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Integrated approach for land use suitability analysis

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A b s t r a c t. An integrated fuzzy spatial multi-criteria evaluation and analytic hierarchy process within a GIS was applied to assess the land use suitability for agriculture in Golestan province, Iran. In this way, a type of multi-criteria evaluation method called weighted linear combination in a spatial domain was employed to incorporate six factors and three constraining criteria into the evaluation of land use suitability for agriculture. A fuzzy set methodology was used to calculate values of a membership function of each factor. The relative importance weights of factors were estimated using analytic hierarchy proces. The application of the presented approach in Golestan province indicated that the soil capability, slope, and precipitation were the most important factors to assess the land use suitability for agriculture. The result showed that 51.6% of the areas are highly suitable for agricultural purposes and 23.3% of the areas are unsuitable or restricted to cultivation. The results suggest that the integration of fuzzy spatial multi-criteria evaluation and analytic hierarchy process technologies has several advantages over the conventional land use planning procedure in Iran and provides the empirical and repeatable process, and the possibility of using expert advices in criteria weighting.

K e y w o r d s: land suitability, fuzzy spatial multi-criteria evaluation, analytic hierarchy process

INTRODUCTION

Over past two decades sustainable development has been a major topic on the political agenda of governments and international organizations. Regarding land as a finite and scarce resource, land use planning helps in sustainable development. The core component of land use planning is land use suitability analysis, which determines the suitability and availability of land for alternative uses, their sustainability, as well as their impact on other environmental resources (Baja *et al*., 2007). Land use suitability analysis can be used as a tool to identify the most suitable places for locating future land uses (Collins *et al.*, 2001).

In a historical overview, Collins *et al.* (2001) classified the developments of land use suitability analysis methods and methodological advances into five general stages:
– early hand-drawn mapping,
– advancement in the literature,
– computer-assisted overlay mapping,
– redefinition of spatial data and multi-criteria evaluation,
– replicating expert knowledge in the process.

Professional discussion of land use suitability techniques was included in the literatures at the second stage. The most significant methodological advance during that stage was the development of the ecological inventory process. According to this method, human-made as well as natural attributes of a study area are presented in individual transparent maps using dark and light values. Then, necessary suitability map for each land use can be constructed by superimposing the individual transparent prints of dark and light values. However, many practical difficulties arose when the number of maps that needed to be manually superimposed increased. The advent of the computer for land use suitability analysis made the third stage in Collins *et al.* (2001) classification of methodological development. Development of GIS resulted further advances in the field of computer-assisted overlay mapping. They involved Boolean overlay whereby all criteria are assessed by threshold of suitability to produce Boolean maps (Jiang and Eastman, 2000). Banai (1993) evidenced many problems with traditional Boolean

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methods of land suitability analysis. Fuzzy set theory (Zadeh, 1965) became a prominent topic of research during 1980s for use within GIS and land use suitability analysis. This approach as well as finding alternative techniques to incorporate decision-makers preferences into the process made the next stage of development in land use suitability analysis. One such alternative technique was the use of multi-criteria evaluation (MCE). Integration of such methods as well as artificial intelligence in GIS-based land use suitability analysis is the current stage of research in the field.

The current procedure of land use planning in Iran, uses concept of an 'environmental unit' (arbitrary ecosystem) which has been introduced and used as a basis of land evaluation. The environmental units of land are selected and depicted on a map, using stationary ecological factors (landform, geology, soils, and plants). The variation of dynamic ecological characteristics (climate, water, wildlife) and the socioeconomic resources of lands under scrutiny are considered, to narrow the selection of a suitable system. Consequently, land suitability is decided on the merits of the ecological and socioeconomic properties of each unit. According methodological development stages classified by Collins *et al.* (2001), the land use planning procedure in Iran is based on the methods in third stage (computer assisted overlay mapping). In this method, all criteria will be standardized to Boolean values and the method of aggregation will be Boolean intersection. While this is a commonly used method of GIS-based multiple criteria evaluation, it is obvious that Boolean standardization and aggregation severely limit analysis and constrain resultant land allocation choices (Banai, 1993). It is clearly appropriate that constraints be expressed in Boolean term, but it is not always clear how continuous data can be effectively reduced to Boolean values. In this case, suitability in one criterion cannot compensate for a lack of suitability in the other. Another limitation of this method is that all factors have equal importance in the final suitability map. Some criteria may be very important to determining the overall suitability for an area while others may be of only marginal importance.

Development of GIS-based techniques for land use suitability analysis, decision making and planning procedures has evolved over the last thirty years or so from the computer-aided map overlay modelling through multi-criteria decision making techniques to a wide range of artificial intelligence approaches (Malczewski, 2004). Contribution of these models and techniques in land use planning could be effective to improve the whole process. Similar spatial data and knowledge engineering technologies have been integrated in the MicroLEIS agroecological decision support system (De la Rosa *et al.*, 2004; Shahbazi *et al.,* 2008) by planning soil-specific use and management strategies for sustainable rural development.

The objective of this study was to present an approach to overcome the problems with the land use suitability analysis procedure of Iran based on spatial decision support system (SDSS) approach. In this study, a fuzzy approach was integrated with spatial multi-criteria evaluation (SMCE) and analytic hierarchy process (AHP) within a GIS environment. This approach was applied to perform agricultural land use suitability analysis for Golestan province in Iran.

MATERIALS AND METHODS

The study area was Golestan province in Iran. Golestan is located in NE Iran, approximately between 36° 30′ and 38° 08′ N, and 53° 51′ and 56° 19′ E (Fig. 1). The absolute minimum temperature is -1.4°C and the maximum is 46.5°C. Elevation ranges from -26 to 3 945 m a.s.l. Annual rainfall ranges between 250 and 700 mm.

In the present study, GIS data layers were used as data sources including the shuttle radar topography mission (SRTM) (Werner, 2001), climate variables based on records from 1950 to 2000 at 1 km grid cell resolution (Hijmans *et al.*, 2008) soil capability and land use data sets prepared by Agricultural Ministry of Iran, and protected areas prepared by environment protect organization. The other needed data sets including slope, soil erosion, and land-slide risk, were produced by analyzing the primary data sources in the R development environment version 2.8.1 (R Development Core Team, 2008). The slope was produced given the SRTM data. The revised universal soil loss equation (RUSLE) was employed to calculate the soil erosion layer. To calculate the land-slide risk a model developed by Larijani (2007) for the study area, was applied. This model uses five factors including slope, bedrock, precipitation, distance to fault, and land use to calculate the relative score of land-slide risk in a scale of 0 to 1.

In contrast to the Boolean approach in which objects are assigned as belonging (1) or not belonging (0) to a set {0, 1}, the Fuzzy approach (Zadeh, 1965) allows differing degrees of set membership using the real number range [0, 1]. Wang *et al.* (1990) proposed the use of fuzzy membership in land suitability analysis, wherein the Boolean classes (suitable and non-suitable) was replaced by fuzzy membership concept (Wang *et al.*, 1990). Fuzzification is a process by which factors are converted into a common suitability scale [0, 1], using a fuzzy membership function. Defining a fuzzy membership function depends on the degree of truth of respective suitability criteria. There are numerous membership functions available to map elements to fuzzy set (Lamb *et al.*, 2010). In this study, linear function (increasing or decreasing) was used to define fuzzy membership for each criterion. Equation (1) is increasing linear function *ie* increasing of the value of factor increases the suitability, and Eq. (2) is decreasing linear function *ie* increasing of the value of factor decreases the suitability.

$$X_i = \frac{(R_i - R_{\min})}{(R_{\max} - R_{\min})}, \tag{1}$$

$$X_i = \left[1 - \frac{(R_i - R_{\min})}{(R_{\max} - R_{\min})}\right], \tag{2}$$

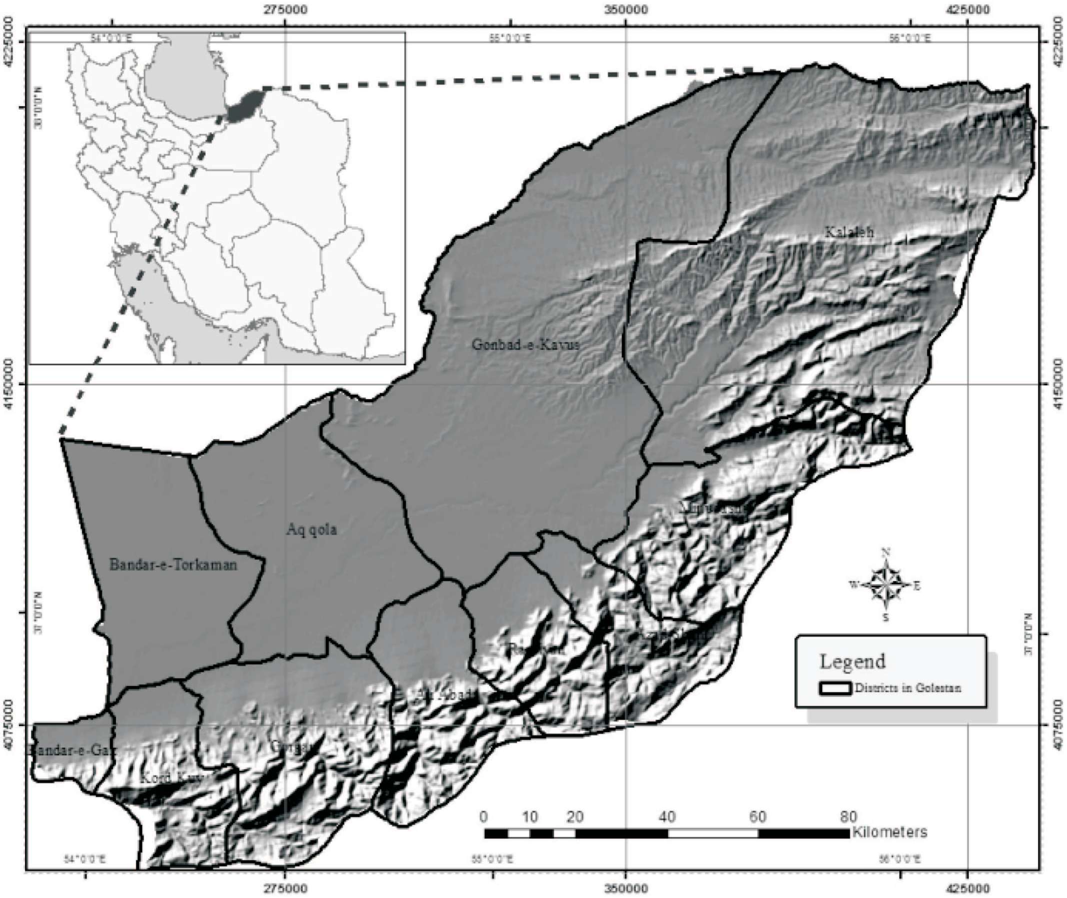


Fig. 1. Spatial multi-criteria evaluation (SMCE).

where: X_i is the fuzzy suitability value of cell i in a raster layer, R_i is the value of cell i before fuzzification, $R_{\min}$ is the minimum value of the factor, and $R_{\max}$ is the maximum value of the factor.

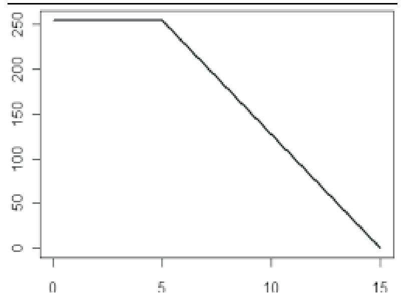
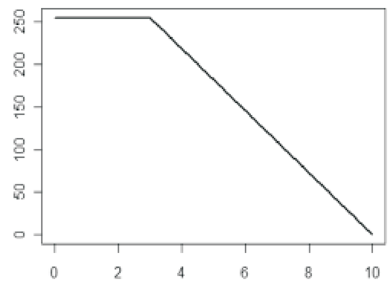
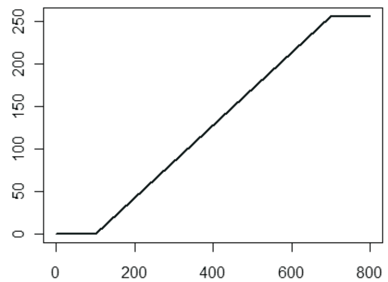
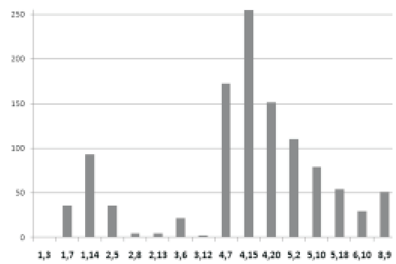
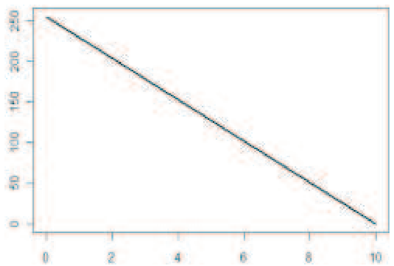
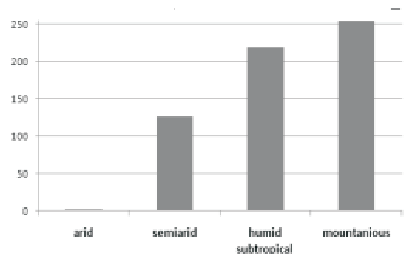
Six factors and three constraining criteria were evaluated in the present study. Slope, climate, landslide risk, soil capability, soil erosion, and precipitation were considered as factors while land use, constraining slope and protected area by environmental conservation agency were considered as constraints.

The slope, precipitation, soil erosion and landslide risk maps were analyzed as continuous maps in a raster format, while the soil capability, climate and land use maps as categorical maps were stored in a vector format. In order to generate the individual suitability maps based on each continuous factor the fuzzy membership functions were adopted (Table 1). For categorical factors the fuzzy number between 0-255 were assigned to each class in the attribute table of the GIS layer. These fuzzy numbers were judged according to the ecological evaluation model of Iran. The individual suitability maps for these factors then were generated by converting them into the raster format based on the assigned fuzzy numbers.

Each GIS layer of constraining criterion was classified into suitable and unsuitable classes (0 and 1) produced a Boolean raster layer for that constraint. The areas having the slope greater than 30% were considered as constraining slope. Residential area, forests, and water bodies from land-use map, as well as protected areas by environmental conservation agency were classified as constraint areas.

The analytic hierarchy process (AHP) is a widely used framework for structuring a decision problem and evaluating alternative decisions (Saaty, 1977). The AHP method is concerned with scaling problem and what sort of numbers to use, and how to correctly combine the priorities resulting from them (Saaty, 1977). In this technique, factor weights are derived by taking the principal eigenvector of the square reciprocal matrix of pair-wise comparison between the criteria, as exemplified for five factors in Table 2. This comparisons concern the relative importance of the two criteria involved in determining the suitability for the decision (Eastman, 2006). The matrix can be filled by expert or decision maker using a 9-point continuous rating scale (1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, 9). In comparing of two factors (for example F1 and F2 in Table 2 [w1/w2]), the scale of 1 means that F1 and F2 are equally important, whereas the scale of 9

T a b l e 1. Fuzzy membership functions used for generating individual land suitability index based on each factors

Membership function	Criterion	Membership function	
	Slope		Land slide risk
$\begin{cases} 255, & \text{If } S_i < 5 \\ \left[1-\left(\frac{S_i-5}{10}\right)\right]255 & \text{If } 5 \le S_i \le 15 \\ 0 & \text{If } S_i > 15 \end{cases}$		$\begin{cases} 255, & \text{If } L_i < 3 \\ \left[1-\left(\frac{L_i-3}{7}\right)\right]255 & \text{If } L_i \ge 3 \end{cases}$	
	Precipitation		Soil
$\begin{cases} 0 & \text{If } P_i < 100 \\ \left[\left(\frac{P_i-100}{600}\right)\right]255 & \text{If } 100 \le P_i \le 700 \\ 255, & \text{If } P_i > 700 \end{cases}$		The fuzzy number is judged and assigned to each class	
	Erosion		Climate
$\begin{cases} \left[1-\left(\frac{E_i}{10}\right)\right]255 & \text{If } E_i \le 10 \\ 255, & \text{If } E_i > 10 \end{cases}$		The fuzzy number is judged and assigned to each class	

means that F2 is extremely more important, and in contrast, 1/9 means F2 is extremely less important. In this study, as evaluation criteria differ in the importance to determine land suitability, the AHP method was used to scale the relative importance of each criterion as an assigned weight. These weights will sum to one, as required by the Weighted Linear Combination procedure (see the next section). According to Saaty (1977), the comparison matrix should be re-evaluated if its consistency ratio (CR) be rated as greater than 0.1. CR indicated the probability that the matrix rating were randomly generated.

To meet a specific objective, it is frequently the case that several criteria will be evaluated using a procedure namely Multi-Criteria Evaluation (Voogd, 1983). The primary issue in MCE is concerned with how to combine the information from several criteria to form a single index of evaluation (Rahman and Saha, 2008). GIS-based analysis of MCE refers to Spatial Multi-Criteria Evaluation (SMCE). A criterion is some basis for a decision that can be measured. Each criterion can be a factor or a constraint. A factor influences the suitability of the decision by enhancing or detracting from it. A constraint serves to restrict the suitability of decision (Eastman, 2006; Lamb *et al*., 2010). To consider of constraints the area is classified into two classes: unsuitable (value 0) or suitable (value 1) (Mahini and Gholamalifard, 2006). One of the most commonly used methods of SMCE for land use suitability analysis is weighted linear combination (WLC) or simple additive weighting (Corona *et al*., 2008). In WLC, each criterion is assigned with a weight according to decision-maker preference indicating the relative importance of the factor. In this study, WLC was used to combine factors and constraints, as in Eq. (3), and produce land use suitability:

$$S = \sum_{i=1}^{n} W_i X_i \prod_{j=1}^{m} C_j \,, \tag{3}$$

where: S represents the overall suitability of land use for a cell in a raster surface, n is the number of factors, X_i is the i^{th} factor, and W_i is the weight (as relative importance) for the factor X_i, m is the number of constraints, and C in the Boolean constraint.

RESULTS AND DISCUSSION

Assessing the relative importance of factors to analyze the land-suitability for agriculture in the Golestan province using AHP method indicated that the soil capability with the relative weight of 0.284 is the most important factor. The slope and precipitation were the second and third important factors (Table 3). The consistency ratio (CR) of the matrix was resulted as 0.08, and therefore, the weights are accepted.

Figure 2 represents the all GIS layers and the procedure of applying the fuzzy membership functions to generate suitability factors from criterion maps as well as combining the factors considering the relative importance weight and the constraints. Applying of the presented methodology in the Golestan province indicated that 51.58% of the area

Table 2. Pair-wise comparison matrix in the AHP method for a five-factor problem

	F1	F2	F3	F4	F5	Weights
F1	1	w1/w2	w1/w3	w1/w4	w1/w5	
F2		1	w2/w3	w2/w4	w2/w5	
F3			1	w3/w4	w3/w5	
F4				1	w4/w5	
F5					1	

Table 3. AHP weight derivation of evaluation criteria

	Slope	Precipitation	Soil	Erosion	Landslide	Climate	Weights
Slope	1	1/2	1/2	3	6	8	0.254
Precipitation		1	1/2	3	5	3	0.250
Soil			1	2	5	2	0.284
Erosion				1	3	1	0.094
Landslide					1	1	0.046
Climate						1	0.072

CR=0.08.

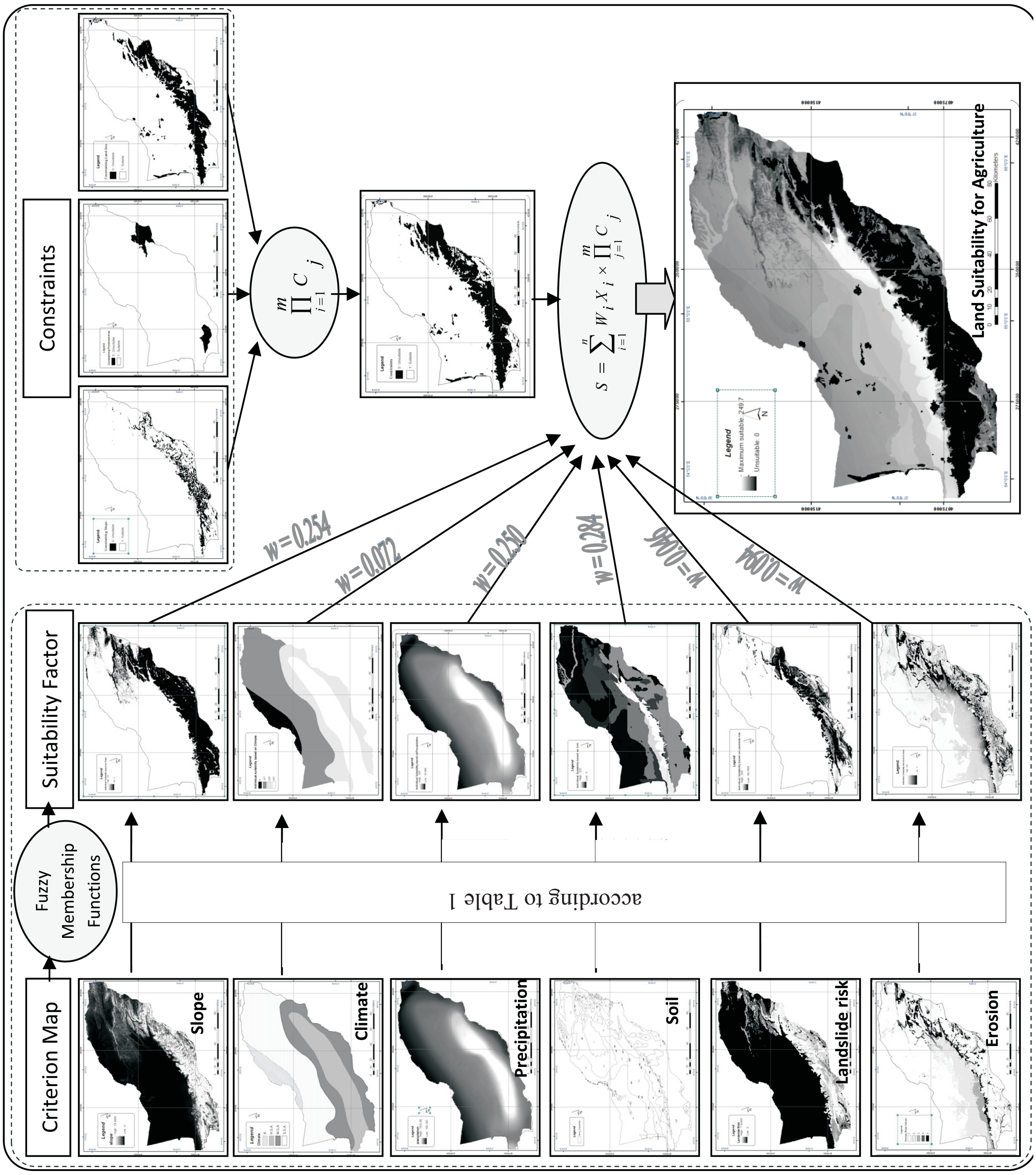


Fig. 2. The procedure of fuzzy SMCE to calculate land use suitability for agriculture in Golestan province, Iran.

(10 326.5 km^2) has the suitability greater than 128 denoted as highly suitable area for agriculture. 23.28% of the area (4 701.5 km^2) is unsuitable for agriculture or is restricted to cultivation.

Comparing the suitability with current land use map indicated that 48% (4 996 km^2) of the highly suitable areas for agriculture are currently rangelands, while 22% (1 492.13 km^2) of current agricultural area has low suitability or is unsuitable for agriculture. Figure 3 represents a graph that compares the percentage of the area in unsuitable and four equal-interval suitability classes.

The system described in this paper utilizes GIS functions to integrate a fuzzy SMCE approach and AHP. It has been proposed to replace this system with the current method of land use planning in Iran which is based on a Boolean combination of criterion maps. The Fuzzy approach provides the opportunity to assess the land suitability as continuous indices of performance when the land is used for agricultural purposes, and therefore, the spatial variability of land quality can be better represented. This approach enables aggregation of individual suitability maps based on key factors considering the relative importance of each factor. It also provides a more appropriate output to be used in a numerical multi-objective land use planning procedure.

The conventional method for ecological capability evaluation for agricultural purposes, part of land use planning in Iran was used as a base to develop the model of land suitability analysis in this study. Based on current procedure of land use planning in Iran, if sustainable land use systems are to be adopted, they should be based on ecological principles. Therefore, the model to assess the land suitability considers the ecological factors (slope, soil, climate, *etc.*). However, in the stage of planning it is necessary to incorporate socio-economic criteria as well. The main advantage of the proposed approach here is that the additional criterion can be easily incorporated into the analysis using the procedure in this study. Inclusion or exclusion of factors can be used to generate 'What-IF' scenarios in order to get insights into the consequences of alternative plans based on varying goals and objectives

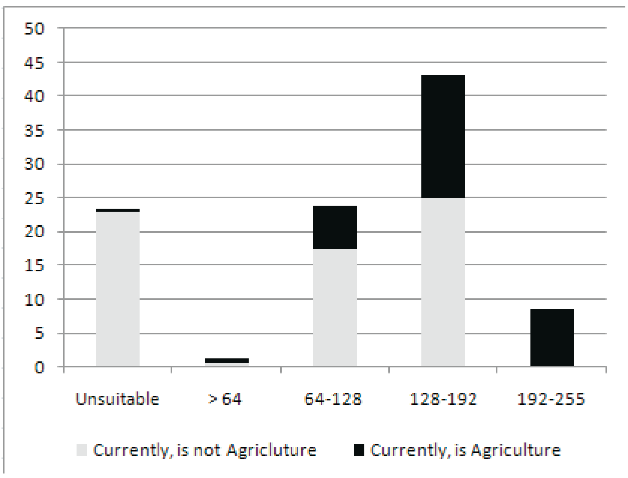


Fig. 3. The percentage of area in different land suitability classes for agriculture comparing with current status of land use.

This system uses expert opinion or stakeholder advices to define the importance of factors that makes the approach flexible enough for using in different areas with various objective of development. For example, in an area land-slide risk may not be a potential issue, and therefore, can be omitted or takes a lower weight of importance. Fuzzy membership functions also could be easily changed (in range and type) in different areas. However, developing appropriate and user friendly software tools might be promising to make this approach be efficiently used by planners and decision makers.

The major drawback to the approach used in this study is that spatial contiguity is not taken into consideration. It means that the land-suitability assessment is independently performed in a cell by cell basis, while it might be worthwhile to consider neighbour cells to calculate the suitability for land. For example, a cell may be more appropriate for agricultural purposes when the neighbour cells have agricultural land use types rather than other land uses. However, developing the method to incorporate spatial relationship into consideration as an additional factor would be promising for future studies.

It should be noted here that the aim of this study was not to provide the land-suitability as an indices for estimating crop yields and production, but it provides a tool for decision making on land use planning where the agricultural development is considered as an objective together with other objectives *eg* urban development. It enables decision maker in optimum allocation of agricultural region as well as finding conflicts by comparing with existing plan or other land use types *eg* urban, forest, *etc*. However, this approach has been used in several studies to assess the land-suitability for specific crops in order to determine the cropping system (Delgado *et al*., 2008; Kurtener *et al*., 2008; Manos *et al*., 2010; Rahman and Saha, 2008; Reshmidevi *et al*., 2009).

CONCLUSIONS

1. The integration of fuzzy SMCE and AHP provides several advantages over the conventional land use planning procedure in Iran. Most importantly, it is an empirical and repeatable process and provides the possibility of using expert opinion in criteria weighting.

2. The weighted linear combination aggregation method offers much more flexibility than Boolean approach. Fuzzy delineations result in improved models and lead to more accurate analysis.

3. The approach should be considered as a decision support system in spatial and environmental domain and can be used in a context of multi-objective land use planning.

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