Land suitability analysis comparing Boolean logic with fuzzy analytic hierarchy process

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***Abstract*— Sustainable land management in agriculture is a very complex and challenging concept, especially in developing countries. Optimal use of land is very important in the context of rapid population growth and urban expansion which make available land for agriculture a relatively scarce commodity. Agricultural land management planning seeks to identify the most beneficial land uses whilst improving and conserving land resources for future. This paper compares land suitability models for barley using Boolean logic theory and Fuzzy Analytic Hierarchy Process method (FAHP) for a test area within North-Western region of Jeffara Plain of Libya. The logic of the different models is explored in relation to land qualities and land characteristics and their influence on the model outputs. The results of the FAHP models are based on standardizing land characteristics using different fuzzy set models and applying the pairwise comparisons for criteria weighting to drive land suitability map for barley. Land suitability results for barley from the use the Fuzzy AHP and the Boolean methodologies have been derived. Error matrix and analysis of the results are presented using two assessment technologies; an overall accuracy and KAHAT statistic.**

Keywords: ***sustainability; land evaluation; pairwise comparisons; Fuzzy Analytical Hierarchy Process; Boolean evaluation.***

I. INTRODUCTION

Land resources are gradually becoming scarce as increases in population place pressure on natural resources. The world population grows; an increase of food supply is urgently needed to meet those demands. Inventory of land recourses is prerequisite for the adequate utilization and sustainable management of the natural resources base of any country. Accurate inventories become imperative for the assessment of available natural resources with reach in each country (FAO, 1976). Good management to keep the equilibrium between human demands and agricultural production is needed. Therefore, it is very important to evaluate the environmental resources to be employed through the best uses, particularly where water scarcity and desertification limit agricultural production such as developing countries. Land evaluation models in many developing countries are needed to be developed. Boolean logic theory was used to the model of land evaluation for 25 years or so. Most of developing countries have utilized the Boolean method to improve the analytical methods for land evaluation studies. The use of the Boolean logic theory to land evaluation methods has criticized by many authors (Burrough, et al., 1992; Davidson et al., 1994; Baja, et al., 2006). In the Boolean method, land characteristics may have the same value of weights and this has made the classification quite strict. The Analytical Hierarchy Process can deal perfectly with the case of land evaluation. It has a number of advantages. First, it gives better result to deal with the uncertainty compared to traditional techniques such as Boolean method. Second, it is able to incorporate different knowledge from different sources into the formwork of decision-making (Malczewski, 1999).This paper compares the results of the FAO framework for land evaluation for barley using Boolean logic theory and Analytic Hierarchy Process method under Fuzzy environment (FAHP) .

II. BACKGROUND OF BOOLEAN LOGIC AND FUZZY ANALYTICAL HIERARCHY PROCESS METHODS

A. Boolean Logic Theroy

Boolean logic theory is mostly employed technique when parameter maps have classified into Boolean suitable (Yes) and Boolean unsuitable (No). It has three basic Boolean operators. Theses operators include: Intersection operator (the logic AND), Union (the logic OR) and Complement (the logic NOT). All these operations can be undertaken in IDRISI and ArcGIS software (Malczewski, 1999). Boolean methodology tends to represent reality in a discrete way, but in the nature can find that few elements are discrete, while others are continuous.

B. Analyitcal Hierachy Process(AHP) methods

The AHP modeling considers as an alternative way to deal with these continuous and uncertain environments. Whilst in Boolean logic a value is true of false, with AHP theory the value could be partially false of partially true which allows for a representation more according to the reality. The AHP method was developed by Saaty in 1977. It is considered very common procedure in Multiattribute Decision Analysis method (MADA). The AHP has shown his ability to incorporate different types of data. It has the capability for comparing two parameters at the same time (Saaty, 1977).

Further to this, the Pairwise Comparisons methods (PCs) which is the basic measurement in employed in the AHP methods is able to identify how important is parameter “A” relative to parameter “B”. Using the AHP models to the model of land suitability analysis can facility and develop the analysis of parameters that are characterized by ambiguity conception (Malczewski, 1999).

III. Methodology

The FAO framework with Boolean logic theory and Fuzzy AHP has been selected for a test area within part of Jeffara Plain in Libya. The main aim from this test is to incorporate local knowledge from local experts and a literature review in order to the model of land-use suitability analysis. The paper methodology has been divided into the following stages. These stages are:

A. Factors Determining Land-Use Suitability Analysis for Barley

According to local experts and literature review, the study area is suitable for number of cash crops. For this paper, land evaluation model for barley has been established using Fuzzy AHP and Boolean evaluation. 14 land characteristics have been identified as the main important factors affecting barley production in the study area. These land characteristics have been defined after the discussion with the local experts for the study area selected. These are: Soil texture, % soil calcium carbonate (% $caco_3$), rootable depth, Available Water Holding Capacity (AWHC), % Organic Matter (% O.M), cation exchange capacity (CEC), soil salinity (EC), % soil alkalinity (% ESP), soil drainage, and soil reaction (soil pH), stones at surface, infiltration rate, erosion hazard and topographic characteristics.

TABLE I. PAIRWISE COMPARSION MATRIX FOR BARLEY IN THE STUDY AREA

Land Characteristics	% slop	soil texture	% $CaCO_3$	% O.M	% ESP	AWHC	EC	% Stones	Soil drainage	Soil pH	CEC	Rootable depth	Infiltration rate	Soil erosion	Average weight
% slop	1														0.0217
soil texture	3	1													0.15
% $CaCO_2$	3	1/3	1												0.043
% O.M	3	1/3	1/3	1											0.036
% ESP	3	1/3	1/3	1/3	1										0.033
AWHC	3	1/3	3	3	2	1									0.124
EC	3	1/5	3	5	2	1/3	1								0.07
% Stones	3	1/3	3	2	2	1/3	1/3	1							0.046
Soil drainage	3	1/3	3	2	2	1/3	1/2	2	1						0.051
Soil pH	3	1/5	3	2	2	2	2	2	2	1					0.124
CEC	3	1/3	3	2	2	1/3	1/2	2	2	1/3	1				0.062
Rootable depth	3	1/3	3	2	2	1/3	2	2	2	1/3	3	1			0.079
Infiltration rate	3	1/3	3	2	2	1/3	2	2	2	1/3	1/3	1/3	1		0.058
Soil erosion	3	1/3	3	2	2	1/3	2	2	2	1/3	3	3	3	1	0.093

B. Weighting Factors

Deriving weights for land characteristics map layers is the base requirement for applying the fuzzy AHP (Malczewski, 1999). Weighting factors for land evaluation for barley in this paper was obtained from discussion with local experts, through a pairwise comparisons statistical analysis in Idrisi environment. Four local experts in Libya have used their knowledge to derive weights for land characteristics for barley (Table I). The Consistency Ratios (CR) was equal to 0.1 and this means that the comparisons of land characteristics were perfectly consistent, and the relative weights were appropriate for applying in land evaluation model that uses Fuzzy AHP model. In addition to weighting factors, eigenvalues for land characteristics for barley were generated.

C. Land Evaluation Model Using Boolean Logic Theory

Boolean land evaluation model have tested in Libya. For this reason, this method was selected as an existing land evaluation technique for this paper. Land evaluation using Boolean logic was divided into four main stages in this paper. These stages are:

- Design GIS spreadsheet models for land suitability rating for barley.
- Writing Boolean "if" function for all measured data for barley in the study area.
- Derivation land suitability maps for all land characteristics that affect barley production in the study area.
- Using Boolean intersection overlay operator to produce the final land suitability map for barley.

D. Land Evaluation Model Using Fuzzy AHP Method

The Fuzzy AHP approach has been divided into five stages in this paper into five steps. These steps are:

- Convert the raw data (land characteristics) into standardized criterion scores scale using fuzzy membership function models (an asymmetric left and right model and symmetric model).
- Generation standardized criterion map layers.
- Derivation weighted standardized fuzzy criterion map layers.
- Derivation fuzzy rating map layers.
- Generation the final land suitability maps.

E. Map Comparsion

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. Therefore, parcels of lands with high MFs will be ranked as classes 1 (most suitable classes) and parcels of lands with low MFs will be assigned as classes 4 (less suitable classes or not suitable classes). To determine the correspondence between land suitability maps, the resulting maps from Boolean and Fuzzy AHP methods they will be cross- tabulated and then the confusion matrix will be created to estimate the relative performance of the Fuzzy AHP and Boolean results. In addition to the confusion matrix, an overall accuracy and the KHAT statistic; represents the agreement between the maps will be generated in this study (Congalton 1991).

IV. Results and Sumarry

The resulting maps for barley from Boolean and Fuzzy AHP methods were derived. Table II summarize the model outputs of suitability for barley from the use the Boolean and fuzzy AHP techniques.

TABLE II. BARLEY SUITABILITY UNDER BOOLEAN THEORY AND FUUZY AHP: SUITABILITY IN PERCENTAGE OF THE TOTAL AREA.

Boolean		Fuzzy AHP	
Suitability	**%**	**Suitability**	**%**
S1	84	0.79 - 0.63	1
S2	2	0.63 - 0.49	78
S3	2	0.49 - 0.36	15
S4	7	0.36 - 0.29	1
No data	5	No data	5

The Kappa statistic analysis and the overall accuracy have been used for evaluating the model outputs. Both of these techniques revealed that there is slight agreement between the maps (Table III).

TABLE III. ERROR MATRIX FOR THE BOOLEAN AND FUZZY AHP CLASSIFICATIONS FOR BARLEY

	Boolean				
Fuzzy AHP	**S1**	**S2**	**S3**	**N1**	**Total**
1	3233	0	0	0	3233
2	55775	467	630	2086	58958
3	205408	304	888	8525	215125
4	4986	0	333	11237	16556
Total	269402	771	1851	21848	293872

Weight Type	KHAT Statistic	% KHAT Accuracy	Kappa Interpretation
Liner	0.05	5	Slight agreement

Producer's Accuracy (%)	User's Accuracy (%)	(%) Overall Accuracy
1.2	100	5.4
60.6	0.8	
48	0.4	
51.4	67.9	

V. CONCLUSION

Using different GIS functions to the model of land evaluation was one of the main objectives of this paper. The results of land evaluation obtained from using Boolean theory show that the most part of the study area was highly suitable for barley, while with Fuzzy AHP classification few locations highly suitable (i.e. high values of MFs for classes 1) have been found for barley.

In land evaluation using Boolean logic theory, only one low factor is enough to reduce the suitability of lands from highly suitable classes to not suitable classes (N1). Factors in land evaluation using Boolean theory may have the same weights and this will make the classification quite strict. An alternative to handle this problem is to use the Analytical Hierarchy Process (AHP) method. The AHP can deal perfectly with the case of land suitability analysis by assigning different weights to the parameters according to their importance for the suitability. It relies on pairwise comparisons between different criteria to assign importance levels and it takes the comparison between the criteria into account.

From this paper a number of conclusions can be drawn. First, land characteristics affecting barley production was very well organized into the hierarchy to fit into the framework of decision-making. Second, the use of the FAHP methods has been facilitated the incorporation of expert knowledge from different sources into the model of land evaluation. Third, weighting of the parameters was made according to their relative importance with taken the crop requirement for barley under local conditions into accounts. Fourth, instead of presenting land suitability classes as neat crisp sets from the use the Boolean theory, the Fuzzy AHP result in continuous value classes, which is a more realistic in nature. Finally, assessing the results using an overall accuracy and KHAT statistic agreed that there is slight agreement between the Fuzzy AHP and Boolean classifications.

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