A GIS-based Spatial Multi-Criteria Decision Analysis: Crisp and Fuzzy Methods

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Abstract

Multi-Criteria Decision Analysis (MCDA) supports decision making through the assessment of a finite set of alternatives on the basis of multiple evaluation criteria. Spatial Multi-Criteria Decision Analysis deals with problems incorporating a spatial reference. Thereby, it places emphasis not only on which alternative will be finally chosen (action) but also on where such alternative will be implemented (location). Alternatives usually represent locations in the geographical space. Evaluation criteria represent a number of layers containing these locations. Thus, spatial MCDA is a map overlay process where a set of layers are combined and produce a decision map. Spatial MCDA is also popular as "Overlay Analysis". This poster focuses on the application of a GIS-based Spatial MCDA aiming at optimal site selection for the development of an agro-tourist infrastructure. Crisp and fuzzy MCDA methods are applied under the framework of a Geographic Information System.
Keywords: Spatial MCDA, Overlay analysis, Weighted overlay, Fuzzy overlay

1 The problem

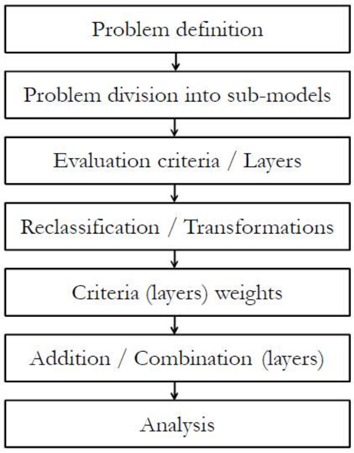
Spatial Multi-Criteria Decision Analysis (MCDA) supports decision making and site selection in the sense that it sets the framework for evaluating alternatives on the basis of multiple evaluation criteria. Both alternatives and criteria incorporate a spatial reference (Malczewski, 1999; Malczewski, 2006; Malczewski and Rinner, 2015). Spatial MCDA is also known as "Overlay Analysis", implying that a map overlay process is taking place and several layers are combined in order a decision map to be produced. Such decision map may then be used as a guide, indicating the most suitable location for the development of a specific activity. In this context, MCDA methods have been embodied in GIS softwares enabling the simultaneous spatial and multi-criteria analysis of a problem.

This poster concerns the exploration of the most suitable location for the development of an agro-tourist infrastructure. An Overlay Analysis is applied through the (ESRI online manual, 2017): a) explicit definition of the problem, b) its division into sub-models, c) definition of evaluation criteria (layers), d) reclassification, e) weighting of criteria, f) combination of layers and g) analysis. Two different Spatial MCDA methods are applied: a) the Weighted Overlay and b) the Fuzzy Overlay. The results are compared and relative conclusions are drawn.

2 Methods

The Spatial MCDA methods applied for implementing Overlay Analysis are: a) the Weighted Overlay (crisp method) and b) the Fuzzy Overlay (fuzzy method). The general steps followed by both methods are presented in Figure 1.

Figure 1: General steps of Overlay Analysis



Source: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/understanding-overlay-analysis.htm

Despite the fact that the general steps are the same in both cases, the methods differ as the first one is based on the classical binary logic while the second exploits fuzzy logic. The specific characteristics of each method are:

Weighted Overlay: overlays a number of rasters based on a common measurement scale and weights each according to its importance (Tomlin, 1990).

- Works only with integer rasters. This means that it does not understand ranges of values for the several classes but a single value. Consequently, floating point rasters should be reclassified before getting used by the Weighted Overlay tool (assignment of a single value to each range of values).

- Utilizes an evaluation scale (crisp values).
- Assigns weights to criteria (layers).
- Implements the Weighted Overlay Analysis algorithm.
- Classifies the alternatives-locations (crisp classification).

Fuzzy Overlay: combines fuzzy membership rasters data together and allows the possibility of a phenomenon belonging to multiple sets in MCDA overlay analysis. It also analyses the relations between the membership of the multiple sets (Raines et al., 2010).

- Performs a fuzzy MCDA process based on the concept of fuzzy sets.
- Fuzzifies the criteria (layers) by using membership functions.
- Combines the fuzzified layers (fuzzy operators).
- Implements the Fuzzy Overlay Analysis algorithm.
- Classifies the alternatives-locations (fuzzy classification).

3 The Case Study

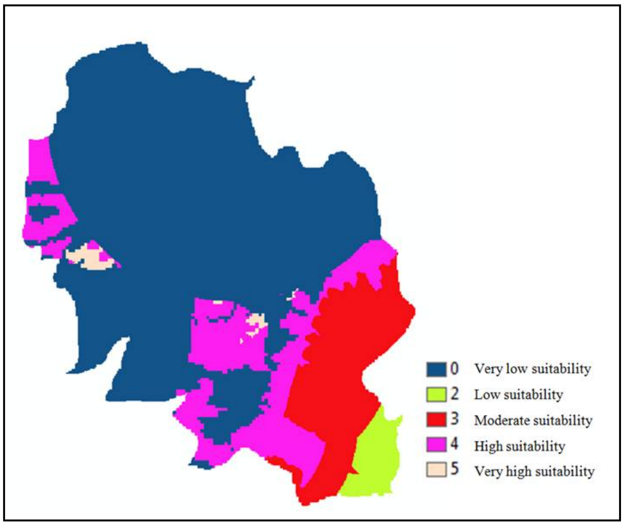
The goal of this study is the exploration of the optimal site for the development of an agro-tourist infrastructure. The area of interest is the Municipal Unit of Kastelli (Crete-Greece). The evaluation criteria (layers) are:

1. Slope suitability, layer: Digital Terrain Model.
2. Suitability of land uses, layer: Corine Land Cover.
3. Protection of water resources, layer: Hydrographical network.
4. Accessibility to settlements, layer: Settlements.
5. Accesibility to the road network, layer: Road network.

Firstly, a Weighted Overlay analysis was conducted. Criteria weights and scores of each site were determined (Weighted Overlay table). The results are presented in Figure 2.

Secondly, a Fuzzy Overlay analysis took place. The criteria (layers) were fuzzified by defining the most appropriate membership function for each one. The results are depicted in Figure 3.

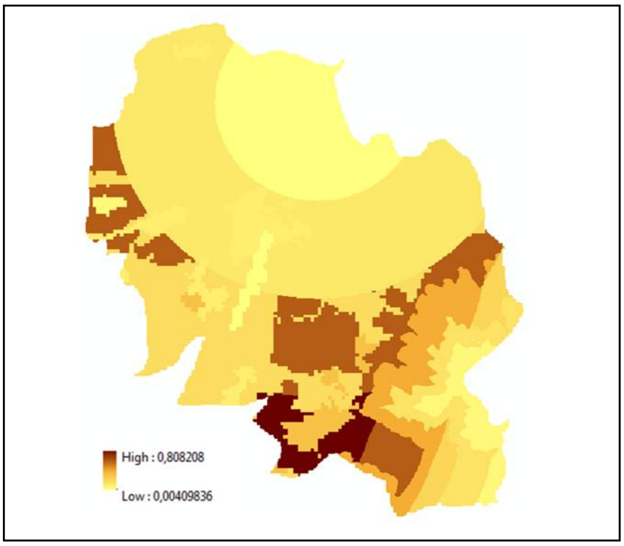
Figure 2: Weighted Overlay – Outcomes

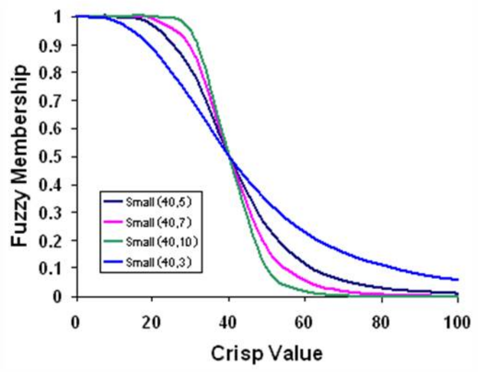


Weighted overlay table

Raster	% Influence	Field	Scale Value
corine_res	20	LABEL3	
		Discontinuous urb	3
		Airports	Restricted
		Mineral extraction	Restricted
		Vineyards	Restricted
		Olive groves	Restricted
		Complex cultivatio	Restricted
		Land principally oc	3
		Coniferous forest	1
		Natural grassland	2
		Sclerophyllous veg	2
		Transitional woodl	2
		Sparsely vegetate	2
		NODATA	NODATA
dtm_rec	20	VALUE	
hydro_rec	20	VALUE	
oikismoi_rec	20	VALUE	
roads_rec	20	VALUE	

Figure 3: Fuzzy Overlay - Outcomes





4 Discussion and Conclusions

The analysis of the methods applied and the overall assessment of the results pointed out the advantages and disadvantages of each method. They also indicated their appropriateness with respect to the characteristics of the problem under study.

In general fuzzy overlay addresses, in a more efficient way, possible inaccuracies in attribute data (mainly definition of classes and measurement of geographic phenomena) that in many cases affect the precise assignment of cells to specific classes. It also supports modeling of such inaccuracies. Weighted overlay is based on Boolean logic and provides more distinct results. It is simpler in use and more comprehensive to the decision maker that is not familiar with fuzzy logic.

Regarding the case study investigated in this poster, some specific conclusions concerning the methods applied are:

Fuzzy Overlay provides smoother results as a soft computing technique, allowing for a more flexible transition from totally non-suitable to totally suitable sites (smoother gradation of 'suitability'). It is more convenient for managing spatial data due to the fuzzy boundaries between different spatial classes (e.g. land uses). It also provides more realistic results as it approaches human reasoning in making decisions and eliciting conclusions.

Weighted Overlay, despite of being more "clear", as a crisp method bears the risk of ignoring possible sites due to the sharp boundaries between spatial classes. It provides more abrupt results and a sharper transition from totally non-suitable to totally suitable sites.

The results produced by the two methods resemble. "Most suitable" sites according to Fuzzy Overlay are classified as "high suitability" sites by Weighted Overlay. Sites of "very high suitability" according to Weighted Overlay are locations with relative high degree of membership in the "high suitability" class in case of Fuzzy Overlay.

Finally, it should be mentioned that the selection of the most appropriate Spatial MCDA method depends on the special characteristics and the specific needs of each problem.

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