SPATIAL MULTICRITERIA DECISION MAKING AND ANALYSIS

A geographic information sciences approach

Edited by
Jean-Claude Thill

Ashgate

To Hubert Beguin,

my mentor

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A geographic information sciences approach

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Ashgate
Aldershot • Brookfield USA • Singapore • Sydney

Published by
Ashgate Publishing Ltd
Gower House
Croft Road
Aldershot
Hants GU11 3HR
England

Ashgate Publishing Company
Old Post Road
Brookfield
Vermont 05036
USA

British Library Cataloguing in Publication Data
Spatial multicriteria decision making and analysis: a
geographic information sciences approach
1. Multiple criteria decision making - Congresses 2. Spatial
behaviour - Congresses
I. Thill, Jean-Claude
304.2

Library of Congress Catalog Card Number: 98-73854

ISBN 1 84014 952 3

Printed in Great Britain

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Mitchell, B. and Hollick, M. (1993), 'Integrated Catchment Management in Western Australia: Transition from Concept to Implementation', *Environmental Management*, vol. 17, pp. 735-43.

Mitchell, B. and Shrubsole, D. (1994), 'Reorienting to Achieve Sustainability in Canadian Water Management', *Canadian Water Resources Journal*, vol. 19, pp. 335-47.

Naveh, Z. and Lieberman, A.S. (1984), *Landscape Ecology: Theory and Application*, Springer-Verlag, New York, NY.

Osmond, D.L., Gale, J.A. and Spooner, J. (1997), 'Watersheds: A Decision Support System for Watershed-scale Nonpoint Source Water Quality Problems', *Journal of the American Water Resources Association*, vol. 33, pp. 327-41.

Papalia, J. (1996), 'An Initial Assessment of Coastal Watershed Management in New-South-Wales, Australia', *Coastal Management*, vol. 24, pp. 365-84.

Reid, Ziemer, R.R., and Lisle, T.E. (1996), 'Approaching Messy Problems: Strategies for Environmental Analysis', in *Proceedings of Watershed '96*, June 8-12, 1996, Baltimore, MD, Water Environment Federation, http://www.epa.gov/owowwtr1/watershed/Proceed/reid.html. [Accessed July 2, 1998].

Reitsma, R.F. (1996), 'Structure and Support of Water-resources Management and Decision-making', *Journal of Hydrology*, vol. 177, pp. 253-68.

Rougerie, G. and Beroutchachvili, N. (1991), *Géosystèmes et Paysages. Bilan et Méthodes*, Armand Colin, Paris, France.

Roy, B. and Bouyssou, D. (1993), *Aide Multicritère à la Décision: Méthodes et Cas,* Collection Gestion, Série: Production et techniques quantitatives appliquées à la gestion, Éditions Economica, Paris, France.

Savabi, M.R., Flanagan, D.C., Hebel, B. and Engel, B.A. (1995), 'Application of WEPP and GIS-GRASS to a Small Watershed in Indiana', *Journal of Soil and Water Conservation*, vol. 50, pp. 477-83.

Schmidt, M.G., Schreier, H.E. and Pravakar, B.S. (1994), 'A GIS Evaluation of Land Use Dynamics and Forest Soil Fertility in a Watershed in Nepal', *International Journal of Geographical Information Systems*, vol. 9, pp. 317-27.

Simos, J. (1990), *Évaluer l'Impact sur l'Environnement. Une Approche Originale par l'Analyse Multicritère et la Négociation*, Presses Polytechniques Universitaires Romandes, Lausanne, Switzerland.

Wilson, R.R. (1994), 'An Integrated River Management Model: The Connecticut River Management Program', *Journal of Environmental Management*, vol. 41, pp. 337-48.

Wylie, B.K., Shaffer, M.J., Brodahl, M.K., Dubois, D. and Wagner (1994), 'Predicting Spatial Distributions of Nitrate Laeching in Northeast Colorado', *Journal of Soil and Water Conservation*, vol. 49, pp. 288-93.

14 GIS-approach for Land Suitability Assessment in Developing Countries: A Case Study of Forest Development Project in Mexico

LUIS A. BOJÓRQUEZ-TAPIA, SALOMÓN DÍAZ-MONDRAGON AND PAOLA GÓMEZ-PRIEGO

Introduction

A land suitability assessment is the planning procedure of determining the fitness of a given tract of land for specified uses. It is a strategic process directed at the evaluation of the natural resources, and the regulation of human activities in a region (Steiner, 1991). Thus, the purpose of suitability assessments is to assist decision makers in finding the most appropriate locations or pattern of locations for fulfilling the goals of the involved stakeholders (that is, socioeconomic sectors and interest groups).

Fitness for a set of land uses is determined by both the socioeconomic forces in a region, and the biophysical characteristics of the land (Bojórquez-Tapia et al., 1994). Land suitability assessment must account for the needs of the stakeholders, as well as the interactions between socioeconomic activities. These interactions have been classified as competitive, complementary, and supplementary (Brooks et al., 1991). Competitive interactions generate conflicts between the implicated stakeholders, and cannot be located in the same tract of land. On the contrary, complementary or supplementary interactions result from compatible land uses and may concur in the same area.

Considering the various types of land-uses and their degrees of compatibility, an important role of a suitability assessment is as a planning tool for settling conflicts among the stakeholders in a region. Collaboration of the stakeholders in the planning process is essential for effective conflict resolution. Such collaboration is formally attained through participatory planning, which allows decision makers and stakeholder representatives to identify the issues, establish common goals, and develop mechanisms for settling conflicts (Steiner, 1991).

Participatory planning schemes have been integrated within geographic information systems (GIS) through multi-criteria and multi-objective decision making procedures (Eastman et al., 1993). Specifically, each grid cell in a raster GIS is valued according to its quality for a particular use, and each thematic layer represents an evaluation criterion (Eastman et al., 1993; Pereira and Duckstein, 1993; Malczewski et al., 1997). Unfortunately, decision making procedures are often hampered by a lack of valid information. Data frequently do not encompass sufficient spatial resolution, or are unavailable (Cowan and Turner, 1988; Price, 1990; Bodini and Giavelly, 1992). Given these limitations, participatory decision making procedures in a GIS environment have to satisfy two conditions: (1) to be capable of producing useful results for conflict resolution with a minimum of data, and (2) to be understandable by lay persons, while yielding at the same time mathematically rigorous results.

The objective of this chapter is to present a GIS-based approach for suitability assessment and conflict resolution. The approach is demonstrated through a case study: the regional forestry development project in the region of Tabasco and north of Chiapas, Mexico. The project involves the implementation of eucalyptus plantations in this region. However, the project faces strong opposition from conservationist groups and agricultural and cattle ranching organizations. Conflict negotiation is achieved through a participatory planning strategy. Decision rules are developed through a multi-criteria/multi-objective process integrated into a GIS. Results identify a land-use pattern that minimizes the likelihood of conflict between the stakeholders and the eucalyptus plantation project.

Problem Description

Main Features of the Study Area

The eucalyptus plantation project is located in the Southeastern Coastal Plain, in the states of Tabasco and Chiapas, Mexico. It encompasses 852,900 ha in two separate areas (Figure 14.1), namely the west zone (48% of the total area), and the east zone (52% of the total area).

These two zones are part of the lowlands of the Coastal Plain (altitude > 500 m above sea level). The region is tropical with high mean annual precipitation (1,500 mm to 3,000 mm), and high mean annual temperature (26°C). Its main geomorphologic traits are the mesetas with a radial drainage pattern in the east zone, and the bajadas, flat lands, and alluvial plains with a dendritic drainage pattern in the west zone. Cambisols, Acrisols, and Regosols are the main soil types. They offer a high productivity for eucalyptus plantations.

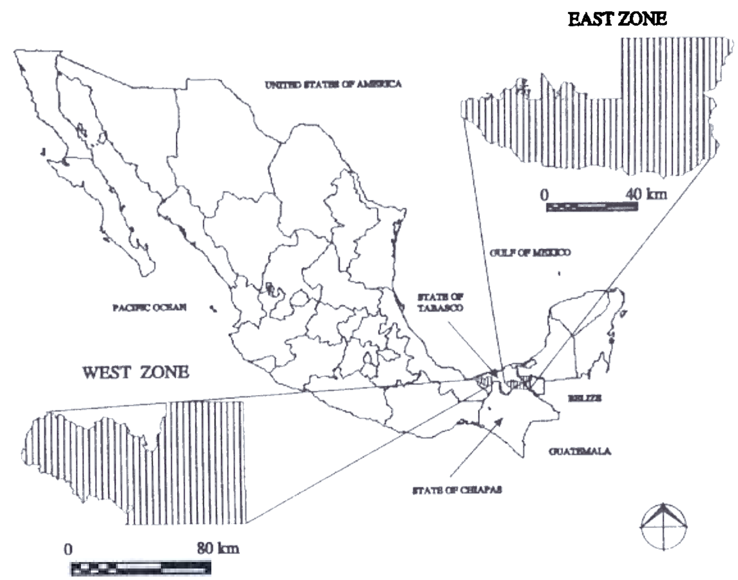


Figure 14.1 Study area

Most of the natural vegetation in the region has been converted to agriculture and pasture. Remnants of the natural cover are restricted to isolated patches of tropical rain forest, riparian vegetation, and wetlands.

The Forest Development Project

A Mexican private corporation is responsible for the design of the forest development project. The goal is to plant 300,000 ha of *Eucaliptus grandis* and *E. europhyla*. This region is selected because its soils and climate are favorable for high production forest plantations.

Plantations are planned in production units of 500 ha, divided into lots of 20 ha. It is estimated that the project will create 3,000 jobs in the rural areas of the study region. The areas to be planted will have to meet specific requirements with respect to soil productivity, water availability, size, and cover (pasture is preferred over crops or natural vegetation).

Stakeholders

Relevant stakeholders in the region include agricultural and cattle ranching organizations, conservation groups, academics, and state and municipal authorities. Agricultural and cattle ranching organizations represent the main socioeconomic sectors in terms of number of jobs in the region. The main concern of these organizations is related to the transformation of agricultural and cattle ranching land into forest plantations.

Similarly, conservation groups are opposed to the project because of the potential transformation of the natural cover to eucalyptus plantations. These groups include several non-governmental organizations and private citizens. State and municipal authorities, in general, show a favorable opinion towards the project; their main concern is with the mechanisms to prevent the potential negative environmental impacts of the project. Local academics provide technical support to the other sectors and do not represent an independent viewpoint.

Development of Decision Rules

Interdisciplinary Team

An interdisciplinary team of fifteen specialists is formed and organized into two groups. The specialists are selected because of their experience, technical capacity, and knowledge of the sectoral interests in the region. Team members are selected independently from the proponent and regulatory agencies.

The first group consists of specialists with backgrounds in geomorphology, hydrology, soils, vegetation, remote sensing, biological conservation, and human ecology. These experts assist the facilitators in the participatory planning workshops to ensure a reliable translation of the information provided by the stakeholders' representatives to land-use criteria.

Based upon the data obtained during the first participatory planning workshop, members of the specialist group are responsible for depicting the land-use criteria and ranking their importance for each sectoral activity.

The second or core group is responsible for the integration and synthesis of information. It includes specialists in GIS and regional planning. The core group is responsible for applying multi-criteria/multi-objective techniques to the suitability assessment, and for conceiving specific compromises to settle land-use conflicts.

Participatory Planning Workshops

Public participation in the project is achieved through a series of three participatory planning workshops. In preparation for these workshops, the relevant stakeholders in the region were identified through consultations with the local authorities, representatives of socioeconomic sectors, and non-governmental spokespersons. During the consultations, the representatives of the potential stakeholders were asked about their perception towards the forest development project and how this project could affect their particular interests.

Sixty representatives from agricultural and cattle ranching organizations, conservationist groups, academics, and state and municipal governments were interviewed and invited to the workshops. The different organizations and groups were included into one of four sectors to simplify the analysis: agriculture, cattle ranching, conservation, and forestry.

The participatory planning workshops included a combination of lectures and group dynamic techniques (Figure 14.2). The lectures were used to provide the participants with a basic understanding of the analytical tools to be used. This elementary knowledge enabled the stakeholders to generate the preference data and to interpret the results. Group dynamics were attained through small-group involvement techniques (Steiner, 1991), that is, the stakeholders were divided into small groups of ten to fifteen people and a facilitator guided a formal discussion to articulate and clarify the key issues, identify problems, and generate solutions.

The three workshops were completed in a period of two years (Figure 14.3). The first workshop was set up to obtain information on the stakeholders' objectives and activities. Through small-group dynamics, the conflicting objectives and the complementary objectives were determined for each sector. Also, the physical, biological, and socioeconomic characteristics needed to carry out each activity were identified. Later, these characteristics were translated into appropriate land-use criteria for the suitability assessment by the interdisciplinary team.

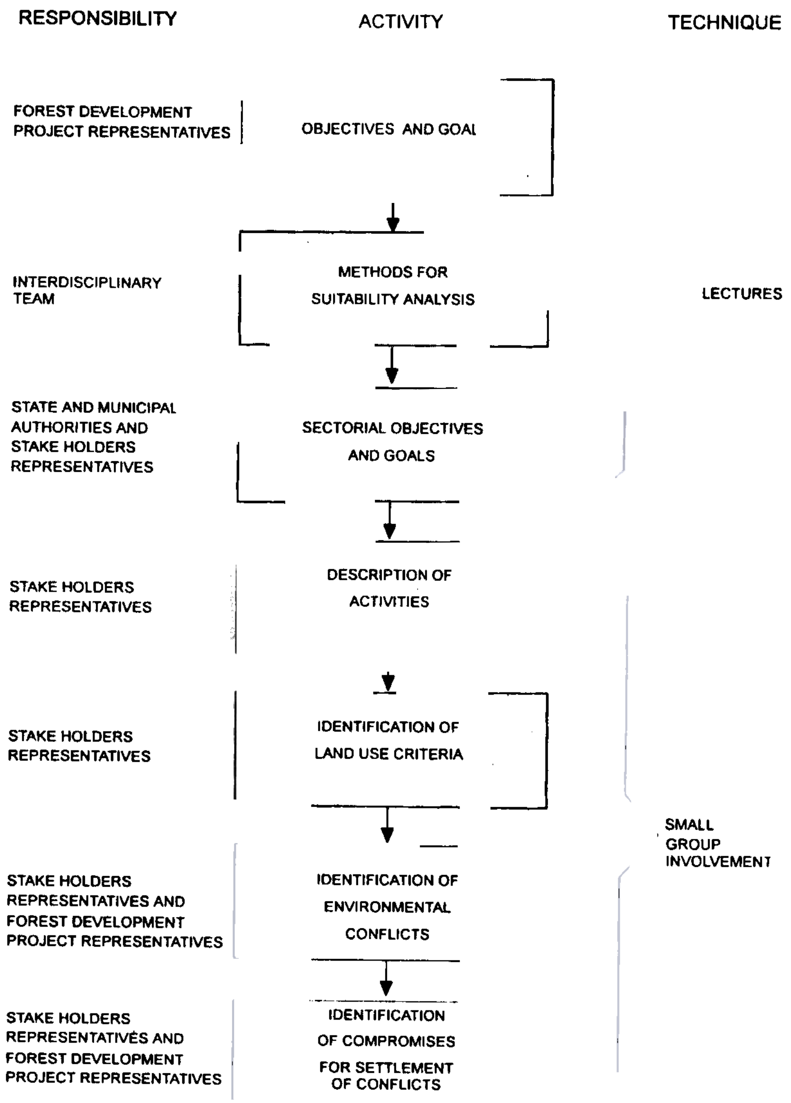


Figure 14.2 Organization of participatory planning workshops

Results of the suitability assessment were presented to the whole group during the second workshop. In small groups and with the assistance of a facilitator, the stakeholders' representatives examined the implications of the suitability assessment with respect to the achievement of their objectives and their perception of competitive land uses. These were analyzed later by the interdisciplinary team to formulate specific mechanisms for the resolution of the conflicts.

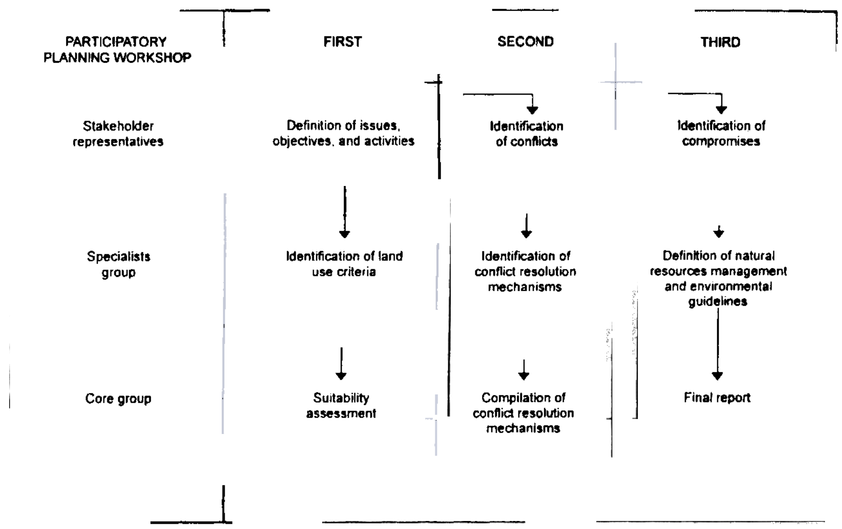


Figure 14.3 Organization of the suitability assessment study

The third workshop involved a presentation of the environmental conflict resolution mechanisms. Again, through small-groups involvement, the stakeholder representatives determined the specific compromises that would have to be assumed by each sector to prevent land-use conflicts within the forestry project.

Land Suitability Assessment

The land suitability assessment involves three tasks (Bojórquez-Tapia et al., 1998):

1. Definition of environmental criteria;
2. Database development;
3. Suitability assessment.

Environmental Criteria

The specialist group examines the results of the first participatory planning workshop in detail. They interpret the information and relate each sectoral activity to specific land-use criteria; that is, the physical, biological, and socioeconomic attributes needed for performing each sectoral activity. Thus, the experts define the apt conditions for each criterion, and rank the importance of the attributes for each activity.

The favorable state of each criterion for each activity is determined by consensus of the specialists and the stakeholder representatives. The criterion rank represents the importance of that criterion for the respective sectoral goals or activities.

The interdisciplinary team generates eight environmental criteria (Table 14.1). A measurement scale is constructed specifically for each criterion (see database development). When a criterion is used for more than one sector, the actual land attribute to be considered depends on each sector's specific requirements.

Because data for landscape productivity for agriculture and cattle ranching are lacking two indicators are used instead. During brainstorming discussions, the interdisciplinary team considered socioeconomic variables related closely to land productivity in the study area. Hence, average salary and percentage of beef and dairy cattle are selected as the indicators for landscape productivity.

Database Development

A large scale (1:50,000) GIS database is developed for the study area. The UNIX-based GIS software Geographic Resource Analysis Support System (GRASS) is used (Westervelt et al., 1987). The database consists of a layer for the favorable state of every environmental criterion. It includes soil type, geomorphology, slope, vegetation and land-use, average salary by municipality, and percentage of beef and dairy cattle by municipality.

The vegetation and land use layer are created by means of satellite image interpretation. The rest of the layers are digitized into the GIS from corresponding thematic maps or, in the case of elevation layer, derived from a digital elevation model.

Table 14.1 Environmental criteria for the suitability assessment

Criteria	Rank
<u>Agriculture</u>	
Landscape productivity	
Soil	2
<u>Conservation</u>	
Natural cover	
Habitat heterogeneity	
<u>Forestry</u>	
Flood-free landscapes	
Pastures	2
Soil	3
Slope	4
Continuity	5
<u>Cattle ranching</u>	
Flood-free landscapes	
Soil	
Landscape productivity	

The binary layers for the favorable state of each criterion are generated as follows. The high yield soils map layer is based on the soil type map of the project (scale 1:20,000). Landscape productivity for agriculture is generated from a municipality map and the socioeconomic census, through a reclassification of the pixels where the average salary is above minimum wage. Flood-free landscapes are located in a geomorphologic map (scale 1:50,000). Landscape productivity for cattle ranching is created by reclassifying the pixels where the percentage of beef and dairy cattle per municipality is above 20%, according to the official census. Habitat heterogeneity is detected through the application of a filter that detects the presence of four vegetation types in a 40 ha neighborhood. Flat slopes (< 5%) are obtained from a topographic map (scale 1:50,000). Finally the landscape size is generated by reclassifying those geomorphologic units that are larger than 500 ha.

Suitability Assessment

The suitability assessment consists of the application of multi-criteria and multi-objective procedures in the GIS. The multi-criteria procedure consists of generating a land suitability map for each sector. A weighted linear combination is used to that end:

$$S_{ij} = \sum_i w_{ij} c_{ij}$$

where c_{ij} and w_{ij} are the i-th criterion and weight for sector j, respectively. The weights w for criterion i are obtained from the importance ranking as follows:

$$w_{ij} = n_j - r_i +$$

where n is the total number of criteria for sector j, and r is the i-th criterion's rank for the j-th sector.

Results are standardized to a 1 (minimum) to 10 (maximum) suitability scale. Thus, each raster cell is rated for its suitability for each sector.

The multi-objective procedure is achieved by identifying groups of pixels with similar suitability scores for the four sectors. The four land-suitability layers are subjected to a multivariate numerical classification through a divisive polythetic partitioning (Pielou, 1984). This method requires the application of principal components analyses (PCA) in successive steps (Figure 14.4). At each step, the first principal component axis is divided into two separate groups; the division is performed at the value that yields the greatest homogeneity (that is, the lowest variance) of the resulting two groups. The groups formed by the numerical classification are transferred to a nominal map.

A mean group suitability matrix Z is generated to compare the relative suitability amongst groups. Matrix Z is adjusted by Gower's double centering procedure (Gower, 1966; Digby and Kempton, 1987; Bojórquez-Tapia et al., 1994):

$$z_{gh} = x_{gh} - x_{g\cdot} - x_{\cdot h} + x$$

where z_{gh} is the Gower´s residual, x_{gh} is the mean suitability score of group g of sector h, $x_{g\cdot}$ is the mean suitability score of group g, $x_{\cdot h}$ is the mean suitability score of sector h, $x_{\cdots}$ is the mean suitability score of the whole

matrix. A positive value of z_{gh} indicates a high mean suitability of group g for sector h, while a negative value denotes the opposite.

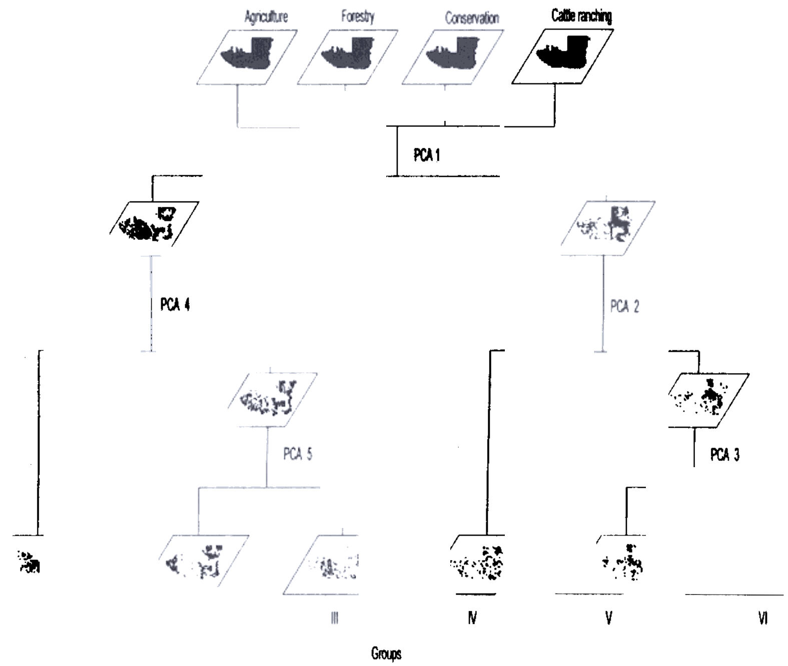
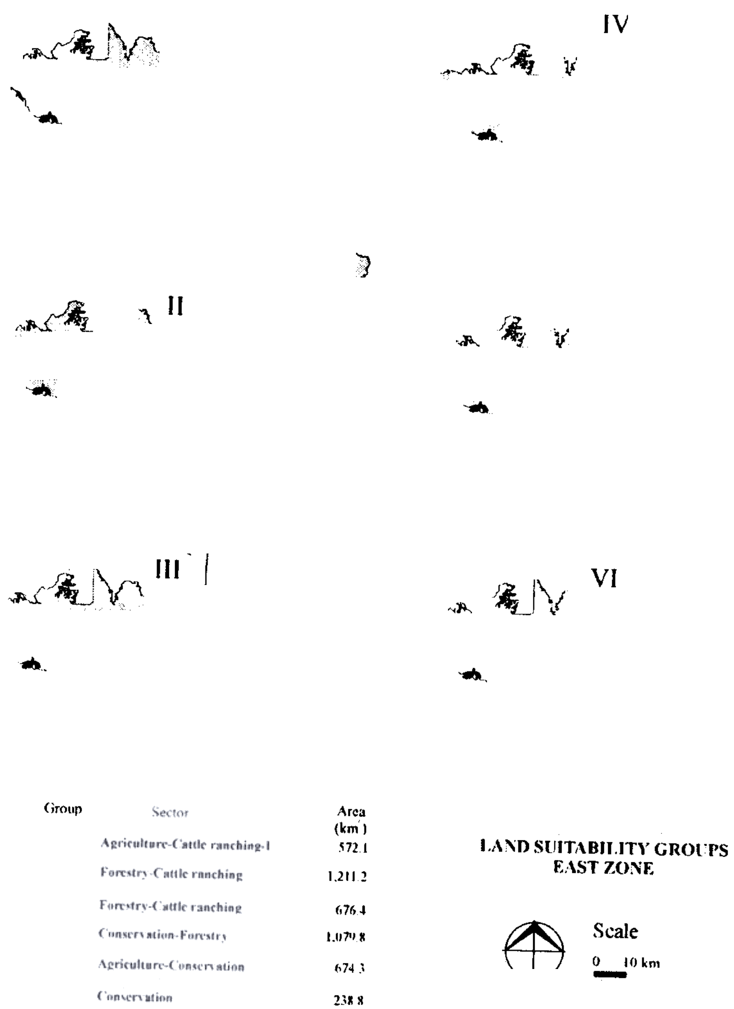


Figure 14.4 Example of numerical classification through five iterations of principal components analysis

Results

Land suitability patterns are assessed by examining both the suitability of each sector in the two zones, and by analyzing the distribution pattern of the suitability groups. In the east zone, the multi-criteria evaluation shows that high suitability scores for forestry occupy about 209,000 ha (47% of the total area in the east zone). A similar result is obtained for cattle ranching (46%), while high suitability scores for the other two sectors are restricted to smaller areas, agriculture (15%), and conservation (13%).



igure 14.5 Distribution of suitability groups for the east zone

The purpose of using a multi-objective evaluation procedure is to dentify potential conflicts between forestry and the other sectors. Conflicts re predicted when two or more sectors with competing interactions show a igh relative suitability for the same tract of land. Comparing the relative

suitability between the sectors reveals the intensity of a conflict, because relative suitability reflects the degree of interest of a sector for a particular tract of land (Gower's residuals compare simultaneously the sectors and land suitability groups).

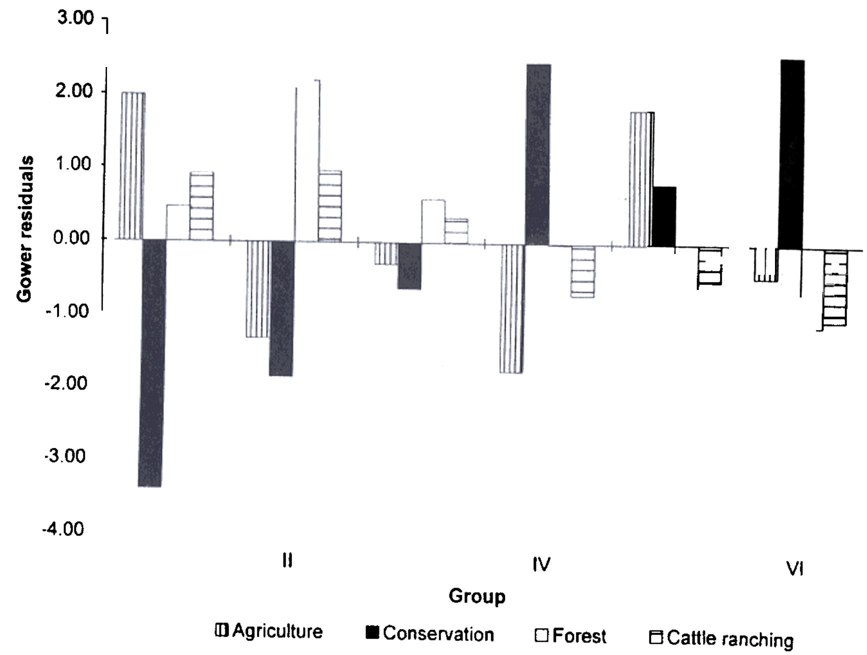


Figure 14.6 Gower residuals for the east zone

The numerical classification depicts six suitability groups in the east zone. Groups I, II, and III are located in the mesetas, while groups IV, V, and VI are located in the riparian areas and flood prone zones (Figure 14.5). Accordingly, groups I, II and III presents a positive relative suitability for forestry; the other three groups present a negative relative suitability for forestry (Figure 14.6). Of the three groups that have a positive relative suitability, Group I is more suitable for agriculture and cattle ranching than for forestry; indeed, agriculture's relative suitability is the highest here among the groups. On the contrary, Group II shows the highest relative suitability for forestry among all the groups; it also presents a positive value for cattle ranching. Group III does not show a clear tendency in relative suitability for a particular sector, although positive values are obtained for forestry and cattle ranching. Groups IV and VI present a clear positive relative suitability for conservation, while Group V presents a positive relative suitability for agriculture and conservation.

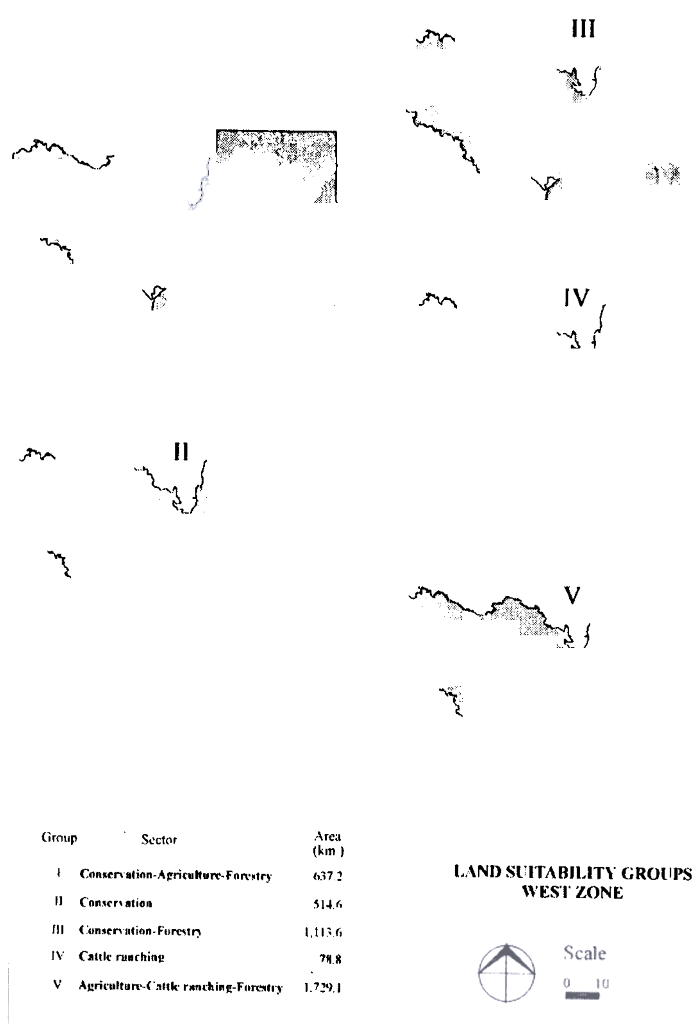


Figure 14.7 Distribution of suitability groups for the west zone

Based on the results of the suitability scores, forestry would face conflicts with agriculture and cattle ranching in Group I (13% of the east zone). The higher relative suitability of agriculture indicates that this sector would present the strongest opposition. Conflicts between forestry and cattle ranching are predicted for Groups II and III (42% of the east zone). However, the relative suitability for forestry is higher than that for cattle ranching, so opposition is not expected to be strong. No potential conflicts between conservation and forestry can be detected (Figure 14.6).

The land suitability patterns are more complicated in the west zone. With respect to land suitability for each sector, cattle ranching is proposed to occupy the largest area (68%), followed by forestry (63%), agriculture (51%), and conservation (30%). This indicates that there are about 256,000 ha with high suitability scores for forestry.

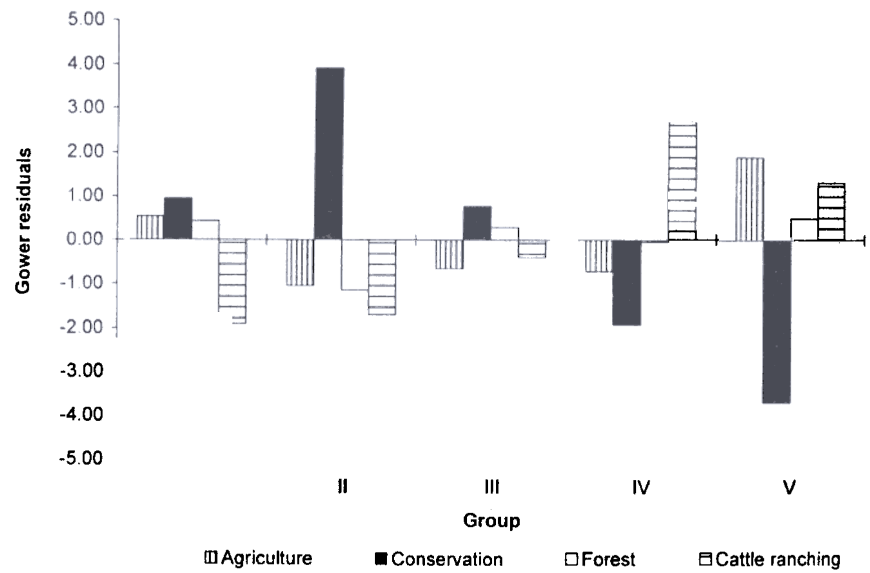


Figure 14.8 Gower residuals for the west zone

The numerical classification separates five suitability groups (Figure 14.7). Groups I, II, and III are located in the lowlands, flood-prone areas, and riparian zones, while groups III, IV and V are located in the hillsides and mesetas. When considering the relative suitability scores (Figure 14.8), it is evident that the relative suitability for forestry is positive in groups I, III, and V; these relative suitability values, however, are lower than those for conservation, agriculture, and cattle ranching. Groups II and III present high relative suitability values for conservation and cattle ranching, respectively.

Figure 14.8 suggests that the forestry project would be in conflict with agriculture and conservation in Group I (16% of the west zone), with conservation in Group III (27% of the west zone), and with agriculture and cattle ranching in Group V (42% of the west zone). In the west zone, opposition to the eucalyptus plantation project is expected to be stronger than in the east zone, given the lower relative suitability values for forestry.

Discussion and Conclusions

Conflict negotiations require that the analytical process should be clear and simple, while being mathematically rigorous at the same time. This condition allows the stakeholder representatives and decision makers to understand the spatial analysis. Consequently, a critical component in land suitability assessments is the construction of a decision rule that is acceptable to all the stakeholders (Eastman et al., 1993).

Our case study shows how participatory planning schemes can be used to help decision makers and stakeholders in defining the issues, and in specifying their interests. However, non-specialists often have difficulties generating a set of criteria that are useful for spatial analysis. This is especially true in countries like Mexico, where the stakeholder representatives may lack any formal education. Thus, the role of the interdisciplinary team is crucial. The specialists have to interpret the sectoral interests and derive a set of spatial variables or indicators for the suitability assessment.

One advantage of the approach presented here is that it requires minimal data. Methods such as the Analytical Hierarchy Process require an estimation of the power of each sector to influence the conflict resolution process for generating the respective weights (Malczewski et al., 1997). In our case study, we find it difficult to obtain this information in a formal way because the stakeholder representatives are concerned with the political significance of their opinion. Moreover, data frequently do not encompass sufficient spatial resolution, or are unavailable (Cowan and Turner, 1988; Price, 1990; Bodini and Giavelly, 1992).

Another advantage of our approach is its simplicity. The weighted linear combination rule that we use is simple enough to meet the simplicity

requirement, but more importantly, it is effective in depicting the preferred areas for each sector in a convincing manner. For example, the multi-criteria layers generated in our analysis are acceptable to the stakeholders as a valid spatial representation of their interests and goals.

Once the multi-criteria maps are created for each objective (the layers of sectoral land suitability), the conflicts between forestry and the other sectors can be analyzed in a rather straight fashion. Although numerical classifications are mathematically complex, the results of the multi-objective analysis are easy to understand: the analysis only identifies the areas (called suitability groups) that are homogeneous with respect to their suitability scores for the involved groups.

Then, a synthesis of the conflicts is achieved by means of the examination of the relative suitability of each sector in each group. The graphical displays of the residual suitability denote the likelihood and potential intensity of conflicts between sectors.

When analyzed under a participatory planning scheme, the relative suitability analyses allows stakeholder representatives and decision makers to generate compromises to settle their conflicts. This is possible because the issues can be related to specific areas with overlapping land-uses.

It should be emphasized that the methodology is useful for strategic planning at the regional level. The results of the case study are useful for designing a strategy for the selection of areas for the eucalyptus plantation project. However, higher resolution studies are needed for resolving issues in selecting individual lots and settling issues at the operational level.

References

Bodini, A. and Giavelly, G. (1992), 'Multicriteria Analysis as a Tool to Investigate Compatibility between Conservation and Development on Salina Island, Aeolian Archipielago, Italy', *Environmental Management*, vol. 5, pp. 633-52.

Bojórquez-Tapia, L.A., Díaz-Mondragon, S. and Ezcurra, E. (1998), *GIS-multivariate Model for Group Decisionmaking and Land Suitability Analysis*, Working paper, Instituto de Ecologia, Ciudad Universitaria, UNAM, Mexico City, Mexico.

Bojórquez-Tapia, L.A., Ongay-Delhumeau, E. and Ezcurra, E. (1994), 'Multivariate Approach for Suitability Assessment and Environmental Conflict Resolution', *Journal of Environmental Management*, vol. 41, pp. 187-98.

Brooks, K.N., Folliott, P.F., Gregersen, H.M. and Thames, J.L. (1991), *Hydrology and the Management of Watersheds*, Iowa State University, Ames, IA.

Cowan, J.H. and Turner, R.E. (1988), 'Modeling Wetland Loss in Coastal Louisiana: Geology, Geography, and Human Modifications', *Environmental Management*, vol. 12, pp. 827-38.
Digby, P.G.N. and Kempton, R.A. (1987), *Multivariate Analysis of Ecological Communities*, Chapman and Hall, London. United Kingdom.
Eastman , J.R, Kyem, P.A.K., Toledano, J. and Jin, W. (1993), *GIS and Decision Making*, UNITAR, Geneva, Switzerland.
Gower, J.C. (1966), 'Some Distance Properties of Latent Root and Vector Methods Used in Multivariate Analysis', *Biometrika*, vol. 53, pp. 325-38.
Malckzewski, J., Moreno-Sánchez, R., Bojórquez-Tapia, L.A. and Ongay-Delhumeau, E. (1997), 'Multicriteria Group Decision-making Model for Environmental Conflict Analysis in the Cape Region, Mexico', *Journal of Environmental Planning and Management*, vol. 40, pp. 249-374.
Pereira, J.M.C. and Duckstein, L. (1993), 'A Multiple Criteria Decision-making Approach to GIS-based and Land Suitability Evaluation', *International Journal of Geographical Information Systems*, vol. 7, pp. 407-24.
Pielou, E.C. (1984), *The Interpretation of Ecological Data: A Primer on Classification and Ordination*', John Wiley & Sons, New York, NY.
Price, A.R. (1990), 'Rapid Assessment of Coastal Zone Management Requirements: A Case Study from the Arabian Gulf', *Ocean and Shoreline Management*, vol. 13, pp. 1-91.
Steiner, F. (1991), *The Living Landscape, An Ecological Approach to Landscape Planning*', Mc-Graw-Hill, New York, NY.
Westervelt, J.D., Shapiro, M.J., Bradshaw, S.J., Bozack, J., Chandra, N., Goran, W.D., Griffin, K.F., Heekin, A., Johnson, M.O., Larson, M.S., Lozar, R.C., Martin, M.V., Norman, K.A., O'Neil, C., O'Shea, M.F. and Van Warren, L. (1987), *Geographical Resources Analysis Support System-Grass, Version 2.0*, U.S. Army Construction Engineering Research Laboratory ADP Report N-87/22. Champaign, IL.

Exploring the Potential of Multi-criteria Spatial Decision Support Systems: A System for Sustainable Land-use Planning and Design

MARIANNE L. MacDONALD AND BRENDA G. FABER

Introduction

Design and planning processes, regardless of the specific application or scale, involve a number of similar steps, from issue identification, to sketch creation, evaluation and selection. Such processes are often complex and political, requiring a combination of analytical and creative thinking. As a result, planners and designers have sought tools and methods to assist them in managing and completing these processes. Computers, and more specifically computer models and decision support systems, represent such a tool. While their application has been controversial at times (Lee, 1973), the interest and expectation of both professionals and academics has continued to spur the development of a myriad of both prototypical and operational systems.

Many design and planning problems involve multiple objectives and multiple criteria. Spatial decision support systems (SDSS) which involve the use of geographic information systems (GIS) have been used to facilitate the application of multi-criteria methods for analytical planning applications such as waste management and route selection (Jankowski and Richard, 1994; Jankowski, 1995; MacDonald, 1996). However, the application of such systems in practice is complicated by the fact that most planning processes involve many stakeholders. Each stakeholder is likely to have a different set of objectives, criteria, and values. It has been recognized that additional consensus building tools must be added to systems involving diverse groups (Faber et al., 1994; 1996; Malczewski, 1996; Jankowski et al., 1997).