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PROCEDURE FOR THE LOCATION OF LANDFILL SITES USING A GIS MODEL

Alistair Allen[1], Graca Brito[2], Paulo Caetano[2], Carlos Costa[2], Valerie Cummins[1], Joe Donnelly[3], Conceicao Fernandes[4], Sotirios Koukoulas[1], Vicki O'Donnell[1], Carlos Robalo[4], Daniel Vendas[2].

Authors in alphabetical order.

ABSTRACT: A selection procedure for the location of landfill sites, combining GIS systematics with rigorous site investigation methodologies, is outlined. The GIS model has been developed by Irish and Portuguese partners as an EU Interreg-funded project. Development of the GIS model was driven by the need to identify sites with suitable geological barriers to reduce potential risks of groundwater contamination by landfill leachate and to establish a scientific, non-biased approach to landfill site selection in order to promote public confidence in the scientific basis and overall transparency of the site selection process.
A three stage approach to the site selection process is recommended :-

Stage 1 Primary GIS screening stage, leading to identification of target areas for location of landfills.
Stage 2 Secondary GIS screening stage to identify suitable individual sites, utilising output from the previous stage, and involving more detailed local information and site-specific analysis.
Stage 3 Geotechnical evaluation stage, involving the rigorous geological/hydrogeological assessment of individual sites employing site investigation and laboratory techniques.

The developed GIS model pertains only to Stage 1. On completion of the site selection procedure, individual sites should be graded on a scale of suitability, and ranked in order of preference.

RÉSUMÉ Nous schématiserons dans ce qui suit une procédure de sélection pour l'emplacement de sites de décharge en combinant les techniques de Systèmes d'Information Géographique (S.I.G.) avec des méthodologies rigoureuses d'enquête sur le site. Le modèle S.I.G. a été développé par des partenaires irlandais et portugais dans le cadre d'un projet Interreg subventionné par l'Union Européenne. Le développement de ce modèle S.I.G. a été motivé d'une part par le besoin d'identifier ces sites dotés des barrières géologiques adécuates à la réduction des risques potentiels de contamination des nappes phréatiques par infiltration de contaminants rejetés, et d'autre part par le besoin d'établir une approche scientifique impartiale de sélection de sites de décharge dans le but de promouvoir la confiance publique par la démarche scientifique et la transparence totale du procédé.

Nous recommandons une approche de la sélection de site en trois étapes:

[1]**Coastal Resources Centre, Environment Research Institute, University College Cork, Ireland.**
[2]**Applied Geosciences Research Centre, New University of Lisbon, 2829 Caparica, Portugal.**
[3]**Cork County Council, County Hall, Cork, Ireland.**
[4]**Sesimbra Town Council, 2970 Sesimbra, Portugal.**

Première étape: étape primaire d'étude S.I.G., aboutissant à l'identification des zones cibles pour l'emplacement des décharges.

Deuxième étape: étape secondaire d'étude S.I.G., consistant à identifier des sites individuels adécuats par l'utilisation des informations reccueillies durant l'étape primaire, et mettant en jeu l'approfondissement de l'information locale et une analyse spécifique au site.

Troisième étape: étape d'evaluation géotechnique, mettant en jeu l'évaluation rigoureuse sur le plan géologique et hydrogéologique de sites individuels par l'emploi de l'enquête sur site et des techniques de laboratoire.

Le modèle S.I.G. développé s'inscrit uniquement dans l'étape primaire. Après avoir complété le procédure de sélection de site, chaque site individuel devrait être pondéré suivant une échelle de valeur convenable et classés par ordre de préférence.

INTRODUCTION

Landfill is the major method of disposal of waste in most countries, and will continue to be so for the foreseeable future. Selection of sites suitable for landfill is a critical part of landfill systematics, but within the EU, as a result of current EU policy of containment of all landfill emissions, which effectively requires the lining of all landfills, siting of landfills has been relegated to secondary importance. The assumption that any site can be engineered for landfill now prevails, with the consequence that unsuitable sites are being developed, on the premise that the landfill liner gives sufficient protection to the environment (Allen, 2001).

Recent research (e.g. Rollin et al., 1991; Thomas & Woods-DeSchepper, 1993; Duquennoi et al., 1995; Surmann et al., 1995) has indicated, however, that landfill liners are subject to severe deterioration over long time-scales due to the corrosive effects of leachate, and to the elevated temperatures generated by the exothermic processes operating within landfills. Furthermore, encapsulation of waste in a lined landfill, minimises the rate of degradation of the waste by isolating it from the natural agents of degradation, particularly rainwater - the main catalyst of degradation, (i.e. the waste is kept dry). This will have the effect of prolonging the activity of the waste and inhibiting its stabilisation to an inert state. Potentially the period of aftercare and monitoring could be prolonged for many tens or even hundreds of years (Allen, 2001). Thus long term, largely unpredictable, maintenance and monitoring costs after completion and capping of the landfill and after revenue earnings have ceased will ensue (Mather, 1995), with major implications for local authorities, landfill operators and regulatory agencies.

It is therefore prudent to seek and develop sites for landfill with natural characteristics, which can provide secondary protection to the environment in the event of failure of the landfill liner. Such sites are not uncommon, particularly in countries with thick overburden sequences, such as glacial overburden or tropical weathering profiles. Clay-rich overburden has a significant attenuation potential with respect to landfill leachate, and could be employed in conjunction with artificial liners or as a natural lining alternative to artificial liners.

With the advent of landsat and other remote sensing imagery defining infrastuctural and land use patterns, highly-sophisticated computerised GIS systems, and digitised map data, it is opportune to develop a more systematic approach to landfill site selection. Such an approach should ideally combine computerised GIS and geotechnical site investigation methodologies (Allen et al, 1997). There is also a need for greater transparency in the site selection procedure, in order to promote public confidence in the non-biased scientific basis of the process as a counter to the widely-encountered NIMBY syndrome.

In this presentation, a site selection procedure, which combines automated and non-automated GIS systematics with rigorous site investigation methodologies, is outlined. To this end, a GIS model for location of landfill sites has been developed under the auspices of an Interreg-funded EU project, by a team of Irish and Portuguese partners from University College Cork, Ireland (UCC), and the New University of Lisbon, (UNL), and from local authorities in each country, Cork County Council (CCC) in Ireland and Sesimbra Town Council (STC) in Portugal. The combination of these methodologies allows a rigorous approach to be adopted towards landfill site selection, and can accelerate the selection process and so reduce costs.

The landfill GIS model has been designed with a flexible site selection framework to enable it to have a transferable, trans-national capability. It has the potential to assist local authorities, both within the European Union and internationally, that are obliged to locate landfill sites over the next few years, with landfill site selection, and can also be of service to associated consultancies assisting in this selection process.

THE SITE SELECTION PROCESS

Future landfill site selection procedures need to be conducted within a framework designed to achieve the following objectives :-

1. To ensure that the most environmentally suitable site in terms of technical criteria, based on its impact on humans, flora, fauna, soil, water, air, climate and landscape, is selected
2. To integrate the site selection into an overall programme of regional development taking into account economic factors in siting the landfill
3. To engender a public consensus on the necessity of the landfill, and a perception that the site selection process has taken account of all relevant considerations and has balanced in a fair way, all sectional interests (eg. farming, tourism, industry, etc.)

The last objective, ultimately the greatest challenge facing local authorities and landfill operators, will only be achieved by openness and transparency in the process through a continuous programme of public consultation and dissemination of information, which should be initiated at the very beginning of the process (Begassat et al., 1995).

The main parameters impacting on the suitability of landfill sites are (Allen & MacCarthy, 1991) :-

- **Geological -** both bedrock and overburden lithology, and geological structure.
- **Hydrological/Hydrogeological -** infiltration and percolation rates and pathways of rainwater passing into and through the subsurface; subsurface hydrogeological features, i.e. aquifers; surface runoff characteristics.
- **Topographic -** height above sea level; surface slopes; exposure to the elements, particularly rain and wind.
- **Ecological -** effect on plant and animal habitats, biodiversity, etc.
- **Climate** - local microclimate, rainfall, wind velocity etc.
- **Geotechnical -** foundation characteristics, side slope stability relations, site design and operation requirements; mitigation of risks.
- **Social Impact -** noise; smell; dust; litter; vermin; insects; birds; visual impact; proximity to housing, domestic water wells, etc.
- **Economic -** distances from waste sources; road networks; site access; management costs arising from the physical characteristics of the site, etc.

In most circumstances, the first three groups of parameters will primarily control the technical suitability of sites, although, in certain circumstances, other factors may override these. For the selection process, it is necessary to establish criteria on a heirarchical scale, with weightings assigned to the different criteria, so that in the final selection process, the various site options can be ranked objectively in order of suitability.

The overall site selection process requires a three stage approach :-

Stage 1 A primary GIS screening stage, which leads to the identification of target areas for the location of landfills.

Stage 2 A secondary GIS screening stage in order to identify suitable individual sites, utilising output from the previous stage, and involving more detailed local information and site-specific analysis of parameters such as *overburden character and thickness, depth to the water table, site visibility impact, cost-distance relations, accessibility and climate*.

Stage 3 A geotechnical evaluation stage, involving a rigorous geological/hydrogeological assessment of individual sites identified within the target areas, employing a combination of site investigation and laboratory techniques.

The developed GIS model deals only with Stage 1. Stage 2 requires data that may not always be available, but theoretically would operate similarly to Stage 1. Stage 2 may also be deemed unnecessary if only a few suitable targets are generated in Stage 1, which then could lead directly on to Stage 3.

Stages 1 - The GIS Model

GIS requires the availability of abundant data sets, either in paper, map or digital form, but permits accurate processing of geographic data, specifically cartographic/numeric data, enabling processing, overlay and derivation of thematic maps, so furnishing tailored solutions for a whole series of applications (Della Bella et al., 1995). The GIS model has been broken down into 2 steps :-

Step 1 Exclusion of areas unsuitable for landfill

Step 2 Weighting of residual areas

Exclusion Areas

Exclusion areas are areas unsuitable for landfill because of risk to the environment, risk to human health, or excessive cost. This step of the landfill model is non-automated, which requires data capture, data input and data manipulation by the GIS user. The data capture process aims to obtain as many digital data sets as possible, but where digital data sets are not available, digitising may be required. For this step, data are in vector format and geo-processing techniques such as buffer and overlay are used to create the exclusion areas. Recommendations on ranges of buffer distances, based on a review of literature on landfill site selection (Zuquette & Gandolfi, 1991; Zuquette *et al,* 1994; Bagchi, 1994; Tecninvest, 1994; Della Bella et al, 1995; Langer, 1995; Chalkias & Stournaras, 1997; Costa, 1997; Heitfeld & Heitfeld, 1997; Jesus & Costa, 1997; Baban *et al*, 1998; Cantwell, 1999; Lin & Kao, 1999), are presented to the user for guidance in data preparation. The exclusion process essentially removes these areas from any further consideration within the model. Exclusion criteria are divided into 'non-geological' and 'geological and associated' factors (Table 1).

Table 1. Buffered exclusion areas in the landfill GIS model. Buffer distances allocated in the model are based on distances obtained from literature reviews. The model allows the user to enter alternative buffer distances if desired.

Exclusion areas	
1 - Non geological (antropic) factors	2 - Geological and correlated factors
Class A. BUILT • Urban & Hi-Tech Industrial Areas: (major/minor administrative centres, areas with > 10 houses per hectare) • Industrial Areas: (hazardous, manufacturing, food/agricultural) • Airports: (national, local, flight paths) • Roads: (highways, motorways, municipal, other etc.) • Railways • Water Supply: (reservoirs, wells, boreholes, springs) • Military Areas • Public Buildings/ Infrastructures: (hospitals, schools, gas stations, treatment plants) • Linear Infrastructures :(cables, pipelines, etc.) **Class B.** DESIGNATED AREAS • Nature Reserves: (ecological, biogenetic, etc.) • Agricultural and Game Reserves • Geological and Archaeological Reserves • Mining Areas not Suitable for Landfill • Leisure Areas: (speleological, parks, etc.)	**Class A.** HYDROLOGICAL AND GEOMORPHOLOGICAL • Rivers/Canals (permanent / temporary) • Floodplains • Lakes, Swamps • Coastline • Steep Slopes (> 20°) **Class B.** OTHER GEOLOGICAL FACTORS • Major Geological Faults:(active and potentially active, M_L >5, prone to surface rupture) • Regionally important aquifers with extreme vulnerability

Residual Areas

Residual areas remaining after the exclusion process is completed can be regarded as suitable for location of landfill sites. However, some land parcels within the residual areas may be more suitable for landfill location than others. For example, there may be environmental concerns about proximity to sites of ecological importance which may be regarded as important locally, but which may not yet be designated or protected in any way. Thus, residual areas need to be further examined in relation to a number of criteria. These have been divided into four main classes (Table 2).

Table 2. Classes and criteria for residual areas.

Class	Criteria
Class A – Susceptibility to Natural Hazards	Mass Movements; Active Erosion Processes; Volcanic Activity; Seismicity; Flood-Prone Areas;
Class B – Aquifer Protection Levels	Local Importance; Vulnerability; Recharge Areas
Class C – Land Use Capability	Agriculture & Silviculture; Ecological; Geological Resources;
Class D - Geo-Environmental Engineering	Natural Barriers; Foundation Workability; Foundation Stability Conditions; Foundation Slope Stability; Potential for Land Regeneration/Remediation Costs.

This step of the GIS model is an automated raster based process with a user-friendly software interface. All of the criteria are labelled with numerical values for the high, moderate and low susceptibility/suitability ranges. Classes such as susceptibility to natural hazards, aquifer protection levels and land-use capability are treated as negative for landfill. Criteria within these classes are mapped according to high, moderate or low susceptibility. The geo-environmental engineering class is treated as positive for landfill. The criteria within this class are mapped according to low, moderate or high suitability.

The GIS model enables the end user to evaluate the residual areas on the basis of multiple and conflicting criteria and objectives. Various weighting criteria were ranked by groups of experts, in a matrix that represents judgments in a pair wise comparison. Saaty's approach was used within the model as a default option (Saaty, 1980). However, the model has been kept flexible to allow the user to input weights based on other methods or knowledge if preferred. Saaty's approach is considered to be one of the most reliable methods in an evaluation of alternatives in single and multi-dimensional decision making problems (Triantaphyllou, 1985). An extension has been developed for ArcView GIS that will automatically calculate the weights for each category following inputs from the user.

The total evaluation (*te*) of the residual areas followed the model below:

$$te = \sum_{i=1}^{cri} C_i * a_i \tag{1}$$

where, C_i : the value of criterion i

α_i : the weight for criterion i

cri : the number of criteria

The range of *te* values are divided into suitability classes using statistical methods. Different numerical values are assigned to the criteria for successive runs of the model. A sensitivity analysis is carried out to evaluate if and how the outputs of each run are different. This will indicate whether the model is sufficiently stable/robust. The Kappa statistic (κ) introduced by Cohen (1960),

$$\kappa = (\text{Map 1 - Map 2}/(1 - \text{Map 2}) \tag{2}$$

is used to quantify the degree of agreement/disagreement of the output maps (of the sensitivity analysis). An assessment of whether these differences are statistically significant, or not, follows this procedure (see Koukoulas & Blackburn, 2001). This step is not part of the model available to end users, however, it is a fundamental component of the Interreg project and tests will be run to establish the robustness of the model prior to its completion.

The remaining, potentially suitable landfill sites require further screening to eliminate sites with unsuitable shapes and sizes. The model was developed using study areas in Ireland and Portugal. For the Portuguese study area, sites of approximately 20 hectares may be required, whereas for the Irish study area, sites of approximately 100 hectares are required for the development of a "superdump".

Stage 2 - The Secondary Screening Stage
The final output layer from stage 1 depicts classes of suitability, which can be further processed in stage 2. Stage 2 may in some circumstances not be deemed necessary, if few suitable target sites remain after stage 1. Furthermore, data sets essential for this more detailed GIS screening are likely to focus on the physical requirements of potential sites, such as type and thickness of overburden, depth to the water table etc. and in the absence of such data bases or if insufficiently accurate, a GIS approach may not be feasible. However it is still a useful exercise to undertake, as analyses such as visibility impact, cost distance relations, accessibility and impact of climate can be more effectively performed by GIS techniques with results readily portrayed by GIS graphics.

Stage 3 - Evaluation Stage
The evaluation process is concerned primarily with the geotechnical characteristics of the potential sites remaining after the screening stage(s). A detailed evaluation stage is essential to the site selection process, in order to establish the thickness and geological/hydrogeological characteristics of the natural geological materials underlying identified potential sites and will also be necessary to fulfil the requirements of an EIS. From a geological/hydrogeological standpoint, parameters which determine the suitability of sites for landfill (Allen & MacCarthy, 1991) are:-

- **Bedrock Lithology** - rock type, grainsize characteristics, texture, homogeneity, bedding characteristics, etc.
- **Overburden Lithology** - character, thickness and homogeneity of unconsolidated overburden.
- **Hydrological Properties** - of both bedrock and overburden, i.e. porosity, permeability, hydraulic conductivity, attenuation potential etc.
- **Geological Structure** - attitude of bedding, folding, faulting, jointing, including discontinuities on all scales.
- **Hydrogeology** - groundwater levels, distibution of aquifers and aquicludes, groundwater flow patterns etc.
- **Surface Runoff Patterns -** size and discharge of streams running through the site - controlled by the topography of the site.
- **Topography -** inclination of sloping sites, shelter from wind, visual impact

This phase of the selection process will mainly involve field and laboratory investigations of the various potential sites, with particular emphasis on the following techniques :-

- **Geophysical Surveys** - useful in determining the characteristics and thickness of the overburden deposits.
- **Hydrogeological Surveys** - mainly to determine the depth to the water table and the velocity and flow regime of the groundwater
- **Meteorological Programme** - to determine local wind velocities and rainfall characteristics.
- **Drilling Programme** - required to confirm the geophysical interpretation, to obtain drill core samples for laboratory investigation, and to use for downhole geophysical measurements of porosity, permeability etc.
- **Laboratory Programme** - primarily to determine laboratory porosity/permeability values and to ascertain the attenuation capacities of the overburden materials.

There are a number of geophysical techniques applicable to landfill site investigations. These are :-

- **<u>Electrical Resistivity</u>**
    - **Constant Separation Traverse (CST) -** contoured resistivity map produced - displays variations in depth to bedrock.
    - **Vertical Electrical Sounding (VES) -** determines depth to bedrock.

➢ **<u>Electromagnetic methods</u>**

❖ **Very Low Frequency (VLF)** - determines presence of fracture zones in buried bedrock.
❖ **VLF-R** - contoured resistivity maps produced - variation in nature of overburden emphasised. Presence of shallow bedrock indicated.

➢ **<u>Magnetics</u>** - differentiates between rock types with significant differences in magnetic properties e.g. basalt and chalk.

Geoelectrical methods are the most useful, but are inconvenient, involving laying out of lengths of cable, which in some types of terrain may not be possible. In such circumstances, the VLF-R technique is more convenient, combining the advantages of the geoelectric methods with electromagnetic methods, which are rapid. Magnetic methods have a limited application, but are useful where different bedrock types, such as basalt and chalk, which have distinctive magnetic susceptibilities (Gibson & Lyle, 1993; Lyle & Gibson 1994). Interpretations of overburden characteristics based on geophysical techniques need to be confirmed by drilling, as they are based on assumptions, which may not be valid in any specific case.

Hydrogeological surveys are necessary to establish the groundwater characteristics of any potential site. Parameters, which need to be ascertained, are (Dörhöfer & Siebert, 1995) :-

♦ General groundwater flow direction
♦ Hydraulic gradient
♦ Depth to the water table
♦ Nature of piezometric surface (confined, unconfined)
♦ Presence of aquifer beneath site
♦ Groundwater yield
♦ Type of groundwater
♦ Vulnerability to contamination
♦ Permeability of the material overlying the aquifer
♦ Location of the site relative to the nearest receiving stream

Whilst some of the above information may be obtainable from various types of groundwater maps provided they exist, it is unlikely that they will show the detail required for the evaluation of potential sites. Therefore, a thorough investigation of all known water wells and springs in the targeted areas will be essential, together with the analysis of all existing well data records. In addition it will be necessary to initiate a systematic well testing programme to determine groundwater levels, groundwater discharge patterns and particularly water quality from the earliest stages. In addition any boreholes existing in the target areas, or drilled as part of the subsequent drilling programme should be subjected to the same series of tests. Finally it may be necessary to undertake pumping tests on selected water wells to determine groundwater flow rates.

A meteorological investigation needs to be initiated early in the evaluation process, in order to obtain statistically acceptable data. This would generally involve the installation of automatic rain and wind gauges at potential sites to determine the climatic characteristics of the sites. However, prior to this, it is necessary to examine local meteorological records to determine rainfall and wind patterns. This investigation not only allows estimates to be made of the precipitation levels and wind velocities at the potential sites, it enables prediction of the recharge potential of groundwater at the sites, and the amount of rainwater which could infiltrate into the sites at any time. This can then be used to ascertain if the attenuation potential of the geological barrier is likely to be exceeded at any point. The need for shelter in the form of windbreaks either natural or artificial can also be assessed, and the types of tree species most suitable to the area surrounding the site for natural windbreaks can be evaluated, also using the overburden information obtained from drilling.

A drilling programme is the last phase of the evaluation process, which needs to be initiated, and is undertaken in order to obtain primary information on overburden characteristics, depth to bedrock and depth to the water table. However, this should only be embarked upon after all available pre-existing borehole data for the targeted areas have been collated as this will determine where drill sites are necessary. Drilling programmes within the potential sites should be constructed to confirm the bedrock and overburden geology and hydrogeological characteristics of the sites, and to determine the attenuation properties of the overburden. Also the drilling programme needs to be designed so that undisturbed drill core samples can be obtained for laboratory testing of porosity, permeability and attenuation properties. In addition, a whole series of in situ down-hole logging techniques, eg. Single Point Resistance, Natural γ Radiation, Caliper, Fluid Temperature, Fluid Velocity and Packer and Piezometric Permeability Measurements can be employed with boreholes to give further information about subsurface units and groundwater characteristics.

A major objective of the above evaluation programme is the assessment of the earth materials underlying the potential sites as geological barriers. A whole series of tests need to be conducted on potential geological barrier materials (Dörhöfer & Siebert, 1995):-

A. Field Characteristics

1. Thickness of the barrier materials
2. Distribution of the barrier materials
3. Homogeneity of the barrier materials
4. Petrography of the barrier materials
5. Structure of the barrier materials

B. Hydrogeological Characteristics

1. Hydraulic conductivity (in situ)
2. Hydraulic conductivity (lab)
3. Effective porosity
4. Hydraulic gradient
5. Groundwater flow direction
6. Groundwater flow velocity
7. Groundwater discharge
8. Depth to water table
9. Groundwater potential

C. Attenuation Characteristics

1. Hydrochemistry
2. Clay mineral content
3. Total porosity
4. Specific surface area
5. Cation exchange capacity
6. Total oxygen demand
7. Oxide/hydroxide content

D. Geotechnical Characteristics

1. Settlement (compressibility)
2. Stability (shear strength)

Environmental impact assessments, mandatory for landfills in many countries nowadays, generally include numerous geotechnical parameters, many of which are listed above, so their inclusion within the framework of the evaluation stage obviates the need to undertake them at a later stage.

It is recommended that a computer register of the sites be developed, and databases for all geological, hydrogeological and geotechnical information collected during the course of the investigation be established. Within the register, sites should be graded on a scale of suitability, and ranked in order of preference. Deficiencies of each of the sites investigated should be clearly indicated, together with an outline of proposed compensatory mitigation strategies.

At each stage in the selection process, particularly initially and at the completion of the screening and evaluation stages, reports should be published and distributed, and public meetings called to inform the public of the results of each stage of the process. At the initiation of the process, information to the public should include details of the local requirements in terms of landfills for the foreseeable future, information which is already available in local authority waste management plans. In addition, details of the criteria to be applied in the screening stage could be published and public participation sought, particularly with respect to the ranking and weighting of the different criteria. On completion of the screening stage, publication of the results of the screening stage should take place and again public consultation engaged in. In addition, an outline of the various components of the evaluation stage should be presented, again with the opportunity for the public to make contributions on any aspect of the evaluation process. Finally, after completion of the evaluation stage, full details of the results of the assessment of the various potential sites should be published, together with the grading in terms of suitability, and the ranking in order of preference. Again participation of the public in a consultation process must be encouraged, and in the event of intense opposition to the preferred site, which cannot be resolved, arbitration should be sought through some statutory body

CONCLUSIONS

Widespread public opposition to planning applications for landfills is a recent trend manifested in a number of countries, indicating that a new approach to the selection of landfill sites must be adopted if public support for the site selection process is to be enlisted. An open and transparent multicriteria landfill site selection procedure, with public consultation and participation at all stages in the process, is essential if public attitudes are to be reversed.

A three stage site selection procedure is proposed, consisting of computerised GIS initial and secondary screening stages, followed by a subsequent detailed evaluation stage, and integrated into regional land use planning. Natural geological barriers, particularly thick overburden sequences should be identified in the screening stage, and should be confirmed by geophysical and drilling techniques in the evaluation stage. Hydrogeological and meteorological investigations are also a necessary part of the evaluation process as are impact assessments on local communities, and the environment and ecology of the area.

Using the landfill GIS model as part of the site selection process can help to make the selection of a potential site for a landfill facility more transparent. The developed landfill GIS model fulfils the legislative and environmental obligations associated with site selection in a non-biased way, and the methodology ensures that there is a clear and scientific rationale behind the choice of a site. Including the methodology for the weighting of the criteria help to reduce the subjectivity of the exercise. The sensitivity analysis is an important step in the process as it assists in examining whether the model is sufficiently stable for operational use. The model provides a tool and a methodology for landfill site selection to local authorities, which will enable them to conduct their own GIS landfill site selection screening process.

Finally, it is stressed that the general public must be involved in the selection process right from the outset, through dissemination of information, consultation and public meetings. Only then will public approval of the site selection process be gained, and the final selection be accepted.

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