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ANALYTICAL HIERARCHY PROCESS IN LAND SUITABILITY ASSESSMENT

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Abstract

Multi-criteria decision-making (MCDM) process is important for sustainable land resource planning and management. Among different MCDM techniques, the Analytical Hierarchy Process (AHP) is popular for its simplicity in use as well as it offers complex unbiased decisions. A GIS (Geographical Information System)-based AHP is essential for land-use suitability analysis. The AHP is a trusted decision-making method proved with a mathematical formula that has multi-purpose utilities. It provides an opportunity to select important alternatives among numerous factors along with proper ranking. It also maintains consistency among the factors using the sensitivity analysis. The limitations of the AHP are that the expert's opinion may vary for the time being, and it always follows straight models. Nevertheless, the AHP could be used by scientists, land-use planners, and land policymakers for suitable land selection with a view to sustainable land management.

***Keywords*:** Analytical hierarchy process, Land suitability assessment.

Introduction

The Analytical Hierarchy Process (AHP) is a structured technique to organize and analyze complex decisions on the basis of mathematics and psychology (Foreman and Gass, 2001). It is a multi-criteria decision-making process developed by Saaty (1990).The AHP has the potential to analyze a problem in a systematic way and to evaluate the problems comprehensively. The AHP could be applied in a group decision-making process and is used in many decision situations in government, healthcare, education, business, and industry. In addition, it could be used to make a decision for land management, focusing cropland suitability assessment.

The AHP could be applied in the decision analysis due to its relative priorities as well as alternatives to select the best criteria. The AHP also offers a flexible and simple model for a problem. It also provides an applicable decision to the decision-makers for the precise judgments, which includes the objective or subjective considerations; or the qualitative or quantitative information that plays an important role in the decision-making process. The overview of the main focus or the stated problem is represented in the AHP, where all the levels of the main focus are structured. Therefore, the AHP could be used widely in decision making, planning as well as benefit and risk analysis by choosing the alternatives. In addition, the AHP relies on the opinion of expert's from different backgrounds. Therefore, the main focus of the given problem is evaluated efficiently and easily from different aspects. Further, the decision-makers can justify the final decision by measuring the consistency ratio through sensitivity analysis, which reflects the judgments of the decision-makers (Oğuztimur, 2011). The objectives of the application of AHP is choosing an alternative in an unbiased manner from a given set of criteria, and to measure the weights of the attributes to solve a problem in decision analysis, and to calculate the weights of the given set of attributes of its hierarchical level to select a goal using the knowledge and experience of the experts from the pair-wise comparison of the criteria.

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Materials and Methods

Steps in the AHP

There are several steps in the AHP for land suitability assessment. In the first step, the decision elements are presented in a hierarchy that includes three classes consisting of the top class (goal), the middle class (criteria), and the bottom class (alternatives). The top class of the hierarchy refers to the selection of goals. The middle class denotes the criteria, and the bottom class refers to alternative decisions. In this process, a survey needs to be carried out to obtain expert's opinions on the relative significance of the criteria and factors. Comparisons for each factor pair would be expressed as integer values of 1 (equal importance) to 9 (extreme differences), where a higher number expresses the alternative decisions which are more important than another's (Table 1).

Table 1. The scale of preference for the AHP pair-wise comparison by Saaty (1989)

Scale	Degree of preference	Description
1	Equal Importance	When two factors contribute equally
3	Moderate importance of one factor over another factor	When experience and judgments slightly favor one over another
5	Strong importance	When experience and judgments strongly favor one over another
7	Very strong importance	When experience and judgments very strongly favor one over another
9	Extreme importance	When the evidence favors one over another, that is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent scales	When it requires compromise
Reciprocal values	Opposite of the above	When it is used for inverse comparisons

For example, in the comparison between soil texture and soil pH, a score of 1 denotes that both factors are equally important for suitability evaluation, and a score of 9 indicates that soil pH is more important than soil texture. All the scores are collected in a pair-wise comparison matrix, with the diagonal and reciprocal values presented in the lower left-hand triangle. Reciprocal values (1/3, 1/5, 1/7, and 1/9) are used in the row criterion. In the second stage, the scoring of the criteria is performed via pair-wise comparisons followed by scoring the scale of relative importance.

The third stage discusses the calculation of the matrix, ensuring consistency among criteria in the pair-wise comparison matrix. The AHP is also used to calculate the normalized values for each criterion and alternatives to determine the normalized principal eigenvectors as well as priority vectors. The pair-wise comparison matrix is calculated according to the following expression (Saaty (1989):

$$\begin{bmatrix} A_{11} A_{12} A_{13} & \cdots & A_{1n} \\ A_{21} A_{22} A_{23} & \cdots & A_{2n} \\ \vdots \;\; \vdots \;\; \vdots & \cdots & \vdots \\ \vdots \;\; \vdots \;\; \vdots & \cdots & \vdots \\ A_{m1} A_{m2} A_{m3} & \cdots & A_{mn} \end{bmatrix} \quad (1)$$

The sum of each column of the pair-wise matrix is expressed as follows:

$$A_{ij} = \sum_{i=1}^{n} A_{ij} \quad (2)$$

Each element of the matrix is divided by its column total to obtain a normalized matrix:

$$P_{ij} = \frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}} = \begin{bmatrix} P_{11} P_{12} P_{13} & \cdots & P_{1n} \\ P_{21} P_{22} P_{23} & \cdots & P_{2n} \\ \vdots \ \vdots \ \vdots & \cdots & \vdots \\ \vdots \ \vdots \ \vdots & \cdots & \vdots \\ P_{m1} P_{m2} P_{m3} & \cdots & P_{mn} \end{bmatrix} \quad (3)$$

The sum of the normalized matrix column is divided by the number of criteria (n) to calculate the weighted matrix of the priority factors:

$$W_{ij} = \frac{\sum_{j=1}^{n} P_{ij}}{n} \begin{bmatrix} W_{11} \\ W_{12} \\ \vdots \\ W_{1n} \end{bmatrix} \quad (4)$$

The initial consistency vectors are generated by multiplying the pair-wise matrix by the vector of weights:

$$\begin{bmatrix} A_{11} A_{12} A_{13} & \cdots & A_{1n} \\ A_{21} A_{22} A_{23} & \cdots & A_{2n} \\ \vdots \ \vdots \ \vdots & \cdots & \vdots \\ \vdots \ \vdots \ \vdots & \cdots & \vdots \\ A_{m1} A_{m2} A_{m3} & \cdots & A_{mn} \end{bmatrix} x \begin{bmatrix} W_{11} \\ W_{12} \\ \vdots \\ W_{1n} \end{bmatrix} = \begin{bmatrix} A_{11} W_{11} & A_{12} W_{12} & \dots & A_{1n} W_{1n} \\ A_{21} W_{21} & A_{22} W_{22} & \dots & A_{2n} W_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ A_{m1} W_{m1} & A_{m2} W_{m2} & \dots & A_{mn} W_{mn} \end{bmatrix} = \begin{bmatrix} X_{11} \\ X_{12} \\ \vdots \\ X_{1n} \end{bmatrix} \quad (5)$$

The principal eigenvector (λ_{max}) is calculated by averaging the values for the consistency vector:

$$\lambda_{max} = \sum_{i}^{n} AX_{ij} \quad (6)$$

Eigenvalues are calculated to determine the relative weight by averaging the rows of each matrix. The greatest value for the eigenvector is equal to the number of the criteria, and when λ_{max} = n, the judgments are consistent. The normalized eigenvalues are estimated to obtain the weights of the priority criteria. The principal value suggests that all criteria are consistent in the pair-wise comparison matrix.

The judgments are also be verified to measure the consistency index (CI) is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (7)$$

Here, n is the number of criteria. Saaty (1989) also suggested the consistency ratio (CR), which is compared with the consistency index and the random index (RI) (Aldababseh *et al.* 2018) **(Table 2)**.

Table 2. Random index (RI)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The consistency ratio is calculated as follows:

$$CR = \frac{CI}{RI} \quad (8)$$

Application of the AHP for land suitability assessment

The AHP represents the importance of the factors involved in the assessment process in the numeric values.The land suitability assessment is performed according to the classification guidelines proposed by the Food and Agriculture Organization (FAO, 1976). The guidelines for suitability classification are utilized to evaluate the suitability of each land unit for a particular purpose. According to the FAO's guidelines, it is primarily determined whether the land is suitable (S) or not suitable (N). The suitable class (S) is further divided as required. In practice, three categories—S1, S2 and S3—are used to assess the lands. Thus, the land suitability assessment is carried out for the prioritized criteria reclassified further into four classes. The suitability classes are determined using the weighted overlay in the ArcGIS environment on the basis of the fraction weights obtained from expert's opinions.

$$Weighted\ Overlay = \sum_{i=1}^{n} A_i * W_n \qquad (9)$$

where A_i refers to the criterion (i) that is reclassified and W_n denotes the number of criteria (n) that were weighted.

Limitation of the AHP

Although having many advantages of the AHP, it has some limitations. The human emotions are obscure, and the judgments may be favoured for the time being - thus, the AHP becomes immaterial. In addition, the AHP follows only the direct model, although this is not a solution to the linear equations (Karthikeyan *et al.* 2016). AHP is performed on the basis of both possibility and probability measures. Another problem in the AHP is the rank reversal that refers to the changes of order in the judgment alternatives when a new alternative is added to a problem, which could be considered meticulously during the application. When the number of the levels in the hierarchy increases, the number of the comparison pair also increases. Therefore, it takes much more effort and time to construct the AHP (Oğuztimur, 2011).

Conclusions

The strength of the AHP is the structuring of complex and multi-attribute problems in a hierarchical process and subsequently investigating the levels of the hierarchy separately, as well as combining the results in the analytical process. The AHP also incorporates the judgments or personal standards rationally that relies on knowledge, experience, and imagination for constructing the hierarchy. Despite having some limitations, the AHP has the potential to find out problems unbiasedly, and it could be used by researchers, land-use planners, and land policymakers for sustainable land management. Thus, the AHP would be one of the most popular techniques to evaluate the land resources, especially the agricultural lands.

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