Available online at www.sciencedirect.com
SciVerse ScienceDirect
APCBEE Procedia 5 (2013) 405 – 409
Procedia APCBEE
www.elsevier.com/locate/procedia

ICESD 2013: 19- 20 January 2013, Dubai, UAE

A Comparison of Parametric and Fuzzy Multi-Criteria Methods for Evaluating Land Suitability for Olive in Jeffara Plain of Libya

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Abstract

Boolean approaches to land suitability treat both the spatial units and the value ranges as clearly defined. This is to ignore the continuous nature of land properties as well as the differences and uncertainties in measurement. The objective of this paper was to compare two approaches to land suitability evaluations; Parametric and Fuzzy Multi-Criteria Methods to model the opportunities for olive production in Jeffara Plain of Libya. In this paper a number of soil and landscape criteria were identified and their weights specified as a result of discussions with local experts. The Fuzzy MCE approach was found to be better than the parametric approach. The Fuzzy MCE approaches accommodate the continuous nature of many soil properties and produce more intuitive distributions of land suitabilities value for olive. The results of Fuzzy MCE showed that the majority of the study area is highly suitable for olive production, while the results obtained from the use the parametric method showed that most of the study area is moderately suitable for olive production.

Keywords: Parametric, Fuzzy MCE, Uncertainty, land suitability evaluation for olive.

1. Introduction

Land evaluation is “the process of assessment of land performance when used for specified purposes”. In other words, land evaluation is defined as the process of estimating the possible behaviour of the land when utilized for a particular purpose; this use could be the current one or a potential one. In this sense, land

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doi:10.1016/j.apcbee.2013.05.070

evaluation could be regarded as a tool to make decisions about the land [1], [7], [8].

Different methodologies applied to develop land evaluation models in many developing countries including Libya. In Libya, the parametric land evaluation system was employed in the North-East and North West to derive land suitability maps for many crops [1]. The deficiencies of parametric model for the land suitability evaluation have been criticized by many authors. According to [6], the main issue with a land evaluation approach based on parametric is that if component scores are very small or very large, they have a considerable effect on the overall suitability. Another critical issue of using parametric land evaluation system is the absence of any uncertainty or vagueness associated with factors determining land use suitability for agricultural crops.

In recent years, there is increasing interest in incorporation geographic information system (GIS) with multi-criterion evaluation approaches (MCE) for land suitability evaluation for agricultural crops .The use of the MCE methods approaches such as Fuzzy MCE method has the capability for addressing and exploring the uncertainties associated with factors determining land use suitability for agricultural crops [14]. Fuzzy MCE approaches such as Fuzzy AHP has not been extensively applied in soil science, land suitability evaluation, soil classification and soil quality indices. The application of Fuzzy AHP methodology in land suitability evaluation allows imprecise representations of vague, incomplete and uncertain information [5]. The use of the Fuzzy AHP approach to the model of land suitability evaluation has the possibility to produce good results compared to parametric approaches because it is able to define uncertainties and vague associated with soil and landscape factors. The Fuzzy AHP approach has the ability to define land suitability classes as continuous scale instead of 'true' or 'false'[10],[11].This paper aims to compare the input of different methods – Parametric and Fuzzy MCE approaches (i.e. Fuzzy AHP) for land suitability evaluation for olive in north-west of Jeffara Plain region, Libya.

2. Materials and Methods

2.1. Data sources

For this work 40 soil profiles were used to derive land suitability map for olive for the study area selected [1], [19]. Factors affecting land suitability model for olive in north-west of Jeffara Plain region, Libya were defined based on previous studies for the study area and discussion with local experts [20]. These factors are: Soil (i.e. available water holding capacity; soil depth; infiltration rate; soil texture; soil salinity; soil reaction), climate, and erosion hazard and slope steepness.

2.2. Land Suitability Evaluation Approaches

2.2.1. Parametric Method

The parametric systems incorporate land characteristics that influence agricultural production by using mathematical equations [1]. Many parametric approaches have been used for land evaluation. Some of these approaches are simple, while others are more complicated. These approaches vary in the specific parameters they include and in their mathematical manipulation [12].

In this paper, a numerical rating with a scale of 0 to 1 is assigned to different suitability categories for olive. If a land characteristic has no limitation for olive growth or production, ratings from 1 to 0.95 are allocated. Ratings from 0.95 to 0.85, 0.85 to 0.65, 0.65 to 0.30, and 0.30 to 0.00 are applied respectively for highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and currently not suitable (N1) [1]. To obtain a final suitability map for olive in GIS environment, the rated criteria maps (i.e. land characteristics or factors) were constructed based on suitability ratings .In order to classify each raster cell within the map into suitability classes, the rated criteria maps were multiplied, using equation 1 [9].

$$LI = \left(R_{min} \sqrt{\prod_{j=1}^{n} Rj} \right) \times 100 \qquad (1)$$

Where LI is the land index, R min is the minimum rating value; Rj is the rating value of the jth criterion map and n is the number of criteria maps.

2.2.2. Fuzzy Multi-Criteria Evaluation Method (MCE)

Multi-criterion evaluation approaches (MCE) were designed to describe the relationship between the data input and the data output. MCE can be separated into main two main groups of methods; multiobjective and multiattribute [10]. There is a number of Fuzzy MCE approaches can be applied to derive land suitability maps.

In this paper, Fuzzy Analytical Hierarchy Process (Fuzzy AHP) selected to obtain land suitability map for olive in study area. The Fuzzy AHP modelling considers as an alternative way to deal with continuous and uncertain environments. The Fuzzy AHP technique has the ability to integrate different types of information and comparing two parameters at the same time by using the pairwise comparisons method; the base requirement for the AHP method [17], [18]. The Fuzzy AHP approach has been divided into four stages in this paper. These steps are:

- Converting the raw data (i.e. land properties) into standardized criterion scores using fuzzy membership function models (i.e. an asymmetric left and right model and symmetric model) [3], [14] and [22].
- Derivation fuzzy maps for land properties for olive in GIS environment.
- Derivation weighted maps for land properties based on Pairwise comparison matrix. The sum of the weights should always be 1. The consistency ratio (CR) of the matrix calculated and determines the internal consistency of the weights relative to the overall solution - it is a measurement that reveals how much difference is allowed [10]. Malczewski [10] states that for good decisions it must be ≤ 0.1, because a consistency ratio ≤ 0.1 shows that the comparisons of criteria or factors were perfectly consistent, and the relative weights are appropriate for applying in AHP approaches.
- Generation the final land suitability map for olive. The final land suitability calculated by combining the weighted fuzzy maps. This function sums the weighted fuzzy maps of the different land properties to obtain land suitability maps at final level.

2.3. Map Comparison

With the Fuzzy AHP method it is possible to obtain high suitable and less or not suitable classes with parcel of lands have the highest and lowest MFs values, respectively. Based on natural breaks of the raster histogram, four defined classes were created to correspond to the four suitability classes obtained from parametric method [13], [15].

3. Results

3.1. Parametric and Fuzzy AHP results

The resulting maps for olive from Parametric and Fuzzy AHP methods were derived. Table 1 summarizes the model outputs of suitability for olive from the use the Parametric and Fuzzy AHP approaches.

Table 1. Suitability classes using Parametric and Fuzzy AHP approaches

Suitability Classes	Parametric method		Fuzzy AHP method	
	%	Hector	%	Hector
S1 (Highly suitable)	30	92819	53	163980
S2 (Moderately suitable)	50	154698	28	86631
S3 (Marginally suitable)	6	18564	10	30940
N1(currently not suitable)	9	27846	4	12375
No data	5	15470	5	15470

3.2. Weighting factors results

The results indicate that, for olive, the eigenvalues or the weights of soil factors are higher than climate, erosion hazard and slope steepness (Table 2). This means soil factors are the most important parameters or properties affecting the growth of olive in the study area.

Table 2. The weights (eigenvalues) for olive

Factors	Weights or eigenvalues for olive
Soil characteristics	0.65
Climate	0.22
Erosion hazard	0.1
Slope steepness	0.03

The eigenvalues obtained from the pairwise comparison revealed that the comparisons of land factors were perfectly consistent (i.e. CR $\leq$ 0.1). The accuracy of these eigenvalues is mainly dependent on discussion with local experts in the study area.

4. Discussion and Conclusion

The aim of using Fuzzy AHP logic is extension of continuous variability concept of soil properties in space. In reality, the overlap of the suitability classes happens usually in the attribute space [2] and the use of fuzzy membership functions can express this partial overlap of the classes. The Fuzzy MCE- Fuzzy AHP approach differs from the conventional land suitability evaluation methods such as parametric method, in its use of calculated eigenvalues and its organization of criteria in the hierarchy levels to fit the suitability problems into the framework of decision-making. In addition, in Fuzzy AHP methodology, the application of fuzzy membership value (MFs) presents valuable information for indentifying the major restraints to olive performance and policies for overcoming them. In the study area, it was found that soil factors are the most important factors affecting the growth of olive. This paper also confirmed that the Fuzzy AHP approach as a believable and perfect method could be useful for incorporation of data from various domains and sources and to define an area in diverse suitability classes for specific crops through the MCE technique in a GIS environment and this is in agreement with [5], [21].

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