Predictive model for areas with illegal landfills using logistic regression

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The existence of illegal landfills is an environmental problem in most countries. However, research on this issue is scarce and limited by the availability and quality of data on the subject. Thus, most illegal landfill studies have only been conducted in a partial manner, focusing on geographical aspects or the causes of these landfills (lack of environmental awareness, inadequate waste management systems, and the role of local government). This research analyses a sample of 120 possible areas with illegal landfills in Andalusia using logistic regression in order to obtain a predictive model for the occurrence of these landfills, including both types of variables (geographical and behavioural) jointly. The results confirm that the variables that most influence the occurrence of illegal landfills are spatial (“Industrial Land”, “Plains” and “Rural Land”); whilst the variables that most reduce the likelihood of illegal landfills are those related to certain characteristics of the municipal waste management system and environmental awareness, such as “Availability of Recycling Facilities”, “Punitive Policies”, “Supervision” and “Awareness-raising Campaigns”. The model obtained shows that variables of very different nature and magnitude interact in the occurrence of illegal landfills, each of which contributes a series of features characteristic of its scale. It is advisable, therefore, to perform an analysis using a multi-scale approach in order to gain an overall understanding of the phenomenon.

Keywords: illegal landfill; logistic regression; topography; construction and demolition waste (C&DW); municipal system waste management; awareness-raising campaigns

1. Introduction

The existence of illegal landfills continues to be an environmental problem in most countries today, as demonstrated by various studies carried out in Germany, Austria (Allgaier and Stegmann 2006), Ireland (Doak et al. 2007), Italy (Biotta et al. 2009; Silvestri and Omri 2008), Romania (Apostol and Mihaei 2011), Serbia (Vasiljević et al. 2012), Macedonia (Gorsevski et al. 2012), Turkey (Keser, Duzgun, and Aksoy 2012), Vietnam (Luong, Giang, and Thanh 2013) and Malaysia (Afroz and Masud 2011). These authors also show that research on illegal landfills is very limited, mainly because very few data are available on the subject (Matsumoto and Takeuchi 2011) and as there is no consistent and homogeneous information (inventories, databases or official statistics).

Most illegal landfill studies have focused on developing methodologies for their identification, studying their spatial distribution and delimiting and/or predicting the probability of the presence of illegal landfills by using remote-sensing tools and geospatial
analysis techniques (GIS) (Apostol and Mihai 2011; Doak et al. 2007; Biotto et al. 2009; Silvestri and Omri 2008; Romeo, Brown, and Stuver 2003). To this end, these studies have used geographical and geo-referenced variables on illegal landfills and the surrounding area among other variables. In this way, this research has shown the influence that geographical attributes have on the location and occurrence of uncontrolled landfills.

Other studies have put the emphasis on examining the causes of illegal landfills/dumps. While some focus on the existence and degree of development of waste management systems at the municipal level in order to explain the phenomenon (Ichinose and Yamamoto 2011; Guerrero, Maas, and Hogland 2013; Alavi-Moghadam, Mokhtaran, and Mokhtaran 2009; Hazra and Goel 2009; Romeo, Brown, and Stuver 2003), others highlight the key role of people’s behaviour and attitude with respect to separating and recycling waste in the occurrence of illegal landfills (Vidanaarachchi, Yuen, and Pilapitiya 2006). These researches, therefore, indicate that certain socio-economic-cultural characteristics of the population have a significant influence on practices that give rise to illegal dumping (Sharholy et al. 2008; Sujauddin, Huda, and Hoque 2008; Ekere, Mugisha, and Drake 2009; Guerrero, Maas, and Hogland 2013).

This has led other authors to analyse the degree of association between the level of awareness and the willingness of the population to separate and recycle in order to prevent uncontrolled dumping. Likewise, the punitive policies and environmental awareness-raising campaigns implemented by local authorities have been addressed in other research work (González-Torre and Adenso-Díaz 2005; Owens, Dickerson, and Macintosh 2002; PCAESG 1999). Thus, it has been possible to demonstrate the effect of the variables that measure people’s behaviour (of a social nature) and the actions of local governments (of a political-administrative type) in the occurrence of uncontrolled dumping.

There are only a few partial studies that have analysed the joint influence of geographical and behavioural variables in the occurrence of illegal landfills. Some have demonstrated through spatial and non-spatial regression techniques (Keser, Duzgun, and Aksoy 2012) that the interdependence between geographical variables and socio-economic and demographic data of certain municipalities serves to explain the different rates of generation of solid urban waste (SUW).

However, studies carried out to date have not taken into account the possible relationship between the spatial characteristics of the location of illegal landfills and the behavioural traits of the people and local governments where the landfills occur. Logistic regression is an appropriate analytical technique to achieve this objective, as it enables spatial and behavioural variables that are presumably related in some way to the presence of these landfills in a specific place to be included simultaneously and within the same model (Vilar del Hoyo, Martín, and Martínez 2008).

Thus, the main aim of this research is to obtain a predictive model for the occurrence of an illegal landfill based on spatial and non-spatial variables using the binary logistic regression technique. This regression model will enable us to:

1. Identify the relationship between spatial and behavioural variables (independent variables) and the presence of uncontrolled landfills (dichotomous dependent variable).
2. Measure the magnitude of these relationships by estimating the regression coefficients $\beta$.
3. Establish, using the logistic regression equation, the probability that an uncontrolled landfill will appear according to the spatial and behavioural variables included in the final model.
2. Variables, data and method

2.1. Theoretical model of the research

This study starts from a theoretical model that includes the variables related to the occurrence of illegal landfills. Binary logistic regression establishes the degree of relationship between a group of independent variables and the existence or not of an illegal landfill (dependent variable). These independent variables are as follows: (1) geographical characteristics of the site; (2) type of waste, management and surrounding area; (3) proximity and distance to different geographical elements of the surroundings of the landfill; (4) socio-economic features of the municipality the landfill is located in; (5) municipal waste management systems; and (6) environmental sensitisation and awareness of the population and institutions. These interrelationships define the proposed theoretical model of analysis, as seen in Figure 1.

2.2. Selection of variables

2.2.1. Geographical characteristics of location and site

The bibliographical review of the geographical characteristics of the location and site of illegal landfills shows that the occurrence of these landfills is basically associated with the following two types of variables:

(1) **Topography.** Tasaki et al. (2004, 2007) have found that in Japan the likelihood of the existence of illegal dumping in a specific place is related to the topography of the terrain. Large illegal dumps were more likely to occur in areas with a slope of
3°–10° due to the propensity to use areas with higher inclination for dumping. In areas with an inclination greater than 10°, it is physically more difficult to dispose of waste due to the relative inaccessibility. Likewise, Matos, Oštir, and Kranjc (2012) have indicated that illegal landfills are 10 times more likely to occur in hilly areas (undulating topography) than on plains.

(2) Land use. Biotto et al. (2009), in a study of probable areas for illegal dumping in the Veneto region (Italy), consider land use (industrial, urban, recreational, natural and agricultural areas) to be a factor in location. These authors explain that illegal landfills occur in industrial areas due to the fact that it is easier to dispose of the waste materials from industrial activities there, especially when workers lack environmental awareness. On the contrary, illegal landfills are less likely to occur in residential and urban areas because, according to these authors, they are controlled by the authorities and by citizens.

The results for the Veneto region coincide with the research conducted by Doak et al. (2007) and Apostol and Mihai (2011) in that illegal landfills are also present in agricultural areas. In particular, Apostol and Mihai (2011), in the case of Romania, found that uncontrolled waste disposal still occurs in rural areas due to the lack of waste management infrastructure.

With regard to the bibliographical review, the following hypothesis is proposed:

**H1:** The occurrence of illegal landfills is conditioned by the topographical characteristics and land use of the site.

2.2.2. Type of waste, accessibility and control

The presence and the size of illegal dumps depend on geographical attributes (visibility of the area, its accessibility) and the type of waste. According to various studies, most illegal dumping takes place in easily accessible areas (at less than 100 metres from tracks), although scarcely visible to the majority of the population (Tasaki et al. 2007, 2004). Hence, as other research shows, the implementation of surveillance and control systems (police, neighbour patrols) contributes to reducing illegal dumping (Matsumoto and Takeuchi 2011; Matus et al. 2003).

With regard to the type of waste that is deposited in illegal landfills, the limited bibliography available coincides in the fact that it is mainly construction and demolition waste (C&DW). In some regions, the illegal dumping of C&DW has taken place extensively in the past two decades, especially in developing countries and regions where the construction sector has been one of the main economic activities (Yuan and Shen 2011; Acosta and Cilento 2005). In Spain, 60% of C&DW ends up in illegal landfills without any kind of previous treatment or control (Solís-Guzmán et al. 2009). The places where the waste is disposed of illegally are usually freely accessible to people; and the illegal dumping of this type of waste gives rise to a vicious circle where the larger the dump, the more waste is left there illegally, so that this may eventually reach significant proportions and become an illegal landfill (Yuan 2013).

Currently, when construction activity has decreased in some countries due to the economic crisis, many sites with an urbanisation project are ideal places to become uncontrolled C&DW landfills (Solís-Guzmán et al. 2009). Another factor to note is the lack of an effective local authority policy of waste inspection and control (supervision)
capable of preventing uncontrolled dumping (Jordá-Borrell, Ruiz-Rodríguez, and Lucendo-Monedero 2013; Villoria et al. 2011).

On the basis of these arguments, the following hypothesis can be formulated:

**H2:** The occurrence of illegal landfills is conditioned by the accumulation of CD&W in easily accessible and unsupervised areas.

### 2.2.3. Proximity and distance to geographical elements of the surrounding area

Apostol and Mihai (2011), Sener, Sener, and Karagüzel (2011), Mahini and Gholamalifard (2006) and Guiqin et al. (2009) recommend studying the physical “proximity” of uncontrolled landfills to different geographical elements of their spatial environment (urban areas, residential and industrial areas, physical infrastructures and communication routes, watercourses, protected areas). This is because these authors consider that, above all at the local scale, how near or far these entities are can become an explanatory aspect of why illegal landfills appear in a specific place and of their spatial distribution at the regional scale. Ichinose and Yamamoto (2011) mention the fact that uncontrolled landfills always originate far from populated areas, in remote areas, thus becoming suitable places for those that intend to dispose of waste illegally.

The models developed to study the spatial distribution of illegal landfills (Romeo, Brown, and Stuver 2003) show a close relationship between the location of the landfill, its proximity to communication routes and inhabited areas and their limits. In particular, such landfills tend to be located in areas far from the urban centre but near marginal zones and the edge of the urban area (where there is not much control by the municipal authorities), coinciding with sparsely populated areas, and barely visible to the population in line with the Nimby syndrome (Bosque et al. 2000). At the same time, the occurrence of illegal landfills in these sites is favoured by their easy accessibility, especially when they are near tracks and secondary roads that facilitate the anonymous and furtive disposal of waste (Romeo, Brown, and Stuver 2003).

On the basis of this bibliography, the following hypothesis is proposed:

**H3:** Uncontrolled landfills are more likely to appear near urban areas and close to secondary communication routes.

### 2.2.4. Socio-economic aspects of the municipality

The influence of socio-economic factors on the areas where illegal landfills occur is based on theoretical arguments and abundant empirical evidence. Reviews of current literature have shown the presence of relationships between socio-economic variables and the occurrence of illegal landfills. Per capita income, population size and the number of companies and industries are the most significant (Silvestri and Omri 2008) due to the magnitude of their impact on the generation of illegal landfills and because they are considered to be key variables for identifying the occurrence of illegal landfills. Different empirical studies have put forward the hypothesis that the larger the population, the higher the per capita income level and the greater the number of companies, the greater the probability of illegal landfills occurring (Gorsevski et al. 2012; Al-Khatib et al. 2007; Matsumoto and Takeuchi 2011; Tasaki et al. 2007). In peripheral countries and regions, highly urbanised municipalities, with a high income, densely populated and economically dynamic, are those that have the greatest number of illegal landfills. In this respect, it can be said that the evidence shows that local economic conditions, culture and illegal
landfills are significantly related (Henry, Yongsheng, and Jun 2006; Tasaki et al. 2004). The formulation of the previous hypothesis is underpinned by the idea that per capita income is linked to economic growth, to the increased productivity and competitiveness of economic activities. In Europe, the high industrial growth of the twentieth century produced a significant increase in uncontrolled landfills. For example, in Germany in 2005 there were more than 91,000 sites suspected of being illegal landfills (Allgaier and Stegmann 2006). The accelerated process of urbanisation in recent decades, the globalisation process (GRM 2008), industrial growth and the modification of the consumption patterns of modern societies have led to shifts in the concentration of population and economic activities (intensive agriculture, industry and services) in the territory becoming key variables in identifying places where illegal landfills occur (Biotto et al. 2009). The spatial distribution of these landfills, therefore, is not random. In view of the above, the following hypothesis can be formulated:

**H4:** The occurrence of illegal landfills is associated with municipalities with larger populations and higher per capita income and a greater number of companies in the industrial and construction sectors.

### 2.2.5. Management system for municipal waste

Researchers coincide in that there is a correlation between the occurrence of illegal landfills and the waste management system at the municipal level. Thus, Ichinose and Yamamoto (2011) arrived at the conclusion that the existence of adequate municipal waste treatment facilities reduces the likelihood of illegal dumping in the municipality. In particular, they showed that the number of cases of illegal dumping falls as the number of intermediate waste management facilities increases. Guerrero, Maas, and Hogland (2013) and Alavi-Moghadam, Mokhtarani, and Mokhtarani (2009) have indicated that the existence of inadequate systems of collection, transport and transfer of municipal waste (bad route planning, insufficient infrastructure) or a lack of information about collection times (Hazra and Goel 2009) tend to increase the dumping of rubbish and other types of waste. Likewise, Tadesse, Ruijs, and Hagos (2008) have demonstrated that the provision of waste management facilities significantly reduces the disposal of rubbish by illegal dumping. Moreover, this author also points out that an insufficient number of waste containers and a greater distance between them increases the likelihood of dumping occurring in areas without any specific use and alongside secondary roads (Romeo, Brown, and Stuver 2003; Matos, Ošir, and Kranjc 2012; Finn 2007).

These conclusions suggest that an adequate provision of waste management services by town and city councils can prevent illegal dumping more effectively than the implementation of punitive measures. However, there are researchers who consider the application of punitive policies to be very effective, especially in countries where the population lacks significant environmental sensitivity. In this respect, it can be said that the municipal councils in Spain that continue to opt mainly for the implementation of punitive measures are permissive when it comes to applying the law (González-Torre and Adenso-Díaz 2005), and many of them are even reluctant to launch awareness-raising campaigns (Casals 2006). On the contrary, in countries such as Germany and Japan (Fujikura 2011; Zou 2011), local governments have managed to eliminate or reduce the number of illegal landfills by implementing punitive and fiscal policies (high payments for the rubbish generated) along with educational campaigns promoting environmental
awareness. It therefore follows that the attitude of municipal institutions also influences the presence or absence of illegal landfills.

Taking these considerations into account, the following hypothesis is presented:

**H5**: The implementation of waste management systems (facilities) and municipal policies reduces the occurrence of illegal landfills.

### 2.2.6. Environmental sensitisation and awareness of households

Waste management is generally considered to be solely the duty and responsibility of local authorities, while not much importance is given to the fact that the population shirks its responsibility in this matter (Vidanaarachchi, Yuen, and Pilapitiya 2006). Nevertheless, the effectiveness of municipal waste management depends on the active participation of the municipal authorities and citizens; hence, some researchers include the socio-economic and cultural characteristics and environmental awareness of the population (Sharholy *et al.* 2008; Alavi-Moghadam, Mokhtarani, and Mokhtarani 2009) in studies on the occurrence of illegal landfills.

Some authors have demonstrated that in municipalities with containers and/or recycling centres, people frequently use them to dispose of their waste and are more inclined to separate part of the waste at home. In this respect, González-Torre and Adenso-Díaz (2005) show that the main reasons for developing good recycling habits are the regulatory and/or punitive factors of the authorities and the social and economic characteristics of the population. According to the work of Sujauddin, Huda, and Hoque (2008), waste generation is directly proportional to family size, level of education and monthly income. Meanwhile, Ekere, Mugisha, and Drake (2009) affirm that the attitude of households to the separation of domestic waste depends on gender, household location and membership of environmental organisations. Thus, it can be seen how the presence of households with low environmental awareness in certain municipalities is interrelated with those places where illegal landfills are created.

Guerrero, Maas, and Hogland (2013) conducted a survey which included variables on: (1) waste separation in households and businesses at the municipal level (plastic, paper, metal, glass, organic materials, building materials, electrical and electronic equipment, etc.); (2) characteristics of collection systems (structured and organised collection of solid waste, available recycling centres, etc.) and (3) environmental awareness and recycling campaigns. The results showed two factors related to waste separation by the population: awareness (the effectiveness of waste separation at the municipal level depends on citizens being convinced of the need to recycle); and knowledge (citizens are inclined to separate when they know that there is a waste recycling infrastructure in their municipality).

Different studies have been carried out in recent decades to analyse the level of awareness of the population regarding the need to recycle in order to prevent dumping. For example, Owens, Dickerson, and Macintosh (2002) show that in the United States only 45% of citizens are aware of this need and that these have a profile of medium–high annual income per household, family homeowners and well educated. For its part, the PCAESG (1999) indicated that, in the UK, the distance to recycling centres and ease of access are the main reasons for recycling. González-Torre and Adenso-Díaz (2005) concluded that in Asturias (Spain) the segment of the population that recycles and separates rubbish at home is inclined to go more frequently to containers and recycling centres to leave more complex materials (C&DW, batteries, electrical household
appliances) instead of leaving them in areas of uncontrolled dumping, provided that these containers are near the home (accessible on foot).

It can therefore be detected that a lack of environmental sensitivity in households favours the occurrence of these sites in certain places and the following hypothesis is proposed:

**H6**: The population’s lack of environmental awareness has a significant influence on the occurrence of illegal landfills.

### 2.3. Data and method

The unit of analysis for this research is the illegal landfill. This is a waste dump that covers an area larger than 2000 m², without supervision by the competent authorities (Regional Government of Andalusia 2012). The uncontrolled landfills used for this study were chosen from sites previously detected by remote sensing and aerial photography (1751 possible landfills, provided by the company Ambisat) in the eight Andalusian provinces (NUTS 3). After filtering these through the application of various deskwork techniques, a population of 518 possible illegal landfills was arrived at (Figure 2). A total of 120 cases of potential uncontrolled landfills, distributed throughout the entire region of Andalusia, were selected from this population through stratified sampling (size, type of dumping, spatial distribution by province or NUTS 3).

The occurrence of illegal landfills was obtained through fieldwork. Carrying out the fieldwork enabled the landfills from the sample to be validated and the dependent variable to be defined in the following way: “Existence of Landfill” (1) and “Non-existence of Landfill” (0). Thus, this study analyses “known” or “observed” illegal landfills”, rather than “all existing illegal landfills”.

![Figure 2. Spatial localisation of Illegal landfills. (See online colour version for full interpretation.) Source: Own preparation on the basis of data provided by Ambisat.](image-url)
The selection of the independent variables (see the Online Supplementary Appendix for definition of these variables) that influence the occurrence of illegal landfills is based on the literature consulted. These variables have served to develop the proposed theoretical model (Figure 1) and to formulate the hypotheses. The data for these variables have been obtained: (1) through fieldwork6 (2012) on the characteristics of the landfills and their location; (2) through the elaboration of variables of distance and proximity of each of the landfills of the sample to different geographical entities (road infrastructures, watercourses and/or aquifers, industrial plants, population centres, urban areas and green spaces) using GIS; (3) from official statistics on: (i) the separation and recycling of household waste, information which is prepared at the municipal level; and (ii) the municipal socio-economic characteristics and the waste management systems of the municipalities. Taking into account that the unit of analysis for this research is the uncontrolled landfill, the previous data at the municipal level are attached to the illegal landfills as properties of the landfills.

With all this information, a file was prepared for each of the 120 cases in the sample, on the basis of which a database was constructed comprising 103 variables of a diverse nature (spatial and non-spatial) associated with the occurrence of illegal landfills. This wide variety of data justifies the use of the logistic regression method when the aim is to study the association of a binary dependent variable with a large number of independent variables (Worku and Muchie2012). The analyses to obtain the binary logistic regression method were conducted using the IBM SPSS Statistics 20 program. The sequential procedure “forward stepwise (LR options)” was applied, which enabled those variables that had a statistical significance greater than 0.05 to be selected from each group of variables (to ensure compliance with the rule of one variable for each ten individuals in the sample analysed). Sánchez Figueroa et al. (2012) affirm that the likelihood ratio test in SPSS reduces the problem of bias of the sample selection.7

In order to check the proposed hypotheses, six partial logistic regression analyses have been conducted, and one final analysis in order to define the joint model that identifies the definitive predictor variables (Table 1). Each partial analysis included a different group of independent variables: “geographical characteristics of the site”, “type of waste, accessibility and control”, “proximity of the landfill and distance to different geographical elements of the surrounding area”, “socio-economic characteristics of the municipality”, “municipal waste management system” and “environmental sensitisation and awareness”.

3. Results

The results of the first partial analysis indicate the existence of a positive relationship between uncontrolled landfills and areas of alluvial plain, industrial land and rural land. This confirms hypothesis H1, which states that the occurrence of illegal landfills is associated with plains, rural land (not for agricultural use) and industrial areas.

The second analysis shows that the occurrence of uncontrolled landfills is associated with the presence of CD&W. This partial model also shows a negative relationship between C&D landfills and two variables: (1) “Access via the Urban Area”, which means that these uncontrolled landfills are reached by alternative routes (tracks or secondary roads); and (b) “Supervision”, indicating that these landfills occur in unsupervised areas. Consequently, these results enable hypothesis H2 to be confirmed, as it states the
| Variable | Hypothesis/model 1: geographical characteristics of location and site | Hypothesis/model 2: type of waste, accessibility and control | Hypothesis/model 3: geographical proximity and distance to geographical elements of the surrounding area | Hypothesis/model 4: socio-economic aspects of the municipality | Hypothesis/model 5: management System for Municipal Waste | Hypothesis/model 6: environmental sensitisation and awareness of households | Final model |
|----------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|----------------|
|          | Coefficient (β) | Wald    | Coefficient (β) | Wald    | Coefficient (β) | Wald    | Coefficient (β) | Wald    | Coefficient (β) | Wald    | Coefficient (β) | Wald    | Coefficient (β) | Wald    |
| Constant | -25.46           | 0.00    | 2.57             | 19.22   | -1.24            | 6.66    | -1.24            | 6.66    | -31.58            | 0.00    |
| Plain (1) (LLANO) | 2.68** | 20.02    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Hills (1) | -2.09* | 5.65    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Industrial land (1) (INDUST) | 2.56** | 6.11    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Rural land (1) (RUS) | 3.58** | 16.21   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| C&DW (1) (RCD) | 3.03** | 23.51   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Access via the urban area (1) | -1.66** | 7.50    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Supervision (1) (VIG) | -0.76* | 16.56   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Distance to highway | -2.05** | 6.26    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Distance to track (CAMINO) | 5.01** | 4.56    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Distance to urban areas | 8.21** | 5.54    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Establishments/companies | 0.04* | 4.36    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Municipal size (TAMAÑO) | 0.54** | 9.266   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Investment in urban infrastructure works (Budget) | -0.74* | 6.12    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Recycling facilities (1) (GESTIÓN) | -4.17* | 22.36   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Associations of municipalities/consortia (1) | -24.52** | 6.00    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Punitive policies (1) (PP) | -2.47** | 10.53   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| There is no glass collection service | -2.47* | 10.53   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| There is no paper collection service | 1.16* | 0.02    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Awareness-raising campaigns (7)(CC) | 0.54** | 9.266   |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| Disposal of C&DW (7) (ERCD) | 3.09** | 0.04    |                      |    |                      |    |    |                      |    |    |                      |    |    |                      |
| $R^2$ Cox and Snell | 0.619 | 0.721 | 0.573 | 0.614 | 0.763 | 0.614 | 0.720 |
| $R^2$ Nagelkerke | 0.659 | 0.862 | 0.731 | 0.783 | 0.886 | 0.863 | 0.961 |
| $\chi^2$ | 47.77** | 48.13** | 36.77** | 30.69** | 56.88** | 60.69** | 76.95** |
| Overall % of predictions | 80.7 | 81.8 | 70.3 | 92.5 | 88.4 | 92.5 | 96.6 |

Source: Own preparation.
* Shows significance at 5% level.
** Shows significance at 1% level.
(1) Value 1 signifies "Yes".
(7) Value 7 signifies "No".
correlation between the type of waste (CD&W) and easily accessible and unsupervised areas.

In the third partial model, the relationship between illegal landfills and their proximity to certain geographical elements was analysed. The results of the model indicate “Remoteness” from highways (distance with a negative sign) and proximity to “Tracks” and “Urban Areas”. Thus, we can affirm that hypothesis H3 is fulfilled in relation to the proximity of uncontrolled landfills to tracks, which also reinforces hypothesis H2 in relation to the type of access.

The fourth partial analysis studies the socio-economic characteristics of the municipalities in which the uncontrolled landfills are located. The results of the model show that the variables “Construction Sector Establishments (number)” and “Municipal Size” (measured by population and income) oppose the variable “Personnel Costs (Budget)”. This seems to indicate that the presence of illegal landfills is more likely to occur in large municipalities (population over 20 thousand inhabitants and per capita income over 17 thousand euros) where there is substantial construction activity, but which allocate very little of the municipal budget to inspecting illegal dumping. Consequently, it can be affirmed that hypothesis H4 is valid, as the presence of illegal landfills is associated with municipalities with larger populations, higher income and greater economic activity.

The fifth partial model analysed the variables related to the municipal waste management system. The results show that the variables of “Existence of Recycling Facilities”, “Punitive Policies”, and “Associations of Municipalities/Consortia” are inversely correlated with the occurrence of illegal landfills. This confirms hypothesis H5 as it proposes that the implementation of municipal waste management systems (recycling facilities) by associations of municipalities/consortia, accompanied by punitive policies, reduces the occurrence of illegal landfills.

The sixth partial analysis focuses on the aspect of the environmental sensitisation and awareness of the population. The results show the correlation between the presence of an uncontrolled landfill and the following variables: “There have not been Environmental Awareness-raising Campaigns”, “There is no Glass Collection Service”, “There is no Paper Collection Service” and “C&DW is not disposed of”. Consequently, hypothesis H6 is validated as it proposes that the lack of waste collection and recycling infrastructure is associated with low environmental awareness, insufficient recycling practices and the occurrence of illegal landfills in the municipalities.

Finally, the 20 significant variables of the partial models were included in a joint analysis (Table 1). The final model obtained contains 11 variables that explain the occurrence of illegal landfills, so that the rule of not exceeding in any case the relation of one variable in the model to each ten individuals in the sample analysed is complied with. According to the joint regression analysis, uncontrolled landfills are associated with the dumping of C&DW in areas of flat rural or industrial land with little supervision and close to tracks. These landfills are located in municipalities with a lack of C&DW collection and recycling infrastructure, where the local authorities do not implement either punitive policies or environmental awareness-raising campaigns. Likewise, these illegal landfills are more likely to occur in municipalities that have greater income and population, with a high level of activity in the construction sector and whose inhabitants do not use the C&DW collection service.

The coefficients β enable the importance of the independent variables used as predictors of the dependent variables to be assessed. This value is measured by the odds ratio or increase in probability (in%). According to the data obtained in the final model
(last column of Table 1), the variables that most influence the occurrence of landfills in a specific place are “Industrial Land” (94.43%), non-existence of “Awareness-raising Campaigns” (91.14%) and “Plains” (66.81%). Meanwhile, the variables that most reduce the likelihood of illegal landfills occurring are “Availability of Recycling Facilities” (−95.23%), “Punitive policies” (−39.81%) and “Supervision” (−31.60%).

With the estimated regression coefficients (β) of Table 1, the probability model for the occurrence of an illegal landfill in Andalusia would be expressed as follows:

\[
\text{Logit}(P) = -31.587 + (4.86' \text{RCD}) + (2.58' \text{LLANO}) + (3.93' \text{INDUST}) \\
+ (2.97' \text{RUS}) - (2.47' \text{VIG}) + (2.10' \text{CAMINO}) \\
+ (0.54' \text{TAMANO}) - (4.20' \text{GESTION}) - (1.59' \text{PP}) \\
+ (3.80' \text{CC}) + (1.17' \text{ERCD}).
\]

The appropriateness of the final model (and of the partial models) has been checked on the basis of goodness-of-fit indicators (\(R^2\) values of Cox and Snell, \(R^2\) of Nagelkerke and \(X^2\), Table 1). All the values obtained enable these models to be validated. In particular, if the joint model is analysed, according to the \(R^2\) of Cox and Snell we have a 0.720 of explained variance, that is, that 72% of the occurrence of illegal landfills is explained by the (independent) spatial and behaviour predictor variables. For its part, the \(R^2\) value of Nagelkerke for the final model obtained is 0.961, which means that using the 11 variables included in the model it may be assumed that the likelihood of an illegal landfill occurring is 96.1%. Both values are above the recommended 50%. Therefore, it is possible to conclude that the overall predictive power of the final model is good, and that the set of independent variables selected adequately distinguishes between those cases that are uncontrolled landfills and those that are not.

Lastly, since it is a predictive model, the appropriateness of the final model has also been assessed by using a classification table, correctly identifying 92.9% of the areas that were not illegal landfills and 93.5% of those that were. Thus, the overall result reached was that 93.1% of the cases analysed were well classified in the final step of the prediction.

4. Discussion and conclusions

The application of logistic regression to the study of the variables associated with the occurrence of illegal landfills has given optimal results as the model correctly classifies 93.1% of the landfills analysed, clearly indicating that this technique is appropriate for analysing phenomena that require variables of a different nature. This research contributes to augmenting the existing literature in the theoretical and methodological fields in relation to the variables that condition the occurrence of illegal landfills. This contribution is based on the construction of a predictive model using binary logistic regression analysis. In particular, one of the contributions of this study is the inclusion of spatial and non-spatial aspects that influence the occurrence of illegal landfills in the model within the same analysis.

The predictive model obtained confirms, as demonstrated in other studies (Apostol and Mihai 2011; Doak et al. 2007; Biotto et al. 2009; Silvestri and Omri 2008; Romeo, Brown, and Stuver 2003; Sener, Sener, and Karagüzel 2011; Bosque et al. 2000; Yuan 2013), that the occurrence of illegal landfills in a specific place is associated with
geographical aspects (location and site, accessibility, proximity, distance) and socio-economic characteristics of the municipality. On the contrary, it disagrees with other authors (Tasaki et al. 2007, 2004) in that some variables included in the proposed model (such as topography and per capita income) influence the occurrence of illegal landfills in the region analysed in this research in the opposite way. This is due, in part, to the topographical differences between the areas studied (Japan and Andalusia). Moreover, it is also due to the fact that the results of this study indicate that higher levels of municipal income are associated with the occurrence of a high number of illegal landfills (Gorsevski et al. 2012; Al-Khatib et al. 2007).

This point may be explained by the scale at which the analysis of illegal landfills is carried out. When these are studied from a local perspective (at the municipal level), it can be seen that the landfills are located in sparsely populated places with low per capita income, situated at the edge of the urban area. At this scale, the spatial characteristics that influence the occurrence of illegal landfills can be appreciated. It thus follows that the analysis of illegal landfills presents a further difficulty apart from the need to include spatial and non-spatial variables, as it is a multi-scale phenomenon. This peculiarity is typical of many geographical events, such as forest fires (Vilar del Hoyo, Martín, and Martínez 2008) or dumping itself (Keser, Duzgun, and Aksoy 2012). Hence, in order to understand geographical events it is necessary to use analyses at different scales, as no level of study is sufficient on its own (Farinos 2001).

However, when illegal landfills are studied at the regional level, the municipalities with the greatest number of landfills have a medium—high per capita income and are densely populated. This is due to the fact that at this scale of analysis the socio-demographic and behavioural variables are emphasised. In this regard, another contribution of this research is that the predictive model confirms the significant role at the regional level of certain non-spatial aspects in the occurrence of uncontrolled landfills. This is the case of the variables related to the characteristics of the municipal waste management system and the behaviour of the population in terms of separating and recycling waste. The proposed model is therefore in line with that indicated by other authors, as it affirms that the occurrence of illegal landfills is associated with the lack of culture of separating waste on the part of both citizens and institutions, insufficient waste collection infrastructure and the absence of punitive policies in this field (Guerrero, Maas, and Hogland 2013; Sharholy et al. 2008; Alavi-Moghadam, Mokhtaran, and Mokhtaran 2009; Tadesse, Ruijs, and Hagos 2008; Ichinose and Yamamoto 2011; Hazra and Goel 2009; Romeo, Brown, and Stuver 2003; Vidanaarachchi, Yuen, and Pilapitiya 2006; Sujauddin, Huda, and Hoque 2008; Ekere, Mugisha, and Drake 2009; Owens, Dickerson, and Macintosh 2002; González-Torre and Adenso-Díaz 2005).

Therefore, the results obtained in this study indicate that geographical factors are not the only determinants of the occurrence of illegal landfills in certain areas. According to the coefficients $\beta$ and the odds ratios, the variables that most influence the occurrence of illegal landfills in a specific place are spatial (“Industrial Land”, “Plains” and “Rural Land”). However, the variables that most reduce the likelihood of illegal landfills are those related to certain characteristics of the municipal waste management systems and environmental awareness (behavioural or non-spatial) such as “Availability of Recycling Facilities”, “Punitive Policies”, “Supervision” and “Awareness-raising Campaigns”.

All of this leads us to conclude that in future studies on the occurrence of illegal landfills it would be advisable to consider different types of variables (geographical, of economic behaviour and on management by public authorities) and to perform analysis using a multi-scale approach in order to gain an overall understanding of the
phenomenon. Thus, variables of very different nature and magnitude interact in the occurrence of illegal landfills, each one of which contributes a series of features characteristic of its scale (level of analysis). Finally, the model obtained for calculating the probability of the occurrence of uncontrolled landfills can also be applied to other regions, provided that the necessary spatial and non-spatial data are available, although the results will differ according to demographic, socio-economic and topographical characteristics, features of municipal management and the level of environmental awareness.

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Supplemental data
Supplemental data for this article can be accessed here.

Notes
1. Observations which take into account absolute location and/or relative positioning (spatial arrangement) (Anselin 1992).
2. Waste may be classified as urban (domestic waste mainly generated by private homes, businesses and services) and non-assimilable (from non-domestic activities that give rise to the creation of illegal landfills without any treatment and amongst which electrical and electronic equipment, end-of-life tyres and, especially, construction and demolition waste or C&DW are differentiated). (ROYAL DECREE 105/2008, of 1 February, regulating the production and management of construction and demolition waste, BOE [Official State Gazette], no. 38; Law 10/1998, of 21 April, BOE no. 96; Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Official Journal of the European Union L312/3) and Law 22/2011, of 28 July, on waste and contaminated land, BOE no. 181).
3. This research study is the result of an R&D contract between the signatories of this paper and the company AMBISAT (Madrid-Spain) and named the VERTEL project: Remote sensing as a tool for identifying landfills. The study was financed by the Andalusian Technology Corporation (CTA) in 2011 and 2012. The areas that potentially house uncontrolled landfills in Andalusia were identified by multi-temporal analyses of satellite images (Landsat and SPOT) and aerial photographs. To do this a methodology based on the spectral analysis of the images through classification has been used, identifying land uses and land degradation spectral indices associated with the surface components of the landfill and distinguishing possible degraded land. These indices were calculated on the basis of vegetative vigour, vegetation humidity and soil response. The characterisation of landfill sites involves the analysis of measurements of the composition of a large number of different surface materials. This has enabled the identification of a series of areas that are likely to be illegal landfills (1751) due to being areas of accumulation of waste material. Subsequently, through analysis with a Geographic Information System (GIS), the degradation rates have been cross-referenced with maps, historical registers and aerial photographs of variables, such as the distance from the road network, urban centres, population density, rurality index, etc. This has enabled us to: a) discard those initial sites that do not meet established standard requirements for illegal landfills; and b) select which places (518) are more likely to be illegal landfills from among the areas previously identified via remote sensing. Finally, a representative sample (120) of these sites has been validated by field visits. These visits not only helped to identify the real landfills among the proposed sites, but also to study their characteristics by gathering information in the field for their posterior analysis.
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. We must take into account that Andalusia, within its 87,598 Km² surface area (17.4% of Spain and 3.7% of the European Union), has a population of 8437,681 inhabitants (INE [Spanish National Statistics Institute], 2012) comprising 17.87% of the Spanish population. The Autonomous Community is divided into 8 provinces and 770 municipalities of which some 150 have a population over 10,000 inhabitants and contain 80% of the population.

6. The fieldwork consisted of: (A) 16 interviews with experts and technicians of the Regional Government, environmental engineers who study landfills, council technicians, university professors specialising in this area, etc., and (B) gathering information in the field on 120 illegal landfills distributed throughout the entire region.

7. The problem of bias in the sample selection appears in studies on environmental incidents, as mentioned by Sigman (1998) and Ichinose and Yamamoto (2011).

8. The proximity variables are continuous and measured in metres, so the lower the value of these variables, the greater the “proximity” of the illegal landfills to these geographical elements.

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