RECORDING, EVALUATION AND CLASSIFICATION OF WASTE DUMP SITES IN CYPRUS USING MULTIPLE CRITERIA DECISION ANALYSIS

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SUMMARY: The Landfill Directive was passed by Europe in 1999 and requires among other things that all member states of European Community have to comply with its obligations under Articles 4, 8 and 9 of Directive 75/442/EEC on waste as amended (now Directive 2006/12/EC - Waste Framework Directive). Cyprus as a new member state must comply with this ruling, in accordance with Article 228 of the EC Treaty. In this regard, the Cypriot authorities prepared "The strategic plan for solid waste management in Cyprus" in June 2002 (approved by the Cypriot Parliament in 2003), which aims at the closure and rehabilitation of all illegal or uncontrolled waste dumping sites by the end of 2009 and their replacement by appropriate waste management infrastructure. In the Republic of Cyprus, 113 uncontrolled waste dump sites have been identified, recorded and assessed for their potential risk to the environment with the use of GIS and multiple criteria decision analysis (MCDA).

1. INTRODUCTION

Waste disposal in the member states of European Community has changed dramatically over the last decades, both with respect to its legislation and its public perception. For a long time it was considered as 'out of sight, out of mind' and somebody else's problem. The majority of the public knew that if they put their waste bin at the end of the drive it would be taken away weekly, but paid little attention to where it was going to be disposed. Only those directly affected by a landfill's location or vehicles entering or leaving waste disposal facilities knew or cared of their existence. In recent years waste disposal has had a higher public profile as the perception of pollution and the environment has grown.

Waste disposal facilities, commonly called landfill sites, were originally located on the outskirts of centres of population, due to the lack of large scale transport to carry the waste away. They were normally found in hollows or depressions in land where people could easily tip their waste and where it would not be seen. As the centres of population have grown, the old landfill sites have been incorporated into the expansion plans of the towns. These sites are normally left as areas of wasteland or developed as car or leisure parks. These areas of wasteland rise in value as the land around them becomes developed. There normally comes a point in time when it becomes economical to develop these sites, and so the nature of the landfill site and surrounding environment may have to be investigated. Modern landfill sites are now located away from centres of population as large scale transport is available to carry the waste away, and so the surrounding environment is less of an immediate consideration.

The identification of uncontrolled landfills is a central environmental problem in all developed and developing countries, where several illegal waste deposits exist as a result of rapid industrial growth over the past century. A geographic information system (GIS) database can potentially provide crucial information for the identification and recording of contaminated sites, while a multiple criteria decision analysis can provide a systematic and transparent approach for the prioritization of closure and restoration of sites.

2. MATERIALS AND METHODS

2.1 Identification and recording of sites

A decision problem is the difference between the desired and existing state of the real world. It is a gap which is recognized by a decision maker. Any decision making process begins with the recognition and the definition of the problem. This stage involves searching the decided environment for conditions; obtaining, processing and examining the raw data to identify the problems. The GIS capabilities for storage, management, manipulation and analysis are used in this stage which provides major support.

The approach followed for the detection of uncontrolled disposal areas, focused on sites that served communities of at least 2.000 habitants. In the first phase of the sites identification, the actions undertaken by the study team were literature research, liaising with the Ministry of Interior and the Ministry of Agriculture, Natural Resources and Environment, as well as with the local authorities (communities and boroughs). In the second phase during the localized examinations of the areas, the following fields were examined.

- Geographical determination of the site using using global positioning system (GPS)
- Recording the access road to the site (length, direction), as well as the internal paths
- Photographic evidence of the site with emphasis on the pollution aspects
- Completion of a detailed report for each site
- Visiting local authorities

Once the identification process of the sites was completed, all the gathered data was imported into a customized database (Microsoft Data Base), recordering in detail all the characteristics of interest of the uncontrolled disposal sites, such as geological / hydrological / meteorological data, area and volume of area, etc.

2.2 Risk assessment of sites

After the realisation of the problem, the set of evaluation criteria which includes attributes and objectives is designated. This stage involves specifying a comprehensive set of objectives that reflects all the concerns relevant to the decision problem and measures for achieving those objectives which are defined as attributes. Because the evaluation criteria are related to geographical entities and the relationships between them, they can be represented in the form of maps which are referred to as attribute maps. GIS data handling and analyzing capabilities are used to generate inputs to spatial decision making analysis.

A contaminated site is a potential hazard to the environment and its receptors. The negative impacts from the pollution can be illustrated by the use of the pollution mechanism, which is illustrated in Figure 1.

Source $\xrightarrow{\text{Path}}$ Receiver

Figure 1. Pollution mechanism

The risk assessment process is based on the above described pollution mechanism, which is further customized for the needs of the particular study in the following stages:

- <u>Source of pollution (M1)</u> – during this stage, the evaluation parameters examined are:
    - waste volume in m^3 is estimated in relation to the four basic types of waste that are disposed of in the sites:
        - municipal waste > 30 years,
        - municipal < 30 years,
        - construction and demolition waste, and
        - hazardous waste
    - distance of industrial zones from the contaminated sites, only however where hazardous waste is a consideration

For site classification based on the pollution source, it is firstly determined which type of waste has been disposed and then the overall quantity is estimated. As there is no reliable data for construction and demolition waste and hazardous waste, assumptions were made.

- <u>Path of pollution (M2)</u> – during this stage, the evaluation parameters examined are:
    - annual precipitation in mm (M2A), and
    - ground permeability (Kf) in relation to the distance of the aquifer from the landfill basin (M2B)
- <u>Receiver of pollution (Max)</u> – during this stage, the evaluation parameter that is examined is the distance from the pollution source in relation to the type of pollution receiver. The distance plays a crucial role in the evalution of the arisen potential hazard. The receivers are divided in three sub-categories:
    - MaxA includes protected areas such as water abstraction (present and future), and protected areas (Natura 2000, SPAs., SCIs, etc.
    - MaxB includes land uses such as playgrounds, agricultural/coastal zones, residential zones, industrial zones, road axes and quarries.
    - MaxC includes surface waters such as water basins, surface waters and water related protected ares.

In cases where there is no sufficient data about the hydro geological characteristics of a site, maximum score values are given. It is important to note that the waste burial method or the years of operation of the site are not taken into consideration.

2.3 Evaluation and categorization of sites

After the determination of the evaluation criteria, the set of criterion weights which indicate the importance in relation to other criteria under consideration are designated. Assigning weights of importance to evaluation criteria accounts for (i) the changes in the range of variation for each evaluation criterion, and (ii) the different degrees of importance being attached to these ranges of variation.

There are different techniques when assigning weights of importance. A ranking method was selected for evaluating the importance of weights where every criterion under consideration is ranked in the order of decision maker’s preferences.

Once the criterion weights are designated, the next step is to integrate the criterion map layers and the weightings in order to provide an overall assessment. This is accomplished by an appropriate decision rule or aggregation function. Weighted linear combination or scoring method was selected as the most appopriate decision rule for the current study. The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision maker followed by summing of the products for all criteria. The weighted linear combination method evaluates each alternative E, by the following formula:

$$E= \ w_i x_i \qquad (1)$$

Where E= hazard, wi= weight of factor i, and xi= criterion of factor i.
In many decision rules it is assumed that complete information is available so that the criterion outcomes of each alternative are precisely known. However, in real world situations, this is not the case and an analysis should be carried out to investigate whether the preliminary conclusions are robust or not. This can be conducted by sensitivity analysis, which aims to identify the effects of changes in the inputs which are geographical data and the decision maker's preferences on the outputs, in other words, on the ranking of alternatives. If the changes do not significantly affect the outputs, then the ranking is assumed as robust and satisfactory. If the result is unsatisfactory, it should be return to the problem formulation step. In order to confirm the sensitivity of the results related to the significance of the criteria, it was decided to examine three scenarios, as described in Table 1.

Table 1 – Scenarios for evaluation and categorization of sites

Criteria Categories	**Scenario A**	**Scenario B**	**Scenario C**
Waste characteristics (M1)	37%	20%	40%
Area hydrogeology (M2)	14%	20%	15%
Water use / protected areas (MaxA)	22%	20%	15%
Land use (MaxB)	22%	20%	15%
Surface waters (MaxC)	5%	20%	15%
Total	100,00%	100,00%	100,00%

After the determination of the weighted criteria and the completion of the sensitivity analysis, a set of equations, which assess the potential hazard arisen for every individual site are worked out as follows:

$$\text{Scenario A:} \quad = M1+M2+MaxA+MaxB+MaxC \qquad (2)$$

$$\text{Scenario B:} \quad = 0{,}54M1+1{,}48M2+0{,}89MaxA+0{,}89MaxB+4{,}44MaxC \qquad (3)$$

$$\text{Scenario C:} \quad = 1{,}08M1+1{,}1M2+0{,}66MaxA+0{,}66MaxB+3{,}32MaxC \qquad (4)$$

3. RESULTS AND DISCUSSION

3.1 Recorded sites

From the collected data, the waste dump sites were categorized based on their current status of operation as shown in Figure 2. From the detailed study, 113 waste dump sites were recorded, which impose a potential risk to the environment and public health in Cyprus. Having completed this stage, it is then possible to proceed to the risk assessment and consequently to the final categorization of the sites that are a priority for closure and restoration.

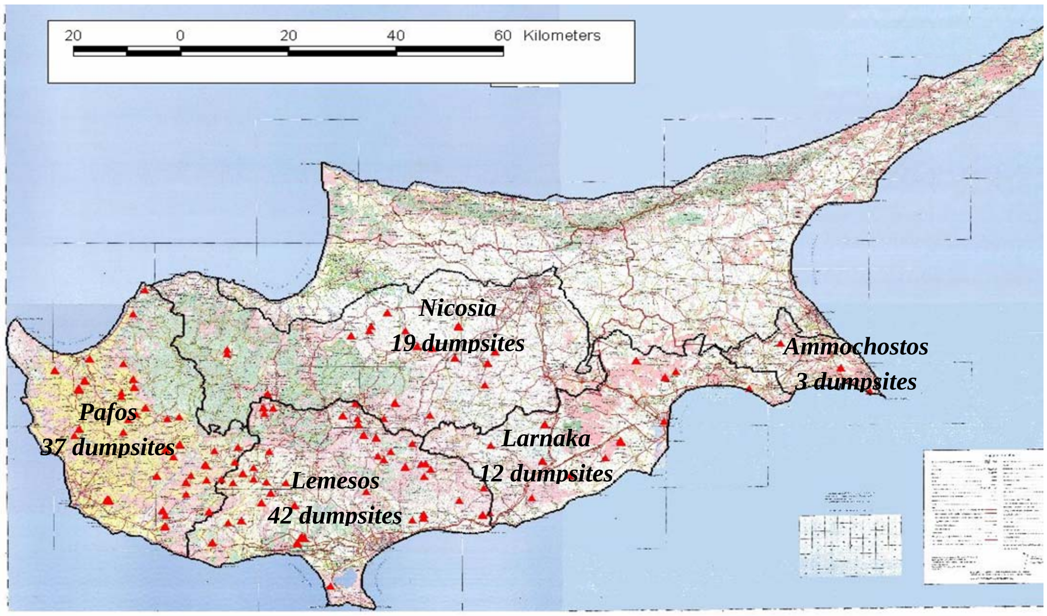

Figure 2. Waste dump sites locations in Cyprus (indicated in red triangles)

3.2 Pollution hazard evaluation

From the analytical and comparative evaluation-categorization processes of the sites, 15 sites were found to have high hazard potential in all the three alternative scenarios examined. Based on these results, seven sites were been found to be constantly present in the top-15, independent of scenario examined. For the consistency of the results, the site passivity is examined analytically for each site for the 3 scenarios, as well as for a random scenario. In Table 2, the top 15 sites are presented according to the passivity category they fall in.

Table 2 – Sensitivity analysis and hazard order

Sensitivity categories	/	Site	Scenario A	Scenario B	Scenario C
1	1	Xylofagou	80	80,7	85,5
	2	Ag. Marinouda	80	59,4	76,4
	3	Paralimni	78	58,3	74,2
	4	Ag. Napa	74	56,2	69,9
	5	Frenaros	74	56,2	69,9
	6	Tersefanou	72	59,4	76,4
	7	Agros	71	70,1	75,6

2	8	Paliometocho	74	56,2	69,9
	9	Avdellero	71	54,5	66,7
	10	Atsas	71	54,5	66,7
	11	Peristerona	70	54,0	65,6
3	12	Kantou	62	65,3	65,9
	13	Kouklia	62	65,3	65,9
	14	Voroklini	60	57,2	72,2

The passivity of the scoring scenario system ranges from 1 to 3. The sites that have the highest hazard potential to the environment and at the same time that are consistently in top-15 are the first 11 sites in Table 2. Furthermore, the consecutive number of each site is also a priority indicator for closure and restoration.

This study presented a comprehensive analytical framework for the prioritization of remedial countermeasures of waste dump sites in Cyprus. The multiple criteria decision analysis (MCDA) model provided a systematic and transparent approach that the Cyprus Government used to clarify the decision making process and facilitated consensus building among decision makers.

The criteria inputs, athough numerous, can be afforded rather easily. In certain cases, in order to overcome the problem where there is no sufficient/reliable data for the sites, either maximum scoring is given, or different ratings are selected for the execution of the categorization process (introduce sensitivity analysis). However, both solutions require careful judgment for safe conclusions. If the criterion is critical to the decision, completion of the data is necessary and then a sensitivity analysis must always be performed.

3.3 Remediation methods

The remediation technologies include mainly containment technologies and in few cases relocation of the waste to a modern lined landfill, as shown in Figure 3.

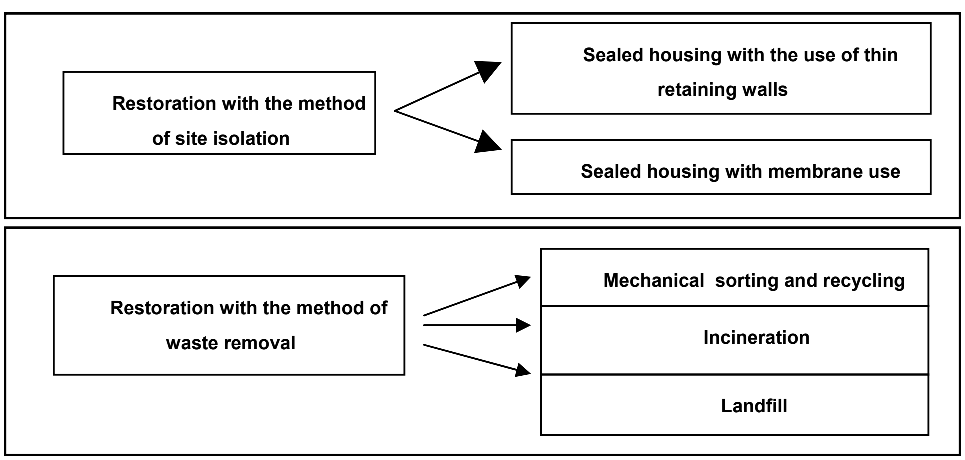

Figure 3. Restoration methods

The selection of technologies is site specific and based on the needed degree of permanence, monitoring ability and system maintenance. The monitoring technologies include environmental monitoring systems for groundwater, run-off water, biogas, leachate, ground settling and top cover. The proposed rehabilitation works for the 10-top priority sites are shown in Table 3.

Table 3 – Proposed rehabilitation works for the 10-top priority sites

A/A	Landfill name	Top cover	Leachate management	Biogas management	Run-off protection	Environmental monitoring
1	Xylofagou	✓	✓	✓ BW	✓	✓
2	Ag. Marinouda	✓GB	✓LTW	✓ BB	✓	✓
3	Paralimni	✓ GB	✓	✓ BW	✓	✓
4	Agia Napa	✓ GB	✓	✓ BW	✓	✓
5	Frenaros	✓ GB	✓	✓ BW	✓	✓
6	Tersefanou	✓ GB	✓LTW	✓ BB	✓	✓
7	Agros	✗	✗	✗	✗	✓
8	Paliometocho	✗	✗	✗	✗	✓
9	Abdellero	✓ GB	✓	✓ BW	✓	✓
10	Atsas	✓	✓	✓ BW	✓	✓

GB = geomembrane, LTW = leachate treatment works, BW = biogas windows, BB = biogas burner

4. CONCLUSIONS

MCDA analysis showed that out of 113 waste dump sites in Cyprus, 10 are of top-priority for closure and restoration, with the remaining 103 sites to be restored gradually depending on their scoring received from the MCDA model. The priority for the rehabilitation of the remaining sites would be also dependant upon the type of restoration works (in site/on site/off site).

The use of MCDA method in waste management sector has many advantages described below:

- The set of factors are clearly described
- If there is a lack of data, the need of completion is obvious
- The sensitivity of the data analysis reveals the main characteristics of any site
- The method can be differentiated and adapted (customizable)

Although the above advantages, the users of the method should be aware of misleading conclusions in cases where there is either lack of critical data and/or the weighting of the critical factors is wrong.

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