MCDA-GIS integration: an application in GRASS GIS 6.4

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To face a spatial decision problem means to apply both Geographical Information Systems (GIS) and a Multi-Criteria Decision Analysis (MCDA) approach [15]. GIS and MCDA are two well defined research areas, but both can benefit one from each other [15]. MCDA methods are a basic tool in the field of environmental valuation, but they cannot easily take into account the spatial dimension. We can define MCDA as "a decision-aid and a mathematical tool allowing the comparison of different alternatives or scenarios according to many criteria, often contradictory, in order to guide the decision maker(s) towards a judicious choice" [19]. The typical MCDA problem is represented as a set of m alternatives to be valued in terms of a vector of n criteria. Sometimes, the Decision Maker's (DM) subjective preferences are represented by the weight vector w. Application of MCDA methodologies give as a solution a recommendation to classify, rank or choose efficient alternatives [19]. As a result of distinctive assumptions, the different MCDA methodologies differ in many aspects, related to the aggregation procedure, which aims at synthesizing the often conflicting evaluations on criteria, and to the exploitation procedure, which aims at using the result from the aggregation procedure, in order to define a proper recommendation.

The conventional MCDA approach assumes spatial homogeneity of alternatives within the case study area, although this is often unrealistic [14]. If alternatives have a geographical classification, ordering or choosing operations have to depend also on their spatial arrangement [14]. On the other hand, GIS provide great capabilities of data acquisition, storage, manipulation and analysis. However, in case of a value structure analysis, this capability is lower [14]. Due to these reasons, in the last twenty years several researchers have paid attention to MCDA-GIS integration and to the development of Spatial Decision Support Systems (SDSS) [2, 3, 10, 11, 14, 15].

MCDA-GIS integration consists in combining value judgments and geographical data, but also their transformation and elaboration [15]. The evaluation procedure needs both the MCDA framework and the GIS possibilities. According to several authors [2, 12], it is possible to classify MCDA-GIS integration in a three-level system. The basic step is the MCDA-GIS indirect integration: MCDA and GIS models are separated, and connected through an intermediate connection system. In the Built-in MCDA-GIS models, the multicriteria part is a component integrated into the GIS system, but it is independent from a logical and functional point of view. Only with the complete, or full, MCDA-GIS integration [15] the two systems use the same interface and the same database. The MCDA model is activated inside the GIS software just like any other analysis function.

We developed an example of a complete integration, implementing five modules, based on five different Multi-Criteria Decision Analysis methodologies, in GRASS GIS 6.4 svn. The methods used in the modules are Electre [18], Fuzzy set [21, 22, 23], Regime [9, 17], Analytic Hierarchy Process [20] and Dominance-based Rough Set Approach [6, 8] The syntax of each module, based on the GRASS GIS one, is the following: ***r.mcda.[algorithm]***. Prefix ***r*** means "raster,» i.e. the type of data elaborated; ***mcda*** is the name of the package, while ***[algorithm]*** is the name of the MCDA method applied. For instance, the module corresponding to the method Electre is named ***r.mcda.electre***, and so on.

We chose GRASS GIS for this application because it is an advanced and well known open source GIS software, used for geospatial data management and analysis, image processing, graphics/maps production, spatial modeling and visualization. Since its first release in 1982 [5], GRASS GIS has been increasingly used by academic and commercial settings all around the world, as well as by many governmental agencies and environmental consulting companies, for the wide range of possible applications [4, 13, 16]. GRASS GIS is a leading open source GIS software. Moreover, it is written in C language, and it is possible, thanks to its libraries and GPL license, to develop easily new modules [16, 5].

We tested the possibilities of our tool in an application to a geological instability management problem. The objective of the application is to identify several zones where realize agro-environmental measures, for territory maintenance and for reducing hydro geological risk. The case study is the area of the hydrographic basin of Menotre (Umbria, Central Italy), a small river, which is extended over 24.000 ha. The basin has an altitude between 257 and 1478 m above sea level. The upper trait is characterized by natural or rural ground, while in the valley it is quite completely urbanized. The basin is largely interested by geological instability, which is not uniform because of the geological characteristics of the ground, the presence or absence of vegetation, the level of urbanization and the type of agricultural activities.

The module used in the case study is the ***r.mcda.roughset***, which represents the first implementation of DRSA in a spatial setting. Several algorithms are available for implementing DRSA. One of the most well-known and widely used is the iterative algorithm DOMLEM [7], which was found to be particularly accurate with large datasets. For this reason, DOMLEM seems particularly suitable for GIS applications, and we chose to use it in the r.mcda. roughset module.

DRSA is different from the majority of other MCDA methods, because it does not involve weights to represent the importance of the considered criteria. In the classical multicriteria methods, to fix the weights of the considered criteria, the DM is often asked to answer questions that require a great cognitive effort, which reduces the reliability of the preference information so obtained. Thus, the non-consideration of weights constitutes a strong point of the DRSA. In the DRSA, the request for more or less direct information on the weights to the DM is replaced by the request of exemplary decisions, in terms of classification of some minimal units, well known to the DM, in predefined classes. As a result of the application of the DRSA methodology, the DM is supplied with some ***"if..., then..."*** rules, explaining the exemplary decisions. Those rules are then used to classify all the minimal units of the GIS. One advantage of the integration of DRSA with GIS is that the exemplary decisions require a much lower cognitive burden with respect to the input required by other GIS methods (e.g., weights of criteria). Additionally, the decision rules and the results of their applications are easily understandable because they are expressed in a natural and simple language. There are three types of rules: certain, possible and ambiguous. In the module, the rules are derived from a raster map, which includes a thematic key essential in the analysis. There are two module outputs: a raster map and a text file. The text file is compatible with 4emka2, Jamm [6] and JMAF [1], which are three software packages developed by the Poznan University of Technology.

The inputs required in the string are the name of the criteria raster map ***(criteria=name[,name,...])***, the preferences in terms of gain and cost ***(preferences=character)***, the name of the decision raster map ***(decision=name)***, the name of the classified output raster map ***(outputMap=string)*** and the name of the output txt files ***(outputTxt=name)***. The criteria raster maps we used are: the tendency toward instability, the Normalized Difference Vegetation Index (NDVI), the slope, the LS factor from the RUSLE model and the use of the ground. As decision raster map we used the frequency of surface landslide in the last ten years. We supposed that the probability to have another landslide will be higher in case of previous events. So a low value for this theme corresponds to a low need for management measures.

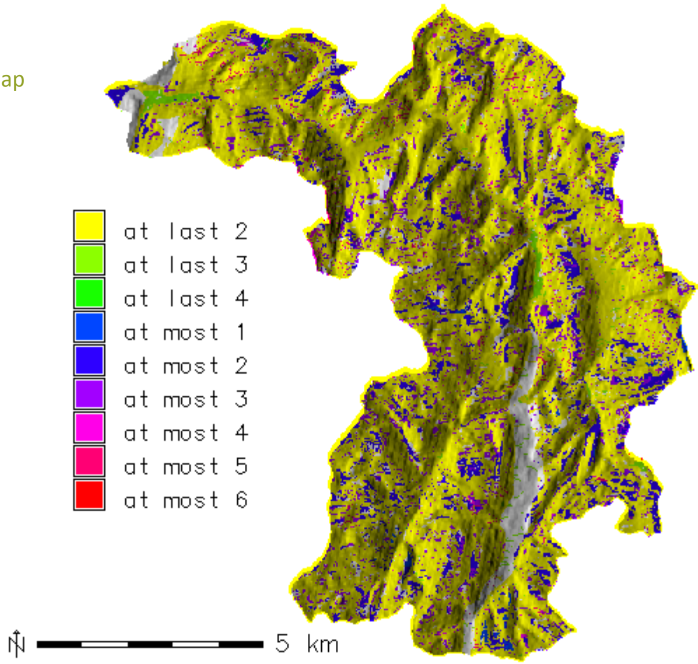

FIGURE 1
Ordinal decision map

Through the elaboration of the geographical criteria described above, and of the decision criterion, we obtained two output, one visual and one textual. The visual output is an ordinal decision map, based on decision rules, which allowed us to identify priority areas of intervention. In particular, we were interested in agro-environmental measures for hydro geological protection. The text output reports all the rules on which the map is based. Through two additional modules, ***r.to.drsa e r.in.drsa***, it was also possible to integrate the analysis with the traditional DRSA software, as 4emka2, jMAF or Jamm, to control the elaboration by means of other algorithms not present in our module.

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