

TS 5C – Advanced Technology for Cadastre and Land Management

THE INTEGRATION OF GIS AND FUZZY MULTIOBJECTIVE LINEAR PROGRAMMING – AN INTERACTIVE DECISION MAKING TOOL IN SUSTAINABLE USE OF AGRICULTURE LAND (3623)

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Content of presentation

- 1. Introduction:
 - What are to solve the problems in land use planning?
 - Why application of Fuzzy MOP and GIS in land use planning?
- 2. Algorithm
 - What's the method for solving the MOLP model?
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 - Studied area: Bao Lam District - Lam Dong province -Vietnam
 - Discussion
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1. Introduction

- Agriculture land allocation is one of the most important aspects in the Agriculture and Rural Development Planning.
- Land allocation exercise is based on land use suitability evaluations (FAO, 1976; 1993a;1993b; 1995).
- Results of land suitability as presented in table:

LMU-ID	LUT ₁	LUT ₂	...	LUT _n	Area (supply)
LMU ₁	S ₁₁ ; [Val ₁₁]; [X ₁₁]	S ₁₂ ; [Val ₁₂]; [X ₁₂]	...	S _{1n} ; [Val _{1n}]; [X _{1n}]	[S ₁]
...			...		...
LMU _m	S _{m1} ; [Val _{m1}]; [X _{m1}]	S _{m2} ; [Val _{m2}]; [X _{m2}]	...	S _{m3} ; [Val _{mn}]; [X _{mn}]	[S _m]
Area (demand)	[S _{LUT1}]	[S _{LUT2}]		[S _{LUTn}]	

1. Introduction (cont.)

- LMU is an area of land whose characteristic is homogeneous.
- LUT: Land Use Type
- S_{ij} represents suitability level of an LMU_i for a certain LUT_j
- LUS: LUT is applied for a certain LMU
- X_{ij} : the area of LUS_{ij}
- IF S_{ij} of LUS_{ij} is “not suitable” THEN $X_{ij} = 0$
- Val_{ij} : input or output values corresponding to a LUS_{ij}

1. Introduction (cont.)

- The question is each particular LUS should occupy how much area, so that the total Land Use in a study area will require:
 - The least production cost,
 - Deliver highest production output,
 - Meet employment required for local community,
 - Minimize negative environmental effect.
- Thus, agriculture land use allocation is a multi objective optimization problem, which can be solved using different approaches:
 - Single Objective Approach
 - Multi Objective Approach.

1. Introduction (cont.)

- **Single Objective Approach:** the linear programming model has been applied.
 - The most important objective is optimized
 - The remaining objectives are treated as constraint conditions
 - Burke and Kendal in their study (2005) observed that in several cases, this approach did not lead to feasible solution.

1. Introduction (cont.)

- **Multi Objective Approach:** Multi-Objective Linear Programming (MOLP) has also been applied.
 - This approach treats the multi-objective problem by converting it into single objective optimization, by introducing a set of objective weights (F.B. Abdelaziz, 2007).
 - Note that decision makers can not determine a satisficing vector of weight right from the beginning.
 - Instead they will interact with the model, modifying the weight vector step by step, until a suitable alternative is established. Therefore, this approach is called **interactive method**.

1. Introduction (cont.)

- **Multi Objective Approach (cont.)**

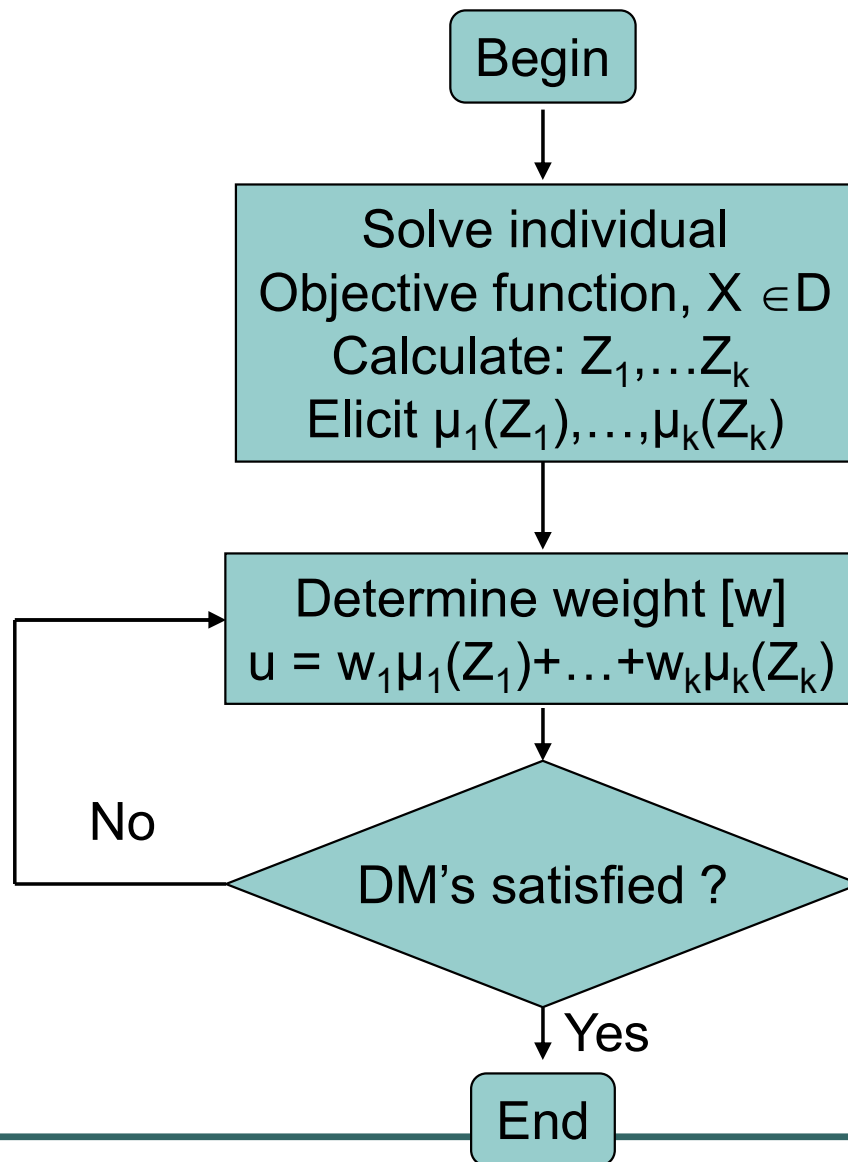
- Different objectives are measured in different measurement units. ...
- To overcome this challenge, objectives are represented in a fuzzy form in which each objective function takes a value between 0 to 1.
- Each objective function indicates the satisfaction of decision maker towards the respective objective.
- All of objectives have never become satisfactory, so Trade-off rates between the objectives (some **satisfying** and some **sacrificing = satisficing**).
- The fuzzy form is closer to intuitive thinking of decision makers, and therefore it is easier for them to select alternatives.
- The interactive method used in conjunction with fuzzy objectives is called **interactive fuzzy satisficing method**.
- According to Sakawa (2003), this method is very suitable for MOLP problem.

2. Algorithm of interactive fuzzy satisfying method

2.1. Introduction of MOLP: The MOLP is described as follows

- The objective function: Max (Min) $Z(x) = (Z_1(x), Z_2(x), \dots, Z_k(x))^T$
- Subject to: $x \in D = \{x \in \mathbb{R}^n \mid Ax \leq B, x \geq 0\}$
- In which :
 - $Z_i(x)$ are objectives, $Z_i(x) = C_i x$; $C_i = (C_{i1}, C_{i2}, \dots, C_{in})^T$, $i=1,2,\dots,k$;
 - A is a matrix $m \times n$;
 - B is a matrix $1 \times m$;
 - D is a set of constraints.
 - x are decision variables (area of LUS).

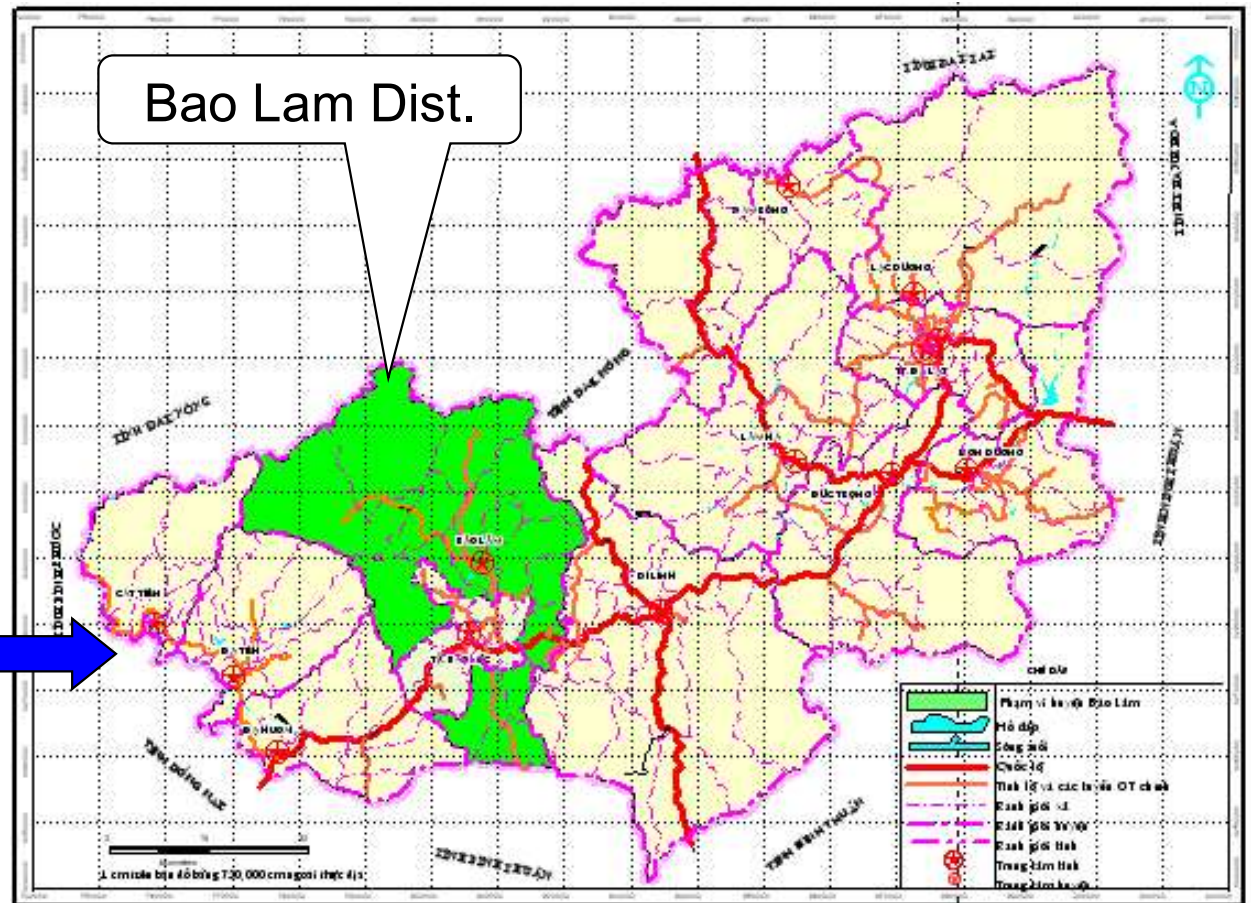
2.2. The Algorithm of Interactive fuzzy satisficing method



Sources: [M. Sakawa,
1981, 1982, 1984, 2003]

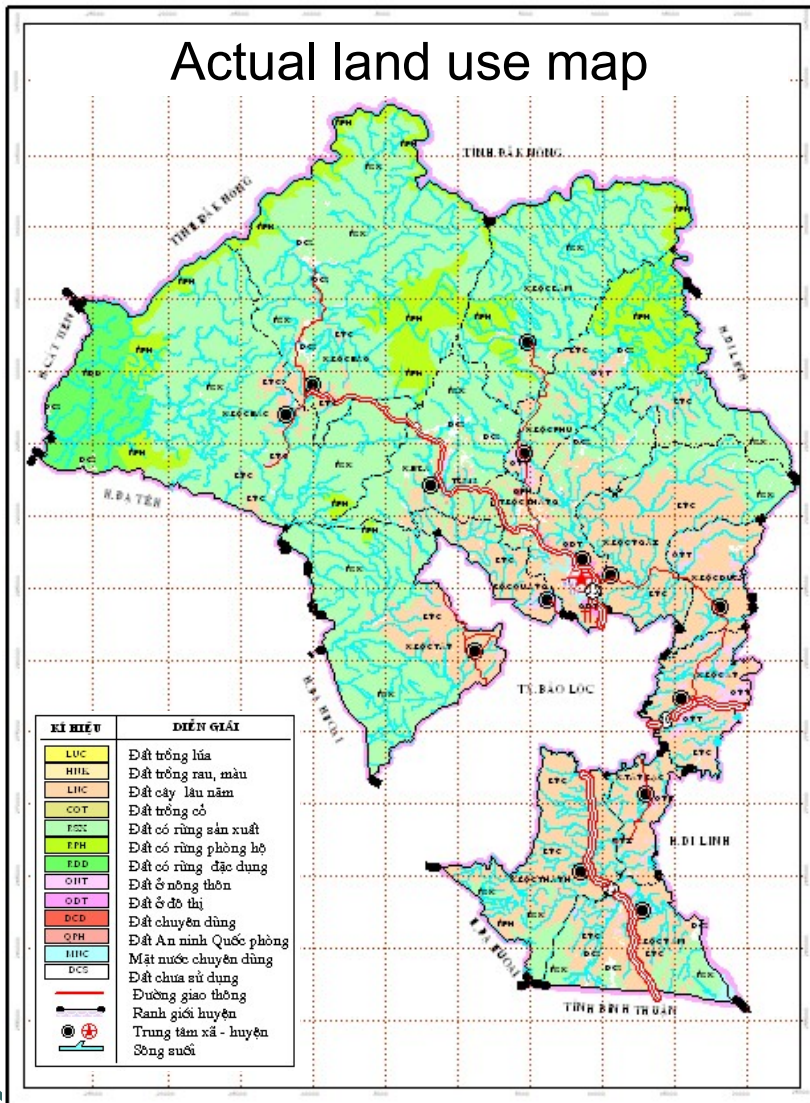
3. Application:

Studied area is Bao Lam Dist. –Lam Dong prov.- The central highland of Vietnam



Actual land use

Actual land use map



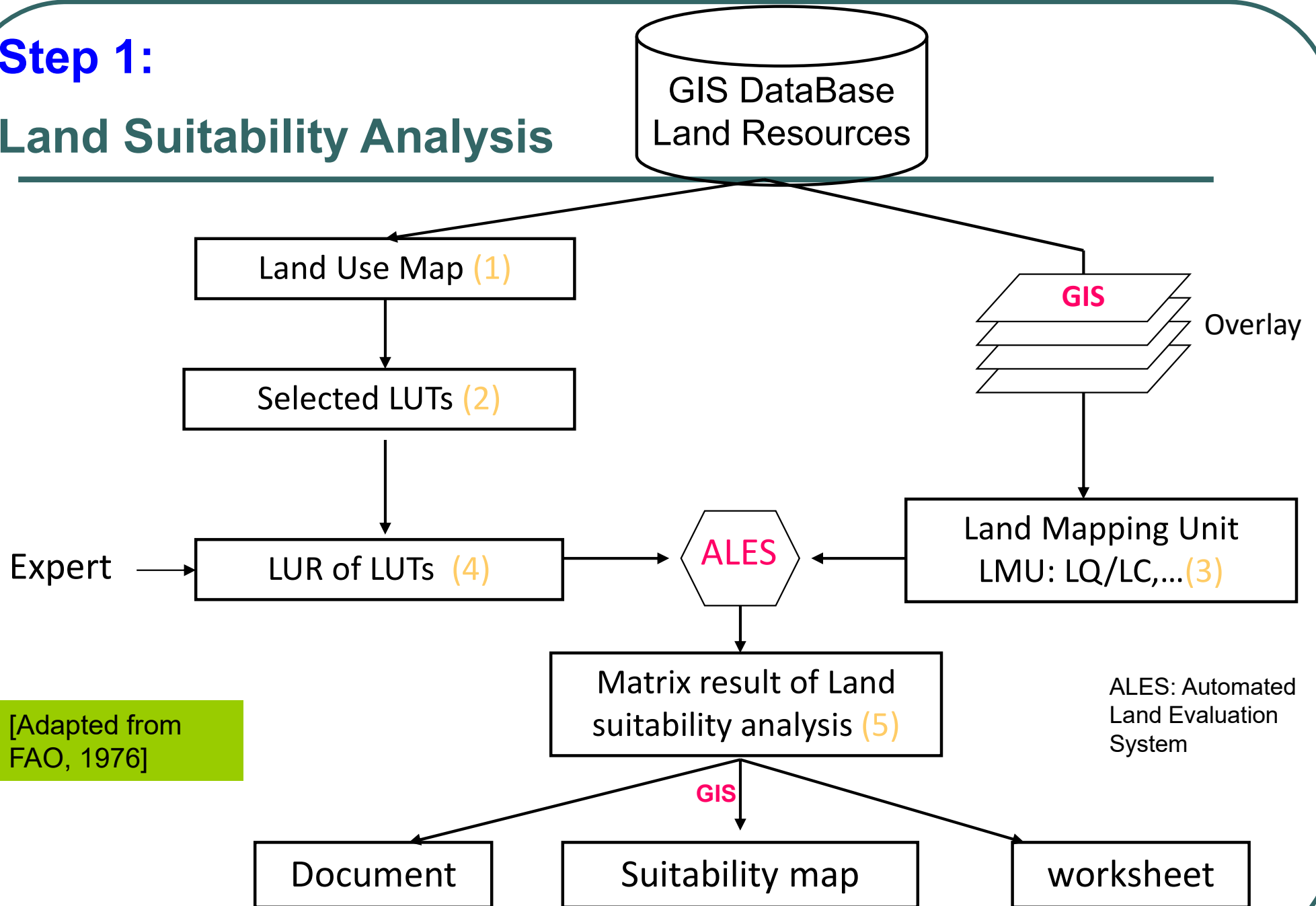
- There are five major Land use types (LUT):

- LUT1: Annual crop,
- LUT2: Mulberry,
- LUT3: Coffee,
- LUT4: Tea,
- LUT5: Fruit trees.

- 5 LUTs were evaluated for land use planning

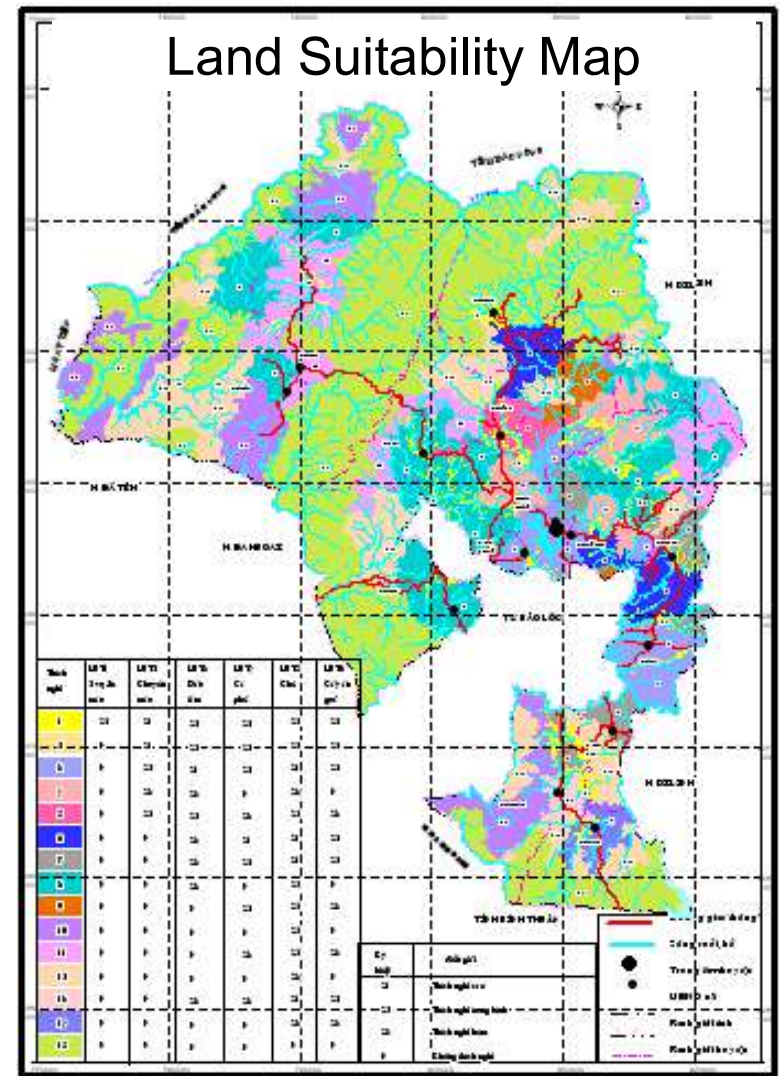
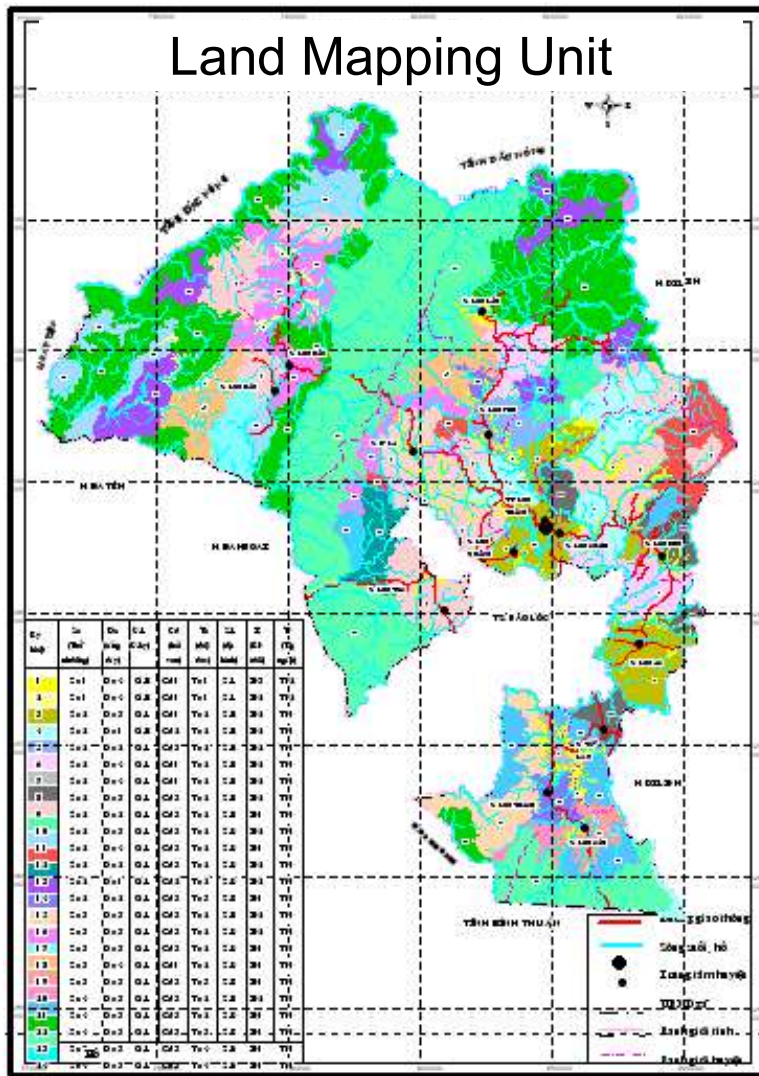
Step 1:

Land Suitability Analysis



Integrated ALES and GIS model for Land Suitability Analysis

The result of land suitability analysis model



Land suitability

Table 2: Land suitability of land use types - Bao Lam Dist. –Lam Dong prov. - Vietnam

Suitable	LMU	LUT1	LUT2	LUT3	LUT4	LUT5	Area	Percent
Types	(code)	Annual crop	Mulberry	Coffee	Tea	Fruit-tree	(ha)	(%)
1	1, 2	S1	S2	S2	S2	S2	8,038	5.5
2	3	S2	S1	S2	S1	S2	6,585	4.5
3	5	N	S1	S3	S2	S3	1,780	1.2
4	6, 7	N	N	S1	S1	S2	5,205	3.6
5	8	N	N	S2	S1	S2	3,217	2.2
6	10	N	N	S2	S2	S3	1,518	1.0
7	15	N	N	S3	S1	S2	1,287	0.9
8	9, 11, 12, 16, 17, 18	N	N	S3	S2	S3	35,905	24.5
9	4, 13, 14, 19, 20, 21, 22, 23, 24	N	N	N	N	N	81,161	55.5
Area of rivers and streams							1,653	1.1
Area of administrative boundary							146,349	100.0

S1: Highly Suitable; S2: Moderately Suitable;
S3: Marginally Suitable; N: Not Suitable

Step 2:

Formulate a MOLP model for land allocation

- Bao Lam three issues have to be taken into considerations:
 - Increasing economic value,
 - Creating more agriculture works,
 - Reducing negative environmental impact
- These considerations are converted into four objectives:
 - Maximize gross output (Z1),
 - Minimize cultivation cost (Z2),
 - Maximize labor requirement (Z3),
 - Maximize land cover in order to reduce soil erosion (Z4).
- From these requirements, the MOLP is formulated as follows:

Step 2:

(1) Establish objective functions:

The parameters:

- P_{ij} is the gross output/ha of LUT_j at suitability zone i,
- C_{ij} is the cost for cultivating/ha of LUT_j at suitability zone i,
- L_{ij} is the labor requirement/ha of LUT_j at suitability zone i,

Table 3: Parameters of economic returns and labor requirement of LUTs

Suitability classes	LUT1	LUT2	LUT3	LUT4	LUT5
	Annual crop	Mulberry	Coffee	Tea	Fruit-tree
Return on farm (million VND/ha/year) – P parameter					
S1	20.300	26.400	77.000	39.595	
S2	17.420	21.560	61.600	30.240	21.948
S3	13.800	18.040	48.400	22.330	16.330
Cultivation cost (million VND/ha/year) – C parameter					
S1	11.571	13.429	39.270	14.560	
S2	10.600	11.025	30.190	12.870	8.796
S3	7.100	11.970	26.620	11.055	7.080
Labor requirement (labor day/ha/year) – L parameter					
S1	250	300	155	350	
S2	263	315	163	368	160
S3	276	331	171	386	180

Source: Sub-National Institute for Agricultural Planning and Projection (2008)

Step 2:

(1) Establish objective functions (conti...):

Decision variable (X_{ij}):

Suitable	LMU	LUT1	LUT2	LUT3	LUT4	LUT5	Area	Percent
Types	(code)	Annual crop	Mulberry	Coffee	Tea	Fruit-tree	(ha)	(%)
1	1, 2	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	8,038	5.5
2	3	X_{21}	...	...	...	X_{25}	6,585	4.5
3	5	X_{31}	...	...	...	X_{35}	1,780	1.2
4	6, 7	...	...	...	...	...	5,205	3.6
5	8	...	...	...	...	...	3,217	2.2
6	10	...	...	...	...	...	1,518	1.0
7	15	...	...	...	...	...	1,287	0.9
8	9, 11, 12, 16, 17, 18	...	...	...	...	...	35,905	24.5
9	4, 13, 14, 19, 20, 21, 22, 23, 24	X_{91}	...	...	...	X_{95}	81,161	55.5
Area of rivers and streams							1,653	1.1
Area of administrative boundary							146,349	100.0

Matrix of decision variable
 $X[i,j]$; $i=9, j=5$:

Step 2:

(1) Establish objective functions (conti...)

The Objective functions:

- Maximize gross output objective (Z1):

$$\sum_{i=1}^9 \sum_{j=1}^5 P_{ij} X_{ij} \rightarrow \max$$

- Minimize cultivation cost objective (Z2):

$$\sum_{i=1}^9 \sum_{j=1}^5 C_{ij} X_{ij} \rightarrow \min$$

- Maximize employment objective (Z3):

$$\sum_{i=1}^9 \sum_{j=1}^5 L_{ij} X_{ij} \rightarrow \max$$

- Maximize land cover objective (Z4):

$$\sum_{i=1}^9 \sum_{j=3}^5 X_{ij} \rightarrow \max$$

Step 2:

(2) Establish resources constraints functions:

- Total of zon $1 \leq 8,038\text{ha}$;(show on table as below)

Suitable	LMU	LUT1	LUT2	LUT3	LUT4	LUT5	Area	Percent
Types	(code)	Annual crop	Mulberry	Coffee	Tea	Fruit-tree	(ha)	(%)
1	1, 2	X_{11}	$+ X_{12}$	$+ X_{13}$	$+ X_{14}$	$+ X_{15}$	$\leq 8,038$	5.5
2	3	X_{21}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{25}$	$\leq 6,585$	4.5
3	5	X_{31}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{35}$	$\leq 1,780$	1.2
4	6, 7	X_{41}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{45}$	$\leq 5,205$	3.6
5	8	X_{51}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{55}$	$\leq 3,217$	2.2
6	10	X_{61}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{65}$	$\leq 1,518$	1.0
7	15	X_{71}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{75}$	$\leq 1,287$	0.9
8	9, 11, 12, 16, 17, 18	X_{81}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{85}$	$\leq 35,905$	24.5
9	4, 13, 14, 19, 20, 21, 22, 23, 24	X_{91}	$+ \dots$	$+ \dots$	$+ \dots$	$+ X_{95}$	$\leq 81,161$	55.5
Area of rivers and streams							1,653	1.1
Area of administrative boundary							146,349	100.0

Step 3: Solve the MOLP

following the algorithm of interactive fuzzy satisficing

- (i) Run the linear programming for each objective function to determine its respective membership function:

Table 4: The individual value of each objective function

Objective function	Gross output	Cultivation cost	Labor requirement	Land cover
	(Mill. VND/ha)	(Mill. VND/ha)	(labor day/ha)	(ha)
Z1: Maximize gross output	2.991.741	1.483.190	13.653.916	63.535
Z2: Minimize cultivation cost	2.037.230	998.544	14.626.164	49.801
Z3: Maximize employment	2.147.377	1.067.386	15.861.074	49.535
Z4: Maximize land cover	2.721.651	1.319.175	14.244.156	63.535

$$\mu_1(Z_1) = \frac{Z_1 - 2,037,230}{2,991,741 - 2,037,230} = \frac{Z_1 - 2,037,230}{954,511}$$

$$\mu_2(Z_2) = \frac{1,483,190 - Z_2}{1,483,190 - 998,544} = \frac{1,483,190 - Z_2}{484,646}$$

$$\mu_3(Z_3) = \frac{Z_3 - 13,653,916}{15,861,074 - 13,653,916} = \frac{Z_3 - 13,653,916}{2,207,158}$$

$$\mu_4(Z_4) = \frac{Z_4 - 49,535}{63,535 - 49,535} = \frac{Z_4 - 49,535}{14,000}$$

Step 3: Solve the MOLP (conti.)

(ii) Determine priority level of each objective function:

- Often, decision makers change the set of weights of objective functions until they arrive at an satisfaction set.
- In cases where decision makers can not decide a desired set of weights, the Analytical Hierarchy Process technique (Satty, 1980) can be applied to support decision makers.

Step 3: Solve the MOLP (conti.)

(iii). Establish an aggregated objective function:

$$U = w_1\mu_1(Z_1) + w_2\mu_2(Z_2) + w_3\mu_3(Z_3) + w_4\mu_4(Z_4) \rightarrow \max (*)$$

$$(*) \Leftrightarrow w_1 \times \frac{Z_1}{954,511} - w_2 \times \frac{Z_2}{484,646} + w_3 \times \frac{Z_3}{2,207,158} + w_4 \times \frac{Z_4}{14,000} \\ - w_1 \times \frac{2,037,230}{954,511} + w_2 \times \frac{1,483,190}{484,646} - w_3 \times \frac{13,653,916}{2,207,158} - w_4 \times \frac{49,535}{14,000} \rightarrow \max$$

$$\Leftrightarrow w_1 \times \frac{Z_1}{954,511} - w_2 \times \frac{Z_2}{484,646} + w_3 \times \frac{Z_3}{2,207,158} + w_4 \times \frac{Z_4}{14,000} \rightarrow \max (**)$$

In which, w_1, w_2, w_3, w_4 are weights of objectives Z_1, Z_2, Z_3, Z_4 respectively

(**) problem is a Linear Programming which can be solved easily

by LINGO software

Step 3: Solve the MOLP (conti.)

(iv) Solve the problem

- There are two scenarios to be considered:
 - Scenario 1 (Most preferred): Economic > Social > Environment
 - Scenario 2: Economic > Environment > Social
- The principle to determine a set of weights is defined as follows
 - For scenario 1: $w_1 \geq w_2 \geq w_3 \geq w_4$
 - For scenario 2: $w_1 \geq w_2 \geq w_4 \geq w_3$
- $w_1, w_2, w_3, w_4 \geq 0$.
- Balance of weights: $w_1 = w_2 = w_3 = w_4 = 0.25$,
- The others: The value of each w will be changed by $\lambda = 0.1$.

Alternative 10 is the most satisfied alternative and is selected

Table 5: The scenarios and alternatives of land use

Scenarios	Alternatives	Set of weight				U (*)	Membership function			
		W ₁	W ₂	W ₃	W ₄		$\mu(Z_1)$	$\mu(Z_2)$	$\mu(Z_3)$	$\mu(Z_4)$
	Objectives	1				1.000	1.000	0.000	0.000	1.000
			1			1.000	0.000	1.000	0.440	0.019
				1		1.000	0.115	0.858	1.000	0.000
					1	1.000	0.717	0.338	0.267	1.000
	balance	0.250	0.250	0.250	0.250	0.560	0.459	0.573	0.544	0.663
	1	0.300	0.300	0.200	0.200	0.575	0.660	0.404	0.279	1.000
	2	0.300	0.300	0.300	0.100	0.598	0.065	0.947	0.981	0.000
Scenario 1	3	0.400	0.400	0.100	0.100	0.558	0.623	0.457	0.385	0.873
	4	0.400	0.300	0.200	0.100	0.562	0.635	0.427	0.542	0.714
	5	0.400	0.200	0.200	0.200	0.568	0.560	0.498	0.336	0.886
	6	0.500	0.300	0.100	0.100	0.497	0.446	0.549	0.383	0.714
	7	0.500	0.200	0.200	0.100	0.587	0.662	0.397	0.525	0.714
	8	0.600	0.200	0.100	0.100	0.603	0.663	0.400	0.478	0.747
	9	0.700	0.100	0.100	0.100	0.629	0.663	0.400	0.498	0.747
Scenario 2	10	0.300	0.300	0.100	0.300	0.598	0.549	0.527	0.506	0.748
	11	0.400	0.300	0.100	0.200	0.576	0.615	0.447	0.466	0.748
	12	0.500	0.200	0.100	0.100	0.536	0.663	0.400	0.498	0.747

(*) u is an aggregated objective function

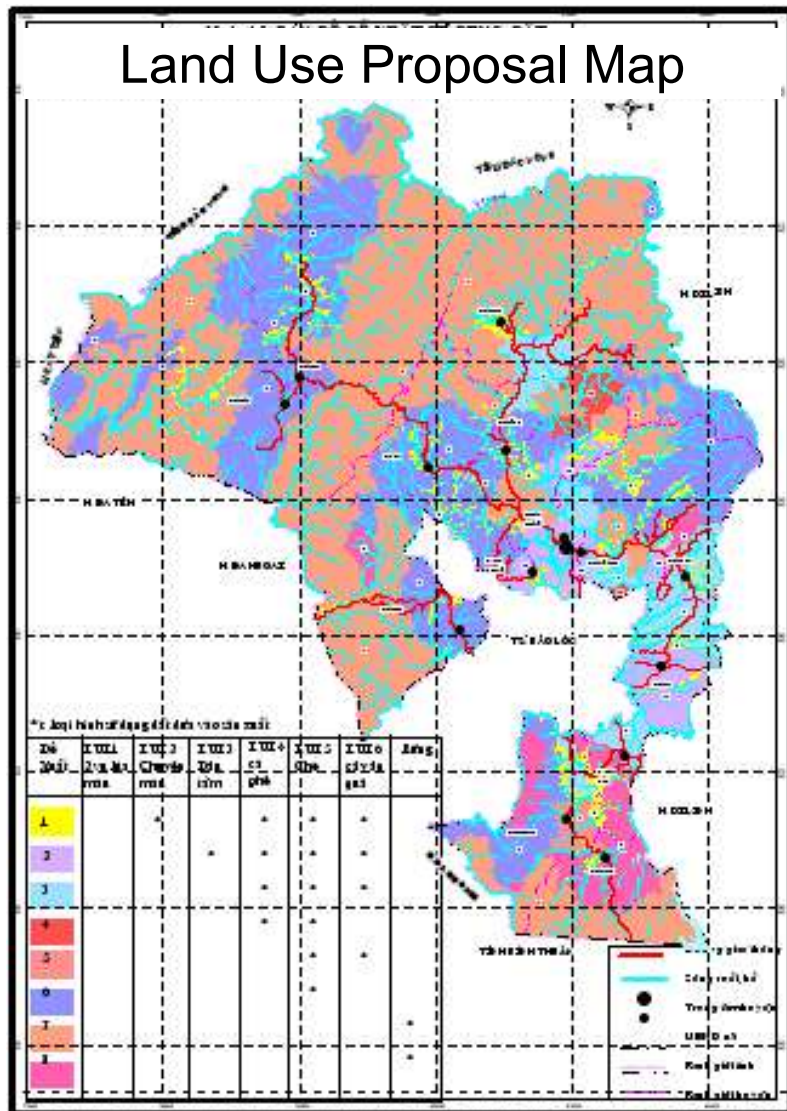
Specific land allocation following alternative 10 are given in table:
Zon 9: 81,161ha;

Table 6: Land allocation of chosen alternative (alternative 10)

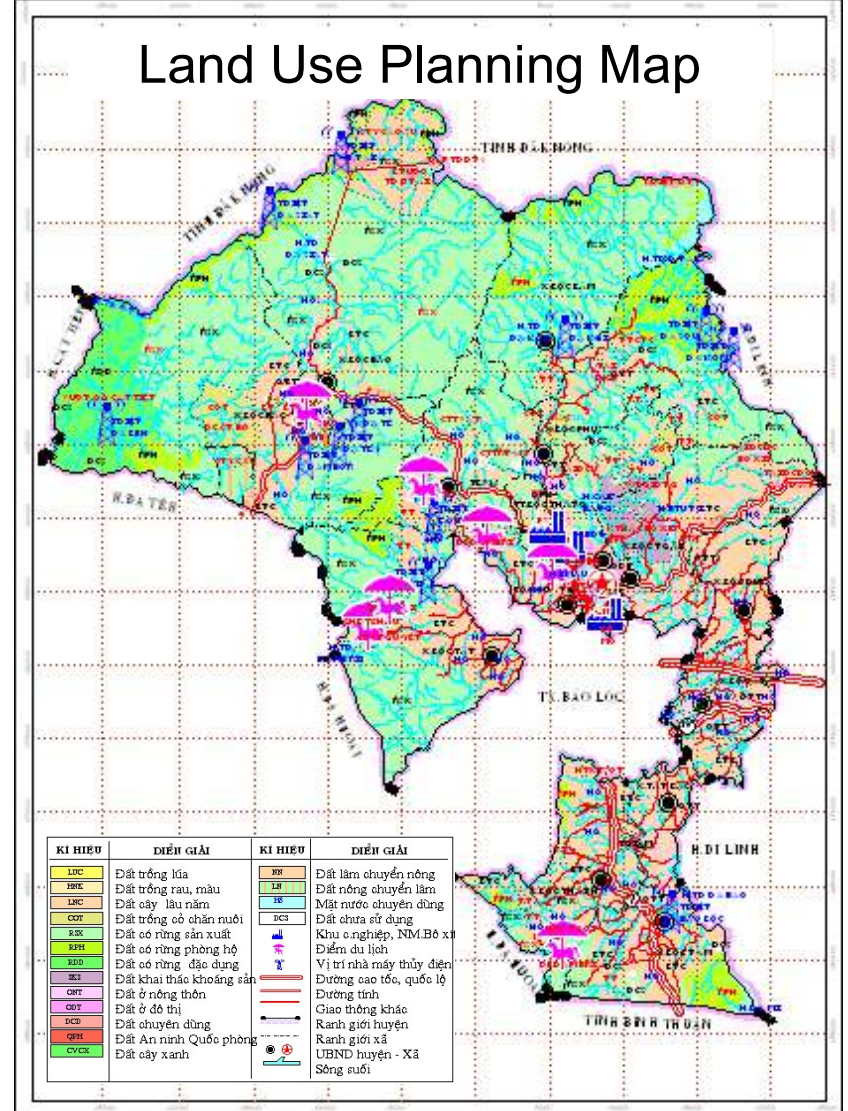
Suitability	LUT1	LUT2	LUT3	LUT4	LUT5	Area
Type	Annual crop	Mulberry	Coffee	Tea	Fruit-tree	(ha)
1	1,535	2,220	4,283			8,038
2			6,585			6,585
3		1,780				1,780
4				5,205		5,205
5			3,217			3,217
6			1,518			1,518
7				1,287		1,287
8			12,397	11,508	12,000	35,905
9	Non-agriculture land					81,161
Total of alt.10	1,535	4,000	28,000	18,000	12,000	
Area of rivers and streams						1,653
Area of administrative boundary						146,349

Land use planning

Land Use Proposal Map



Land Use Planning Map



4. Conclusion

- To determine best agriculture land distribution for a studied area, an integrated model method is introduced.
 - GIS is used to create suitability input data for a multi objective linear programming,
 - LINGO is used to solve linear planning problems,
 - AHP to determine relevant set of weights of the considered objectives.
 - The multi-objective problem is converted into a linear programming problem by using the algorithm of interactive fuzzy satisficing method.
- To obtain all possible solutions of an MOLP problem will take a lot of time. The **interactive fuzzy satisficing method** allows decision makers to interact with the model, the most satisfied solution could be obtained much quicker, in some cases, just after few iterations of the process.

4. Conclusion (cont.)

- The integrated method enables direct interactions with decision makers in the process of determining the best desirable set of relative weights of the considered objectives.
 - In this way, development viewpoint of the government as well as preference of local farmers are taken into consideration.
 - As a result of this, the land distribution solution obtained from the model was very well received by the decision makers of the studied district, which in turn will guarantee the application of the solution.
- GIS is a useful technique for spatial analysis including building land resources database, analyzing land suitability and visually supporting decision makers in land distribution.
- Integration of the Fuzzy MOLP with GIS supports decision makers to generate several good options that meet multiple objectives in land distributing, before arriving at the best option that most satisfied the decision makers.

Thank You very much

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