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Factor analysis and geographic information system for determining probability areas of presence of illegal landfills

Rosa Jordá-Borrell*, Francisca Ruiz-Rodríguez, Ángel Luís Lucendo-Monedero

Physical Geography and Regional Geographic Analysis Department, Geography and History Department – Seville University [Universidad de Sevilla], C/María de Padilla s/n, 41004 Seville, Spain

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ABSTRACT

The objective of this study is to develop a methodology for determining areas in which there is a distinct probability of the presence of illegal landfills. This methodology is developed in three stages: (a) the application of factor analysis (FA) to identify relevant geographical factors (factor model); (b) the construction of a geostatistical model to calculate spatial patterns based on the identified factors; and (c) the integration of the geostatistical model into a geographic information system (GIS) to determine and locate the illegal landfill sites (spatial model).

This methodology has proven to be valid because it confirmed that a verified population of illegal landfills (518) is not randomly distributed; instead, most of the illegal landfills (63.6%) are found in the areas of highest probability (over 36%). Additionally, the study confirmed that the application of this methodology (FA and GIS) provides adequate results at the regional and local level.

The described method may also be applied to other spatial environments, as long as the necessary thematic and spatial data are available (although results would vary according to demographic, socio-economic, geomorphological, and environmental management characteristics).

Finally, the benefit of this methodology lies in the fulfilment of two necessary and sufficient demands. (a) The model does not arbitrarily include variables related to the probability of the presence of illegal landfills and considers those variables that have been shown via FA. (b) The variables included in the spatial model are not considered to have the same importance.

Thus, the integration of FA and GIS offers an alternative tool to the application of multi-criteria evaluation as this approach determines the criteria and their relative weights based on substantiated and non-aprioristic indications. Moreover, the methodology used in this study enables the creation of models because the GIS makes an excellent platform for the development, application, and validation of these models.

1. Introduction

The existence of illegal landfills continues to be a problem in the developed and peripheral countries of Europe. Research conducted in Germany, Austria (Allgaier and Stegmann, 2006), Ireland (Doak et al., 2007), France (Biotto et al., 2009), Italy (Silvestri and Omri, 2008), Romania (Apostol and Mihai, 2011) and Serbia (Vasiljević et al., 2012) demonstrates the severity of this problem and indicates that the analysis of illegal landfills is complicated. This complexity is due to the lack of consistent and homogenous data (inventories, databases, official statistics, satellite images. . .); thus the characteristics and the spatial distribution of illegal landfills have been little studied. Furthermore, most landfill studies are centred on verifying appropriate variables for locating controlled landfills.

In both types of studies a methodology integrating geographic information systems (GIS) and multi-criteria evaluation techniques is applied. The aforementioned research identifies the factors and criteria required to calculate the probability of an illegal landfill occurring within a given territory and demonstrate that these landfills are not randomly distributed in spatial terms (Doak et al., 2007; Silvestri and Omri, 2008; Biotto et al., 2009).

The objective of this paper is to develop a methodology for identifying and locating areas with different probabilities of the presence of illegal landfills. This methodology consists of three stages: (a) the application of factor analysis (FA) to identify geographical factors (factor model), (b) the definition of decision rules for calculating spatial patterns based on the factors (geostatistical model) and (c) the integration of the geostatistical model into a geographic information system (GIS) (spatial model).

* Corresponding author. Tel.: +34 620191 928.
E-mail addresses: borrell@Us.Es (R. Jordá-Borrell), fruiz@Us.Es (F. Ruiz-Rodríguez), angeluis@Us.Es (Á.L. Lucendo-Monedero).

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This work, therefore, focuses on the development of a similar yet alternative methodology to that used by the above-mentioned authors. The methodology that we propose is similar because it uses GIS as the basis of the entire process of spatial analysis and for locating probable landfill sites on the basis of the criteria that determine these areas. And alternative because, among the existing methods for obtaining the criteria (Analytic Hierarchy Process, AHP, or the Delphi Method[1]), we have used the Principal Component Factor Analysis (FA) with the goal of obtaining these criteria[2] or factors and their relative importance or rank (eigenvalues). According to Chang et al. (2008) and Kontos et al. (2005) the problem caused by the presence of illegal landfill sites is influenced by a series of complex factors that are not known a priori. An appropriate means of identifying these factors is the use of AHP (Barredo and Bosque, 1995) or FA in order to subsequently define a spatial pattern analysis that specifies areas where the presence of illegal landfills is likely through the construction of a GIS (Barredo, 1996). Thus, the use of FA as a criterion or factor selection method requires that the factors have normal characteristics.

The application and verification of this methodology was carried out with data from Andalusia (Spain) (Fig. 1). It must be taken into account that this region has a surface area of 87,598 km^2 (17.4% of Spain and 3.7% of the European Union) and a population of 8,437,681 inhabitants (INE Spanish National Statistics Institute, 2012) which comprises 17.87% of the Spanish population. The Autonomous Community of Andalusia is divided into eight provinces and 770 municipalities of which some 150 have a population above 10,000 inhabitants and contain 80% of the population. Located in southern Europe at latitude 36–38°45′ N, Andalusia is characterized by its Mediterranean nature which gives it a considerable variety of landscapes and resources. From an economic perspective, it is one of the most backward regions of Europe (€17,500 GDP per capita at current prices), and is far below the EU average (€23,500 500 per capita in 2009, according to EUROSTAT).

2. Methodology for calculating probable areas of uncontrolled landfills

2.1. Data, variable selection, and factor analysis

The object of analysis in this paper is the illegal landfill. This is a waste deposit in an area without monitoring by the competent authorities, and not the result of previous waste treatment systems. The Regional Government considers an illegal landfill to be when dumping covers an area of 2000 m^2 or more.

The references on illegal landfills (Doak et al., 2007; Biotto et al., 2009; Silvestri and Omri, 2008; Apostol and Mihai, 2011; Tasaki et al., 2007, 2004) have used many geographical variables for studies to identify possible uncontrolled landfill sites. These variables (always geo-referenced) match those selected by other authors to study the optimal location of a landfill using GIS (Chang et al., 2008; Basnet et al., 2001; Akbari et al., 2008; Sener et al., 2011, 2010; Kontos et al., 2005). These variables are different in nature and can be grouped into:

- Geophysical variables, such as geomorphological and lithological characteristics, vegetation, elevation, hydrology, types of land use and protected areas.
- Management and activity variables, such as accessibility and visibility of illegal landfills, type of waste, administrative efficiency, existence of punitive policies and environmental culture.
- Socio-economic variables, such as the resident population, rent, road infrastructure and economic activities.

Fieldwork and interviews carried out with (16) technical experts in waste management suggested the inclusion of new types of variables. This is the case of: distance measures of the physical proximity of these landfills to different surrounding geographical elements, references to soil use, the number of records opened by the administration and the time dedicated to monitoring the territory. Therefore, due to the above reasons and the multivariate nature of the analyses for the determination and location of illegal landfills, we also believe that it is necessary to begin with the selection of a wide and diverse enough set of variables to obtain a set of representative geographical factors.

It is important to stress that data for most of these variables are not currently available. Thus, it has been necessary to conduct fieldwork[3] to obtain this information. Related social and economic characteristics of the municipalities in which are located and discovered illegal discharges that come from official statistical sources (Table 2) are appended to these data, given the lack of availability of these data for illegal dumping areas. In the end we selected a total of 78 variables to perform statistical analyses (supplementary data).

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2013.10.001.

To do fieldwork, we calculated a sample of 110 cases distributed across the eight Andalusian provinces in accordance with the Nomenclature of Territorial Units for Statistics 3 (NUTS 3[4]) These cases were selected through stratified sampling (size, discharge type, spatial distribution) from a population of all the illegal landfills detected via remote sensing and aerial photography (1751 possible illegal landfills supplied by the Ambisat Company[5]). After cleaning up the data using different techniques and validating the data via fieldwork, a population of 518 illegal landfills was determined (Table 1).

When combining FA with the GIS techniques, it is necessary to use the same variables for the GIS as those used with the multivariate technique but with geo-referenced information. This allows to create a map for each variable distribution. We may perform not only pertinent spatial analysis using GIS to map the factors determining the location of illegal landfill sites in Andalusia but also analyze how different variables in the region are interrelated. For this purpose, we selected a series of vector coverages using databases from different sources (Table 2) with scales ranging between 1:10,000 and 1:100,000.

[1] The Delphi method has mainly been used in studies on forest fires (Meddour-Sahar et al., 2013), and in the formulation of pollution indices (Sharma et al., 2008; Kumar and Alappat, 2005).

[2] Criterion is a factor derived from factor analysis and has an eigenvalue above 1, and therefore in this study, factor is the same as criterion.

[3] The fieldwork comprised interviews with relevant experts and managers (local and regional government) and information gathering during visits to 110 illegal landfills distributed throughout the regional territory with the goal of identifying, validating, and gathering information on the illegal landfill terrain for the representative sample. For this purpose, a file of 45 variables was created, adjusting the reference images (topographical and orthophotographic maps) and the photos taken in situ. Using these data, we obtained 78 variables (Supplementary data) to which others were added from the information sources listed in Table 2, with the goal of creating different databases for conducting the statistical analysis and building the GIS.

[4] Level 3 (NUTS 3) in the Spanish state corresponds to the administrative division of the province. The Spanish State is organized territorially into municipalities, provinces and autonomous regions.

[5] This research study on remote sensing as a tool for identifying landfills, named the VERTEL project, was conducted by the signatories to an R&D contract with the Ambisat Company (Madrid). The study was financed by the Andalusian Technology Corporation (CTA) in 2011 and 2012.