INTEGRATION OF GIS, GROUP AHP AND TOPSIS IN EVALUATING SUSTAINABLE LAND-USE MANAGEMENT

Le Canh DINH (1), Tran Trong DUC (2)

(1) Sub-National Institute of Agricultural Planning and Projection (Sub-NIAPP)
20 Vo Thi Sau Street, District 1, Hochiminh city, Vietnam
(2)Hochiminh city University of Technology, Vietnam National University HCMC.
268 Ly Thuong Kiet Street, District 10, Hochiminh city, Vietnam

ABSTRACT:

Land evaluation for sustainable land-use management (ESLM) has to take into accounts several different issues - such as natural, environmental and socioeconomic conditions – and thus it is multi-criteria decision analysis. This paper presents the results achieved in the integration Of GIS, AHP group and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) in solving ESLM problem. The integration process is as follows: i) Identify sustainability indicators using the FAO approach (1993b, 2007); ii) Calculating weight of each sustainability element by using AHP in group decision making; iii) Using GIS to build thematic layers corresponding to suitability elements and to combine layers; iv) Using TOPSIS method to calculate and to rank land suitability. This integration model is used to evaluate land in Duc Trong district, Lam Dong province, Vietnam. The similarities and differences are drawn through comparing results obtained by this method with the results obtained by using GIS, AHP group and weighted average method.

1. INTRODUCTION

Land evaluation plays an important role in land-use planning. It provides critical information to support sustainable land-use management (SLM). Land evaluation for SLM must take into account several different considerations including natural conditions, economic, social and environmental development conditions. Therefore, evaluating sustainable land-use management is a multi-criteria decision analysis (MCDA).

MCDA (sometimes referred to as multi-criteria decision making) implies techniques used to analyze a set of criteria providing decision makers with the priorities, or weights, of these criteria (Zopounidis and Pardalos, 2010). More than 80% of the researches in this area have used the analytic hierarchy process technique, referred to as the AHP of Saaty (1980), to determine weights of criteria (Lu et al., 2007).

In the field of land evaluation, where decisions should be based on inputs from a group of experts coming from very different backgrounds (such as agronomists, economists), quite a number of studies applied AHP allowing individual decision making to determine the weights of considered criteria. The results of such studies are therefore considered quite subjective (Thapa and Murayama, 2008; Chen, Yu and Khan, 2010). To facilitate the involvement of many experts in land use evaluation process and reducing individual's subjectivity, the AHP-group method (Lu et al., 2007), i.e. AHP in group decision making (AHP-GDM) is considered to use in this study. *Technique for Order Preference by Similarity to Ideal Solution* (TOPSIS) is used to calculate and to rank the suitability value (Si); The basic concept of this method (Hwang and Yoon, 1981) is that the selected alternative (the best suitable zone) should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) in a geometrical sense. The suitability value (Si) is classified to determine the suitable classes.

The integration model of GIS, group AHP and TOPSIS is important in solving the problem of the spatial multi-criteria decision making for selecting the cultivation land... In which, GIS is as a spatial analysis tool, group AHP is as a determined weights of indicators, TOPSIS is as a classified and determined priority of the suitable region. Combined GIS, group AHP and TOPSIS bring tremendous benefits in many fields, particularly, the evaluating sustainable land-use management.

2. CONTRUCTION OF MODEL

GIS, AHP group and TOPSIS are integrated to construct a model for evaluating sustainable land-use management (ESLM). The model includes the following steps (Figure 1):

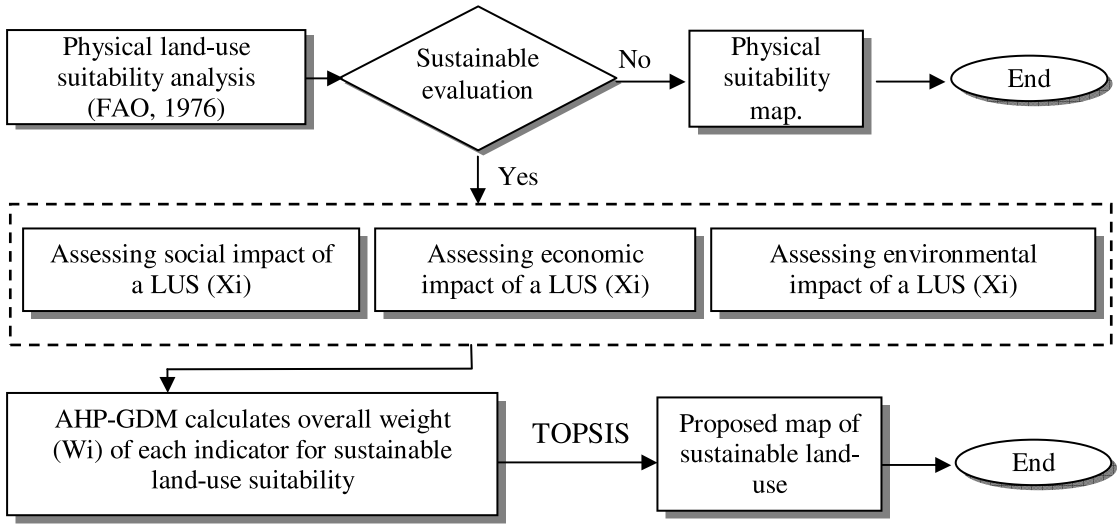

Figure 1: Integration of GIS, AHP-GDM and TOPSIS for sustainable land-use suitability analysis

Step 1 (Evaluating physical land-use suitability): Application of the integration of GIS and ALES for land evaluation (Le Canh Dinh, 2005) to evaluate physical land-use suitability. Only land use systems (LUSs) with high- to -marginally physical suitability orders (S1, S2, S3) are selected for total sustainability evaluation.

Step 2 (Evaluating sustainable land-use management): Consists of two stages: *i)* identify the indicators that affect the sustainability of the land use system (LUS), then determine the weights of these indicators by applying the AHP-GDM (Jaskowski et al., 2010; Lu et al. 2007); *ii)* the thematic information layers are built in GIS, overlay layers including economic, social, environmental impacts with physical suitability layer (results of step 1) and then calculate the suitability index (Si) using TOPSIS (Hwang and Yoon, 1981). Si is ranked to determine the suitable region with regards to all sustainability aspects (Figure 2).

i). Determine the weight of indicators by applying AHP-GDM:

+ Identify and construct the hierarchy of sustainability indicators. Next ask each k^{th} expert to judge the relative importance of the criteria, generating the pair-wise comparison matrix $[a_{ijk}]$. Check to ensure the consistency ratio $CR_k<10\%$.

+ Aggregate judgment matrices of the group (K.Goepel, 2010): $A_{ij} = \left(\prod_{k=1}^{n} a_{ijk}\right)^{1/n}$.

+ Based on $[A_{ij}]$, use the AHP algorithm of eigen vector to calculate the weights of criteria

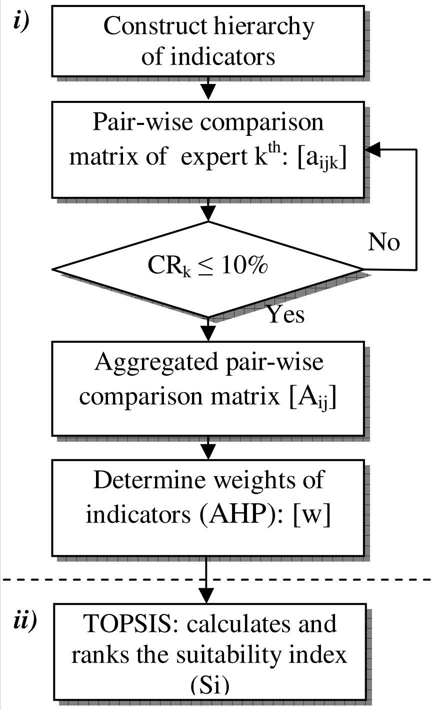

Figure 2: The ranked model of suitability region

ii). Rank the suitability index applying the TOPSIS:

Given a set of alternatives, $A=\{A_k| k=1,2,\ldots n\}$, and a set of criteria $C =\{C_j| j=1,2,\ldots m\}$; where $X =\{x_{kj}| k=1,2,\ldots n; j=1,2,\ldots, m\}$ denotes the set of performance ratings, and $W =\{w_j| j=1,2,\ldots m\}$ is a set of weights, the information I(A,C,X,W) can be presented as:

	C_1	C_2	…	C_m
A_1	x_{11}	x_{12}		x_{1m}
A_2	x_{21}	x_{22}		x_{2m}
A_n	x_{n1}	x_{n2}		x_{nm}
W	w_1	w_2		w_m

- *Step 1:* Calculate normalized matrices R and V

$$r_{kj}(x) = \frac{x_{kj}}{\sqrt{\sum_{k=1}^{n} x_{kj}^2}}, \quad k=1,..n; \quad j=1,..m; \quad (1)$$

$$v_{kj}(x) = w_j \times r_{kj}(x), \quad k=1,..n; \quad j=1,..m; \quad (2)$$

- *Step 2:* The positive ideal solution (PIS) and the negative ideal solution (NIS) are defined as follows:

$$PIS = A^+ = \{v_1^+(x), v_2^+(x), ..., v_m^+(x)\} = \{(\max_k v_{kj}(x) \mid j \in J_1), (\min_k v_{kj}(x) \mid j \in J_2) \mid k=1,..n\} \quad (3)$$

$$NIS = A^- = \{v_1^-(x), v_2^-(x), ..., v_m^-(x)\} = \{(\min_k v_{kj}(x) \mid j \in J_1), (\max_k v_{kj}(x) \mid j \in J_2) \mid k=1,..n\} \quad (4)$$

Where J_1, J_2 are the benefit criteria (larger is better) and the cost criteria (smaller is better).

- *Step 3:* Calculate the separation from the PIS, NIS between alternatives. The separation values can be measured using the Euclideean distance, which is given as:

$$D_k^* = \sqrt{\sum_{j=1}^{m} [v_{kj}(x) - v_j^+(x)]^2}, \text{ k=1,…,n; } (5); \quad D_k^- = \sqrt{\sum_{j=1}^{m} [v_{kj}(x) - v_j^-(x)]^2}, \text{ k=1,…,n; } (6)$$

- *Step 4*: Calculate the relative closeness to the ideal solution $C_k^* = \frac{D_k^-}{D_k^* + D_k^-}$; where

$C_k^* \in [0,1] \quad \forall k = 1,...,n; \quad (7)$

- *Step 5*: Rank the preferred orders $PIS(C_k^*)$ in descending order respectively with suitable classes from highly suitable to marginally suitable.

3. APPLICATION OF THE MODEL TO DETERMINE SUSTAINBLE LAND-USE FOR A STUDIED AREA

The studied area is Duc Trong district, Lam Dong province in the central highland of Vietnam. Seven major land use types (LUT) were selected for evaluating sustainable land-use. They consist of paddy crops (LUT1), two-seasonal-paddy and annual crop (LUT2), vegetable and flower (LUT3), annual crops (LUT4), mulberry (LUT5), coffee (LUT6), tea (LUT7).

Step 1 (evaluating physical land-use suitability): Five layers information are built in ArcGIS such as: soil type, slope, depth, irrigation, soil texture. Then 5 layers information are overlaid for building the land mapping unit that consists of 59 land mapping units (LMU).

Based on the land use requirement (LUR) of each land use type (LUT), the decisions tree is constructed in software ALES to evaluate physical land-use suitability. ALES data is linked to land mapping unit (in ArcGIS), then it is automatically matching LUR of each LUT with each land characteristic or land quality (LC/LQ) to evaluate the physical land-use suitability. The result is a physical land-use suitability map and database of each land use system (LUS); only the LUSs with high- to -marginally physical suitability orders (S1, S2, S3) are selected for total sustainability evaluation.

Step 2 (Evaluating sustainable land-use management):

i). Determine the weights of sustainable indicators*:* Based on the actual condition of Duc Trong district, the key indicators affect the sustainability of LUS presented in table 1. Application of AHP-GDM in determining the weights of indicators: interview the economic, social and environmental experts for pair-wise judgement matrices (Le Canh Dinh, 2011), all the weights of indicators are show in table 1.

Table 1: Hierarchical structure and weights of sustainable indicators.

Level 1		Level 2		Overall weights
objectives	w_1	*Sub- objectives*	w_2	$w_i=w_1*w_2$
Economic indicators	0.6860	1.1. Gross value return on farm (GO)	0.5853	0.4015
		1.2. Gross margin (GM)	0.2904	0.1992
		1.3. Gross value production/cost for cultivation (B/C)	0.1244	0.0853
Social indicators	0.1159	2.1. Labors (LB)	0.1811	0.0210
		2.2. Financial resources (FR)	0.1221	0.0142
		2.3. Use of farmer skill (FS)	0.0832	0.0096
		2.4. Government policy (GP)	0.5496	0.0637
		2.5. Farming habits (FH)	0.0640	0.0074
Natural resources and environment	0.1981	3.1. Physical land-use suitability (PS)	0.4267	0.0845
		3.2. Land cover level (LC)	0.2362	0.0468
		3.3. Water protection (WP)	0.2348	0.0465
		3.4. Enhance biological diversity (BI)	0.1023	0.0203

ii). Rank order of priority using the TOPSIS: Overlay all layers of information on economic, social, environmental with physical suitability layer and calculate the sustainable suitability index (Si) based on TOPSIS.

Table 2: The decision matrix –TOPSIS for vegetable and flower (LUT3)

LMU	PS (*)	Economic indicators			Social indicators					NRE (*)			
		GO	B/C	GM	LB	FR	FS	GP	FH	PS	LC	WP	BI
W =		*0.4015*	*0.1992*	*0.0853*	*0.0210*	*0.0142*	*0.0096*	*0.0637*	*0.0074*	*0.0845*	*0.0468*	*0.0465*	*0.0203*
1	S2	9	9	9	9	7	9	9	9	7	7	7	9
2	S3	9	5	1	9	7	9	9	9	5	7	7	9
…	…	…	…	…	…	…	…	…	…	…	…	…	…
59	N	0	0	0	0	0	0	0	0	0	0	0	0

(*) PS: Physical land-use suitability, NRE: natural resources and environment indicators

The decision matrix –TOPSIS consists of 4 components (table 2): 59 alternatives (equal to numbers of LMU in Duc Trong); 12 criteria; weights vector (table 1); x_{kj} denotes the performance measure of the k-th alternative in term of the j-th criterion, if LUS with none suitable (N) then $x_{kj}=0$, $x_{kj} \in [0,9]$, each LUS will be rated on how it scores against each sustainability indicator. The scoring scales and values along each indicator are defined in consultation with the experts and experienced farmers in Duc Trong district – Lam Dong province.

Based on table 2, calculate the $r_{kj}(x)$, $v_{kj}(x)$, PIS, NIS; rank the preferred orders C_k^* in descending order respectively with suitable classes from highly suitable to marginally suitable. In Duc Trong, if $C_k^* \geq 0.7$ then highly suitable (S1); $0.55 < C_k^* < 0.7$: Moderately suitable (S2); $0.4 \leq C_k^* < 0.55$: Marginally suitable (S3); $0 \leq C_k^* < 0.4$: None suitable (N).

Table 3: Rank the preference order (for LUT3: vegetable and flower)

Land mapping unit (LMU)	D_k^*	D_k^-	C_k^*	Classification of suitable classes
1	0.0046	0.0838	0.9478	S1
2	0.0286	0.0720	0.7160	S1
..	…	…	…	
59	0.0848	0	0	N

Apply similarly to rank the preference order for the remaining 6 LUTs, the result is a sustainable suitability map with of agriculture land (figure 3).

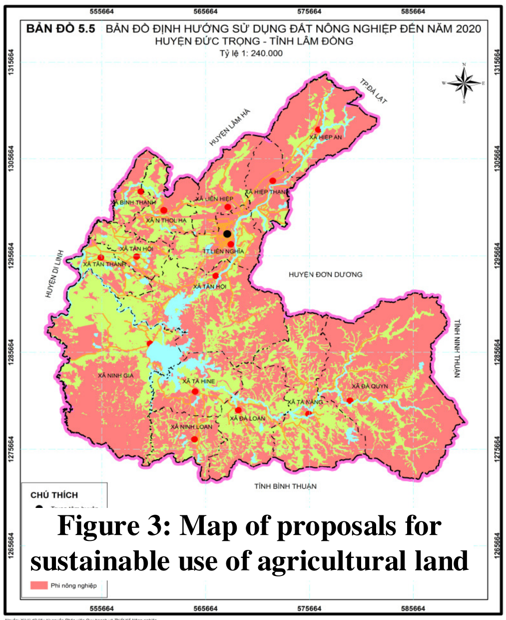

Figure 3: Map of proposals for sustainable use of agricultural land

+ ***Propose of sustainable land use***: Using GIS to overlay the proposed map (figure 3) and the current land-use map 2010 and the oriented land-use map 2020, the sustainable agricultural land-use are proposed for future use as follows: 2,000ha of paddy crops (LUT1); 2,500ha of two-seasonal-paddy and annual crop (LUT2), 3,000ha of vegetable and flower (LUT3), 8,200ha of annual crops (LUT4), 1,000ha of mulberry (LUT5), 13,000ha of coffee (LUT6), 300 ha of tea (LUT7).

+ ***Evaluation of results obtained from the model***: Results of the applied model are then compared with results obtained from the weighted average method (WAM) and the method of FAO(1976) (Figure 4).

The following observations are drawn from the comparison:

+ Both weighted average method (WAM) and TOPSIS consider the interaction between sustainability indicators. Areas of none suitable (N) of two methods are equal and greater than that of FAO (1976) method. It means that a LUS with not physical suitable is not sustainable suitability, even LUS with high physical suitability but low economic value and negative environmental impact is also not sustainable suitability.

+ In case of paddy crop with high and medium physical suitability (S1, S2), if applying WAM in evaluating sustainable land-use then results reduced to one level of suitable class, the result has medium and low suitability (S2, S3), because paddy crop is low economic value; however using TOPSIS, all results are high suitability (S1), because this method to promote the dominant indicator (the policy of area paddy crops protection) so that the suitability value closeness to the positive ideal solution (PIS).

+ Thus, with TOPSIS, the value of the suitable classes closeness to the positive ideal solution (PIS) and not- suitable class closeness to the negative ideal solution (NIS), so it is easy to choose suitable (S1, S2, S3) or not-suitable (N). However, in the same suitable class (S1, S2, S3), suitability values are close to PIS, so it is difficult to distinguish between levels S1, S2, S3.

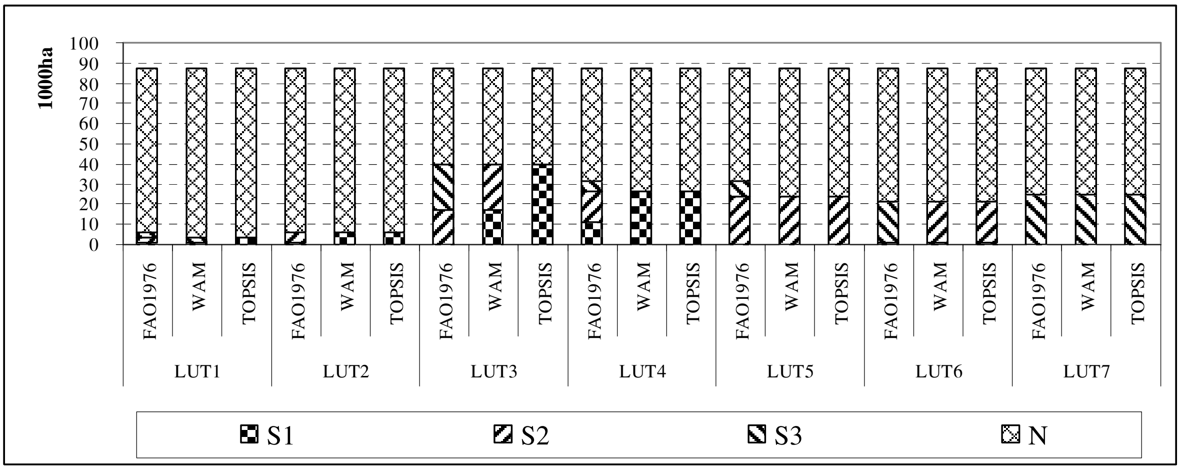

Figure 4: Comparison of results of three methods: FAO1976, WAM, TOPSIS.

4. CONCLUSION

The integrated model of GIS, group AHP and TOPSIS creates a useful tool for evaluating sustainable land-use management. In this model GIS is used to analyze spatial data, group AHP is used to determine weights of land-use sustainability indicators, TOPSIS is used to calculate and rank the suitability region. The model enables i) involvement of several experts coming from very different background while reducing subjective ideas encountered in the original AHP approach, ii) promoting the characteristic of the dominant indicator affect to sustainability evaluation. This integrated model is applied to evaluate sustainable land-use management in Duc Trong district, Lam Dong province. All key stakeholders of land resources in Duc Trong and Lam Dong have their representatives joint in the process including farmers, agronomists, economists, policy makers. Hence, the evaluation results are considered appropriate for the local practice and therefore should be proposed to use in the sustainable land-use management in Duc Trong district.

5. REFERENCES

Le Canh Dinh (2005). *Integration of GIS and ALES for land evaluation.* Master thesis, HoChiMinh city university of technology.

Le Canh Dinh (2011). *The integration of GIS and multi-criteria group decision analysis for land evaluation.* Science and Technology journal of Agriculture and Rural Development, Ministry of Agriculture and Rural Development, Vietnam, vol.9/2011, pp 82-89.

Y. Chen, J. Yu, S. Khan (2010). *Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation.* Environmental Modelling & Software 25 (2010), 1582-1591, Science Direct, Elsevier.

P. Jaskowski, S. Biruk, R. Bucon (2010). *Assessing contractor selection criteria weight with fuzzy AHP method application in group decision making.* Automation in construction 19 (2010), Elsevier.

J. Lu, G. Zhang, D. Ruan, F. Wu (2007). *Multi-Objective Group Decision Making: Method, software, and application with fuzzy techniques.* World scientific Publishing, Singapore.

R.B.Thapa, Y.Murayama (2008). *Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: A case study of Hanoi.* Land use policy, Vol.25, issue 2, pages 225-239, Elsevier.

C. Zopounidis, P. M. Pardalos (2010). *Handbook of MultiCriteria Analysis.* Applied optimization, Springer, USA.