ΔΗΜΟΣΙΕΥΣΗ No 93

UNIVERSITY OF THE AEGEAN

DEPARTMENT OF ENVIRONMENTAL STUDIES

GlobalNEST

GLOBAL NETWORK FOR ENVIRONMENTAL SCIENCE AND TECHNOLOGY

PROCEEDINGS

OF THE

8TH INTERNATIONAL CONFERENCE ON ENVIRONMENTAL SCIENCE AND TECHNOLOGY

VOLUME OF ABSTRACTS

EDITOR: T.D. LEKKAS

MYRINA, LEMNOS ISLAND, GREECE
8 – 10 SEPTEMBER 2003-07-22

ISSN 1106-5516
ISBN 960-7475-24-0

FOUNTOULIS, I., MARIOLAKOS, D., SPYRIDONOS, & ANDREADAKIS, EMM., (2003). – Geological criteria and methodology for landfill sites selection. *In Proceedings of the 8th International Conference on Environmental Science and Technology, Lemnos Island, Greece, 8-10 September 2003. Full paper* vol. **B**, pp. 200-207.

Proceedings of the 8th International Conference on Environmental Science and Technology
Lemnos Island, Greece, 8 – 10 September 2003
Full paper vol. B, pp. 527-534

GEOLOGICAL CRITERIA AND METHODOLOGY FOR LANDFILL SITES SELECTION

FOUNTOULIS, I.[1], MARIOLAKOS, D.[1], SPYRIDONOS E.[1,2], ANDREADAKIS, E.[1]

[1]National and Kapodistrian University of Athens, Department of Dynamic, Tectonic and Applied Geology, Panepistimioupoli Zografou, GR-15784 Athens, Greece
[2]Free University of Berlin, Institute of Geological Sciences, AG Mathematical Geology, Malteserstr. 74-100, Haus D, D-12249 Berlin, Germany
fountoulis@geol.uoa.gr

EXTENDED ABSTRACT

The landfill siting problem composes a very complex process due to its multifaceted character. To come up with the best available solution, a series of alternative options has to be assessed based on a variety of criteria, by utilising the methodology of multicriteria analysis. The selection of the most appropriate criteria, based on which the process will be assessed, has to be interdisciplinary hence has to cover the entire landfill siting process holistically, from every perspective (economical, social, environmental, operational, land-planning). This paper focuses on indicating the significance of the geological factor for the landfill siting process, and attempts to categorize the various geological criteria based on their weight factor.

In that multicriteria analysis system, the comparative evaluation of the alternative scenarios, is taking place in 2 steps: (i) criteria groups are defined, each one consisting of a series of individual criteria and the weight factor of each group is defined based on the experience of the working group, and on any potential data from relevant applications. Based on the defined criteria groups and the relative weight factors, the proper cumulative function is extracted based (ii) the Criteria Groups (CG) are getting extracted into their individual evaluation criteria (IC), where by using the appropriate weight factors, their own relative significance is defined, within each criteria group.

The geological criteria, regarding hydro-geological characteristics of the examining areas, should compose the starting point even from the initial selection of the potential landfill sites, aiming at preserving surface and underground water quality in case of any potential malfunction of the whole facility. Slope stability characteristics, seismicity, active faults etc. have to be investigated in order to gain a reliable estimation, as far as natural hazards in the study area are concerned. Thus, once natural hazard is considered highly probable for an area, the site should be automatically excluded from the process.

The advantages of this approach are: (i) it takes into account a large number of criteria, and the effects on each other, utilising tree analysis (ii), it permits more analytical and precise definition of the criteria importance by using a table N*(N-1)/2 of comparison for all criteria (iii), it permits the gradation of a landfill site, even if all evidence is given with a degree of uncertainty, and (iv), the final relative evaluation of the landfill sites is trustworthier as sites that haven't any remarkable differentiation are grouped in the same category

Key Words: geology, neotectonics, groundwater, landfill siting, multicriteria analysis

1. INTRODUCTION

Landfill sitting, permitting and appropriateness have become the most contentious and difficult parts of the solid waste management process. The procedure of landfill site selection must therefore involve scientists coming from different fields such as geologists, planers, engineers, as well as representatives of the public. Methods and criteria for landfill site-selection have been proposed by several researchers such as [1], [2], [3], [15, [17].

All evidence coming from the various scientific fields must come together, evaluated and combined in order to have the best results for the landfill site selection. Finding sites that are both technically feasible and environmentally and socially acceptable can be difficult. Many communities have experienced intense political conflicts centred on sanitary landfill selection and especially on landfill sitting decision-making process. It is widely accepted that in every decision making process, the extracted results are characterized by stakeholder's – decision makers' objectivity. The question raised here might be who are going to be –or even better– who should be the stakeholders in those landfill-sitting cases? Experience has shown that the most common sitting process, called the "*decide-announce-defend*" model, hasn't easily been accepted by the interested parties. In many cases citizens have demonstrated that they desire and demand to be a part of this process and furthermore ask for a comprehensive landfill sitting strategy.

The public involvement in waste management problem solving processes, is more than vital. Consequently, the decision making processes should shift from the strict documental and institutional character into the more participatory one, since public's voices compose the credentials of the program's final success or failure [10]. Additionally, another issue of major importance for any proposed waste management policy, is the public's education. Special and concrete educational programs regarding waste management issues have to be set up prior to any potential public participation.

Most experts agree that no perfect sitting model exists [9]. Even so, lessons from successful sittings do offer insight into which strategies should be pursued and how public authorities can resolve particularly difficult issues. The "*learning – sensing – doing model"* is the most appropriate social instrument for a community to utilize for that purpose [10]. By the time a community asks from its people to become active members of a waste management scheme chosen by the community, these people have and deserve to know why they are supposed to act accordingly.

Allthough geological evidence plays a crucial role in the site selection in this multidisciplinary approach, mainly dealing with the best geoenvironmental protection, it is often misinterpreted or not correctly understood in its importance. Additionally, geological issues are often not easy to bring in the public discussion. Therefore in this work we focus on the geological criteria affecting the landfill site selection decision and the way they can be incorporated in multicriteria analysis approach [6], [7], [8], [13], [14], [18], [19], [20].

2. MULTICRITERIA ANALYSIS AND ENVIRONMENTAL MANAGEMENT

Without any dispute, the decision making process, concerning environmental problems, due to the nature of those problems (multidimensional character) is a formidable task. As such, facility siting and licensing compose a very complicated and difficult procedure, since a series of alternative sites / scenarios have to be assessed, taking into consideration numerous of restricting factors and prerequisites. In order to accomplish the justification of all alternative scenarios, their comparison under only one parameter, even the most vital one, is inadequate; although sometimes a criterion might be determinative (e.g. Intensive karstification). The analysis and graduation of series of criteria are needed in order to come up with the objectively best option. The examined criteria are common for every examined site/ scenario and the importance of each one of those is characterized by a weight factor. The selection of the most appropriate criteria is rather vital for the extraction of the best conclusions and results. The classes of the selected criteria are stimulated: (1) directly, by the character of the problem and its particular characteristics, (2) indirectly, since the problem by itself is going to influence or be influenced by the attitude of the interested groups. The simultaneous analysis of each characteristic of all alternative scenarios, the assessment and graduation of different criteria, aiming at the extraction of the optimum solution, defines the methodology of Multicriteria Analysis.

2.1 Stages Of Multicriteria Analysis Methodology

The methodology for the implementation of a multicriteria analysis system, includes the following stages:

1. Problem identification and selection of the possible alternative options
2. Selection of the proper model
3. Selection and classification of criteria
4. Mathematical description of criteria
5. Estimation of the weight of each criterion, accompanied by a holistic approach of the problem
6. Designation of any potential limitations in relation with the subject of the examined problem
7. Final ranking of the examined alternative options based on the final graduation and on the peculiarities of each selected model.

As it has previously been mentioned, the aim of multicriteria analysis is the multiple assessment of various scenarios under the same criteria – criteria groups. Consequently, the most vital phase of that analysis is the third stage, that is the stage of criteria selection and classification which has to have the following characteristics:

1. comprehensive and interdisciplinary, meaning all criteria have to cover the examining problem holistically (from any perspective)
2. operational, meaning all criteria have to be able to get graduated with specific, for each alternative option / scenario, figures, or to get classified in a specific graduated range.
3. lack any confusing or conflicting criteria.

2.2 Estimation Of Criteria Weights

The importance rate of the examined criteria, for the evaluation of alternative options, is designated by the weight factor, each one of those criteria has been attributed to. Depending on the studying situation, the attributed weight factors can be classified into two categories:

Direct weight factors are used in cases where the criteria number is small and the selection of the weight factors is feasible.
Indirect weight factors are defined by the importance classification of criteria, the performance of an overall weight factor, or of the maximum weight factor and then, with the identification of the weight factors in relation to the summation of all weight factors, or

in relation to the highest weight factor. Additionally, the use of criteria is possible, which happen not to have any weight factor.
The identification of the importance of each criterion is based on the significance, each involved working group, gives. In other words the process could be characterized as a subjective one and consequently the involved parties might give higher significance in the environmental criteria compared to economical ones, and the other way round.

2.3 Selection Of The Optimum Scenario – Scenarios Classification

Numerous methods and software implementations [5] have been developed aiming to identify the optimum scenario, for multidimensional managerial problems. These methods are based on the estimation of the overall performance of each scenario, in relation to the individual performances of each criterion, which is included in that specific scenario.

These methods can be classified into the following three categories:

Category 1: Estimation of the overall preference of each scenario. In that case, the optimum scenario is selected by taking into account the highest graduation, independently of the individual criteria.

Category 2: Estimation of the preference of one scenario comparing to another one, which is based on the assumption that the scenario A is better than the scenario A', provided that scenario A is at least as good as the scenario A' (not worse). That kind of estimation is based on the development of a bilateral relation between two scenarios in order to get assessed the relation of each scenario. In that case, before the comparative classification of all criteria, based on their graduation, some limitations are set, which express the preference on some criteria in relation to the rest. By using that method, the selection of the optimum scenario is based partly on the designation of the overall graduation of each scenario and mostly on the comparison of all alternative scenarios.

Category 3: The models used for the estimation of the optimum scenario, are based on iterative methods.

3. DECISION MAKING SYSTEM BY USING CUMULATIVE FUNCTION OF CRITERIA GROUPS

In that multicriteria analysis system, the comparative evaluation of the alternative scenarios, is taking place according to the following steps:

Step 1
Firstly the criteria groups are defined, each group consisting of a series of individual criteria (as described on the 2nd Step). Also in this Step, the weight factor of each criteria group is defined, expressing the relative significance of that group in the examining scenario. Then, based on the defined criteria groups and the relative weight factors, the proper cumulative function is extracted. The summation of those groups' weight factors is 100%. The designation of the relative significance of each criteria group, is turning out, based on the experience of the working group, as well as, on any potential data from relevant applications.

These following Table I has been calculated taking into account the suggestions of the planning authorities (ACMAR) [2] of the major area of Athens municipality, which are responsible for the solid waste management:

Table I: Criteria Groups and Weight Factors

	Description	Weight Factor
CG1	Geological Criteria	0.40
CG2	Planning Criteria	0.25
CG3	Environmental Criteria	0.20
CG4	Economic – Operational Criteria	0.15

Based on the previous, the extracted cumulative function is the following:

$$f = 0.40\ CG1+0.25\ CG2+0.20\ CG3+0.15\ CG4$$

Step 2

In this second step, the Criteria Groups (CG) are getting extracted into their individual evaluation criteria (IC), where by using the appropriate weight factors, their own relative significance is defined, within the criteria group on which they belong. The summation of the weight factors of all individual criteria, within each Criteria Group, has to be 100%, as well. In this paper we intend to evaluate only the geological criteria, where in our opinions they should be treated with meticulousness. Actually these criteria should compose the starting point even from the initial selection of the potential landfill sites.

Table II: Geological Criteria

GEOLOGICAL
Topography – Slope's stability
Ground Characteristics
Underground Characteristics
Tectonic and Seismic Data

As it has already been mentioned, the sanitary landfill sitting and permitting process composes the most crucial stage in every solid waste management policy. The main goal has to be the preservation of public health and conservation of natural environment. In the following, are explicitly presented the criteria under which all potential landfill sites should be compared.

Geological

Within this criteria group, the criteria regarding hydro-geological characteristics of the examining areas, aiming at preserving surface and underground water quality in case of any potential malfunction of the whole facility, as well as slope stability characteristics, seismicity, active faults etc. are embedded.

A large number of attributes has to be investigated in order to have a clear view and a reliable estimation, as far as natural hazards in the study area are concerned. In tectonically and seismically active areas, such as Greece, a wide variety of natural disaster could affect almost any area. Through this point of view, minimisation of the consequences of such a potential event is a high priority in the landfill site selection process. Thus, once such a hazard is considered highly probable for an area, the site should be automatically excluded from the process (e.g. active fault(s) crossing the landfill area, landslide or rock fall zones etc.).

Protection of water bodies and especially the highly vulnerable ones, such as karstic aquifers, is of high priority and also with an exclusive function. Landfill siting upon a highly karstified formation should be considered out of the question.

4. METHODOLOGY

The method we are going to describe is distinguished in the following stages:

1st stage: Desk Study Stage
Definition of the major study area (e.g. province, municipality etc.). Use of existing bibliography, topographic and geological maps in regional scale (e.g. 1/50.000 or 1/25.000). The research team together with the planning authorities of the province or municipality decide about the most interesting factors that must be examined for the landfill site selection. Using these main factors and evaluating the existing data, the research team must propose a number of candidate sites - at least eight (8) - for detailed investigation. These sites must discussed with the planning authorities and finally reduced to (4). In this point we have to mention that in Canada twenty (20) sites were initially proposed and then were reduced to eight (8), [4].

2nd stage: Detailed investigation
The four (4) sites selected during the 1st stage must be studied in detail in order to define the site with the less geoenvironmental impact assessment. The approach of this study must be realized in two scales: 1/25.000 and 1/5.000.
In the scale of 1/25.000 the following must be done:

i. Geological and hydrolithological mapping at least 5 km around every study site in order to have a better knowledge of the geological structure of the major area of each site and furthermore the hydrogeological behaviour.
ii. A map depicting the drainage pattern in order to define the location of the site in the hydrological basin as well as some parameters of the basin (e.g. linear erosion at, the extension etc.), that will be discussed in detail later in the quantification paragraph.
iii. Tectonic map with special regard to active faults and relative structures.

In the scale of 1/5.000 the following must be done:

i. Detailed geological mapping at least 1.000 m. around every site.
ii. Map of morphological gradient of every candidate site must be compiled.
iii. Map of drainage pattern depicting the locations in which linear erosion is observed.
iv. Map depicting all surficial karstic forms and possible zones of intense karstification.
v. Map depicting locations vulnerable to landslides and rockfalls and generally areas, which are very sensitive to slope instability.

The evidence coming out of these research tasks will be evaluated and compared on the basis of a Multiple Criteria Decision Analysis. Five steps compose this model:

1st step: Target
The main target of all this work is to minimize the negative consequences on the geoenvironment before the landfill site selection and development. The mathematical coefficients that are determined for every criterion and the final gradation, give us a size for measurement of the degree that geoenvironment will restrain or permit the spreading of the contaminants out of the landfill area.

2nd step: Criteria Quantification

The first step for the model development is the definition of the consequences of the landfill site according to each criterion separately, by the description of the consequences and the definition of its gradation, which corresponds to each one in a scale 1-10. Usually it does using a mathematical function of a natural size with the corresponding consequences, or with a table that gives the consequences as a gradual function in scale 1-10. In some cases a criterion could be analysed furthermore in some other sub-criteria using a consequences tree. Each one of the sub-criteria is used in a way already mentioned, that is like a separate criterion. This site of the model give us the possibility to examine the interaction between the criteria, where a criterion appears as sub-criterion of another criterion.

3rd step: Definition of relative criteria importance

In many decision problems, we can ascertain that all criteria do not contribute in the same way to succeed the basic target, or from the decision responsible side, the criteria have a variable grading of importance. The relative importance of the criteria is defined by a separate tables analysis and applied as an importance vector at the step of gradation. The criteria are compared and result the criterion importance vector, as the main vector of the comparison table.

4th step: Gradation of the candidate landfill site

Decision on the site selection, based on the multicriteria method (Paragraph 4).

5th step: Relative Evaluation of the candidate landfill sites

For the relative evaluation of the candidate landfill sites, every site takes its own gradation resulting from the sum coefficient (1) and finally the sites are arranged according to their final gradation. So, the site with the higher gradation is first, and next gradation second etc.. From the step 4, the coefficient of a criterion might be resulted not as a single number but as a space number, as already has been mentioned; we take the final gradation in the same way as a space number. So, the final gradation of the site is a space of numbers in scale 1-100, and this space must be evaluated for the comparison of all sites. A site X is considered better from another site Y if the lower limit X_1, of the gradation space (X_1, X_2) is higher or equal to the upper limit Y_2 of the gradation space (Y_1, Y_2).

5. CONCLUSIONS

The advantages of the described methodology can be summarized as follows:

1. It takes into account a large number of criteria, as well as the effects on each other, utilising tree analysis (2nd step).
2. It permits more analytical and precise definition of the criteria importance by using a table N*(N-1)/2 of comparison for all criteria (3rd step).
3. It permits the gradation of a landfill site, even if all evidence is not completely precise, but is given with a degree of uncertainty, by using a space of confidence (4th step).
4. The final relative evaluation of the landfill sites is trust worthier as sites that haven't any remarkable differentiation are grouped in the same category (5th step).

This methodology has already been applied with success in two cases in the Attiki region, Greece [11], [12].

REFERENCES

1. Allen, A.R., Dillon, A. & O'Brien M. (1997) 'Approaches to landfill site selection in Ireland', in: Marinos, Koukis, Tsiambaos & Stournaras (Eds.): *Engineering Geology and the Environment*, 1569-1574, Balkema, Rotterdam
2. Association of Communities and Municipalities of Attiki Region- A.C.M.A.R. (1996) 'Environmental Impact Assessment Study for the development of landfill site at North and North East Attiki. Technical Report, Unpublished, 422 p. (in Greek).
3. Bertakis, G., Lekkas, E., Lozios, S. (1995) 'Landfill selection criteria with emphasis in engineering geology and environment'. *In proceedings of the XV Congress of the Carpatho-Balcan Geological Association, Geol. Soc. Greece, Sp., Publ.,* No 4, pp. 1011-1016.
4. Cooper, A.G. (1991) 'Waste disposal site selection techniques in Quaternary terrain'. *In Ontario - Canada. Quaternary Engineering Geology (Edit. A. Foster et al.,), Geological Society, Special Publ.,* No 7, pp. 211-217.
5. Hokkanen, J., Salminen, P. (1994) 'The choice of a solid waste management system by using the ELECTRE III decision-aid method'. In: Paruccini, M. (Ed.), *Applying Multiple Criteria Aid for Decision to Environmental Management*. Kluwer Academic Publishers, Boston, pp. 111±155.
6. Hwang, C. L., & Masud, A. S. M. (1979) *'Multiple objective decision making – methods and applications'.* New York : Springer.
7. Jankowski, P. (1995) 'Integrating geographical information systems and multiple criteria decision-making methods'*. International Journal of Geographical Information Systems*, 9(3), 251-273
8. Janssen, R., Nijkamp, P. (1984) 'A multiple criteria evaluation topology of environmental management problems'. In: Yacove, Y.H., Chankong, V. (Eds.), *Proceedings of Decision Making with Multiple Objective*s. Cleveland, Ohio, pp. 495± 514.
9. Janssen, R., Nijkamp, P., & Voogd, H. (1984) 'Environmental Policy analysis : which method for which problem?' *Revue d'Economie Regionale et Urbaine*, 5, 839-855.
10. Mariolakos, D.I. (2000) '*Development Of An Integrated System For The Management Of Municipal Waste In The Island Of Lesvos (Greece)*', Msc Thesis, EAEME
11. Mariolakos, I.D., Fountoulis, I.G. & Logos, E.K. (1997) 'The crucial role of the neotectonic deformation in landfill site selection: 'The geoenvironmental conditions at the proposed landfill site close to Varnavas village, N. Attiki, Greece', in: Marinos, Koukis, Tsiambaos & Stournaras (Eds.): *Engineering Geology and the Environment*, 2003-2006, Balkema, Rotterdam
12. Mariolakos, I.D., Fountoulis, I.G. & Logos, E.K. (1997) 'The crucial role of the neotectonic deformation in landfill site selection: 'The case study of Avlonas, Attiki, Greece', in: Marinos, Koukis, Tsiambaos & Stournaras (Eds.): *Engineering Geology and the Environment*, 2007-2010, Balkema, Rotterdam
13. Munda, G., Nijkamp, P., Rietveld, P. (1994) ‚Qualitative multicriteria evaluation for environmental management'*. Ecological Economics* 10 (2), 97±112.
14. Nijkamp, P. (1989) 'Multicriteria analysis: a decision support system for sustainable environmental management''. In: Archibugi, F., Nijkamp, P. (Eds.), *Economy and Ecology Towards Sustainable Development*. Kluwer Academic Pub- lishers, London, pp. 203±259.
15. Oweis, I.S., Khera, R.P. (1990) *'Geotechnology of Waste management'*. Butterworths
16. P.J. Korhonen, (1987) 'A visual interactive support system for multiple criteria decision making', *Belgian Journal of Operations Research, Statistics and Computer Science,* 27 3±15.
17. Petts, J. & Eduljee, G. (1994) *'Environmental Impact Assessment for waste treatment and disposal facilities'*. Wiley*.*
18. RAC. (1992) ;Multi-criteria analysis as a resource assessment tool;. *Resource Assessment Commission*, Research Paper No. 6, Canberra.
19. Romero, C., Rehman, T. (1989) ;Multiple Criteria Analysis for Agricultural Decisions'. *Elsevier*, Amsterdam.