Journal of Environmental Management xxx (2014) 1–14

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Decision Support Systems for environmental management: A case study on wastewater from agriculture

Gianluca Massei [a], Lucia Rocchi [a,*], Luisa Paolotti [a], Salvatore Greco [b,c], Antonio Boggia [a]

[a] Dept. of Agricultural, Environmental and Food Sciences, University of Perugia, Borgo XX Giugno, 74, 06121 Perugia, Italy
[b] Dept. of Economics and Enterprise, Corso Italia, 55, 95129 Catania CT, Italy
[c] Portsmouth Business School, Operations & Systems Management University of Portsmouth, Portsmouth PO1 3DE, United Kingdom

ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form
11 August 2014
Accepted 18 August 2014
Available online xxx

Keywords:
GIS
Multicriteria analysis
GIS-MCDA integration
Spatial Decision Support Systems
Modular package

ABSTRACT

Dealing with spatial decision problems means combining and transforming geographical data (input) into a resultant decision (output), interfacing a Geographical Information System (GIS) with Multi-Criteria Decision Analysis (MCDA) methods. The conventional MCDA approach assumes the spatial homogeneity of alternatives within the case study area, although it is often unrealistic. On the other side, GIS provides excellent data acquisition, storage, manipulation and analysis capabilities, but in the case of a value structure analysis this capability is lower. For these reasons, several studies in the last twenty years have given attention to MCDA-GIS integration and to the development of Spatial Decision Support Systems (SDSS). Hitherto, most of these applications are based only on a formal integration between the two approaches. In this paper, we propose a complete MCDA-GIS integration with a plurality of MCDA methodologies, grouped in a suite. More precisely, we considered an open-source GIS (GRASS GIS 6.4) and a modular package including five MCDA modules based on five different methodologies. The methods included are: ELECTRE I, Fuzzy set, REGIME analysis, Analytic Hierarchy Process and Dominance-based Rough Set Approach. Thanks to the modular nature of the package, it is possible to add new methods without modifying the existing structure. To present the suite, we applied each module to the same case study, making comparisons. The strong points of the MCDA-GIS integration we developed are its open-source setting and the user friendly interface, both thanks to GRASS GIS, and the use of raster data. Moreover, our suite is a genuine case of perfect integration, where the spatial nature of criteria is always present.

1. Introduction

Several fields of research may benefit from the integrated use of geographical information systems (GIS) and Multi-criteria analysis (MCDA): environmental and land management issues, or territorial and urban analysis, just to give a few examples, face spatial multi-criteria decision problems. In a spatial multi-criteria decision problem, geographical data (input) is combined and transformed into a resultant decision (output) (Laskar, 2003; Malczewski, 1999, 2006). One method of dealing with this matter is to interface a Geographical Information System (GIS) with Multi-Criteria Decision Analysis (MCDA) methods (Drobne and Lisec, 2009; Malczewski, 2006).

MCDA methods are basic tools in the field of environmental valuation and management; environmental management is a multidimensional challenge, and MCDA is able to support decision-making, involving several different aspects to be taken into account at the same time. But MCDA methods cannot easily take into account the geographical dimension (Laskar, 2003). The conventional MCDA approach assumes the spatial homogeneity of alternatives within the case study area (Figueira et al., 2005), although this is often unrealistic, because evaluation criteria may vary across the space (Jankowski, 1995; Laskar, 2003). If alternatives have a geographical nature, classifying, ordering or choosing operations also depends on their spatial arrangement (Laskar, 2003), and both value judgments and geographical information are needed to define them (Laskar, 2003). Spatial MCDA problems are, for instance, location choice or land suitability (Geneletti and van Duren, 2008; Goncalves Gomes and Estellita Lins, 2002; Joerin et al., 2001; Johnson, 2005; Maniezzo et al., 1998; Ruiz et al.,

* Corresponding author. Tel.: +39 0755857140; fax: +39 0755857143.
E-mail addresses: agr.gianluca.massei@gmail.com (G. Massei), lucia.rocchi@unipg.it (L. Rocchi), luisa.paolotti@gmail.com (L. Paolotti), salgreco@unict.it (S. Greco), antonio.boggia@unipg.it (A. Boggia).

http://dx.doi.org/10.1016/j.jenvman.2014.08.012

Please cite this article in press as: Massei, G., et al., Decision Support Systems for environmental management: A case study on wastewater from agriculture, Journal of Environmental Management (2014), http://dx.doi.org/10.1016/j.jenvman.2014.08.012

2012; Sahnoun et al., 2012; Scheibe et al., 2006), as in the present application.

In a Spatial MCDA, geographical data (input maps) is combined and transformed into a decision (output maps) (Drobne and Lisec, 2009; Jankowski, 1995; Malczewski, 1999). Therefore, both the MCDA framework and GIS possibilities are required in spatial, multi-criteria evaluation, and their integration has become one of the most useful approaches in environmental management and planning (Chang et al., 2008; Chen et al., 2010; Papadopoulou-Vrynioti et al., 2013; Rahman et al., 2012; Zucca et al., 2008). Several studies over the last twenty years have thus focused on MCDA-GIS integration and on the development of Multi-criteria Spatial Decision Support Systems (MCSDSS) (Chakhar and Martel, 2003; Jankowski, 1995; Lidouh, 2013; Malczewski, 2006) as a fundamental instrument for managing the environment (Rahman et al., 2012; Zucca et al., 2008). Web GIS-MCDA applications have also been developing in very recent years (Bouroushaki and Malczewski, 2010; Karnatak et al., 2007). Although several applications and examples of GIS-MCDA integration are found in the literature, there are fewer studies concerning the development of a theoretical framework (Chakhar and Mousseau, 2007, 2008).

The objective of this study is to present a new MCDA-GIS integration tool and its use in land management problems, as the land application of wastewater from agricultural activities. We developed a modular suite (*r.mcda*) based on different Multi-Criteria Decision Analysis methodologies in an open-source GIS (GRASS GIS 6.4) (Massei et al., 2012).

The paper is structured as follows: Section 2 describes the methodology; Section 3 presents the case study; Section 4 reports the results; Section 5 is the discussion. The paper ends with the main conclusions.

2. Methodology: MCDA-GIS integration

The multi-criteria spatial decision support system (MCSDSS) can be considered a specific part of the more general group of Spatial Decision Support Systems (SDSS) (Ascough et al., 2002). SDSSs have received a great deal of attention from researchers, since their usefulness in spatial decision problems has been clearly demonstrated (Crossland et al., 1995): SDSSs produce more efficient results in a shorter solution time.

An MCSDSS consists of three components (Ascough et al., 2002; Laskar, 2003; Malczewski, 2010): a geographical database and the relevant management systems, an MCDA model-based management system, and an interface.

According to certain authors (Chakhar and Martel, 2003; Laskar, 2003), it is possible to classify MCDA-GIS integration in three ways. The basic step is MCDA-GIS indirect integration: MCDA and GIS models are separated, and linked through an intermediate connection system, handled by the analyst. Each part has its own database and its own interface, which may affect their interaction. This procedure has the advantage of its low development cost, but the separation of MCDA and GIS parts makes it difficult to completely comprehend the spatial nature of the problem (Lidouh, 2013). Moreover, errors may occur during the transfer, due to the human element involved (Lidouh, 2013). There are some examples of this type of integration (Cavallo and Norese, 2001; Chang et al., 2008; Geneletti, 2004), where the complexity of the analysis is nevertheless quite high. The second type of system is represented by MCDA-GIS tools (Laskar, 2003), in which the multi-criteria component is integrated into the GIS system, but remains independent from a logical and functional point of view. In particular, the MCDA part has its own database, whereas the interface is the same. There is no need for an intermediate system, and the exchange data and analysis between the two parts are performed directly, which is a good step forward compared to indirect integration (Chakhar and Martel, 2003). It is a sort of one-directional integration (Malczewski, 2006), where one of the two softwares works as the main software. This type of integration is the one most successfully applied (Lidouh, 2013).

It is only at the third level, known as complete, or full MCDA-GIS integration (Greene et al., 2010; Laskar, 2003), that the two systems use the same interface and the same database. The MCDA model is activated inside the GIS software in the same way as any other analysis function (Chakhar and Martel, 2003). In a full-integration scheme (see Fig. 1), the user can access both the MCDA and the GIS tools at any time during analysis, and interaction is complete: it is possible to change the parameters and the methods, visualise results or the spatial elements (Lidouh, 2013), until the goal of the research is achieved.

As Lidouh reports (2013), some integration options are also possible in well-known commercial software, such as ArcGIS by ESRI (Lidouh, 2013). The weak point of the applications implemented in commercial software lies in the very nature of the products. In ArcGIS, for instance, the researcher cannot choose the algorithms he wishes to include, and he cannot improve them since ArcScripts closed down. Moreover, frontier methods are excluded, since preference is given to the most widely used and most well-known methods. In contrast, open-source options give more possibilities for developing new tools, even though there are few open components (Lidouh, 2013).

The modular suite *r.mcda*, based on five different Multi-Criteria Decision Analysis methodologies presented in this paper, is developed in GRASS GIS 6.4 svn (Grass Development Team, 2012a, 2012b). As all geographical processing in GRASS GIS is carried out by separate modules, we developed our Multi-Criteria tools as modules. We chose GRASS GIS for our application because it is an advanced and well-known open-source GIS software (Frigeri et al., 2011), used for geospatial data management and analysis, image

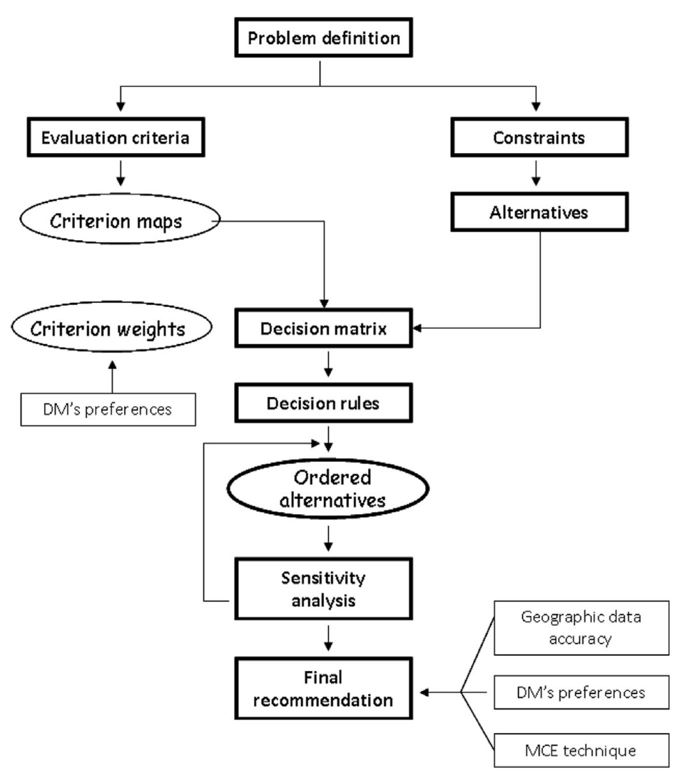

Fig. 1. Represents a Decision flowchart for spatial multicriteria analysis, proposed by [40]. In the flowchart GIS and MCDA parts are clearly tightly bound.