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Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology

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ABSTRACT

Landfill siting should take into account a wide range of territorial and legal factors in order to reduce negative impacts on the environment. This article describes a landfill siting method, which is based on EVIAVE, a landfill diagnosis method developed at the University of Granada. Geographical Information Systems (GIS) technology is also used to generate spatial data for site assessment. Landfill site suitability is assessed on a scale based on territorial indices that measure the risk of contamination for the following five environmental components: surface water, groundwater, atmosphere, soil, and human health. The method described in this article has been used to evaluate an area in Granada (Spain) where there is a currently operating landfill. The results obtained show that suitable locations for the disposal of municipal waste were successfully identified. The low environmental index values reflect the suitability of this landfill site as well as its minimal negative impacts on the environment.

1. Introduction

Landfill siting is a complex process involving social, environmental and technical parameters as well as government regulations. As such, it evidently requires the processing of a massive amount of spatial data. Various landfill siting techniques have been developed for this purpose. Some of them use Geographic Information Systems (GIS) to find suitable locations for such installations [1–3]. For example, Lin and Kado [4] developed a mixed-integer spatial optimization model based on vector-based data to help decision makers find a suitable site within a certain geographic area. Other researchers propose the use of multiple criteria analysis by itself [5,6], or with GIS [7]. The use of artificial intelligence technology, such as expert systems, can also be very helpful in solid waste planning and management. Fuzzy inference systems have also been proposed [8,9].

EVIAVE is an environmental diagnosis method developed by researchers at the University of Granada. It provides information concerning potential environmental problems caused by currently operating landfills. It is basically a tool for assessing the suitability of landfill sites and for monitoring their operation. Its main objective is to develop a decision support system for integrated municipal waste management, more specifically for decisions related to renovating or closing landfill sites. EVIAVE has been validated with data from more than fifty landfills in Spain [10], Venezuela [11] and Chile [12].

2. Landfill siting using a GIS

Over the last three decades, advances in computer science have led to the creation of GIS, initially based on McHarg's [13] basic map layering concept. GIS combines spatial data (maps, aerial photographs, and satellite images) with quantitative, qualitative, and descriptive information databases, which can support a wide range of spatial queries. All of these factors have made GIS an indispensable tool for location studies [14], particularly for landfill siting.

Processing such data with conventional drawing and calculation tools is generally time-consuming. GIS, however, converts georeferenced data into computerized maps, while GIS map analysis tools also make it possible to efficiently manipulate maps with a computer. The advantages of using GIS for waste disposal and landfill site selection have been demonstrated by various researchers. Jensen and Christensen [15] demonstrate the use of GIS in the

Abbreviations: GIS, Geographical Information Systems; CRI, Contamination Risk Index; Pbc, Probability of Contamination Indicator; eV, Environmental Value; ERI, Environmental Risk Index; LSI, Landfill Suitability Index.

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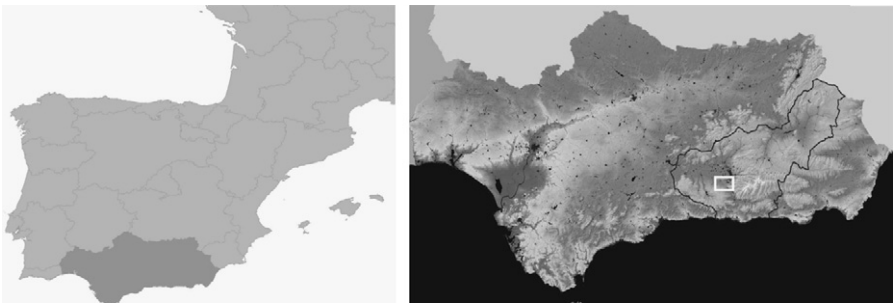

Fig. 1. Map of situation and localization of existing landfill site.

selection of solid and hazardous waste disposal sites. GIS was subsequently used by Fatta et al. [16] for the site selection of an industrial waste facility. Siddiqui [1] presents a method that identifies and ranks potential landfill areas for preliminary site assessment. This method combines GIS with a decision-making method based on the analytic hierarchy process (AHP). GIS technology has also been combined with AHP and fuzzy set theory [9]. Lin and Kado [4] developed a mixed-integer programming model to obtain a site with optimal compactness. The compactness model was further extended to include multiple siting factors with weights that were determined by the GIS map layer analysis function.

According to Michaels [17] a GIS can be used to combine various demographic, geological, land use and census tract maps to apply landfill criteria, and find suitable areas to place a landfill. Kao et al. [18] developed a prototype network GIS to increase the efficiency of complex solid waste landfill siting. Furthermore, this system makes site-related information available to the general public; assists local environmental protection agencies in maintaining a GIS; and helps the central environmental protection agency to manage, instruct, and evaluate the local siting process. Kontos et al. [7] describe a spatial method that integrates multiple criteria analysis, GIS, spatial analysis, and spatial statistics with a view to evaluating a region for landfill siting.

This article describes an EVIAVE-based method developed at the University of Granada for the assessment of landfill sites in accordance with European Union legislation. This method is innovative because it establishes general indices to quantify overall environmental impact as well as individual indices for specific environmental components (i.e. surface water, ground water, atmosphere, soil, and human health). Quantification variables and impact indicators represent indices more precisely as well as make the results more objective.

Since this method requires processing large quantities of spatial data, we used GIS and its spatial analysis tools to create the digital geodatabase. Commercial GIS software packages include analytical tools that perform spatial analysis processes. To automate the processes of establishing composite evaluation criteria, performing multiple criteria analysis, and carrying out spatial clustering, algorithms were developed in a Microsoft Visual Basic programming environment compatible with ESRI ArcGIS, a GIS software. Although POPSIS [19] and Compromise Programming [20] are multiple criteria analysis methods that have been proposed for the evaluation of the final suitability index, we decided to use simple additive weighting (SAW) to solve the multiple criteria problem.

The GIS-aided landfill siting method presented in this article combines GIS spatial analysis tools with MCA to evaluate an entire region. We describe how this method was applied to a region in Granada (Spain) to assess the suitability of a currently operating landfill site. The hydrogeological, environmental, social, and technical/economic evaluation criteria are the same as those used in EVIAVE.

3. Area of study

The area studied measures 300 km^2, and is located to the south of the metropolitan area of Granada on the western edge of the Sierra Nevada mountain range (Fig. 1). After Seville and Malaga, Granada has the third largest population in Andalusia, and two thirds of its inhabitants live in the metropolitan area of the city. 55% of the population of the province of Granada (817,000) is concentrated in a surface area of 830 km^2, i.e. less than 7% of the total area. The population density in the metropolitan area is thus 530 inhabitants per km^2 as compared to 32 inhabitants per km^2 in the rest of the province.

In this area there is a landfill of medium density and high density. This landfill is used to dispose and eliminate waste from a solid waste treatment plant located in the town of Alhendín at Loma de Manzanares. This plant handles the waste from 26 municipal districts, whose 677,505 inhabitants generate 300,000 t of waste per year.

4. Methodology

4.1. Definition

The presence of a landfill in this area evidently has an important effect on the environment. Its impact is largely dependent on the affected elements at the site as well as on the spatial distribution of the effects. The first step in the evaluation of the environmental impact of the landfill is the identification of any elements, which may be sensitive to this impact. In different Environmental Impact Assessment (EIA) processes [21], these elements are known as *environmental components*. The components in our study are ground water, surface water, soil, atmosphere, and human health [22–25] because of their interactions with the dynamics of the release point. This means that the landfill is regarded as an active installation that can produce emissions.

Our evaluation method is based on the use of environmental indices to provide a quantitative assessment of the possible environmental interactions between a landfill and potentially affected environmental components because of the siting of the landfill. Similarly to EVIAVE, this method evaluates municipal solid waste landfills classified as non-hazardous waste landfills by Directive 31/99 [26]. It is thus applicable in the European Union, and in any other country where similar legislation exists, or indeed, where there is no legislation or where the legislation is less prescriptive than this Directive.

Fig. 2 shows the hierarchical structure of the decision problem, which has four levels. The first level represents the criteria and subcriteria used. It takes into account spatial attributes for landfill siting, and the quantification of landfill variables and environmental impact indicators used to calculate different environmental indices. The second level represents the Probability of Contami-