GIS-BASED MULTICRITERIA LAND SUITABILITY EVALUATION USING ORDERED WEIGHT AVERAGING WITH FUZZY QUANTIFIER: A CASE STUDY IN SHAVUR PLAIN,IRAN

M. Mokarram [a],*, F. Aminzadeh [b]

[a] Dept. of Remote Sensing and GIS, Shahid Chamran University,Ahwaz, Iran (m.mokarram.313, kazemrangzan) @gmail.com

[b] Dept. of Computer Engineering, Shahid Chamran University,Ahwaz, Iran, ln.aminzadeh@gmail.com

Member of young researcher club of Islamic Azad university of Safashahr, Iran

ABSTRACT:

Cell-based Multicriteria Evaluation (MCE) methods are used to analyse the land suitability evaluation. Land evaluation is carried out to estimate the suitability of land for a specific use such as arable farming or irrigated agriculture. land suitability evaluation is a prerequisite for land-use planning and development (Sys 1985; Van Ranst and others 1996). It provides information on the constraints and opportunities for the use of the land and therefore guides decisions on optimal utilization of land resources (FAO1983). The aim in integrating Multicriteria Decision Analysis (MCDA) with Geographical Information Systems (GIS) is to provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors. Furthermore, By changing the parameters in this type of method, a wide range of decision strategies or scenarios can be generated in some procedures. The goal of this research is to take the advantage of incorporation of fuzzy (linguistic) quantifiers into GIS-based land suitability analysis by ordered weighted averaging (OWA). OWA is a multicriteria evaluation procedure (or combination operator). The nature of the OWA procedure depends on some parameters, which can be specified by means of fuzzy (linguistic) quantifiers. The quantifier-guided OWA procedure is illustrated using land-use suitability analysis in Shavur plain,Iran.

1. INTRODUCTION

Land-use suitability mapping and analysis is one of the most useful applications of GIS for spatial planning and management (Collins et al., 2001; Malczewski, 2004). Land-use suitability analysis is a multicriteria evaluation,which aims at identifying the most appropriate spatial pattern for future land uses according to specify requirements, preferences, or predictors of some activity (Hopkins, 1977; Collins et al., 2001). Geographic information systems (GIS) serve the multicriteria evaluation function of suitability assessment well, providing the attribute values for each location and both the arithmetic and logical operators for combining attributes (Jiang and Eastman 2000). Furthermore multicriteria evaluation may be used to develop and evaluate alternative plans that may facilitate compromise among interested parties (Malczewski, 1996). In general, the GIS-based land suitability analysis assumes that a given study area is subdivided into a set of basic unit of observations such as polygons or rasters. Then, the land-use suitability problem involves evaluation and classification of the areal units according to their suitability for a particular activity. Over the last 10 years or so, land-use suitability problems have increasingly been conceptualized in terms of the GIS-based multicriteria evaluation procedures (e.g. Banai, 1993; Jankowski and Richard, 1994; Joerin, 1995 ; Barredo, 1996; Antonie et al., 1997; Lin et al., 1997; Beedasy and Whyatt, 1999; Malczewski, 1999; Barredo et al., 2000; Mohamed et al., 2000; Bojorquez-Tapia et al., 2001; Dai et al., 2001; Joerin et al., 2001). There are two fundamental classes of multicriteria evaluation methods in GIS: the Boolean overlay operations (noncompensatory combination rules) and the weighted linear combination (WLC) methods (compensatory combination rules). They have been the most often used approaches for land-use suitability analysis (Heywood et al., 1995; Jankowski, 1995; Barredo, 1996; Beedasy and Whyatt, 1999; Malczewski, 2004).

These approaches can be generalized within the framework of the ordered weighted averaging (OWA) (Asproth et al., 1999; Jiang and Eastman, 2000; Makropoulos et al., 2003; Malczewski et al., 2003; Malczewski and Rinner, 2005; Malczewski .,2006). OWA is a family of multicriteria combination procedures (Yager, 1988). Conventional OWA can utilizes the qualitative statements in the form of fuzzy quantifiers(Yager, 1988, 1996). The main goal of this paper is to produce the land suitability maps according to OWA operators for GIS-based multicriteria evaluation procedures.

2. METHODS

OWA is a multicriteria evaluation procedure (or combination operator). The nature of the OWA procedure depends on some parameters, which can be specified by means of fuzzy (linguistic) quantifiers. The GIS-based multicriteria evaluation procedures involve a set of geographically defined alternatives (e.g. parcels of land) and a set of evaluation criteria represented as map layers. The problem is to combine the criterion maps according to the attribute values and decision maker's preferences using a combination rule. each alternative (i = 1, 2, . . . ,m) is represented as a cell (raster) or a polygon and is

described by a set of standardized criterion values: $a_{ij} \in [0, 1]$

for j = 1, 2, . . . ,n. A multicriteria evaluation problem involves also preferences which are typically specified as the criterion

weights, $w_j \in [0, 1]$ for j = 1, 2, . . ., n, and $\sum_{j=1}^{n} w_j = 1$. Given

the input data (a set of criterion map layers and criterion weights), the OWA combination operator associates with the i-th location (e.g., raster or point) a set of order weights v = v_1, v_2,

$$\sum_{j=1}^{n} v_j = 1$$

. . . , v_n such that $v_j \in [0, 1]$, j=1,2,..,n, , and is

defined as follows (see Yager, 1988; Malczewski et al., 2003):

$$OWA_i = \sum_{j=1}^{n} \left(\frac{u_j v_j}{\sum_{j=1}^{n} u_j v_j} \right) z_{ij} \quad , \quad (1)$$

where $z_{i1} \geq z_{i2} \geq . . . \geq z_{in}$ is the sequence obtained by reordering the attribute values a_{i1}, a_{i2}, . . ., a_{in}, and u_j is the criterion weight reordered according to the attribute value, z_{ij}. It is important to point to the difference between the two types of weights (the criterion weights and the order weights). The criterion weights are assigned to evaluation criteria to indicate their relative importance. All locations on the j-th criterion map are assigned the same weight of w_j. The order weights are associated with the criterion values on the location-by-location basis. They are assigned to the i-th location's attribute value in decreasing order without considering from which criterion map the value comes. With different sets of order weights, one can generate a wide range of OWA operators including the most often used GIS-base map combination procedures: the weighted linear combination (WLC) and Boolean overlay operations, such as intersection (AND) and union (OR) (Yager, 1988; Malczewski et al., 2003). The AND and OR operators represent the extreme cases of OWA and they correspond to the MIN and MAX operators, respectively. The order weights associated with the MIN operator are: $v_n = 1$, and $v_j = 0$ for all other weights. Given the order weights, $OWA_i(MIN) = MIN_j(a_{i1}, a_{i2}, . . . , a_{in})$. The following weights are associated with the MAX operator: $v_1 = 1$, and $v_j = 0$ for all other weights, and consequently $OWA_{i(MAX)} = MAX_j(a_{i1}, a_{i2}, . . ., a_{in})$. Assigning equal order weights (that is, $v_j = 1/n$ for j = 1, 2, . . . , n) results in the conventional WLC, which is situated at the mid-point on the continuum ranging from the MIN to MAX operators (Malczewski, 2006).
Given a set of criterion maps and a fuzzy linguistic quantifier Q, one can perform a procedure for combining the criteria based on a statement regarding the relationship between the evaluation criteria.
Based on the type of linguistically quantified
statements one can distinguish between: the absolute linguistic quantifiers and the relative (or proportional) linguistic quantifiers (Zadeh, 1983). There is no empirical evidence to show which of the two classes of linguistic quantifiers is more

suitable for multicriteria evaluation. Here we will focus on a class of the proportional quantifiers known as the regular increasing monotone (RIM) quantifiers (Yager, 1996). To identify the quantifier we employ one of the simplest and the most often used methods for defining a parameterized subset on the unit interval (Yager, 1996). Specifically,

$$Q(p) = p^\alpha , \alpha > 0 \quad (2)$$

Q(p) is represented as a fuzzy set in interval [0, 1]. Table 1 shows a selection of the RIM quantifiers and their characteristics. By hanging the parameter, α, one can generate different
types of quantifiers and associated operators between the two extreme cases of the all and at least one quantifiers. For a = 1, Q(p) is proportional to α and therefore it is referred to as the identity quantifier. As α tends to zero, the quantifier Q(p) approaches its extreme case of at least one, which corresponds to the MAX
operator. As α tends to infinity, the quantifier Q(p) approaches its extreme case of all, which corresponds to the MIN operator. The order weights according to RIM quantifier is defined as follows:

$$v_j = \left(\sum_{k=1}^{j} u_k \right)^\alpha - \left(\sum_{k=1}^{j-1} u_k \right)^\alpha \quad (3)$$

Given the criterion weights, w_j, and order weights, v_j, the quantifier-guided OWA is defined as follows:

$$OWA_i = \sum_{j=1}^{n} \left(\left(\sum_{k=1}^{j} u_k \right)^\alpha - \left(\sum_{k=1}^{j-1} u_k \right)^\alpha \right) z_{ij} \quad (4)$$

3. CASE STUDY

3.1.Study area
The study area, Shavoue, lies in the Northern of Khouzestan province,Iran. It is located within coordinate of latitude 31°37'30'' and 32°30'00'' North and longtitude 48°15'00'' and 48°40'40'' East with the area of 77404/23 ha (hectar). (figure1.)

α	Quantifier (Q)	OWA weights (v_j)	ORness	Tradeoff	GIS combination procedure
$\alpha \to 0$	At least one	$v_1 = 1$; $v_j = 0$, for all other weights	1.0	0.0	OWA (OR, MAX)
$\alpha = 0.1$	At least a few	a	a	a	OWA
$\alpha = 0.5$	A few	a	a	a	OWA
$\alpha = 1$	Half (identity)	$v_j = 1/n$, for all j	0.5	1.0	OWA (WLC)
$\alpha = 2$	Most	a	a	a	OWA
$\alpha = 10$	Almost all	a	a	a	OWA
$\alpha \to \infty$	All	$v_n = 1$; $v_j = 0$, for all other weights	0.0	0.0	OWA (AND, MIN)

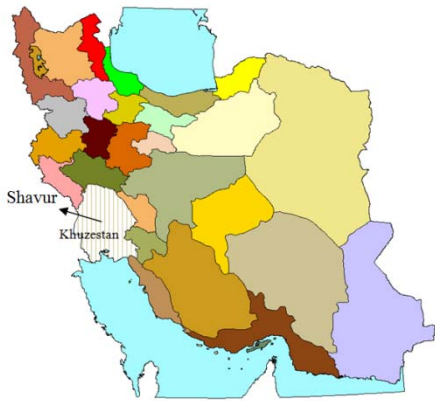Table 1. Some properties of the RIM quantifiers for selected values of the a parameter

Figure 1. Location of study area

3.2. Criteria Evaluation

For all criteria that are seen as map layer, the criterion values are generated. The causative factors for the land suitability evaluation are EC, pH, ESP, CaCO$_3$, Gypsium, wetness, texture, slope, depth and topography. The data in this study is validated by Power Ministry of Khouzestan.

3.3. Assigning Criteria Weights

The purpose of the criterion weighting is to express the importance of each criterion relative to other criteria. The more important criterion had the greater weight in the overall evaluation. Using Eq. (3), the following estimated values for the criterion weights of EC & ESP, topography, wetness, texture, PH, CaCO$_3$, Gypsium and depth are 0.222, .028, 0.194,

0.083, 0.111, 0.167, 0.139 and 0.056. Given the standardized criterion maps and corresponding criterion weights, we apply the OWA operator using Eq. (4) for selected values of fuzzy quantifiers: at least one, at least a few, a few, identity, most, almost all, and all. Each quantifier is associated with a set of order weights that are calculated according to Eq. (3). Fig. 2 shows the seven alternative land suitability patterns.

4. CONCLUSIONS

The optimal use of reserved land resources for agriculture is a complex problem that involves subjective assessments with multiple criteria. This paper has presented a GIS-based multicriteria land suitability evaluation using Ordered Weight Averaging with fuzzy quantifier approach for effectively solving this problem. An empirical study in Shavour, Iran has been conducted using the approach presented.

The fuzzy-quantifier-based OWA approach is capable of capturing qualitative information the decision maker or analyst may have regarding his/her perceived relationship between the different evaluation criteria. It is in this effort one can see the benefit of the fuzzy quantifier approach to GIS-based multicriteria analysis. This is especially true in situations involving a large number of criterion maps. In such situations, it is impractical or even impossible to specify the exact relationships between evaluation criteria. The OWA approach provides a mechanism for guiding the decision maker/analysis through the multicriteria combination procedures. It allows him/her to explore different decision strategies or scenarios. Consequently, the approach facilitates a better understanding of the alternative land-use suitability patterns
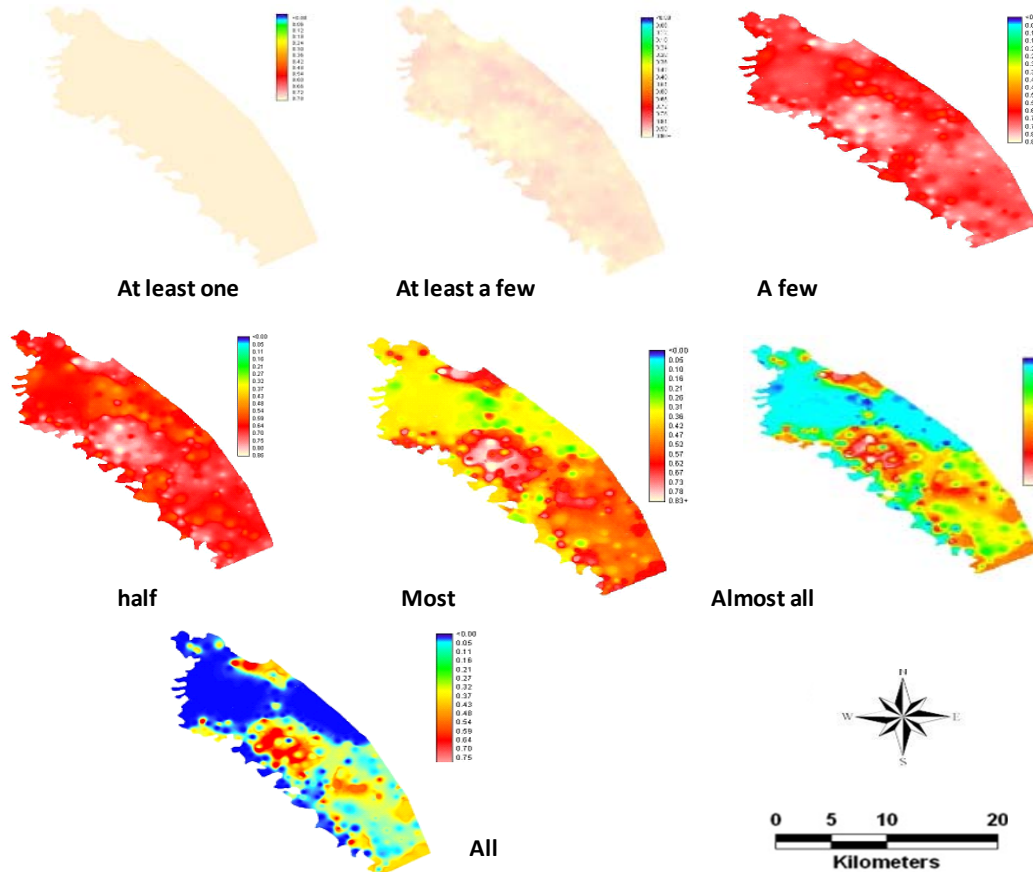

Figure 2. Land suitability maps of OWA results for selected fuzzy linguistic quantifiers in Shavur

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