COMBINING GEOGRAPHICAL INFORMATION SYSTEM AND MULTICRITERIA EVALUATION TO DEAL WITH LAND USE PROBLEM.

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ABSTRACT

The geographical information systems (GIS) provide the decision-maker with a powerful set of tools for the manipulation and analysis of spatial information. The functionality of GIS is, however, limited to certain deterministic analyses in key application areas such as spatial search.
Land suitability evaluation has to face two major difficulties. First, there is a huge number of alternatives because each different coordinate is a possible solution (raster representation). Second, the decision making process is generally based on different criteria, which can be defined on a quantitative or a qualitative scale.
Multicriteria evaluation (MCE) is one of the solutions for such complex choices situations as they appear in land suitability evaluation and territory management. The integration of multicriteria methods with GIS is forwarded as providing the user with the means to evaluate various alternatives on the basis of multiple and conflicting criteria and objectives.
This paper explore the possibility of improving communication between land use and decision makers, using an interactive system combining GIS and multicriteria methods. An example application based on the search for the best 1000 hectares of industrial land in Nakuru (Kenya) using IDRISI (raster GIS) and ELECTRE (MCE methods) is included.
The finality of our study is to compare results obtained from the classic approach (without multicriteria analysis) and those obtained from the approach combining SIG and MCE.

RESUME

Les systèmes d'information géographique (SIG) fournissent au décideur des outils puissants de manipulation et d'analyse des données spatiales.
Cependant, les fonctionnalités qui y sont implantées se limitent à de simples analyses de type déterministique. Les problèmes relatifs au territoire impliquent, généralement, plusieures actions où chacune peut répondre aux objectifs fixés et où chacune a ses propres coûts et conséquenses qu'il s'agit d'évaluer.
L'évaluation de l'adéquation du sol à un usage donné doit faire face à deux difficultés majeures. Le grand nombre d'alternatives possibles, car chaque position est une solution potentielle (représentation matricielle). Le processus de prise de décision est en général basé sur différents critères, lesquels peuvent se rapporter à des échelles qualitatives ou quantitatives. Dans ce contexte, ce papier explore la possibilité d'améliorer l'interface décideur/utilisation du sol en utilisant un system interactive combinant les potentialités du SIG et les techniques d'analyse multicritère.
Un exemple d'application concernant la recherche de sites convenant à l'irrigation dans la région de Tlemcen (Algérie) est présenté, en utilisant les potentialités du SIG IDRISI et les méthodes multicritères ELECTRE.
Le potentiel d'intégration SIG-ELECTRE constitue une voie intéressante pour faire évoluer les SIG vers de véritables systèmes d'aide à la décision à référence spatial (SADRS).

1 INTRODUCTION

Until now, the spatial decision making and the integration of multicriteria into a GIS are less used. The most significant work in this field was that of Eastman and al. [1993] which provide the new version of IDRISI GIS 4.1 by a decision support analytical ring. It includes multicriteria evaluation based on the weighted sum using Analytical Hierarchy Process methods. It is the only one which includes analytical rings of decision aid especially the multicriteria analysis.

[R. Eastman and al., 1993], [pereira and Duckstein, 1993] and [Vidal et al., 1994] integrated full aggregated multicriteria procedures into a raster GIS.

However, the different studies done until now showed that this approach was not reliable (A. Schärlig, 1985) but it is still used since the partial aggregation (outranking) approach cumbersome due to the inter-comparison of all the alternatives (actions) which represents, in the case of an image (pixels), about 100 million of operations (F. Joerin, 1995).

Our study is based on the integration of ELECTRE (ÉLimination Et Choix Traduisant la RÉalité) methods into a raster GIS aiming to resolve spatial decision problems. This helps to build a model of the decision maker preferences to process it while choosing one of the several alternatives.

2 METHODOLOGY

When modelling a real world decision problem using multiple criteria decision aid, several problematic (or problem formulations) can be considered. [Roy, 1985] distinguishes three basic problematic: choice *(□)*, sorting *(□)* and ranking *(□)*.

Given a set *A* of alternatives (or actions), the choice (or selection) problematic consists in a choice of a subset $A' \subset A$, as small as possible, composed of alternatives being judged as the most satisfying.

he sorting problematic consist in formulating the decision problem in terms of classification so as to assign each alternative *a* to the appropriate category should rely on the intrinsic value of *a* (and not on the comparison of *a* to other alternatives from *A*).

The ranking problematic consists in establishing a preference pre-order (either partial or complete) in the set of alternatives *A*.

The outranking methods deal with only one of the reference problematic. Therefore ELECTRE methods are also concerned by this rule:

- ELECTRE I: □ problematic,
- ELECTRE II: □,
- ELECTRE III: □,
- ELECTRE IV: □,
- ELECTRE TRI: □,
- ELECTRE Is: □.

ELECTRE Tri is a multiple criteria sorting method, i.e., a method that assigns alternatives to predefined categories. The assignment of an alternative *a* results from the comparison of *a* with the profiles defining the limits of the categories. This method requires the elicitation of parameters (weights, discrimination thresholds, category limits,...) in order to construct a preference model of the decision maker.

The main objective of our approach is to reduce the number of the alternatives using ELECTRE Tri (sort). In fact, when the problematic used is different from sorting (choice or ranking), the other ELECTRE should be applied involving the best category yielded by ELECTRE Tri (see fig.1).

The level III of Goraducci [1993] was adopted to build our prototype. The user is now provided by a programme and its data base which contains both spatial data and multicriteria methods base. The multicriteria algorithm is performed either in GIS language or in an external routine to be called using the same language. This algorithm will be used as a function such as the spatial analysis modules.

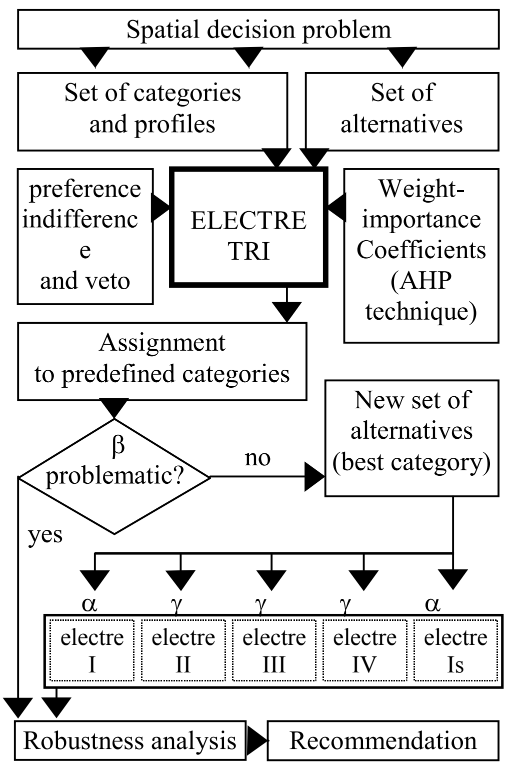

Figure 1. ELECTRE approach scheme.

3 PRACTICAL PROBLEMS

The main factors of the agricultural development is irrigation. Taking into account of the importance of agriculture and food-invoice, scientists constantly look for new soils able to be irrigated and then apply a policy of management. This study requires a multidisciplinary approach involving topography, pedology, geology, geomorphology, agronomy, ecology, economy,...

The study area is situated at 20 km from Maghnia and 150 km from Oran. It represents the Northwest extension of the plain of Maghnia along the borders between Algeria and Morocco. This area is called Zriga; it is 420m higher and is bordered to the north by Beni Snassen, to the east by the plain of Maghnia, to the south by the plain of Angads (Morocco) and to west by the borders between Algeria and Morocco.

In this study, we have to determine a map illustrating three categories:

- category 1: irrigation suitable land,
- category 2: fairly suitable land,
- category 3: not suitable land.

This is based on the six following criteria:

- proximity to habitations,
- to roads,
- to wells,
- to hydrographic network,
- slope,
- soils types.

The objective, hence, is to illustrate how the integration of ELECTRE methods into a GIS does contribute in land suitability evaluation.

First of all, we process the "classical" procedure then we apply ELECTRE approach. The images showing proximity to roads and hydrographic network were created by rasterizing the roads and hydrographic vectors and then running DISTANCE. The image illustrating the proximity to habitations and wells were created by using the cost module using the COSTGROW algorithm. Running SURFACE on a digital elevation model for the study area, the image representing the slope factor was created. The land cover was obtained from the pedologic map 1/25000. The main types of soils are:

- isohumic,
- calcimagnesic,
- immature alluvial deposited,
- unweathered mineral alluvial deposited,
- fersiallitic.

3.1 Idrisi Approach

Each of these images expresses the basic nature of the factors identified in this study. However, using the weighted linear combination procedure (MCE module), the factor maps should be standardised to a consistent range of byte binary integers. In addition, it requires that each be constructed such that higher values indicate areas that are more suitable on that factor.

To develop a set of weights for the factors such that they add up to 1, the pairwise comparison method was used (Saaty's technique, WEIGHT module). Weights can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria. The comparison concern the relative importance of the two criteria involved in determining suitability for the stated objective. Ratings are provided on a 9-point continuous scale [1(equal), 3 (moderate), 5 (strong), 7 (very strong), 9 (extreme)].

The MCE (MultiCriteria Evaluation) process combine the criteria into a single decision image called "suitability map" (in the sense that it shows varying degrees of suitability for the objective under question) in the form of a weighted linear combination (Voogd, 1983):

i.e., $S = Sw_i x_i$, where: S=suitability, x_i =criterion score of factor i and w_i =weight of factor i (see fig.2).

This procedure is not unfamiliar in GIS and has a form very similar to the nature of a regression equation.

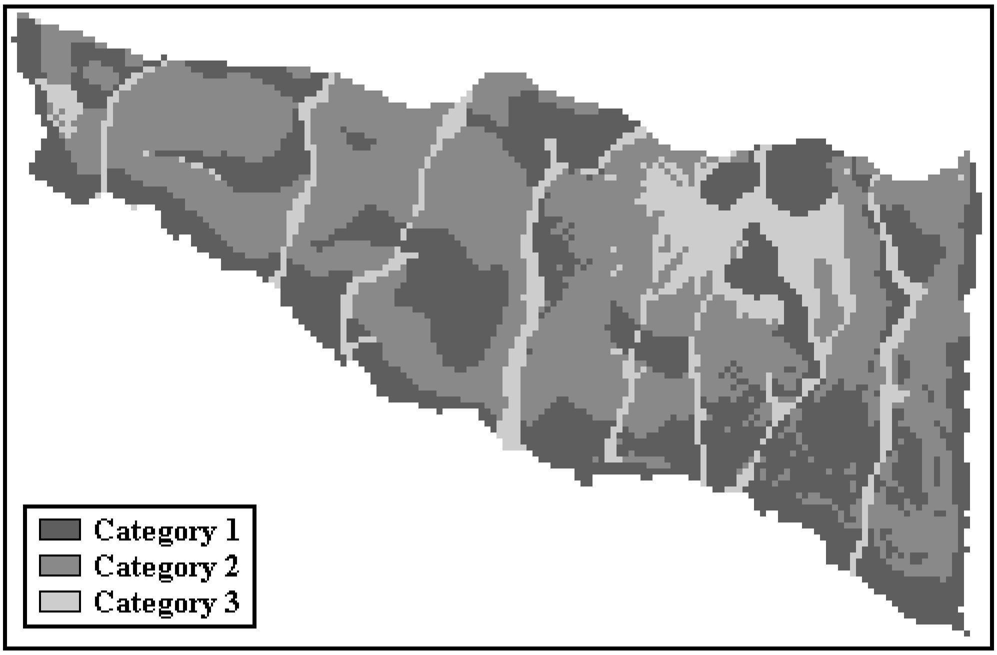

Figure 2. IDRISI approach results.

3.2 Electre Approach

Using ELECTRE Tri method we do not have to standardise the factor maps. However, the image illustrating the soils should be in a quantitative scale (see fig.3).

ELECTRE Tri builds an outranking relation S, i.e., validates or invalidates the assertion aSb_h *(and* b_hSa*)*, whose meaning is "*a* is at least as good as b_h"; where F denote the set of the indices of the criteria $g_1, g_2, ..., g_m$ *(*$F=\{1,2, ..., m\}$*)* and B the set of indices of the profiles defining $p+1$ categories *(*$B\{1, 2, ..., p\}$*)*, b_h being the upper limit of category C_h and the lower limit of category C_{h+1}, $h= 1, 2, ..., p$ (see table 1).

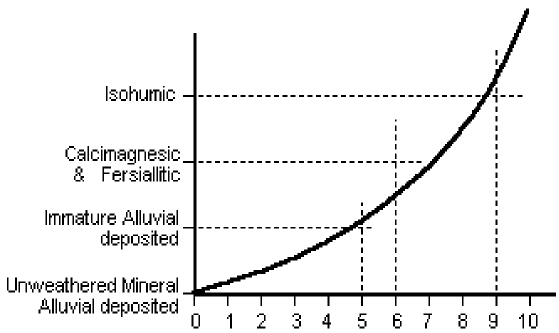

Figure 3. An example of soil scale quantification.

	Scale	b_1	b_2
Habitation	- 4234.67 / 0 (m)	-1500	-200
road	- 3471.31 / 0 (m)	-800	-200
well	- 3832.75 / 0 (m)	-1000	-500
hydrography	- 3429.65 / 0 (m)	-600	-300
Slope	-32 / 0 (%)	-20	-4
Soil	0-1-5-6-7-9	+4	+6

Table. Profiles evaluations.

Preferences restricted to the significance axis of each criterion are defined through pseudo-criteria. The indifference and preference thresholds *($q_j(b_h)$ and $p_j(b_h)$)* constitute the intra-criterion preferential information.

At the comprehensive level of preferences, in order to validate the assertion *aSb_h (or b_hSa)*, the conditions of concordance and non-discordance should be verified.

Two types of inter-criteria preference parameters intervene in the construction of *S*:

- the set of weight-importance coefficients *(k_1, k_2, ..., k_m)* is used in the concordance test when computing the relative importance of the coalitions of criteria being in favour of the assertion *aSb_h*,
- the set of veto thresholds *($v_1(b_h)$, $v_2(b_h)$, ..., $v_m(b_h)$)* is used in the discordance test. *$v_j(b_h)$* represents the smallest difference *$g_j(b_h)$-$g_j(a)$* incompatible with the assertion *aSb_h*..

The parameters used in this study are illustrated in the following table :

Criteria	k_j	q_j	p_j	v_j
Habitation	0.06	100	500	1000
road	0.06	100	500	1000
well	0.12	100	500	1000
hydrography	0.12	100	500	1000
Slope	0.23	0.5	1	10
Soil	0.41	1	2	5

Table 2: an example of initial parameters.

ELECTRE Tri builds an index *□$(a,b_h)\in[0, 1]$ (□(b_h,a), resp.)* that represents the degree of credibility of the assertion *aSb_h (b_hSa, resp.)*, $\forall a\in A$, $\forall h\in B$. The assertion *aSb_h (b_hSa, resp.)* is considered to be valid if □$(a,b_h)\geq$□ *(□$(b_h,a)\geq$□,resp.)*, □ being a "cutting level" such that □$\in[0.5, 1]$.

Two assignment procedures are then available:

- Pessimistic procedure (see fig.4):

a- compare *a* successively to b_i, *for* $i=p, p-1, ..., 0$,
b- b_h being the first profile such that aSb_h,
assign *a* to category C_{h+1}.

- Optimistic procedure (see fig.5):

a- compare *a* successively to b_i, *for* $i=1, 2, ..., p$,
b- b_h being the first profile such that b_h ϕ a,
assign *a* to category C_h.

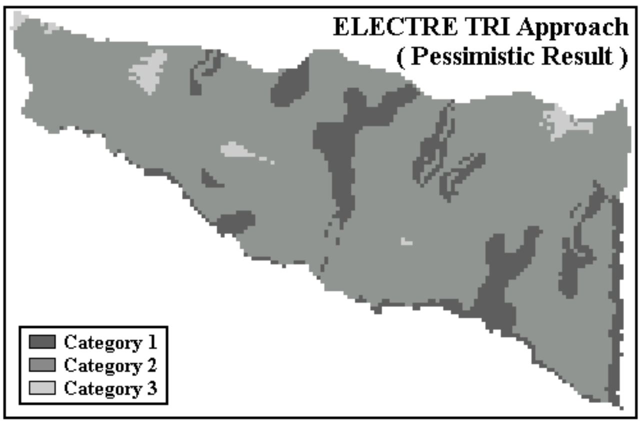

Figure 4: Pessimistic results

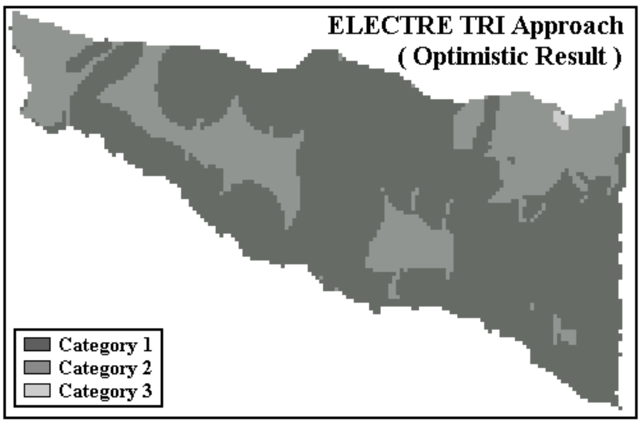

Figure 5. Optimistic results.

3 RESULTS

Decision problem may be resolved in several ways according to the way of thinking of the decision maker:
-Restrictive hypothesis are introduced in such a way that the problem should be resolved using a classical method.
-A multicriteria method based on models using both restrictive mathematical hypothesis and information acquired by the decision maker.

When using the unique criterion approach, the problematic became at the same time choice, ranking and sorting.

The drawbacks of the weighted sum "classical method" are:

- sensitivity to scale transformation; In fact, if the proximity to roads criteria is expressed in km, then the result will be wrong (pixel score is divided by 1000).
- criteria compensation: a pixel may have very bad scores on almost all the criteria but it may be compensated by a good evaluation on a highly weighted criterion.

On the other hand the scale transformation and criteria compensation do not take part of ELECTRE approach. The major difficulty is, however, to give a right interpretation of the result. This would point out the conflict and multicriteria features of the decision problem.

Furthermore, the robustness analysis is very useful for choice of the initial values of the parameters. When the parameters are changed regarding their initial values, the results do not change and this represents a robust recommendation.

4 CONCLUSION

The objective of the study was not to compare these two methods since they are based on different mathematical bases.
It was noted that the use of IDRISI modules facilitated the interpretation of the results. But this would never say that ELECTRE methods are not suitable for such a study, since these methods lead to an intermediate result between dominant relationship (very poor to be useful) and multi attribute utility function (very rich to be reliable).
This study confirms that GIS constitutes a powerful tool for deterministic analysis of all the spatial data as well as the analysis of spatial multicriteria problems.

Much work has been carried out on the development of both GIS and MCE techniques, but mostly in isolation.
Besides the integration of GIS and ELECTRE methods this work would find out a wide thought on the relationship between GIS and multicriteria decision making.

Integrating MCE with GIS for spatial decision -making purposes is both a worthwhile aim and one which will be of widespread utility to those involved in what is (and will continue to be) a mainstay application of GIS technology.

This will in turn create the opportunity fore the increased use of GIS based technology as the bases of spatial decision support systems.

It is important to note , however, that GIS and MCE techniques are merely tools which provide a means to an end. Without the knowledge and expertise of the operator and decision-maker, and without appropriate data, such tools would be useless.

Nevertheless, GIS-MCE applications appear to represent potentially fruitful areas for further research and development.

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