FINDING OPTIMAL INFRASTRUCTURE INVESTMENT LOCATIONS WITH GIS-MCDA

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ABSTRACT

Infrastructure investments are increasingly challenged by environmental conflicts in both public and private sectors. Here, we present a land suitability approach based on geographic information system multicriteria decision analysis (GIS-MCDA) to support collaborative planning processes. Our approach involves the Analytic Hierarchy Process (AHP) and the Ordered Weighted Average (OWA) to develop multiple land suitability scenarios regarding opposing views of multiple stakeholders. We illustrate our approach with the consensus building process for the location of a major investment swine plant in the environmental sensitive region of Yucatán, México.

Keywords: AHP, OWA, risk attitudes, environmental conflicts, collaborative process.

1. Introduction

Infrastructure investments from governments and private sector are increasingly challenged by environmental conflicts. Settling these conflicts entails finding the optimal location for infrastructure and, simultaneously, minimizing the risk of environmental impacts across a region. Typically, optimal location for infrastructure entails the implementation of land suitability analysis through GIS-MCDA, in which AHP has played a fundamental role. However, finding the locations of minimum risk of environmental conflicts is far from simple. One prominent reason is that these conflicts involve the values and interests of multiple stakeholders with opposing views about the fitness of the land. Therefore, finding the optimal locations for infrastructure requires the development of a common understanding of a region through collaborative planning processes.

2. Literature Review

Land suitability analysis involves alternative plans, evaluation criteria, and stakeholders (Malczewski *et al.* 1997). It has been implemented through GIS-MCDA to classify alternative land use patterns and determine their relative appropriateness so that consensus among stakeholders can be maximized (Bojórquez-Tapia *et al.* 2001; Pedroza *et al*. 2020). Usually, land suitability analysis entails non-compensatory (boolean) or compensatory combination rules (weighted linear combination, WLC). These approaches can be generalized through OWA, for it can be used to generate a wide range of alternative land suitability maps in multi-stakeholder planning processes (Malczewski 2006).

3. Objectives

In this paper, we present a GIS-MCDA-OWA implementation to enable consensus building among stakeholders with opposing views regarding infrastructure investments. We illustrate the approach with collaborative planning process of a major investment swine plant (200 ha; 2 million pigs annually; 10,000 jobs) in an environmental sensitive region in Yucatán, México.

4. Methodology

Consider a raster cartographic database with a universe or set of pixels, $X = \{x^1, x^2, \ldots, x^k\}$; $k = 1,2, \ldots, K$. Each pixel, x^k, is associated with thematic layers that describe the set of geographic attributes, I, with respect to the set of activities, J, and a set of restrictions, R, which denote that the activity cannot be carried out. Consequently, pixels, $x_{ij}^k = \{x_{1j}^k, x_{2j}^k, \ldots, x_{ij}^k\}$, take the normalized value, $x = [0,1]\ \forall x_{ij}^k \in X$, that corresponds to each attribute, $i = 1,2, \ldots, I$, of an activity, $j = 1,2, \ldots, J$, and restrictions, $r = 1,2, \ldots, R$. Hence, suitability, S_j^k, is evaluated with WLC:

$$S_j^k = \sum_j^J w_{ij}\, x_{ij}^k \prod_j^J r_{ij}$$

where w_{ij} are the importance weights obtained from the AHP.

OWA involves: (a) the normalized values of the attributes, x_{ij}^k, are arranged as $z_{1j}^k \geq z_{2j}^k \geq \cdots \geq z_{Ij}^k$; (b) the importance weights , w_{ij}, are reordered as $u_{ij} = u_{1j}, u_{1j}, \ldots u_{Ij}$, according with x_{ij}^k; and (c) a linguistic quantifier, $Q(p) = p^\alpha$, is selected from a fuzzy set, $Q = \{at\ least\ one, very\ few, a\ few, half, many, most, all\}$. Thus, suitability, $S_j^{k\alpha}$, is determined by:

$$S_j^{k\alpha} = \sum_i^I \left(\left(\sum_{k=1}^{j} u_{ij} \right)^\alpha - \left(\sum_{k=1}^{j-1} u_{ij} \right)^\alpha \right) z_{ij}^k; \quad \alpha > 0$$

5. Model Analysis

Participatory workshops were carried out to develop the land suitability AHP models (see appendices), one for swine plant (n=58) and another for environmental protection (n=81). OWA was then implemented to depict the land suitability patterns according to stakeholders' opposing attitudes towards risk (Figure 1). Next, a rule-based model was implemented to find the optimal sites for locating swine plants, which combined the risk seeker attitude of environmental protection and risk averse attitude of swine plant investment (Figure 2).

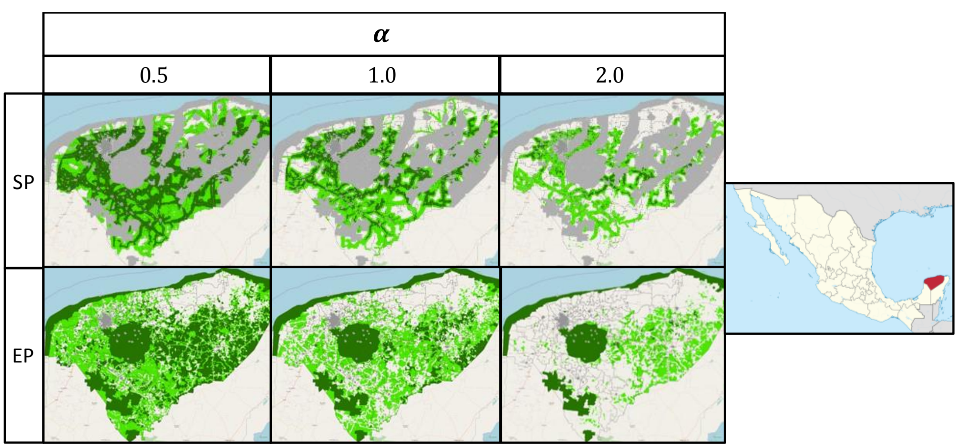

Figure 1. Results of OWA for swine plant investment (SP) and environmental protection (EP), and risk scenarios averse ($\alpha = 2$), neutral ($\alpha = 1$), seeker ($\alpha = 0.5$). Land suitability: very high (dark green), high (light green), restricted (gray), null (white).

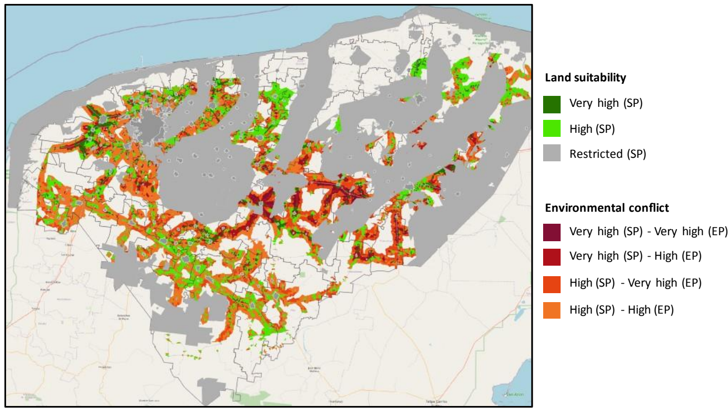

Figure 2. Results of rule-based model ($\alpha(SP) = 2 \wedge \alpha(EP) = 0.5$).

Results of the rule-based model showed that land suitability for swine plant investments was optimal in 488 km^2 and high in 2,394 km^2. These areas did not overlap zones of high and very high land suitability for environmental protection. In contrast, results identified the area in conflict (6,617 km^2) between swine plant investment and environmental protection (Table 1).

Table 1. Area (km^2) of environmental conflict.

		Environmental protection	
		High	Very High
Swine plant investment	High	4,164	1,580
	Very High	638	235

6. Limitations

The approach does not identify the locations where swine infrastructure should be built, but rather the most suitable locations to be considered in the investment planning process. More detailed analysis is necessary to reach a conclusion regarding possible investments. The computations of GIS-MCDA-OWA not only required the development of a program in Python (available upon request), but also was time consuming (4 hours per scenario), which limits its use during participatory workshops.

7. Conclusions

We have shown an approach to address the challenges faced by governments and the private sector in infrastructure investments. The approach extends the capabilities of the AHP in GIS-MCDA modeling for environmental conflict resolution. OWA enabled the analysis of different possible attitudes towards risk of the stakeholders. The integration of OWA with the AHP proved fundamental to build consensus among stakeholders regarding the optimal swine plant suitable locations.

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8. Key References

Bojórquez-Tapia, L. A., Diaz-Mondragón, S., & Ezcurra, E. (2001). GIS-based approach for participatory decision making and land suitability assessment, *International Journal of Geographical Information Science*, 15(2), 129-151.

Malczewski, J. (2006). Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. *International Journal of Applied Earth Observation and Geoinformation*, 8(4), 270–277.

Malczewski, J., Moreno-Sanchez, R., Bojorquez-Tapia, L.A., & OngayDelhumeau, E. (1997). Multicriteria Group Decision-making Model for Environmental Conflict Analysis in the Cape Region, Mexico, *Journal of Environmental Planning and Management*, 40(3), 349-374.

Pedroza, D., Bojórquez-Tapia, L.A., Delgado, R.G.C., & Lazos, E.C. (2020). Understanding translation: Co-production of knowledge in marine spatial planning, *Ocean and Coastal Management*, 190(105163), 1-10.

9. Appendices

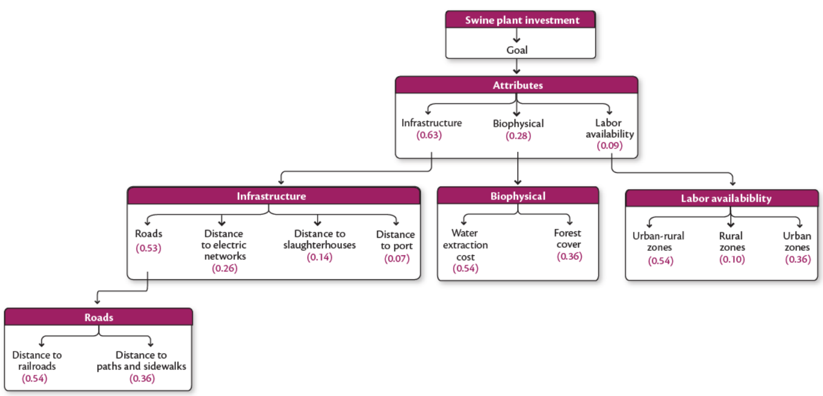

Figure 3. AHP model for swine plant investment.

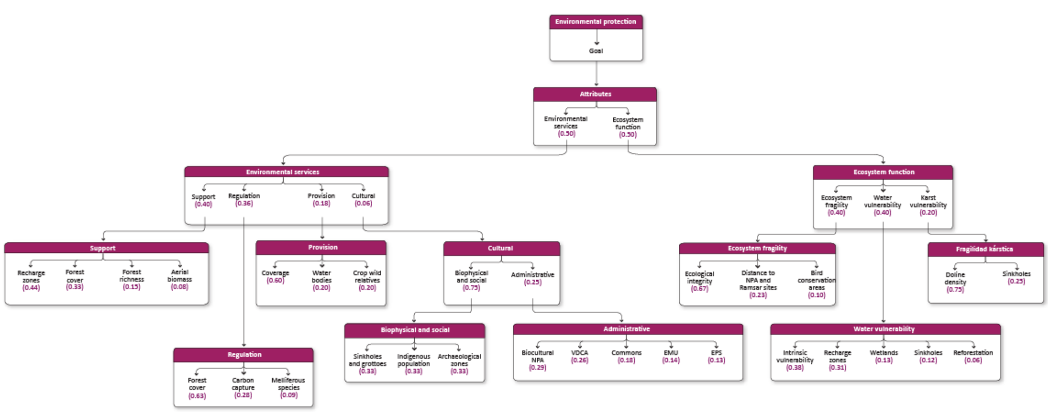

Figure 4. AHP model for environmental protection.