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A spatial multicriteria decision making tool to define the best agricultural areas for sewage sludge amendment

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ABSTRACT

Sewage sludge amendment on agricultural soils has recently become a practice of heightened interest, as a consequence of sewage sludge production increase. This practice has benefits to soil and crops, however it may also lead to environmental contamination, depending on the characteristics of the fields. In order to define the suitability of the different agricultural fields to receive sewage sludge, a spatial tool is proposed. This tool, elaborated in GIS platform, aggregates different criteria regarding human exposure and environmental contamination.

The spatial tool was applied to a case study in the region of Catalonia (NE of Spain). Within the case study, each step of the tool development is detailed. The results show that the studied region has different suitability degrees, being the appropriate areas sufficient for receiving the total amount of sewage sludge produced. The sensitivity analysis showed that "groundwater contamination", "distance to urban areas", "metals concentration in soil" and "crop type" are the most important criteria of the evaluation.

The developed tool successfully tackled the problem, providing a comprehensive procedure to evaluate agricultural land suitability to receive sewage sludge as an organic fertilizer. Also, the tool implementation gives insights to decision makers, guiding them to more confident decisions, based on an extensive group of criteria.

1. Introduction

Sewage sludge (SS) is a residue produced as a consequence of contaminants removal in different parts of the wastewater treatment plants. Its production has recently risen in several countries due to population increase and improvements in the collection and treatment systems. In consequence, the management of an enlarged production of sewage sludge has become an environmental problem. One of the most applied disposal alternatives is its reuse as an agricultural fertilizer. This alternative is encouraged by the European Community because of the recycling of organic matter and nutrients to soils.

However, SS matrix contains also some contaminants of concern, such as heavy metals and persistent organic pollutants (POPs) (Clarke et al., 2010; De La Torre et al., 2011; Eljarrat et al., 2003; Harrison et al., 2006; Khadhar et al., 2010; Martínez et al., 2007; Metcalf and Eddy, Inc., 2003; Wong et al., 2001) that may move between the environmental matrices, leading to contamination of soil, crops, groundwater, open waters, and finally reaching the human food chain (Passuello et al., 2010). The likelihood of contaminating each of these compartments is strongly related not only to SS parameters but to local characteristics of the fields. Therefore, the use of spatial tools for land classification is essential to identify different suitability degrees in the existing agricultural fields of a defined study region. In addition, these tools allow evaluating the amount of land which is appropriate to be amended with SS.

In recent years, Geographic Information Systems (GIS) have been extensively applied in several environmental fields such as vulnerability assessment (Kattaa et al., 2010), human health (Nadal et al., 2006, Poggio and Vrscaj, 2009), and ecological exposure and risk models (Johnson et al., 2009, Schriever and Liess, 2007). Another area of increased use of GIS platform is in the development of environmental decision support systems (Passuello et al., 2011, Pérez et al., 2010). Spatial multicriteria decision analysis (SMCA) refers to the application of Multicriteria Decision Analysis (MCDA) tools in a GIS platform, to solve spatial decision problems. MCDA is a tool of increased interest in the environmental field, as it allows the combination of quantitative and qualitative inputs, like risks, costs, benefits and stakeholders views (Giove et al., 2009).

In this kind of problems, the decision involves the selection of the best option among several potential alternatives that are associated with geographical locations. Two considerations have been cited as important to solve spatial decision problems: (i) GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the

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models' capabilities of combining the geographical data and the decision maker's preferences into unidimensional values of alternative decisions (Malczewski, 2004).

Several examples of SMCA application in environmental management are reported in the literature. Among these, agriculture is one of the major application areas of SMCA (Malczewski, 2006). For instance, Ceballos-Silva and López-Blanco (2003) applied SMCA to identify areas with optimal growth conditions for the production of maize and potato crops. Also, Morari et al. (2004) applied SMCA for selecting criteria of best management practices in agricultural sites, considering yield production and environmental effects. However, to the best of our knowledge, the management of sewage sludge on agricultural soils has not yet been studied through a spatial analysis.

The objective of this work was to develop a land classification tool to determine the suitability of different agricultural areas to be amended with sewage sludge. To facilitate the understanding of the study, this tool was applied to a case study in Catalonia (northeast of Spain).

2. Case study

The geographic region of Catalonia (NE of Spain) is characterized by a diverse morphology, being mostly mountainous in the north (Pyrenees) and flat at the center and the coast. The region is also characterized by the presence of a littoral mountain system, between the central depression and the coast. The Ebro catchment is the largest basin of Catalonia (Fig. 1). The region has a temperate climate, with warm summers and cold winters. The mean annual temperature varies between 5 °C (in the colder regions of the Pyrenees) and 17 °C (in coastal zones). The precipitation levels vary along the territory. The northern and mountainous regions present the higher mean precipitation levels (between 700 and 1250 mm yr^{-1}), while the southern and the coastal regions present lower rainfall levels (between 450 and 700 mm yr^{-1}).

Among the crops produced in the region, wheat, rice, barley, olive, grapes, fruits, nuts and vegetables are the most representative ones (IDESCAT, Institut d'Estadistica de Catalunya, 2009). The available agricultural area has more than 1 million ha. More than 85% of this area is covered by fruit and cereal fields (DMAiH, Departament de Medi Ambient i Habitatge, 2009), especially at the central depression.

Sewage sludge amendment is a common practice in this area, as a consequence of the increased production of this residue in the last few years. Reported data for the year 2007 show that between the 140,000 tons dry weight (dw) produced in Catalonia, 83% (114,000 tons dw) are applied on agricultural soils (ACA, Agència Catalana de l'Aigua, 2008). An important constraint regarding the organic amendment in the area is groundwater contamination by nitrates. In fact, several areas are classified by the local environmental agency as highly vulnerable to groundwater contamination (ACA, Agència Catalana de l'Aigua, 2005). Other related issues to take into account are open waters and soil protection, as well as human exposure to the contaminants present in the sludge matrix.

3. Development of the spatial multicriteria decision support tool

Complex spatial decision problems are difficult to structure as they involve the consideration of intangible factors related to multiple groups with conflicting objectives. In order to avoid erroneous judgments of the results, a clear definition of the framework for the assessment of the decision problem must be performed at the beginning of the evaluation. Fig. 2 shows the main steps of the analysis. First, the problem must be precisely characterized and the objectives defined. The

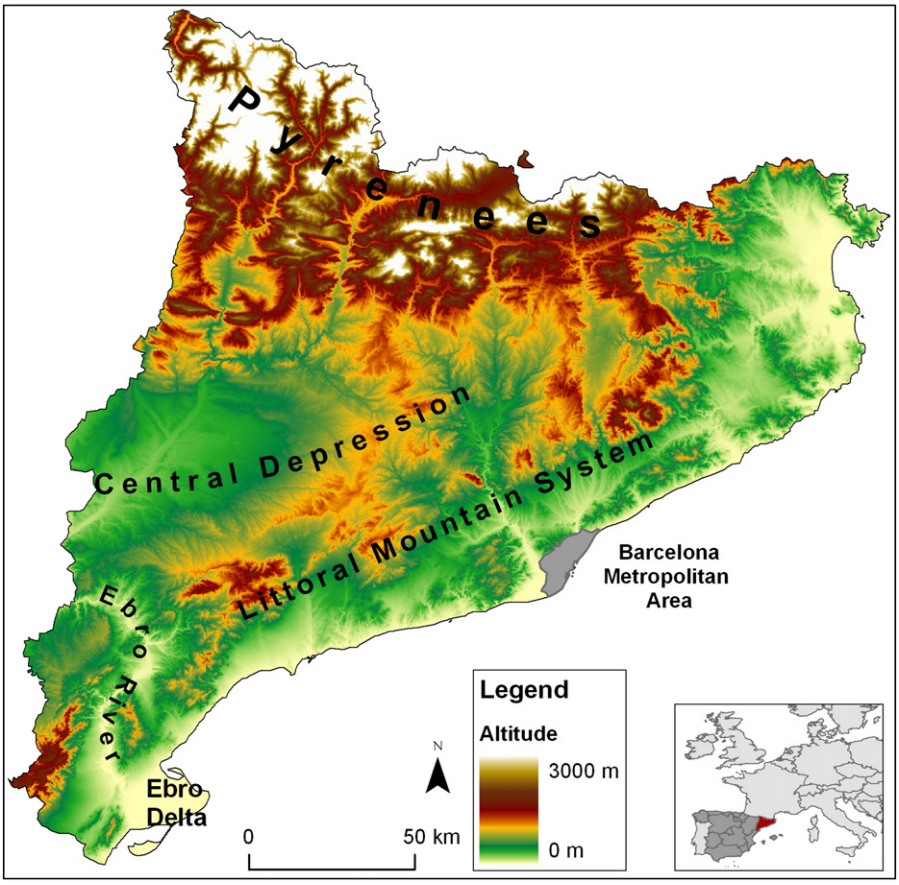

Fig. 1. Location map of Catalonia.