Geotechnical aspects of a Landfill site Selection Study in North Evoia - Greece

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ABSTRACT

In Greece Sanitary landfilling is the most common way of disposing of municipal solid wastes. However, one of the major problems in waste management now a days concerns is the selection procedure of the most appropriate site for their final disposal. In this paper a two-stage, multicriteria evaluation is presented. In the fist stage, in order to establish the promising sites, waste disposal is merely based on geotechnical criteria as it touches upon issues of the geoenvironment and the landscape as well as the suitability of geoenvironment for siting is depending mainly on its stability and on the danger of groundwater pollution. In the second stage these sites are evaluated using economic efficiency, environmental and technical economic criteria. It is interesting that the method sets the factors clearly and helps experts and local communities to participate. The method was easily applicable to a new landfill site selection in Northern Evoia and the results were accepted by the local communities.

KEYWORDS: land fill site selection, multi criteria evaluation, geotechnical criteria

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INTRODUCTION

The district of Northern Evoia has decided in the construction of a waste disposal site. The 13 municipalities to be served selected by same geomorphological characteristics and geographical position have a population of 10431 habitants. The corresponding production comes up to 3464 tons per year.

This district is located from Vassilika Ellinika in central Evoia to the Northern part of the inland (Istiaia). The region of N Evoia where the new municipal landfill should be situated, basically consists of a hilly-mountainous part and the Xirias river valley part.

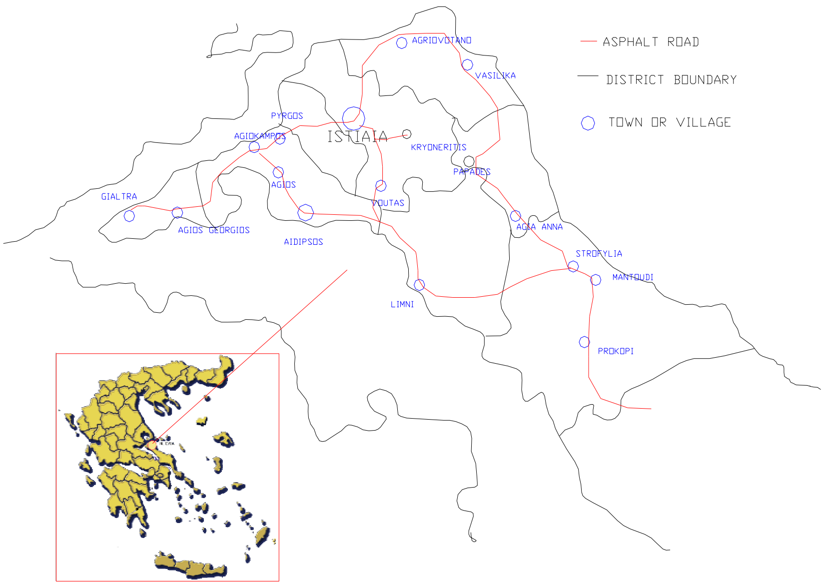

Figure 3 Study area

Most of the non hilly-mountainous part is restricted for landfill construction because of existing nature protection zones, water sources protection zones. Also some thermal water protection zones of nearby spas Aidipsos have to be respected.

Most of the Xirias river valley part is considered to be a potential flood-plain, also restricted for landfill construction. Also that part is densely populated, comprising a chain of villages with the Istiaia city in the centre.

The criteria to be evaluated in this matter and to be depicted on the land suitability maps are reported in Hasna (1996) (see Table 1). Though there numerous criteria used for evaluation (ref work Landfill Criteria For Municipal Solid Waste Municipal Waste Reduction of The Environmental Protection Compendium (1993) the ones used here representing local factors are classified according to in geotechnical, environmental, economic and technical as follows.

Geotechnical criteria

The degree of the danger of groundwater pollution in waste disposal subsoil is determined mainly by geotechnical criteria i.e. the quality and the structural arrangement of the aquicludes and aquifers occuring near the land surface which, affecting at the same time the cost of protective technical measures necessary for groundwater protection.

If a natural sealing layer (an aquiclude) overlies the aquifer the danger of groundwater pollution and possibilities of its prevention depend mainly on the quality and the thickness of the aquiclude, and, on the degree of transmissivity of the aquifer.
If a permeable layer (an aquifer) is at the land surface and overlies an aquiclude, the danger of groundvater pollution is proportional to the transmissivity of the aquifer and the possibility of an economically feasible groundwater protection depends mainly on the aquifer thickness or on the depth to the surface of the underlying aquiclude.
The classification system (Hasna, 1993) for geoenvironment evaluation from this point of view is given in Table 2.

Danger of groundwater pollution and/or costs of remedial measures Structural arrangement of aquicludes and aquifers danger of groundwater pollution and/or cost of protective measures. The first two categories induce unsuitability and the third one the conditional suitability of the geoenvironment for waste disposal siting. The fourth and fifth category present suitable conditions for waste disposals development.

Besides the aquifers transmissivity, the type of their permeability can be included into the complex symbol of the geoenvironment. This makes it possible to determine the way of infiltration, circulation and accumulation of groundwater, and, the conditions for technical works preventing its pollution, as well.
The applied classification system enables to express also the aquicludes inhomogeneity and the shortage of date about the thickness or position of the underlying aquicludes (see the table).

Type of aquifers permeability Examples of geoenvironment complex symbols The characterization of the sites is depending upon the aquicludes thickness or the depth to the surface of aquicludes, used in the table, on the one hand reflect their retardation capacity and on the other hand correspond with the strata thickness presented on engineering geological maps. This enables their easy transformation for the given purpose. The classification system of the aquifers transmissivity presented in the table is in harmony with that one currently used by the compilation of hydrogeological maps.

Table 1. Geotechnical criteria

Criteria	*Index*
Aquifer thickness	e^{11}
Permeability	e^{12}
Infiltration-Percolation	e^{13}

ENVIRONMENTAL CRITERIA

Cover and final cover for landfill sites is to consist of a minimum of low permeability (<1 x 10 - 5 cm/s) compacted soil plus a minimum of 0.15 metre of topsoil with approved vegetation established. The depth of the topsoil layer should be related to the type of vegetation proposed (ie rooting depth). Soils of higher permeability may be approved based on leachate generation potential at the landfill site. Final cover is to be constructed with slopes between 4% and 33% with appropriate run-on/run-off drainage controls and erosion controls. An assessment of the need for gas collection and recovery systems shall be made so that, in the event such systems are required, cover can be appropriately designed and constructed. Final cover is to be installed within 90 days of landfill closure or on any areas of the landfill which will not receive any more refuse within the next year. Completed portions of the landfill are to progressively receive final cover during the active life of the landfill.

Additional layers of natural materials including earth and aggregate and/or synthetic materials may be necessary for inclusion in the final cover design due to site specific conditions and the presence of management systems for leachate and landfill gas (e^{21}).The aesthetics play a significant role in the design of landfill. Absence of landfill intrusion (e^{22}).Landfills must not be operated in a manner such that gas emissions create a public odour nuisance, or that federal, provincial or local air quality criteria are exceeded (e^{23}). A landfill must not be operated in a manner such that a significant threat to public health or safety or a public nuisance is created with respect to: unauthorized access, roads, traffic, noise, dust, litter, vectors or wildlife attraction (e^{24}).

Table 2. Environmental criteria

Criteria	*Index*
Land cover and ecological character	e^{21}
Absence of optical intrusion	e^{22}
Odors nuisance	e^{23}
Public health, safety and nuisance	e^{24}

ECONOMICAL -LAND USE/ SOCIAL

Net present value and Depreciation cost are used to evaluate the tota; profitability of the project's alternative sites (e^{31}, e^{32}) The impacts on housing tourist development of the project is calculated in monetary units and classified in a scale from 1 to 10 (e^{32}).

Table 3. Economical criteria

Criteria	*Index*
Net present value	e^{31}
Depreciation cost	e^{32}
Impacts in housing/touristic development	e^{33}

TECHNICAL OPERATIONAL CRITERIA

Landfill capacity is dependant upon the actual life of the facility and is dominant for any decision process.(e^{41}).The availabilty of the appropriate cover material is also taken into consideration. Soils of low permeability approved based on leachate potential of the facility are desiarable.(e^{42}).An appropriately constructed and maintained access road to and a road system within the landfill site capable of supporting all vehicles hauling waste are required during the operating life of the landfill.(e^{43}). The distance between the landfill site and places of waste consumption (e^{44}).

Table 4 Technical Operational criteria

Criteria	*Index*
Landfill capacity	e^{41}
Cover material availability	e^{42}
Access roads	e^{43}
Distances from the Waste consumption	e^{44}

Finally the following are the rates of each criterium

Table 5 Rates of criteria

Criteria	A (1-2)	B (3-4)	C (5-6)	D (7-8)	E (9-10)
Aquifer thickness (GE1)	Very High	High	Medium	Low	Very low
Permeability (GE2)					
Infiltration Percolation (GE3)	porous	fissure-porous	fissureous	fissure-karst	karst
Land cover and ecological character (EN1)	Very good	Good	Medium	Bad	Very bad
Optical intrusion (EN2)	Very good	Good	Medium	Bad	Very bad
Odors nuisance (EN3)	Very good	Good	Medium	Bad	Very bad
Public health, safety and nuisance (EN4)	Very good	Good	Medium	Bad	Very bad
Net present value (EC1)	Very good	Good	Medium	Bad	Very bad
Depreciation cost (EC2)	Very good	Good	Medium	Bad	Very bad
Industry and mineral exploitation or reserve (EC3)					
Housing/touristic development					
Landfill capacity	Very Large	Large	Medium	Low	Very low
Cover material availability					
Access roads	Very good	Good	Medium	Bad	Very bad
Distances from the main source of residents, public places, Waste consumption					

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METHOD OF ANALYSIS

The steps of the method used consist a two stage, multicriteria methodological framework which is presented in the following paragraphs. The paper presents a theoretical analytical framework to guide the site selection process for this kind of facilities and provides an illustrative case study application

1st stage

The method used in the first stage is described in Hasna(1996).First, geological maps at a scale of 1:200 000 are compiled. Their purpose is to serve as preliminary source of information for local authorithies and other users about the possibilities of waste disposal siting and about the enviromental impact of old landfills, as well.

Land suitability maps for waste disposal siting (of both above mentioned scales) consist of three parallel map sheets. Two of them are documentation maps which comprise all data needed, the third one is the proper land suitability map elaborated on the base of zoning.

The first documentation map includes all legally protected areas: nature reserves, protected forests and mineral resources, protective zones of potable, mineral and thermal water resources and some other hydrological phenomena. The second documentation map represents the danger of groundwater pollution expressed by the complex symbols of the geoenvironmet and the geodynamic phenomena affecting the land use. The nearest residence, water supply well, water supply intake, hotel, restaurant, food processing facility, school, church or public park is to be a minimum of 300 metres. Greater or lesser separation distances may be approved where justified. For those landfills designed to collect and recover methane gas generated, the issue of potential on-site or off-site users of the energy should be addressed in siting the landfill, consistent with the preceding regarding public places. The distance between an airport utilized by commercial aircraft and a landfill containing food wastes which may attract birds is to be a minimum of 8.0 kilometres, unless bird control measures acceptable international standardsl.

The zoning map (or land suitability map) is compiled on the base of two previous maps. It devides the mapped area into suitable, moderately suitable and unsuitable territorial units (zones) taking into account the degree of legal protection, the risk of groundwater pollution and presence of hazardous geodynamic phenomena.

Besides the main purpose (which follows the name of the maps), the maps of land suitability for waste disposal siting provide the basic information about the geological conditions of new landfills building and about the conditions of reclamation the old ones, as well. This follows mainly the complex symbols of the rock environment and the data about other geofactors, mainly of geodynamic phenomena. As a result the proposed sites are derived.

2nd stage

However, the suitability of the territory for waste disposals is not evaluated on the maps in whole. It is only the partial suitability which extent is given by the range of the factors taken into account by their compilation. At selection of suitable sites for waste disposals, it is necessary to take into consideration further factors which cannot be represented on the maps of the small and medium scales (such as protective zones of airports, railroads, etc.) and those which are connected with the distance of sites from water courses and reservoirs, urban areas, etc. The problem consists a multicriterion decision making process where the criteria to be considered are environmental, economical and technical.

The methodology used in this research was Compromise programming. The method a linear multiobjective programming (MOP) technique is described originally by Zeleny (1974). This technique allows one to find the complete set of efficient solutions from two or more objectives finding the most appropriate solution from this set of efficient solutions. The efficient set includes all feasible non dominated solutions, i.e. all the pareto-optimal solutions such that no better outcome can be achieved without making at least one objective worse off. An ideal solution is specified with co-ordinates by the optimal values for each objective. Using this solution as reference the compromise technique allows selection of the compromise set, i.e. the set of feasible efficient solutions closest to the ideal solution. The optimal solution depends on the distance function and the compromise set, is composed of the optimal solutions from the following minimisation problem

$Lr=\Sigma\alpha\iota\Sigma\alpha j$ (R(x)-R(I)

where Lr indicates the distance measure and R(i) is the ideal value

αi αj the relative weights (as described below)

The compromise programming algorithm used in the current research is capable of handling a large number of objectives into series of lower dimensions in order to gain a deeper understanding of the inter-relationships of the subsystems . Selection of the specific was not arbitrary since it was based on decision makers' prior knowledge and experience about the site as well as previous experience of landfill sites.

After these basic criteria have been identified, the process of building the management system from its elementary components by defining the structure of the compromise programming model begins. The process can be characterised as grouping the basic criteria into clusters based on either similar characteristics or the desire to contrast different features through trade-off analysis.

The initial set of corresponding indicators that result from grouping are called first level indicators. After the first level indicators have been specified, the grouping process continues until the highest level indicators have been specified. In the case of the landfill site selection this final level may describe the trade-off between environmental and economic interests.

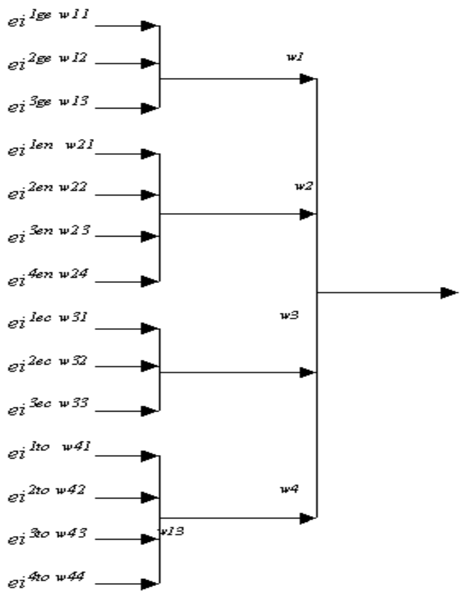

Figure 2 Compromise programming structure

There are two kinds of weights assigned (αj and ai). The weight assigned to the particular management performance index reflects the relative preference to other elements within the same group and the weight assigned to the the preference to the trade-off analysis (Fig 2) Therefore, compromise programming uses a double weighting scheme to reflect the importance of the maximal deviation between the indices used. Then the decision maker must specify a value for the balancing factors.

The impact relationship is a measure of the basic index value for each of the management options and serves as an input to the management system model.
Evaluation of the alternatives is accomplished by calculating the distance of the ideal point. The preferred management option is then identified from the candidates by locating the system nearest the ideal point.

3.1 Combination of the two stages

The impact relationship R(x) is a key link between composite programming and impact assessment of alternative sites using environmental indices. Impact relationships (equation 1) are measures of basic index values for each alternative in terms of system performance. Once an alternative is identified the impact relationship *R(x)* is obtained, used as an input to the compromise programming algorithm as a data table in the discrete case of alternatives that is examined.. Analysis of the results may proceed after all compromise distances have been computed. Consequently it is possible to characterise the areas surrounding the ideal state based on a radial distance from the ideal point. Using the exclusionary criteria, although the limits are somewhat subjective and the values may be modified, the area is divided into desired acceptable and non acceptable regions.

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APPLICATION-RESULTS

Results of the first stage-Suitability maps and proposed sites

The land suitability maps for waste disposal siting at a scale of 1:50 000 have been prepared from a background based on HAGS by the Army Crops of Greece. Due to their greater capacity and detailness these maps can give more complete and precise information. The information that this background g ives is presented in Table 6.

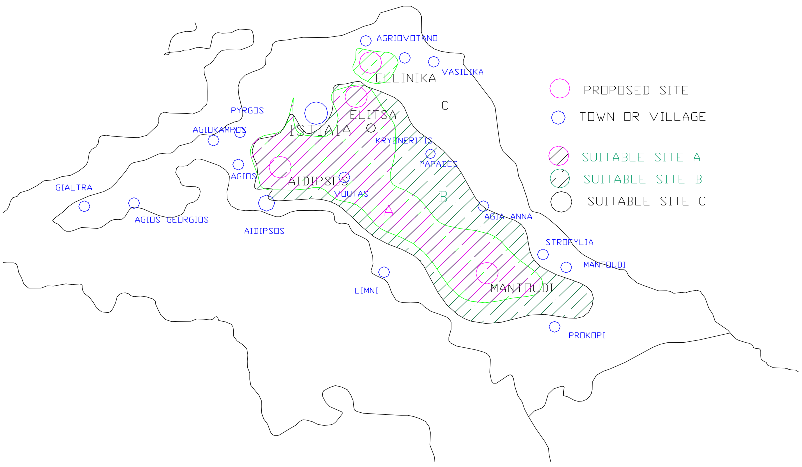
With regard to the smaller capacity of the maps at the scale of 1:200 000, some simplifications were done by their compilation. The transmissivity of aquifers was evaluated in four degrees (the transmisivity marked as D and E in the table 2 are put together) and the thickness of the aquicludes in two degrees only. The structural arrangements in which the superficial stratum is formed by an aquifer with the thickness of more than two metres are regarded as unsuitable in these maps.

In (Table 6) the characteristics of proposed sites (i.e. visual contact, altitude, access road, hydrogeological, land use vegetation and livestock) are presented. The landfill sites position is presented in Figure 4.

TABLE 6 Landfill site characteristics.

Site Name	Visual contact	Altitude (m)	Access road	Livestock	Vegetation	Hydrogeological	Land Use
ISTIAIA (Elitsa)	Yes	620	Asphalt road	N	Y	Not-permeable	Annual Crops
AIDIPSOS (Lithsyrtis)	No	720	Asphalt road	N	Y	Not-permeable	Annual crops
ELLINIKA (Kalyvia)	No	770	Road	N	Y	Semi-permeable	Annual crops
MANTOUDI Paraskevorema	Yes	700	Asphalt Road	N	Y	Not-permeable	None

Figure 4 Land suitability map and proposed sites



The estimation of environmental indices is presented in Table 7.

Table 7. Values of environmental indices

CRITERIA	ELITSA	AIDIPSOS	ELLINIKA	MANTOUDI
Aquifer thickness	8	7	8	8
Permeability	8	7	7	8
Infiltration Percolation	7	8	8	7
Protection of ecosystems and water resources	10	5	7	7
Absence of optical intrusion	10	6	8	7
Odors nuisance	10	5	7	7
Public health, safety and nuisance	9	7	7	7
Net present value	10	7	9	8
Depreciation cost	9	7	7	8
Impacts in housing/touristic development	10	5	7	7
Landfill capacity	7	8	8	7
Cover material availability	7	5	7	7
Access roads	6	7	6	7
Distances from the Waste consumption	10	7	5	4

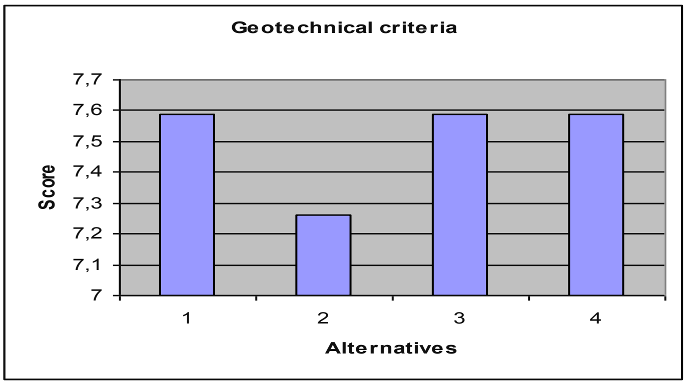
Table 7 summarizes the weights assigned to each index for the compromise programming

Criteria	*Index*	*1st level*	*2nd level*
	ei^{11}	*w11=0.33*	
Geotechnical	ei^{12}	*w12=0.33*	*w1=0.2*
	ei^{13}	*w13=0.33*	
	ei^{21}	*w14=0.25*	
Environmental	ei^{22}	*w21=0.25*	
	ei^{23}	*w22=0.25*	*w2=0.4*
	ei^{24}	*w23=0.25*	
	ei^{31}	*w31=0.20*	
Economical	ei^{32}	*w32=0.20*	*w3=0.3*
	ei^{33}	*w33=0.60*	
Technical-Operational	ei^{41}	*w41=0.20*	
	ei^{42}	*w42=0.30*	*w4=0.10*
	ei^{43}	*w43=0.10*	
	ei^{44}	*w44=0.40*	

Table 8 summarizes the results of the compromise programming for the four alternatives examined.

CRITERIA	ELITSA	AIDIPSOS	ELLINIKA	MANTOUDI
GEOTECHNICAL	7,59	7,26	7,59	7,59
ENVIRONMENTAL	7,25	5,75	7,25	7,75
ECONOMICAL	9,2	7	7,4	7,8
TECHNICAL-OPERATIONAL	6,7	5	4,7	4,4
SCORE	7,848	6,352	7,198	7,398

Examining the results in terms of the first management option "*Express a strong concern for environmental quality* alternative 4 is ranked first (7,75) followed by 1 and 4 (7,25).



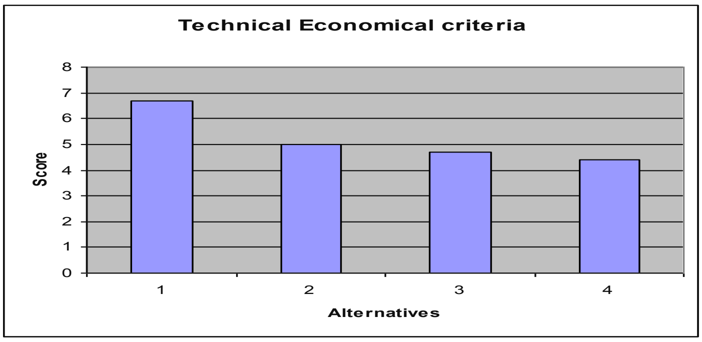
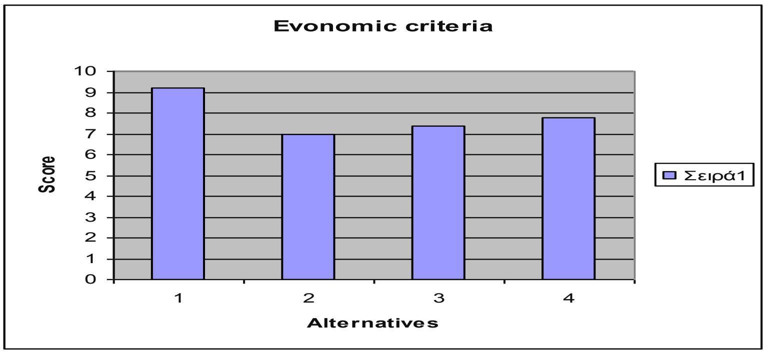


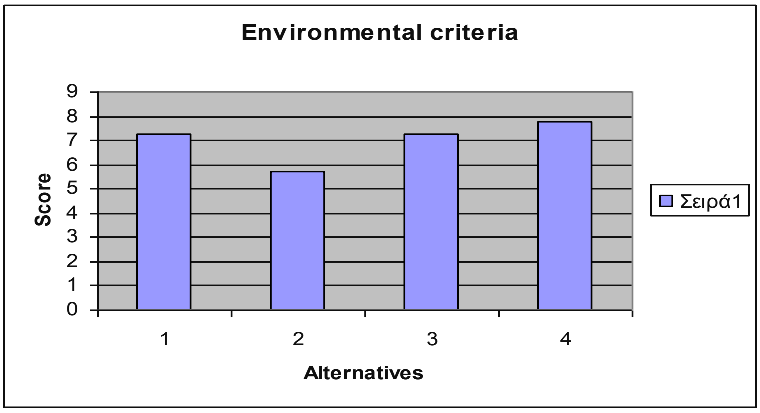
Figure 5. Geotechnical criteria

Finally in terms of geotechnical criteria alternatives 1, 3 and 4 (7.59) ranked first followed by 2 (7.26).

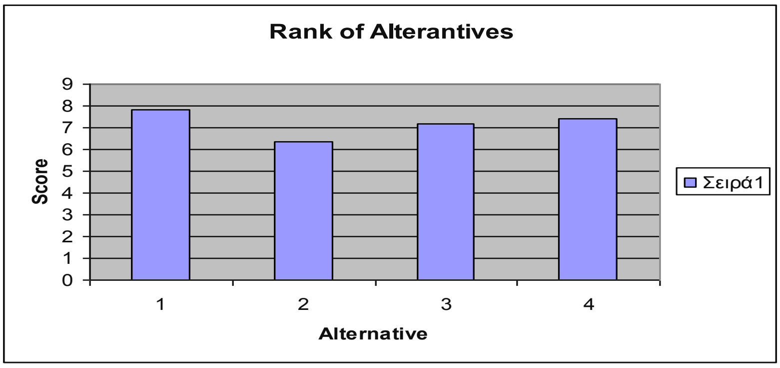
In terms of economic criteria alternative 1 (9.20) is ranked first followed by 4 (7.80).



In terms of the technical operational criteria alternative 1(6.70) followed by 2 (5.00).



The score of each alternative computed as the relative distance of the ideal solution, assuming the weights assigned to each index (Fig. ?) is as follows:
1(7.85), 2(6.55), 3(7.20), 4(7.40)



Therefore the solution is that ranks first to all management options is alternative number 1 since it has the closest distance from the ideal.

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CONCLUSIONS

The method offer a two stage approach useful for environmental studies for landfill site selection.

In the first stage the maps of small scales make possible a simplified process of waste disposal factors evaluation regarding to their small capacity and detailness. Their goal is to provide the preliminary information on suitability of the territory for waste disposal siting and for estimation of environmental impact of old landfills, the majority of which belong to uncontrolled ones in Greece.

The maps of large scales are precisive to the previous maps and make possible the evaluation of those factors which directly affect the way of waste disposals building (mainly with respect to stability of geoenvironment) and the mode of groundwater protection

The fundamental base for waste disposal sites selection are the maps of medium scales which due to their greater detailness and capacity evaluate in a sufficient extent all relevant factors of land use for the given purpose and afford sufficient base for the application of multicriteria methods, as well.

The present work presents also issues of introducing a compromise programming approach into landfill sites selection. Two primary objectives that often conflict in sustainable development are economy of application and environmental performance. The final decision often involves a trade-off between these two objectives.

A case study has been presented to demonstrate the use of different objectives combined with compromise programming for solving the system selection problem within a multicriteria decision making framework. It should be noted that the methodology can be used in several cases of landfill management (development of existing sites, selection of alternative options). The approach used to select the final management alternative was to determine an alternative that is “the better existing alternative” with respect to different decision makers and possibly not the best for all management options. In summary, the present research extends previous efforts in landfill sites selection decision making using one stage objective approaches. It is felt that this extension using compromise programming provides a more realistic perspective of the management procedure.

These features combined with the social concern for landfill site selection warrant further investigation into decision support studies, multicriteria decision making approaches and the incorporation of the landfill sites selection.

Conclusively the proposed methodology: (1) allows for the consideration of more than one stages where preference criteria can be left in the final stage. The criteria in siting waste management facilities which belong to different hierarchical levels (stages) of the siting decision process; (2) places special emphasis on the geotechnical criteria both as regards the provision of specific environmental functions and attributes as well as regards the environmental impacts of these facilities; (3) offers a framework to deal with multiactor decision settings and conflict resolution; (4) provides for computer support of certain phases of the site evaluation and the group decision-making phases of the siting process; (5) it is simple and understandable, a feature especially important for its implementability.

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REFERENCES

Bogardi, I. "*Uncertainty in Water Resources decision making"* Proceedings of the UNDP/UN Interregional Seminar on River Basin and Interbasin Development, Budapest, Hungary, 1975

Briassoulis H. and Installe M., An Integrated, Multistage, Multicriteria Methodology for Siting Hazardous Waste Management Facilities: Theoretical Framework and Illustrative Application.

Cohon, J.L. *"Multiobjective Programming and Planning",* Academic Press, New York, 1975.

Czurda, K. A. - Wagner, J. F. (1991): Cation transport and retardation process in view of the toxic waste deposition problem in clay rocks and clay liner encapsulation. Engineering Geology. Elsevier Science Publisher, Amsterdam, 103-113.

Daniel, David E. Geotechnical Practice for Waste Disposal. London, 1993.

Hrasna M, Land Suitability maps for Waste Disposal Siting, Acta Geologica Universitatis Comenianae. Nr. 51, Pages:27-30 Bratislava 1996

Katsamaki, A., E. Diamantopoulos and Y. Siskos, *Landfill site selection based on a multimedia decision analysis methodology (March 1996), 26p.*

A. K. Saxena, Y. Gupta Bhatti P. D. Environmental Impact Assessment Study for the Selection of Sites for Developing a Hazardous Waste Disposal Facility – A Case Study

Province of British Columbia. Landfill Criteria for Municipal Solid Waste. Vancouver: Ministry of Environment, Lands and Parks, 1995

Zeleny M., "*Multiple Criteria Decision Making",* Mc Graw Hill Company, New York, 1974, 167-182.

Manoliadis O. and Sachpazis C, 2000 *Geotechnical Aspects of Landfill Site Selection* ….