USING GIS AND AHP TECHNIQUE FOR LAND-USE SUITABILITY ANALYSIS

Tran Trong Duc
Department of Geomatics
Polytechnic University of Hochiminh city, Vietnam
E-mail: ttduc@hcmut.edu.vn

ABSTRACT

Nowadays, analysis of land-use suitability requires consideration of variety of criteria including not only natural/physical capacity of a land unit but also socio-economic and environmental impact implications. While GIS has been a powerful tool to handle spatial data in land-use analysis, application of this tool alone could not overcome the issue of inconsistency in expert opinion when trying to judge and assign relative importance to each of many criteria considered in a suitability analysis. To address this issue, the Analytical Hierarchy Process method is used in combination with the GIS tool. The paper presents how the integrated tool has handled effectively a land use suitability analysis for Lam Ha district, Lam Dong Province of Viet Nam which considered simultaneously 12 different criteria.

1 INTRODUCTION

Land-use suitability is the ability of a given type of land to support a defined use. The process of land suitability Analysis involved evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The principles of sustainable development make land-use suitability analysis become increasingly complex due to consideration of different requirements/criteria. It includes consideration not only inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, but also the socio-economic and environmental costs.

In many situations it is extremely difficult to assign relative weights to the different criteria involved in making a decision on suitability of land mapping unit for a land-use type. Therefore it is necessary to adopt a technique that allows an estimation of the weights. One such technique is the Analytical Hierarchy Process (AHP).

Geographic Information System (GIS) is the powerful tool for input, storage and retrieval, manipulation and analysis, and output of spatial and attribute data. Meanwhile, land-use suitability analysis requires to handle both spatial and attribute data in many data layers. Therefore, it is appropriate to use GIS to exploit its strong capability in handling spatial data.

Thus, an integration of GIS and AHP to land suitability analysis expect to produce promising results. This paper presents results obtained through integrating GIS and AHP in analyzing land-use suitability. A case study of Lam Ha district, Lam Dong Province, Viet Nam is illustrated.

2 METHODOLOGY

The general process for land-use suitability analysis is shown in figure 1. In this process, land-use types are selected based on local farming practices, opinions of farmers, scientists, and local district and province leaders. Land-use requirements are necessary conditions to adopt successfully a land-use type. Therefore, investigating and determining land-use requirements for each land-use type are essential and basic for evaluating land-use suitability for each land mapping unit. Each land-use requirement could be organized in form of one map layer in GIS. The overlay of these map layers in GIS produces a composite map of land mapping units. Each land mapping unit is an area which has common land-use characteristics. Sustainable evaluation of land-use suitability requires to evaluate not only natural physical conditions but also socio-economic and environmental conditions. In order to determine which criteria (and at what levels or weights) affect to land-use suitability for each land-use type experts are consulted to provide judgments on important of criteria. Using AHP technique these judgments on important of criteria are converted to criteria weights (w_i). Score for each criterion (x_i) on each land mapping unit is then determined. The weighted linear combination of w_i and x_i give suitability index for each land mapping unit. By the above process, land-use suitability map is produced.

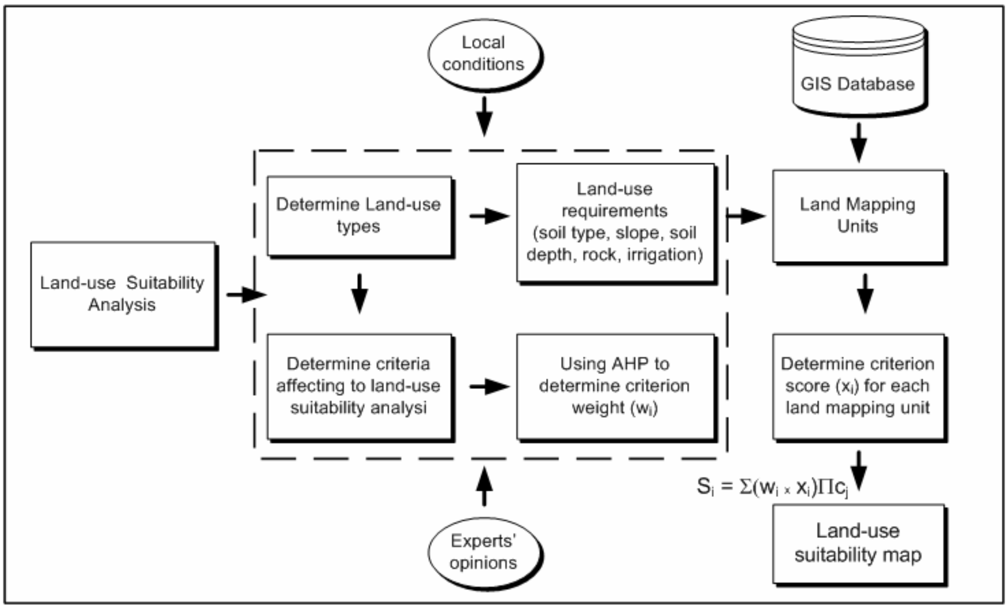

Figure 1. Land-use suitability analysis process

The following parts explain the process in more details.

2.1 AHP Technique

The Analytical Hierarchy Process (AHP) is developed by Saaty (Saaty, 1980). The principles utilized in AHP to solve problems are to construct hierarchies. The hierarchy allows for the assessment of the contribution individual criterion at lower levels make to criterion at higher levels of the hierarchy.

The AHP has three basic steps. It begins by decomposing the overall goal (Suitability) into a number of criteria and sub-criteria. The goal itself represents the top level of the hierarchy. Major criteria comprise level two, sub-criteria make up level three, and so on.

Applying this step to land-use suitability analysis, decision criteria relevant to our goal were identified and arranged in the hierarchy illustrated in Figure 2.

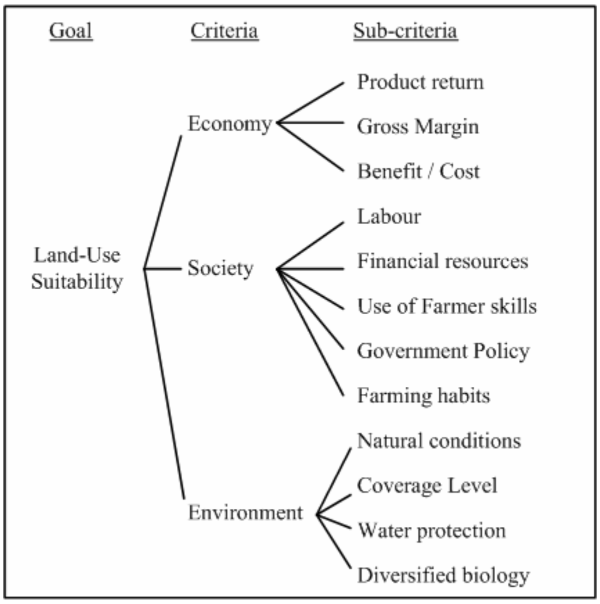

Figure 2: Land-use suitability analysis hierarchy

Such structure allows the incorporation and accommodation of both qualitative and quantitative criteria for assessing land-use suitability.

Once modelled, the second basic step of the AHP begins. Within each level of the hierarchy, the relative importance between each pair of criteria (or among pairs of sub-criteria relating to an upper single criterion) to the overall goal is evaluated. A nine-point scale is used for these evaluations. For example, if comparing criteria *economy* to criteria *environment*, a score of 1 indicates that they are equally relevant to the evaluation of suitability and a score of 9 indicates that *environment* is of little significance relative to *economy*. All scores can be assembled in a pair-wise comparison matrix with 1s on the diagonal (e.g., *economy* to *economy* is 1) and reciprocal scores in the lower left triangle (e.g., if *economy* to *environment* is 5, then *environment* to *economy* is 1/5). Pair-wise comparisons generated for the levels of the hierarchy contain expert opinion regarding the relative importance of criterion.

The third and final step in the AHP requires evaluation of the pair-wise comparison matrices using measurement theory. A standardized eigenvector is extracted from each comparison matrix, allowing us to assign weights to criteria, sub-criteria. These weights allow us to assemble a suitable value for each land mapping unit.

For each level in the hierarchy it is necessary to know whether the pair-wise comparison has been consistent in order to accept the results of the weighting. The parameter that is used to check this is called the Consistency Ratio. The consistency ratio is a measure of how much variation is allowed and must be less than 10%.

Applying the above following steps, the final weights for criteria are shown in Table 1

In our model, consistency ratio is less than 0.1. This indicates that the comparisons of criteria were perfectly consistent, and the relative weights were suitable for use in the suitability analysis.

Table 1. Weights of criteria in land-use suitability analysis

Level 1		Level 2		Overall weight
Criteria	**w_1**	**Criteria**	**w_2**	**($w_i = w_1$ x w_2)**
Economy	0.458	Product return	0.466	0.213
		Gross margin	0.101	0.046
		Benefit / cost	0.433	0.198
Social considerations	0.126	Labour force	0.205	0.026
		Financial resources	0.460	0.058
		Use of farmer skills	0.124	0.016
		Government policy	0.139	0.018
		Farming habits	0.072	0.009
Environment	0.416	Natural conditions	0.365	0.152
		Coverage Level	0.281	0.117
		Water protection	0.235	0.098
		Diversified biology	0.120	0.050

2.2 Weighted linear combination

Value or score of each level 2 criterion is computed for each land mapping unit (LMU). These values are combined with the above overall weight to provide suitability value for each LMU corresponding to each land-use type. The formula is as follows:

$$S = \left(\sum_{i=1}^{n} w_i \text{ x } x_i \right) \text{x} \prod c_j$$

S: Suitability index
w_i: weight of criterion i
x_i: score of criterion i
c_j: Boolean value of limited criterion

The above formula is applied to each LMU. In the overall result, the higher S value is the higher suitability of land-use for specified land-use type. In our experiment, c_j take value 1 or 0. Value 0 is applied to land mapping unit which is not suitable on natural conditions and 0 for the others.

This process is done in Arcview GIS through the composite map of land mapping units. The composite map has two components. Spatial component is used to show locations and shapes of land mapping units. Attribute component, represented as a table, is used to input and to store scores of criteria. Arcview GIS function is used to perform the calculation based on the above equation as well as scores and weights of criteria. Calculated suitability index is stored in one column. Integrating both spatial component and suitability index produces a continuous map of suitability.

2.3 Calculation of score value for each criterion

Based on FAO ((Food and Agriculture Organization of the United Nations) Framework for Land Evaluation, the suitability value for “Natural condition” criterion for each land mapping unit is determined through the method of maximum limitation method that affects the potential yield. The 5 natural characteristics are used in the calculation, including: soil type, slope, soil Depth, rock surface, and irrigation.

A socioeconomic evaluation is implemented base on the FAO methodology through the ALES (Automated Land Evaluation System) software. Score of "Product return" criterion is a function of productivity and unit price of product. Score of "Gross margin" is obtained by subtracting production cost from "Product return". Production cost is a function of material, labour, tax, …. Score of "Benefit / cost" is equal product return divided by production cost.

Scores for the other criteria are calculated based on expert and farmer opinions as well as local conditions.

Before applying weighted linear combination equation to calculated suitability index, these calculated scores are standardized to measure scale 1 (Low), 5 (medium), 7 (High), and 9 (very high suitability). The conversion is shown in table 2.

Table 2: Standardized score corresponding to criteria attribute values

Level 1's criteria	Level 2's criteria	Attribute values of criteria	Score (x_i)
1. Economy	1.1. Product return (1000 đ/ ha / year)	+ > 20000 + 15000 - 20000 + 10000 - 15000 + < 10000	9 7 5 1
	1.2. Gross margin (1000 đ/ ha / year)	+ > 15000 + 10000 - 15000 + 5000 - 10000 + < 5000	9 7 5 1
	1.3. Benefit / cost	+ > 2.5 + 1.8 – 2.5 + 1.5 – 1.8 + < 1.5	9 7 5 1
2. Social considerations	2.1. Labour force	+ Use local labour force very good (VH) + Use local labour force good (H) + Use local labour force medium (M)	9 7 5
	2.2. Financial resources	+ Need medium financial resources (M) + Need high financial resources (H)	9 7
		+ Need very high financial resources (H)h	5
	2.3. Use of farmer skills	+ Use existing farmer skills + Require to learn	9 7
	2.4. Government policy	+ Expand production area + Stabilized current production area	9 7
	2.5. Farming habits	+ Suit to local farming habits + Require to change local farming habits	9 7
3. Environment	3.1. Natural conditions	+ S1: High suitability + S2: Medium suitability + S3: Low suitability	9 7 5
	3.2. Coverage Level	+ cover surface area continuously + Cover surface area partly	9 7
	3.3. Water protection	+ Good water protection + Medium water protection	9 7
	3.4. Diversified biology	+ Poly-culture + Mono-culture	9 7

3 STUDY RESULTS

The above methodology is applied to Lam Ha district, a mountainous area. It is a western district of Lam Dong Province, Viet Nam. The final land-use suitability map of Lam Ha district is shown in figure 3 for land-use type coffee.

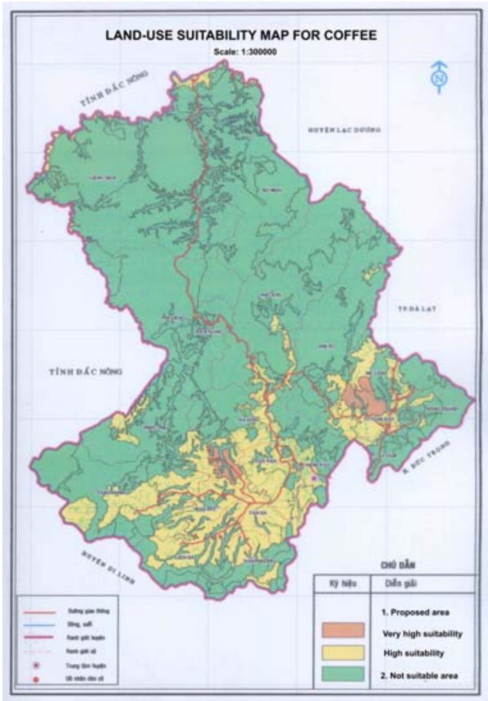

Figure 3. Land-use Suitability map for coffee

4 CONCLUSIONS

The Analytic Hierarchy Process (AHP) method commonly used in multi-criteria decision making exercises was found to be a useful method to determine the weights. Compared with other methods used for determining weights, the AHP method is superior because it can deal with inconsistent judgments and provides a measure of the inconsistency of the judgment of the respondents. The GIS is found to be a technique that provides greater flexibility and accuracy for handling digital spatial data. The combination of AHP method with GIS in our experiment proves it is a powerful combination to apply for land-use suitability analysis.

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