Risk assessment and evaluation of uncontrolled landfill sites in Cyprus

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Abstract
The Landfill Directive was passed by Europe in 1999 and requires among other things the Cyprus waste management industry to classify landfill sites according to their hazards to the environment. In the Republic of Cyprus, 113 uncontrolled waste dump sites have been identified and recorded. Once the sites have been identified, a GIS database was developed with complete information for each site. Risk assessment of the sites was carried out using a method of multiple criteria decision analysis. The method was based on the highest scores achieved for each criterion. The 10 sites that have the highest scores are the ones prior to immediate restoration.
Keywords: Landfill Directive; uncontrolled waste dump sites; risk assessment; restoration.

1. INTRODUCTION

The protection of the environment from the cease of operation of all uncontrolled / semi controlled disposal areas comes up to a necessity and a priority for the Republic of Cyprus as a new member of European Community. For the complete harmonization with the principles of sustainable development and European legislation (99/31/EC on the landfill of waste and 94/62/EC on packaging and packaging waste), The strategic plan for solid waste management in Cyprus was prepared in June 2002 (it has been approved by the Cypriot Parliament in 2003).

The purpose of the plan was the creation of an integrated solid waste management plan for each waste category in order to ensure the protection of the environment and public health. The state of the art for waste management in Cyprus, as well as the Community s environmental policy and legislation was taken into consideration during the preparation of the Strategic Plan.

In Cyprus, municipal solid waste is currently collected by either the local authorities or individual companies. Until 2005, officially there were in operation 7 disposal sites. However, none of these 7 sites fulfilled the requirements of the Directive 99/31/EC on the landfill of waste. Particularly, 2 out of the 7 official disposal sites were operated under controlled disposal procedures (Kotsiatis site at Nicosia Region and Vati at Lemesos Region), while the remaining 5 sites were operated under semi-controlled disposal procedures. Beyond these 7 official disposal sites, there were identified and recorded 113 unofficial and uncontrolled disposal areas in operation during the elaboration of the current study.

2. MATERIALS AND METHODS

2.1 Identification and recording of sites

The approach followed towards the detection of uncontrolled disposal areas focused on sites that served settlements of at least 2.000 habitants. In the first phase of the sites identification, the actions undertaken by the study team were literature research, contacting the Ministry of Interior and the Ministry of Agriculture, Natural Resources and Environment, as well as 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 global positioning system (GPS)
Recording the access road to the site (length, direction), as well as the internal paths
Photographical evidence of the site with emphasis to 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 in a customized database (Microsoft Data Base), which recorded 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

A contaminated site is a potential hazard to the environment and its receivers. The negative impacts from the pollution could be brought out only by the usage of the pollution mechanism, which is illustrated in Figure 1.

Source ——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> in this stage, the total volume and composition of waste is estimated in relation to 4 basic types of waste that are disposed in the sites, as shown in Table 1.

Table 1. Evaluation of the pollution source (M1)

A/A	Evaluation parameters	Types of wastes			
		municipal > 30 years	**municipal < 30 years**	**Construction and demolition waste**	**Hazardous waste**
1	**Waste volume (m^3)**				
1.1	< 1,000	10	15	5	
1.2	1,001 5,000	14	19	5	
1.3	5,001 10,000	18	23	5	
1.4	10,001 20,000	22	27	5	
1.5	20,001 50,000	26	31	5	
1.6	50,001 100,000	29	34	5	
1.7	100,001 500,000	32	37	5	
1.8	> 500,000	35	40	5	
2	**Distance of industrial zones from landfill***				
2.1	x ≤1.0 km				6
2.2	1.0< x ≤ 3.0 km				5
2.3	3.0< x ≤ 5.0 km				4
2.4	5.0< x ≤ 9.0 km				2
2.5	x ≥ 9.0 km				0

*only for hazardous waste

For site classification based on the pollution source, determined first the type of waste that is disposed and then the overall quantity is estimated. As there is no reliable data for construction and demolition waste, as well as for hazardous waste, assumptions were made.

- Path of pollution (M2) examined in this stage, is the precipitation (M2A) and the ground permeability in relation to the distance of aquifer from the landfill basin (M2B), as shown in Table 2.

Table 2. Evaluation of pollution path

Precipitation (M2A)		**Aquifer (M2B)**			
Precipitation pa	**Value**	**Distance from aquifer**	**Ground permeability (m/sec)**		
<300mm	0.80		**Kf $<10^{-6}$**	**$10^{-4}>$Kf $>10^{-6}$**	**Kf $>10^{-4}$**
300 500mm	0.85	> 10 m	0	4	8
500 700mm	0.90	> 2 10 m	1	5	10
700 900mm	0.95	< 2 m	3	8	13
>900mm	1.00	In the aquifer	9	12	15

- Receiver of pollution (M3) examined in this stage, is the distance of sites related to water use/protected areas (MaxA), land use (MaxB) and surface waters (MaxC), as shown in Table 3.

Table 3. Evaluation of pollution receiver

Receivers	**> 1000m**	**501 - 1000m**	**101 -500m**	**< 100m**	**Inside**	Sub category
Water reservoirs	0	15	25	25	25	MaxA
Future water reservoirs	0	0	0	0	10	
Protected areas	0	0	12	12	25	
Playgrounds	0	0	10	10	25	MaxB
Agricultural/coastal zone	0	0	10	10	20	
Residential zone	0	0	10	10	20	
Industrial zone	0	0	0	5	20	
Road axes	0	0	0	5	10	
Quarries	0	0	0	2	10	
Water basins	0	0	0	2	5	MaxC
Surface waters	0	0	2	2	5	
Protected areas	0	0	0	2	4	

From the above table, it is clear that the distance of the disposal site from the receiver plays a crucial role in the evaluation of the arisen potential hazard. In cases that there is no sufficient data about the hydro geological characteristics of a site, maximum-score values are given. It is important to notice that neither the waste burial method nor the years of operation of the site are taken into consideration.

2.3 Evaluation and categorization of sites

A multiple criteria decision analysis (MCDA) was used similar technique was developed by the Hellenic Ministry for the Environment, Physical Planning and Public Works. It is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transparent process. When using a MCDA method, different criteria are combined together into a single decision image. The criteria can be of two types:

- Constraints serve to limit the choice of alternatives under consideration, and
- Factors act as continuous modifiers to the suitability of a location for the objective in question

The criteria are combined in the form of weighted linear combination: $E= \Sigma wixi$ (I)
where E= hazard, wi= weight of factor i, and xi= criterion of factor i.

The method was based on the highest scores achieved for each criterion. In order to confirm the sensitivity of the results related to the significance of the criteria, 3 scenarios were examined in the current study as described in Table 4.

Table 4. 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%

By using the maximum criterion weight for each scenario, Table 5 emerges.

Table 5. Highest scores for each criterion related to different scenarios

Criteria Categories	Scenario A			Scenario B			Scenario C		
	Max weight (%)	Max score	Weight factor	Max weight (%)	Max score	Weight factor	Max weight (%)	Max score	Weight factor
M1	37%	41	1	20%	22,2	0,54	40%	44,4	1,08
M2	14%	15	1	20%	22,2	1,48	15%	16,6	1,1
MaxA	22%	25	1	20%	22,2	0,89	15%	16,6	0,66
MaxB	22%	25	1	20%	22,2	0,89	15%	16,6	0,66
MaxC	5%	5	1	20%	22,2	4,44	15%	16,6	3,32
Total	100%	111		100%	111		100%	111	

By using the 5 criteria categories (M1, M2, MaxA, MaxB, and MaxC), as well as the resulting weight factors of Table 5, it is then possible to calculate the hazard for each site under different scenario.

Scenario A: $E_A = M1 + M2 + MaxA + MaxB + MaxC$ (II)
Scenario B: $E_B = 0,54M1 + 1,48M2 + 0,89MaxA + 0,89MaxB + 4,44MaxC$ (III)
Scenario C: $E_\Gamma = 1,08M1 + 1,1M2 + 0,66MaxA + 0,66MaxB + 3,32MaxC$ (IV)

For a better inspection of the results, the overall score can be expressed in a scale from 1 to 111.

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 Table 6.

Table 6. Waste dump sites in Cyprus

Region	In operation	Semi operation	Closed	Total
Nicosia	6	4	9	19
Lemesos	10	7	25	42
Larnaka	5	1	6	12
Ammochostos	3	0	0	3
Pafos	15	0	22	37
Total	39	12	62	113

From the detailed study, 113 waste dump sites were recorded, which impose a potential risk to the environment and public health in Cyprus. Once this stage is completed, it is then possible to proceed to the risk assessment and consequently to the final categorization of the sites that are prior to closure and restoration.

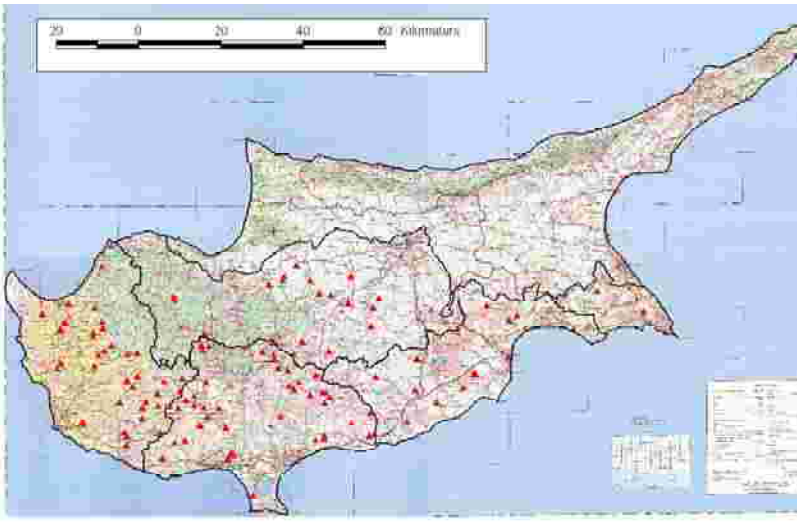

Figure 1. Waste dump sites in Cyprus

3.3 Pollution hazard evaluation

From the analytical and comparative evaluation-categorization processes of the sites, 15 sites were found to have high potential of hazard in all the 3 alternative scenarios examined. In Table 7, the final scores of the first 15 positions are presented according to the different scenario, as well as the order of these sites based on the numerical scores that the sites have received during the categorization process.

Table 7. Final score for the first 15 sites according to scenario

	Scenario A		Scenario B		Scenario C	
A/A	Site	Score	Site	Score	Site	Score
1	Xylofagou[a]	80	Xylofagou[a]	80,7	Xylofagou[a]	85,5
2	Ag. Marinouda[a]	80	Agros[a]	70,1	Tersefanou[a]	76,4
3	Paralimni[a]	78	Kantou[b]	65,3	Ag. Marinouda[a]	76,4
4	Ag. Napa[a]	74	Kouklia[b]	65,3	Agros[a]	75,6
5	Frenaros[a]	74	Ag. Konstantinos	63,1	Paralimni[a]	74,2
6	Paliometocho[b]	74	Prastio Kellakiou	61,0	Voroklini[b]	72,2
7	Tersefanou[a]	72	Agridia	61,0	Ag. Napa[a]	69,9
8	Avdellero[b]	71	Souskiou	61,0	Frenaros[a]	69,9
9	Atsas[b]	71	Ag. Marinouda[a]	59,4	Paliometocho[b]	69,9
10	Agros[a]	71	Tersefanou[a]	59,4	Avdellero[b]	66,7
11	Peristerona[b]	70	Paralimni[a]	58,3	Atsas[b]	66,7
12	P.Chrisochous	66	Voroklini[b]	57,2	Kantou[b]	65,9
13	Mari	64	Arediou	56,4	Kouklia[b]	65,9
14	Kofinou	63	Ag. Napa[a]	56,2	Mouttagiaka	65,7
15	Ag. Trimithias	63	Frenaros[a]	56,2	Peristerona[b]	65,6

a: sites that are in top-15 in all scenarios, b: sites that are in top-15 in only 2 scenarios, c: sites that are in top-15 in only 1 scenario

Based on the results presented in Table 7, there are 7 sites that are constantly present in 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 8, the top 15 sites are presented according to the passivity category they fall in.

Table 8. Sensitivity analysis and hazard order

Sensitivity categories	A/A	Site	Scenario A	Scenario B	Scenario C
	1	Xylofagou	80	80,7	85,5
	2	Ag. Marinouda	80	59,4	76,4
	3	Paralimni	78	58,3	74,2
1	4	Ag. Napa	74	56,2	69,9
	5	Frenaros[a]	74	56,2	69,9
	6	Tersefanou	72	59,4	76,4
	7	Agros	71	70,1	75,6
	8	Paliometocho	74	56,2	69,9
2	9	Avdellero	71	54,5	66,7
	10	Atsas	71	54,5	66,7
	11	Peristerona	70	54,0	65,6
	12	Kantou	62	65,3	65,9
3	13	Kouklia	62	65,3	65,9
	14	Voroklini	60	57,2	72,2

1: sites that are in top-15 in all scenarios, b: sites that are in top-15 in scenario A and 1 random, c: sites that are in top-15 in 2 random

The passivity of the scoring scenario system ranges from 1 to 3. The sites that have the highest potential of hazard to the environment and at the same time there are consistently in top-15 are the first 11 sites in Table 7. Furthermore, the consecutive number of each site is also a priority indicator to closure and restoration.

4. CONCLUSIONS

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 inputs to the criteria, though they are numerous can afforded rather easily. In cases, there is no sufficient/reliable data for one of the sites, in order to overcome this problem, 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.

MCDA analysis showed that out of 113 waste dump sites in Cyprus, 10 are of top-priority to closure and restoration. The remaining 103 sites would be restored gradually depending on their scoring received from the MCDA model. The priority of 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 is 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 (customization)

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

References

1. Saaty T.L., 1980. *The Analytic Hierarchy Process.* McGraw-Hill Inc., New York.
2. Linkov I., Vargee S., Jamil S., Seager T.P., Kiker G., Bridges T., 2004. *Multi-criteria decision analysis: a framework for structuring remedial decisions at contaminated sites* (eds. Linkov I. and A. Ramadan).
3. Saaty T.L, 2001. *Decision making with Dependence and Feedback: The Analytic Network Process.* 2nd ed., RWS Publications.
4. Belton V., Stewart T.J., 2002. *Multiple Criteria Decision Analysis: An integrated approach*. Kluwer Academic Publishers, Dordrecht.
5. Kreith F., 1994. *Handbook of Solid Waste Management*, McGraw-Hill, New York.
6. Thill J. C., 1997. *Spatial Multicriteria Decision Making and Analysis: A geographic information system approach.* Ashgate Publishing, England.
7. Enviroplan S.A., 2002. *The strategic plan for solid waste management in Cyprus*.
8. Hellenic Ministry for the Environment, Physical Planning and Public Works, 2005. *Standard technical specifications for the restoration of uncontrolled landfill sites.* Circular 135977/5051.