographic trend of the plain is NW–SE (average length 160 km) and the plain is surrounded by two mountainous zones, Kopet-Dagh in the north and Binaloud in the south (based on

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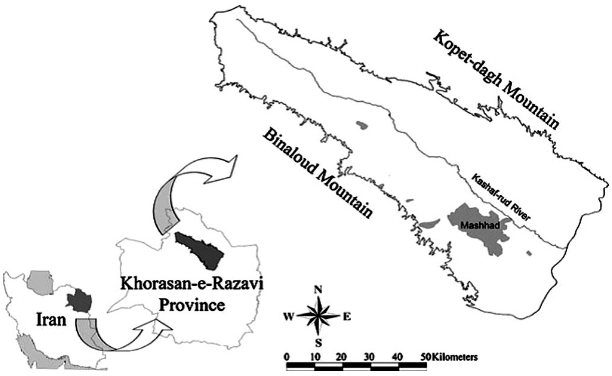

Figure 1. Location and geographical position of the study area

visual interpretation of the satellite image and field observations) (Figure 2). The topographical elevation values of the study area range between 900 m and 1500 m a.s.l., while the main topographical elevation reaches over 1200 m a.s.l. Geologically, the main alluvial nature of the plain has developed into a thick sediment dominated environment belonging to the Quaternary period. The main soil textures are loam, sandy loam, and sandy clay loam. The dominant soil types include Calcaric Cambisols, Gypsic Regosols, Calcaric Regosols, and Calcaric Fluvisols which cover pediment plains, plateaus, upper terraces, and gravelly colluvial fans, respectively. In order to have confident soil data at the study area, 28 soil profiles were investigated. The soil orders were classified based on the USDA classification system (USDA 2003) as Aridisols and Entisols. The main land use practiced at the study area is irrigated farming around the Kashaf-roud River, with a semi-arid climate, mean annual precipitation of 222.1 mm, and mean annual temperature of 15.8°C. The rainiest month is March (44.8 mm) and the driest month is September (1.2 mm).

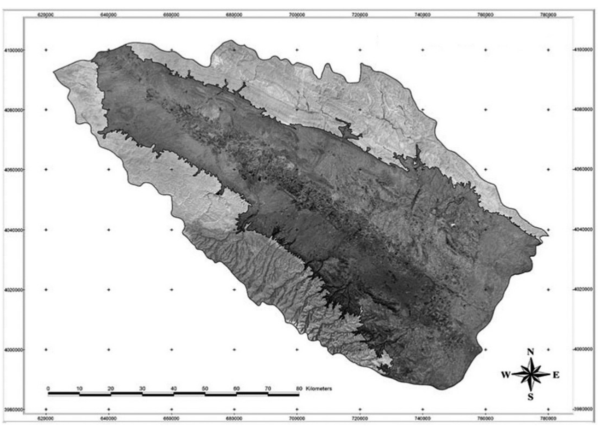

Figure 2. Satellite image of the study area

Parametric approach. The land suitability evaluation in this model is based on determining land qualities/characteristics including soil physical properties (soil texture, gravel percentage, and depth), soil chemical properties (calcium carbonate and gypsum content, soil salinity and alkalinity), and land terrain (slope and drainage) as well as climate characteristics including wind velocity affecting sprinkler irrigation. Based on morphological and physico-chemical properties of soil profiles some 41 land units were identified in the study area. For determining the mean values of the soil physical, chemical, and terrain parameters for the upper 1 m of the soil depth, the profile was subdivided into 4 equal sections and weighting factors of 1.75, 1.25, 0.75, and 0.25 were attributed for each section, respectively (Sys *et al.* 1991).

Estimating land capability index. The proposed method is a parametric approach developed by author to estimate the land capability index in order to overcome the limitations of classical methods such as Storie and Square Root. Based on this method the capability index of each land unit is calculated by multiplying the geometrical mean value of the scores given to each land quality/characteristic as well as climate for sprinkler irrigation in the interaction of the square root values of scores according to the following formula:

$$LI = \prod_{i=1}^{n} x_i^{\left(\frac{1}{n}\right)} \times \sqrt[n]{\frac{\prod_{i=1}^{n} x_i}{100^n}} \quad (1)$$

where:
LI – land index
x – score given to each land quality/characteristics
n – number of land qualities/characteristics

Tables 1 and 2 show the ranges of land capability indices and the corresponding suitability classes both in parametric and fuzzy logic approaches.

Fuzzy set approach. The Fuzzy set theory (Zadeh 1965) is a body of concepts and a technique that gives a form of mathematical precision to human thought processes that are imprecise and ambiguous in many ways. At the present study, we considered the fuzzy approach on the singleton fuzzifier, centroid defuzzifier, and Mamdani minimum inference engine (Matlab R2012a software). The block diagram of the fuzzy system (Wang 1997) is given in Figure 3. Accordingly, the application of the fuzzy set theory to determine the impact of land qualities on irrigating sugar beet comprises several steps:

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Table 1. Values of land capability indices and capability classes based on parametric approach for irrigation systems

Capability class	Definition	Capability index
S1	highly suitable	75–100
S2	moderately suitable	50–75
S3	marginally suitable	25–50
N1	currently unsuitable	12.5–25
N2	permanently unsuitable	0–12.5

– Defining the inputs and output of the fuzzy system;
– Determination of membership functions;
– Determination of membership values;
– Determination of reference weight and reference suitability matrices;
– Determination of weight values for different land qualities;
– Determination of fuzzy If and Then rules.

In this study the membership function was defined as Kandel extension membership function:

$$\mathrm{MF} = \frac{1}{\left\{1 + \left(\dfrac{Z(x) - b_1 - d_1}{d_1}\right)\right\}} \quad \text{If } Z(x) < b_1 + d_1$$

$$\mathrm{MF} = 1 \quad \text{If } b_1 + d_1 \leq Z(x) \leq b_2 - d_2 \qquad (2)$$

$$\mathrm{MF} = \frac{1}{\left\{1 + \left(\dfrac{Z(x) - b_2 - d_2}{d_1}\right)\right\}} \quad \text{If } Z(x) > b_2 - d_2$$

where:

MF – membership function
$Z(x)$ – value of the parameter
b_1, b_2 – lower and upper limits
d_1, d_2 – width of transition regions

Table 2. Values of land capability indices and capability classes based on fuzzy logic approach for irrigation systems

Capability class	Definition	Capability index
S1-1	highly suitable	91.67–100
S1-2	highly suitable	75–91.67
S2	moderately suitable	58.3375
S3	marginally suitable	41.67–58.33
N1	currently unsuitable	25–41.67
N2-1	permanently unsuitable	8.33–25
N2-2	permanently unsuitable	0–8.33

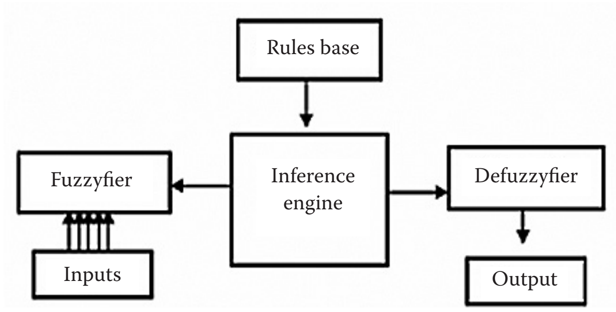

Figure 3. Block diagram of the fuzzy system

RESULTS AND DISCUSSION

Parametric approach in determining land capability index. The values of land capability indices for surface irrigation at the study area ranged from 59.53 to 84.03. The most important land limiting qualities/characteristics for surface irrigation system at the study area are land terrain properties, which resulted in moderate capability class (S2) with 81.79% to non-limiting capability class (S1) with 18.3% of the surface area, respectively (Table 3). The geographic distribution of capability classes for surface irrigation at the study area revealed that the areas with moderate limitations (S2 class) extensively expanded in the

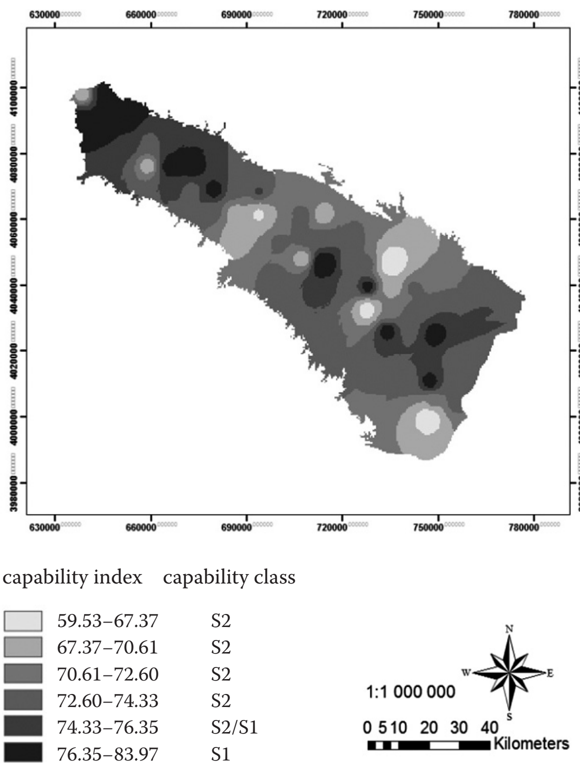

Figure 4. Zonation of land capability for surface irrigation by parametric approach in the Mashhad Plain

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Table 3. The values of capability indices and capability classes for different irrigation methods by parametric approach in the Mashhad-Chenaran Plain

Land unit	Surface irrigation		Drip irrigation		Sprinkler irrigation	
	capability index	capability class	capability index	capability class	capability index	capability class
1	71.00	S2	78.96	S2	74.55	S2
2	73.38	S2	81.61	S1	76.98	S2
3	68.58	S2	76.26	S2	72.07	S2
4	78.52	S2	80.96	S1	76.38	S2
5	63.58	S2	70.70	S2	66.96	S2
6	73.38	S2	81.61	S1	76.98	S2
7	71.00	S2	73.20	S2	69.26	S2
8	61.64	S2	67.87	S2	64.34	S2
9	73.38	S2	75.66	S2	71.51	S2
10	78.52	S2	84.49	S1	79.62	S1
11	73.38	S2	75.66	S2	71.51	S2
12	73.38	S2	75.66	S2	71.51	S2
13	78.52	S2	84.49	S1	79.62	S1
14	78.52	S2	84.49	S1	79.62	S1
15	73.38	S2	75.66	S2	71.51	S2
16	73.38	S2	75.66	S2	71.51	S2
17	73.38	S2	75.66	S2	71.51	S2
18	75.98	S2	84.49	S1	79.62	S1
19	67.58	S2	84.49	S1	79.62	S1
20	84.03	S1	90.42	S1	85.04	S1
21	73.38	S2	75.66	S2	71.51	S2
22	73.38	S2	75.66	S2	71.51	S2
23	59.53	S3	65.55	S2	62.20	S2
24	73.38	S2	75.66	S2	71.51	S2
25	68.17	S2	78.33	S2	73.97	S2
26	73.38	S2	78.96	S2	74.55	S2
27	73.38	S2	75.66	S2	71.51	S2
28	73.38	S2	75.66	S2	71.51	S2
29	73.38	S2	81.61	S1	76.98	S2
30	73.38	S2	81.61	S1	76.98	S2
31	68.58	S2	73.07	S2	69.14	S2
32	78.52	S2	84.49	S1	79.62	S1
33	73.38	S2	75.66	S2	71.51	S2
34	73.38	S2	75.66	S2	71.51	S2
35	78.52	S2	87.33	S1	82.22	S1
36	66.10	S2	73.51	S2	69.54	S2
37	68.03	S2	73.20	S2	69.26	S2
38	74.73	S2	87.48	S1	82.36	S1
39	73.38	S2	81.61	S1	76.98	S2
40	73.38	S2	78.96	S2	74.55	S2
41	68.17	S2	78.33	S2	73.97	S2
42	78.52	S2	84.49	S1	79.62	S1
43	68.58	S2	70.70	S2	66.96	S2
44	78.52	S2	84.49	S2	79.62	S1
45	78.52	S2	84.49	S2	79.62	S1
46	75.98	S2	84.49	S2	79.62	S1
47	78.52	S2	84.49	S2	79.62	S1
48	78.52	S2	84.49	S2	79.62	S1
49	78.52	S2	84.49	S2	79.62	S1

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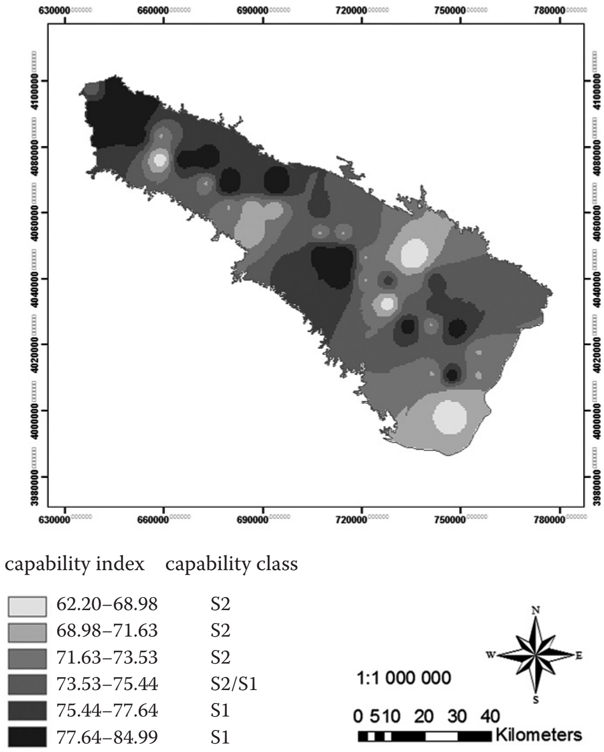

Figure 5. Zonation of land capability for sprinkler irrigation by parametric approach in the Mashhad Plain

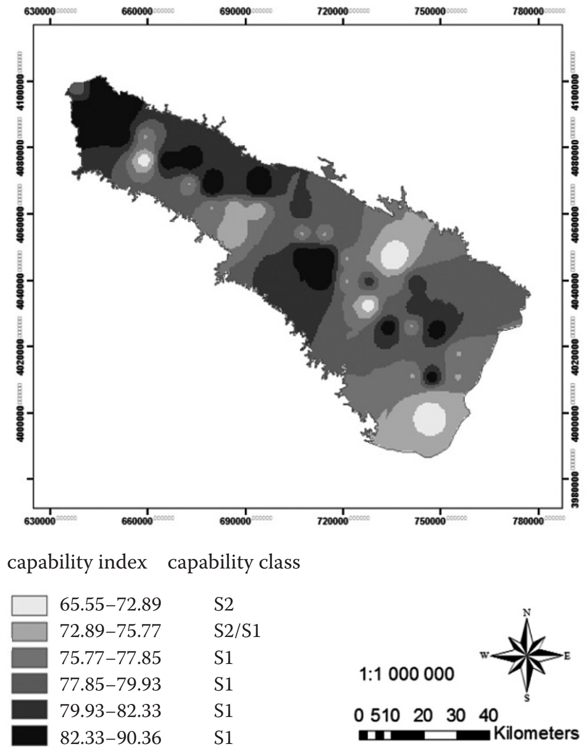

Figure 6. Zonation of land capability for drip irrigation by parametric approach in the Mashhad Plain

southeast and scattered parts in the middle of the plain, while the areas considered as highly suitable (S1 class) are located mainly in the northwest with vast areas also in the middle of the plain (Figure 4). The values of land capabilities for drip and sprinkler irrigation by parametric approach ranged from 65.55 and 62.20 to 90.42 and 85.04, respectively (Table 3). The analyses of land capability indices for drip and sprinkler irrigations indicate that great parts in the north, northwest, middle, and south of the plain are considered highly suitable (S1) due to deep soil, good drainage, soil texture, salinity, and proper slope, which resulted in 90.9% and 37.84% of the surface area. Accordingly, the moderate capability class (S2) with some soil texture and drainage limitations, accounts for 9.1% and 62.16% of the study area scattered mainly in the centre and southeast (Figures 5, 6).

Fuzzy approach in determining land capability index. The values of land capabilities for surface irrigation by fuzzy approach varied between 73.5 and 82.6, which resulted in moderate (S2) to high suitability (S1) classes (Table 4). The soil calcium carbonate content was found to be the major limitation for this practice. The map of land capability for surface irrigation (Figure 7) shows that 99.49% of the study area has

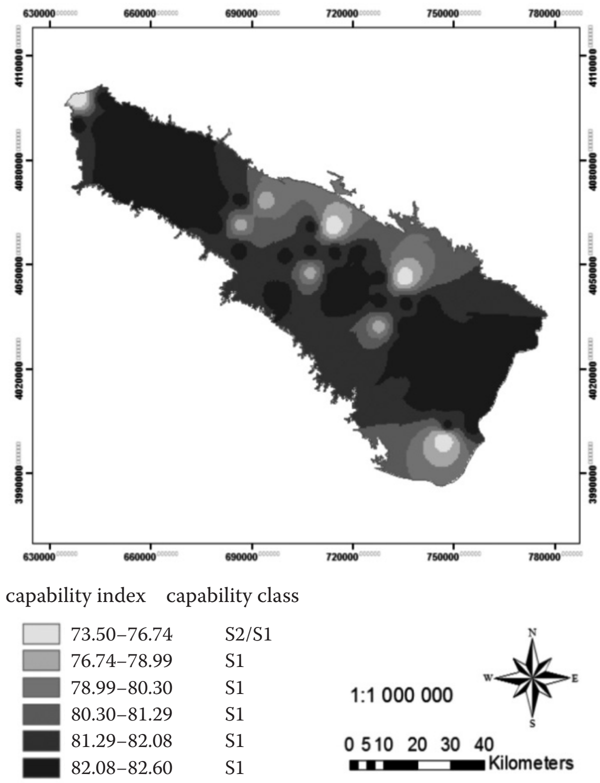

Figure 7. Zonation of land capability for surface irrigation by fuzzy logic approach in the Mashhad Plain

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Table 4. Values of capability indices and capability classes for different irrigation methods by fuzzy logic approach in the Mashhad-Chenaran Plain

Land unit	Surface irrigation		Drip irrigation		Sprinkler irrigation	
	capability index	capability class	capability index	capability class	capability index	capability class
1	82.6	S1	86.5	S1	86.5	S1
2	82.6	S1	86.5	S1	86.5	S1
3	82.6	S1	86.5	S1	86.5	S1
4	82.6	S1	82.6	S1	82.6	S1
5	77.9	S2	83.2	S1	83.2	S1
6	82.6	S1	86.5	S1	86.5	S1
7	82.6	S1	83.2	S1	83.2	S1
8	73.5	S2	82.6	S1	82.6	S1
9	82.6	S1	82.6	S1	82.6	S1
10	82.6	S1	86.5	S1	86.5	S1
11	82.6	S1	82.6	S1	82.6	S1
12	82.6	S1	82.6	S1	82.6	S1
13	82.6	S1	86.5	S1	86.5	S1
14	82.6	S1	86.5	S1	86.5	S1
15	82.6	S1	82.6	S1	82.6	S1
16	82.6	S1	82.6	S1	82.6	S1
17	82.6	S1	82.6	S1	82.6	S1
18	82.6	S1	86.5	S1	86.5	S1
19	77.9	S2	86.5	S1	86.5	S1
20	82.6	S1	89.8	S1	86.5	S1
21	82.6	S1	82.6	S1	82.6	S1
22	82.6	S1	82.6	S1	82.6	S1
23	73.5	S2	82.6	S1	82.6	S1
24	82.6	S1	82.6	S1	82.6	S1
25	73.5	S2	82.6	S1	82.6	S1
26	82.6	S1	86.5	S1	86.5	S1
27	82.6	S1	82.6	S1	82.6	S1
28	82.6	S1	82.6	S1	82.6	S1
29	82.6	S1	86.5	S1	86.5	S1
30	82.6	S1	86.5	S1	86.5	S1
31	82.6	S1	82.6	S1	82.6	S1
32	82.6	S1	86.5	S1	86.5	S1
33	82.6	S1	82.6	S1	82.6	S1
34	82.6	S1	82.6	S1	82.6	S1
35	82.6	S1	86.5	S1	86.5	S1
36	80.7	S1	83.3	S1	83.3	S1
37	77.9	S2	83.2	S1	83.2	S1
38	77.9	S2	86.5	S1	86.5	S1
39	82.6	S1	86.5	S1	86.5	S1
40	82.6	S1	86.5	S1	86.5	S1
41	73.5	S2	82.6	S1	82.6	S1
42	82.6	S1	86.5	S1	86.5	S1
43	82.6	S1	83.2	S1	83.2	S1
44	82.6	S1	86.5	S1	86.5	S1
45	82.6	S1	86.5	S1	86.5	S1
46	82.6	S1	86.5	S1	86.5	S1
47	82.6	S1	86.5	S1	86.5	S1
48	82.6	S1	86.5	S1	86.5	S1
49	82.6	S1	86.5	S1	86.5	S1

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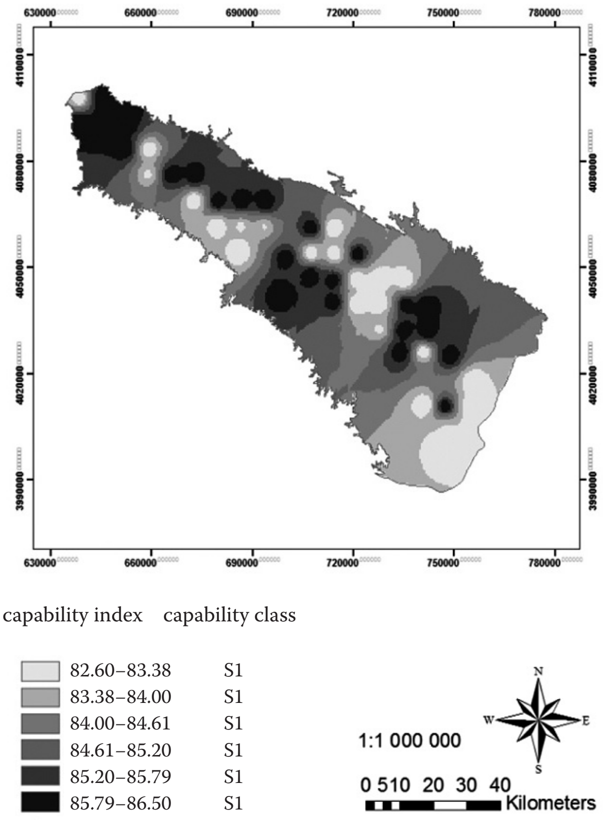

Figure 8. Zonation of land capability for sprinkler irrigation by fuzzy logic approach in the Mashhad Plain

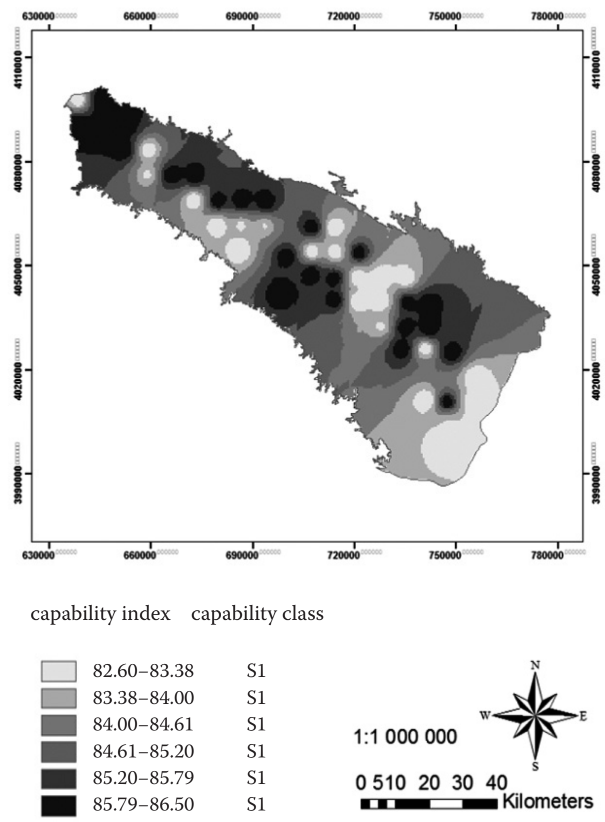

Figure 9. Zonation of land capability for drip irrigation by fuzzy logic approach in the Mashhad Plain

high capability (S1 class) and the rest accounts for moderate suitability (S2 class). Regarding sprinkler and drip irrigations, the values of land capabilities ranged from 82.6 mainly in the southeast and scattered parts along the plain to 86.5 nd 89.8, distributed in most parts of the study area (Table 4).The zonation of land capabilities for sprinkler and drip irrigations revealed that the whole plain is currently highly suitable (S1 class) for both practices (Figures 8 and 9). The values of land capabilities obtained from parametric and fuzzy logic approaches were compared using the coefficient of determination (R^2) defined by Nash and Sutcliffe (1970):

$$R^2 = 1 - \frac{[\sum_{i=1}^{n}((CI_{\text{fuzzy}}) - (CI_{\text{parametric}}))^2]}{[\sum_{i=1}^{n}(CI_{\text{fuzzy}}) - (CI_{\text{parametric}})^2]} \quad (3)$$

where:

CI_{fuzzy}, $CI_{\text{parametric}}$ – capability indexes by fuzzy and parametric approaches, respectively

The coefficient of determination (R^2) estimated from the above formula for surface irrigation was $R^2 = 0.976$, while the corresponding values for sprinkler and drip practices accounted for 0.977 and 0.970, which demonstrates a high correlation between the observed land index values from the two approaches.

CONCLUSION

It was revealed that the values of land capability index by applying drip and sprinkler irrigation systems were in higher classes (S1 to S2) compared to the surface irrigation system. The soil texture was detected as the most limiting factor by using the surface irrigation system. According to parametric approach, some 1116.5 ha of the study area were classified as highly suitable (S1 class) for surface irrigation, in contrast to 6099.7 ha of the region determined by the fuzzy approach. Also, the moderately suitable class (S2) determined by parametric and fuzzy approaches includes 5014.5 and 31.3 ha of the plain, respectively. Since the water supplies in the study area are limited, it is essential to use pressurized irrigation systems to increase water use efficiency in irrigated lands.

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References

Albaji M., Landi A., Boroomand Nasab S., Moravej K. (2008): Land suitability evaluation for surface and drip irrigation in Shavoor Plain Iran. Journal of Applied Sciences, 8: 654–659.

Albaji M., Boroomand Nasab S., Naseri A.A., Jafari S. (2010): Comparison of different irrigation methods based on the parametric evaluation approach in Abbas plain – Iran. Journal of Irrigation and Drainage Engineering, 136: 131–136.

Bazzani F., Incerti F. (2002): Land evaluation in the province of Larache, Morocco. In: 22nd Course Professional Master, Geomatics and Natural Resources Evaluation, Nov 12, 2001–June 21, 2002, IAO, Florence. Available at http://www.iao.florence.it/training/geomatics/Larache/Morocco_22.pdf

Bienvenue J.S., Ngardeta M., Mamadou K. (2003): Land evaluation in the province of Thies, Senegal. In: 23rd Course Professional Master, Geomatics and Natural Resources Evaluation, Nov 8, 2002–June 20, 2003, IAO, Florence. Available at http://www.iao.florence.it/training/geomatics/Thies/senegal23.pdf

Briza Y., Dileonardo F., Spisni A. (2001): Land evaluation in the province of Ben Slimane, Morocco. In: 21st Course Professional Master, Remote Sensing and Natural Resource Evaluation, Nov 10, 2000–June 22, 2001, IAO, Florence. Available at http://www.iao.florence.it/training/geomatics/BenSlimane/Marocco21.pdf.

Dengize O. (2006): A comparison of different irrigation methods based on the parametric evaluation approach. Turkish Journal of Agriculture and Forestry, 30: 21–29.

FAO (1976): A Framework for Land Evaluation. FAO Soil Bulletin 32. Rome, FAO.

Liu W., Qin Y., Vital L. (2006): Land evaluation in Danling county, Sichuan province, China. In: 26th Course Professional Master, Geomatics and Natural Resources Evaluation, Nov 7, 2005–June 23, 2006, IAO, Florence. Available at http://www.iao.florence.it/training/geomatics/Danling/China_26.pdf

Mbodj C., Mahjoub I., Sghaiev N. (2004): Land evaluation in the Oued Rmel catchment, Tunisia. In: 24th Course Professional Master, Geomatics and Natural Resources Evaluation, Nov 10, 2003–June 23, 2004, IAO, Florence. Available at http:// www.iao.florence.it/training/geomatics/Zaghouan/Tunisia_24lq.pdf

Nash J.E., Sutcliffe J.V. (1970): River flow forecasting through conceptual models, part I: A discussion of principles. Journal of Hydrology, 10: 282–290.

Sys C., Van Ranst E., Debaveye J. (1991): Land Evaluation, Part l, Principles in Land Evaluation and Crop Production Calculations. International Training Centre for Postgraduate Soil Scientists, University Ghent. Available at http://www.plr.ugent.be/publicatie.html

Wang L.X. (1997): A Course in Fuzzy Systems and Control. New York, Prentice Hall.

Zadeh L.A. (1965): Fuzzy sets. Information and Control, 8: 338–353.

USDA (2003): Keys to Soil Taxonomy. 9th Ed. Washington, D.C., Soil Survey Staff, USDA.

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