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Land Suitability Analysis for Wheat Using Multicriteria Evalution and GIS Method

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Abstract: The aim in integrating multi-criteria evaluation with Geographical Information Systems (GIS) is to provide more flexible and more accurate decisions to the decision makers in order to valuate the effective factors. A GIS has been used to match the suitability for wheat crop based on the requirements of the crop and the quality and characteristics of land. The methodology used for the physical land suitability analysis for wheat is a multi-criteria evaluation approach within GIS context. This study, land suitability evaluation based on FAO has been determined for wheat irrigated area about 5400 ha, the South of plains Damghan. The study was carried out by overlapping all individual maps (soil map units, soil depth map, slope map, texture soil map and soil fertility) with GIS techniques for physical land suitability classification. The results show that 21.94% of the area is moderately suitable (S3) and 9.40 not suitable (N1) and 68.66% severe limitations and unchangeable (N2) for wheat crop. Lack of irrigation suitable water, Exchange Sodium Percent (ESP) and salinity (EC), insufficient rainfall and poor soil fertility are the most serious problems influencing yield and quality of wheat.

Key words: Land suitability, wheat, climate, soil, GIS, multicriteria evalution

INTRODUCTION

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. The advent of modern GIS and remote sensing technologies opened the door to the wide application of quantitative and qualitative evaluation methods. Land can be evaluated on different levels from the fine one to guide land management in the context of precision agriculture to the more course classifications to inform regional land use planning and allocation (Franzen *et al*., 2006). Recently methodologies are being developed to facilitate and streamline the process of evaluation (Van Lanen *et al*., 1992; Ghaffari *et al*., 2000). These methodologies should be based on sound ecological principles and also take into account the availability of data.

They should preferably be underpinned be generally accepted framework and yet be flexible enough to accommodate for local differences on ecological, environmental and social conditions. Thus instead of collecting large amounts of ground data, efforts should prioritize on the search for the ways to utilize the available data. It is apparent that the accomplishment of almost any project aimed at land resources planning may be greatly facilitated by the use of and efficient GIS (Dragan *et al*., 2003). The main aim of this study was to identify, the suitable land parcels for a production wheat in the Damghan plain. The objectives include identification of suitability criteria for a production wheat and compilation of the information in GIS for further analysis.

MATERIALS AND METHODS

Study area: The study area chosen is Damghan plain in Iran at approximately 54°21'56.73"E, 54°27'24.13"E, 36°02'31.63" and 36°08'28.53" N and covers an area of 5400 ha. Base map is selected from topographic map with 1:50,000 scale. It falls in drought-prone region of Semnan, Iran. The Damghan is located in desert margins and plant has some difficulties. The study area soils are new alluvial sediments in the 4th period of geology and parent material in the Northern and Western of plain are sediments mixed with sand and gravel. Figure 1 shows schema of the Damghan plain in Iran map.

Methodology: The methodology used for the physical land suitability analysis is a multi-criteria evaluation based on FAO land evaluation framework (FAO, 1976, 1985). The methodology consists on matching soil/land qualities against wheat needs and assigning a suitability rating to each land characteristic. In order to develop, a set of themes for evaluation and ultimately to produce a

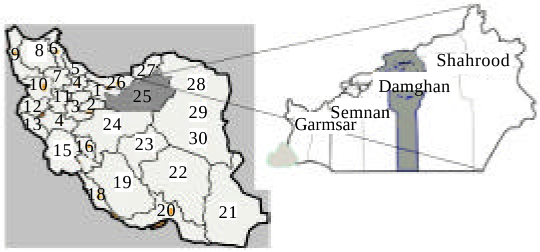

Fig. 1: The schema of the evaluation of the study area

Table 1: Determine classes of land suitability for FAO methods

Order	Class	Description
Suitable (S)	S1: (Highly suitable)	Land having not insignificant limitations
	S2: (Moderately suitable)	Land having minor limitations
	S3: (Marginally suitable)	Land having moderate limitations
Suitable (N)	N1: (Permanently unsuitable)	Land that have so severe limitations that are very not suitable (N) difficult to be overcome
	N2: (Permanently unsuitable)	Land that have so severe limitations that are very difficult to be overcome

suitability map for Damghan Plain, the crop requirement in terms of land qualities was reviewed (Sys *et al*., 1993). Determine classes of land suitability for a plant based fitness indicators obtained from the Table 1. Classes are divided into subclasses which indicate the nature of the limitations that make the land less than completely suitable. The subclass code contains a suffix which indicates the nature of the limitations, e.g., S3w-subclass of land marginally uitable (S3) because of the excessive wetness.

The divisions of subclasses are suitability units which while having the same degree and general kind of limitation have different anagement requirements. The actual classification is made by mapping and analyzing a set of diagnostic land characteristics that pertain to appropriate land qualities. The actual classification is made by mapping and analyzing a set of diagnostic land characteristics that pertain to appropriate land qualities. A set of data was selected and preprocessed to characterize spatially these land qualities. Detail scale (1:50,000) topographical maps for study area were digitized and interpolated in Arc GIS to produce correct Digital Elevation Models (DEM). Basic concepts in land suitability assessment in Multi Criteria Evaluation (MCE) has expressed by four steps following (Malczewski, 1999):

Factors: Factor is a general category of information concerning the site being evaluated. The factors often considered in land suitability studies include natural environment factors (slope, soil type, geologic hazards present, land cover, etc.).

Rating: Rating is an evaluation usually expressed in numerical terms of how suitable a site is supporting a specific land use. Numeric scores to a total of ten (one as least and ten as most suitable) are assigned to each factor attribute class (classification of factor attribute classes used in assessing site suitability for residential land application).

Comparisons between classes were based on their level of suitability with respect to residential land use. Since, environment factors for each specific study areas are different with others, there is no uniform standard for rating factors. In parametric approach, the researchers always rated the factors based on the situation of study area, review of literatures and suggestion from experts (Table 2).

Weight: Weighting in suitability analysis refers to assigning a numeric value to each factor in order to recognize its relative importance and usually expresses in percent format (Pease *et al*., 1996). A set of weights are usually used to represent the relative importance of parameters and normalized to a constant as; the weight value for the suitability of one factor used in this research was based on interpretation of published materials as well as several experts. Table 3 shows values of rating and weight for each influencing factor on wheat growth.

Score: Score is the numerical total of the calculated land suitability when the ratings and weights for all factors are considered. As described by Eastman and Labs (1999) and Pereira and Duckstein (1993), each thematic layer represented an evaluation criterion and grid cells were valued according to their quality for a particular land use. The first step, initially suitability class value and weight are assigned to individual land characteristic and then calculated the suitability score. The score for an individual site is used as a basis for comparing its suitability with other sites.

The information collection includes the data collection, literature information collection and expert knowledge collection. Based on the classification of suitability each factor has been divided into five classes from highly suitable to permanently not suitable. On the other hand, the available data are gathered together for transformed into digital format. The weight and value of factors should be identified 1st for calculating the suitability score for each land unit. The suitability map presents, the result of the construction land suitability assessment in terms of the land unit suitability scores. In this study, land suitability assessment is done by the following equation:

$$S = \sum_{jiWjiXji}$$

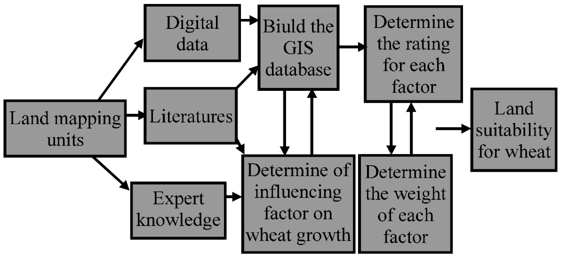

Fig. 2: Process of land suitability evaluation in this study

S = Suitability index (score)
wi = Weight of criterion i
Ri = Rating of criterion i

Figure 2 shows process of land suitability evaluation in this study.

RESULTS

With regarding to results obtained from description of soil profiles and physical and chemical analysis of soil samples (Table 3 and 4) soils were classified as Entisols and Aridisols on the basis of soil taxonomy system 2006. In study area, two order, three family, nine soil series and two physiogrphy were identified (Table 5). The cycle of wheat growth in study area is shown in Table 6. Table 6 shows that wheat growth cycle in Damghan plain starts from 1 Nov to 21 Jun. Table 7 shows the qualitative land suitability results for wheat plant. Table 7 shows the range of classes in different land units according to Multicriteria Evaluation and GIS method that are S_3-N_2. Evaluating the land suitability using Multicriteria evaluation and GIS method indicated that two units of separated units were marginal suitable (S_3) and 1 unit was

Table 2: The determine of rating and weight for each factor

Ceriteria	Lime	Gypsum	Fertility (pH)	EC (Salinity)	ESP (Alkalinity)	Rainfall	Temperature
Weight	0.118	0.01	0.06	0.33	0.12	0.13	0.03
Rating	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9
Ceriteria	Slop	Dranage	Soil physics	Surface stoniness	Gravel	Soil depth	
Weight	0.002	0.04	0.1	0.02	0.02	0.02	
Rating	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9	1.5,7,9	

Table 3: Some physico-chemical properties of representative pedons

Pedons	Depth (cm)	Sand	Silt	Clay	Sp	Ec	pH	C (%)	$CaCo_3$	$CaSo_4$	Esp
Ap	0-30	70.00	25.00	5.00	22	8.0	7.70	0.30	20.00	0.0	16.0
C1	30-65	58.00	32.00	10.00	28	7.0	7.90	0.40	22.00	0.0	18.0
C2	65-95	56.00	30.00	14.00	33	9.5	7.55	0.05	21.00	0.0	13.0
C3	95-130	50.00	25.00	25.00	34	9.0	8.00	0.03	18.00	0.0	17.0
Ap	0-20	58.00	30.00	14.00	19	10.0	7.71	0.45	14.70	5.0	9.0
C1	20-58	52.80	29.60	17.60	25	8.0	7.50	0.30	16.00	3.0	10.0
C2	58-95	53.00	28.00	19.00	27	8.5	7.55	0.10	14.50	0.0	12.0
C3	95-130	56.00	30.00	14.00	32	7.0	7.60	0.10	13.00	0.0	15.0
Ap	0-25	60.00	26.00	14.00	27	19.0	8.10	0.40	25.00	2.0	20.0
C1	25-60	58.00	34.00	8.00	32	15.0	8.15	0.03	29.00	0.0	23.0
C2	60-95	56.00	30.00	14.00	34	18.0	7.75	0.02	33.00	0.0	30.0
C3	95-150	52.00	36.00	12.00	34	20.0	7.75	0.02	33.00	0.0	35.0
A1	0-30	45.00	35.00	20.00	27	15.0	8.00	0.22	34.70	11.0	25.0
C1	30-60	22.00	37.00	41.00	44	18.0	8.10	0.23	36.20	0.0	35.0
C2	60-85	32.00	32.00	36.00	52	24.0	8.20	0.18	31.50	0.0	30.0
C3	85-120	30.00	33.00	37.00	41	15.0	8.10	0.22	32.00	0.0	25.0
Ap	0-25	52.00	36.00	12.00	23	20.0	7.50	0.50	30.45	6.0	25.0
C1	25-60	46.80	24.60	28.60	28	16.0	8.44	0.08	28.00	0.0	28.0
C2	60-95	48.00	27.60	27.60	27	8.0	8.75	0.05	31.50	0.0	23.0
C3	95-125	23.27	45.43	31.30	30	10.0	8.50	0.05	33.00	0.0	29.0
Ap	0-25	67.40	28.59	4.05	19	9.0	7.60	0.30	18.00	2.0	13.0
C1	25-60	53.00	25.30	21.70	30	10.0	7.90	0.15	20.00	0.0	15.0
C2	60-95	51.00	24.00	25.00	32	12.0	8.10	0.15	19.00	0.0	18.0
C3	95-125	55.50	21.00	23.50	33	14.0	8.20	0.13	20.00	0.0	16.5
A1	0-20	45.00	35.00	20.00	40	111.0	7.70	0.50	32.50	9.8	50.0
B	20-60	35.00	30.00	35.00	31	110.0	8.10	0.09	27.00	6.8	56.4
C2	60-100	36.00	29.00	35.00	30	113.0	8.20	0.04	38.50	14.0	28.5
C3	100-160	25.00	37.00	38.00	27	116.0	8.30	0.07	38.20	16.0	34.6
A1	0-25	51.00	25.50	23.50	40	100.0	7.70	0.30	32.50	8.0	47.0
C1	25-65	20.00	45.00	35.00	31	98.0	7.90	0.09	27.00	6.0	38.0
C2	65-95	36.00	30.00	34.00	30	80.0	8.00	0.04	38.50	10.0	45.0
C3	95-150	25.00	37.00	38.00	27	120.0	8.10	0.07	38.00	14.0	49.0
A1	0-20	44.00	36.00	20.00	25	40.0	8.18	0.35	31.00	4.0	40.0
C1	20-65	45.00	27.00	28.00	30	25.0	7.70	0.08	28.00	2.0	38.0
C2	65-95	35.00	28.50	36.50	28	60.0	7.80	0.05	34.00	0.0	40.0
C3	95-155	16.40	58.40	25.20	24	50.0	8.10	0.00	35.00	0.0	42.0

Table 4:Morphological characteristics of representative pedons

Pedons	Depth (cm)	Color (dry)	Color (moist)	Texture	Structure	Boundry	Consistence dry	Consistence wet	HCl reaction
Ap	0-30	5YR3/4	5YR4/4	SL	1fabk-ma	gw	sh	ss/ps	esf
C1	30-65	10YR7/2	10YR 5/3	SL	ma	gw	h	ss/ps	esc
C2	65-95	10YR7/2	10YR 5/4	SL	ma	gw	h	s/p	esc
C3	95-130	10YR7/2	10YR 5/4	SCL	ma		h	s/p	esm
Ap	0-20	5YR3/4	5YR4/4	SL	1fabk-ma	gw	sh	ss/ps	esf
C1	20-58	5YR3/4	5YR4/4	SL	ma	gw	sh	ss/ps	esf
C2	58-95	5YR 5/4	5YR4/4	L	ma	gw	h	s/p	esf
C3	95-130	5YR 4/4	5YR5/4	L	ma		h	s/p	esf
Ap	0-25	10YR6/2	10YR 5/3	SL	1fabk-ma	gw	sh	ss/po	esm
C1	25-60	10YR7/2	10YR 5/3	SL	ma	gw	sh	ss/ps	esm
C2	60-95	10YR7/3	10YR 5/3	SL	ma	gw	h	ss/ps	esm
C3	95-150	10YR7/2	10YR 5/4	SL	ma		h	ss/ps	esm
A1	0-30	10YR5/4	10YR4/4	L	ma	gw	h	s/p	esm
C1	30-60	10YR5/4	10YR4/4	CL	ma	gw	vh	s/p	esm
C2	60-85	10YR5/54	10YR4/4	CL	ma	gw	vh	s/p	esm
C3	85-120	10YR5/4	10YR4/4	CL	ma		vh	s/p	esm
Ap	0-25	10YR6/3	10YR 4/3	SL	1fabk- ma	gw	h	ss/po	esm
C1	25-60	10YR6/3	10YR 4/3	SCL	ma	gs	h	s/p	esm
C2	60-95	10YR6/3	10YR5/3	SCL	ma	gs	h	s/p	esm
C3	95-125	10YR 7/3	10YR5/3	CL	ma		h	s/p	esm
Ap	0-25	10YR6/3	10YR 4/3	SL	1fabk-ma	gw	sh	ss/po	esf
C1	25-60	10YR7/2	10YR5/3	SCL	ma	gw	h	s/p	esc
C2	60-95	10YR 6/2	10YR5/3	SCL	ma	gw	h	s/p	esf
C3	95-125	10YR7/3	10YR5/3	SCL	ma		h	s/p	esc
A1	0-20	10RY5/4	10YR4/4	L	ma	gw	h	ss/ps	esm
C1	20-60	7.5RY5/4	7.5YR4/4	CL	ma	gw	vh	s/p	esm
C2	60-100	7.5YR4/4	7.5YR4/4	CL	ma	gw	h	s/p	esm
C3	100-160	7.5YR4/4	7.5YR4/4	CL	ma		h	s/p	esm
A1	0-25	10RY5/4	10YR4/4	SCL	ma	gw	h	ss/ps	esm
C1	25-65	7.5RY5/4	10YR4/4	CL	ma	gw	vh	s/p	esm
C2	65-95	7.5YR4/4	10YR4/4	CL	ma	gw	vh	s/p	esm
C3	95-150	7.5YR5/4	7.5YR4/4	CL	ma		vh	s/p	esm
A1	0-20	10RY5/4	10YR4/4	L	ma	gw	h	s/p	esm
C1	20-65	10RY6/4	10YR4/4	SCL	ma	g	vh	s/p	esm
C2	65-95	10RY5/4	10YR4/4	CL	ma	gs	vh	s/p	esm
C3	95-155	7.5YR4/4	7.5YR4/4	CL	ma		vh	s/p	esm

Table 5: Soil classifiation of study region

Physiography	land units	Taxonomy USDA soil
Alluvium plain	1.1	Coarse loamy, mixed, thermic Typic Torrifluents Entisols
Alluvium plain	1.2	Coarse loamy, mixed, thermic Typic Torrifluents Entisols
Alluvium plain	1.3	Coarse loamy, mixed, thermic Typic Torrifluents Entisols
Alluvium plain	2.1	Fine loamy, mixed, thermic Typic Torriorthents Entisols
Alluvium plain	2.2	Fine loamy, mixed, thermic Typic Torriorthents Entisols
Alluvium plain	2.3	Fine loamy, mixed, thermic Typic Torriorthents Entisols
Low land	3.1	Fine loamy, mixed, thermic Typic Aquisalids Aridisols
Low land	3.2	Fine loamy, mixed, thermic Typic Aquisalids Aridisols
Low land	3.3	Fine loamy, mixed, thermic Typic Aquisalids Aridisols

Table 6: Study of wheat growth cycle in the region

Plant	Planting to stability	Vegetative stage	Flowering stage	Ripening stage	Harvest	Growing cycle
Wheat	1 November to 21 November	21 November to 10 April	10 April to10 May	10 May to 21 June	21 June	233 days

Table 7: Results of the qualitative suitability evaluation of different land series for wheat under study, using Multicriteria evalution and GIS method

Land units	Area	Percentage	Land class
1.1	868.32	16.08	S3
1.2	316.44	5.86	S3
1.3	507.60	9.40	N1
2.1	986.04	18.26	N2
2.2	457.38	8.47	N2
2.3	369.90	6.85	N2
3.1	844.02	15.63	N2
3.2	738.18	13.67	N2
3.3	312.12	5.78	N2

corrigible non-suitable (N_1) and six units had non-suitability (N_2) for wheat cultivation. The results of climatic suitability evaluation showed that the climatic characteristics of the region according to that given by Sys *et al.* (1991) and climatic and growth data are suitable (without regarding o rainfall) for wheat plantation.

DISCUSSION

The results showed that from total units, 21.94% were under marginally suitable (S3) for wheat crop. This

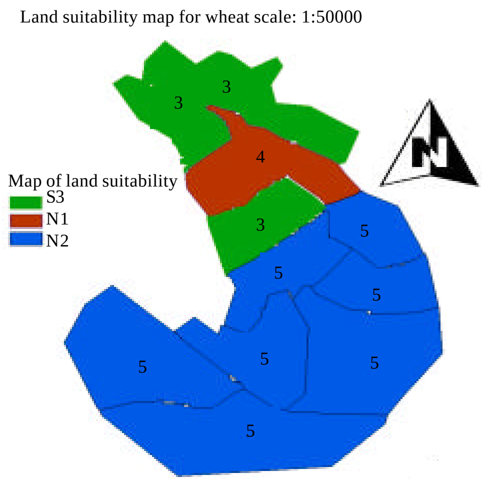

Fig. 3: Map of land suitability units for wheat in Damghan plain

suitability of units, Northern is because of long distance from desert and had soil, Exchangeable Sodium Percentage (ESP) and salinity lower than Southern units.

The results showed that 9.40% of study areas were not suitable (N1) and 68.66% severe limitations and unchangeable (N2) that this can be because of close to salt desert and lack of irrigation suitable water, soil salinity and poor soil fertility. Generally, not suitable areas (N) were located south of Damghan plain. The results showed that most suitable areas (S3) were found mostly in the soil mapping unit 1.1, 2.1 (Fig. 3).

CONCLUSION

In this study, we applied Remote Sensing (RS) and GIS techniques to identify suitable areas for wheat crop. The proposed procedure for land suitability assessment and mapping can by utilizing analytical capability of modern GIS, make use of the limited available data for the assessment of the suitability of land for a certain land utilization type. By utilizing available data, it reduces the need of field and laboratory researches thus, reducing costs of evaluation. This investigation is a biophysical evaluation that provides information at a local level that could be used by farmers to select their cropping pattern. In this study, the most serious problems influencing yield and quality of wheat are Exchange Sodium Percent (ESP) and salinity (EC) and Northern units of Damghan plain have more suitability for wheat production. Therefore, based on obtained results, cultivation of wheat can be recommend in Northern areas.

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