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Using GIS in waste management – some conceptual considerations

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Abstract. Landfill has been recognized as the cheapest form for the final disposal of municipal solid waste and as such has been the most used method in the world. However, siting landfill is an extremely complex task mainly due to the fact that the identification and selection process involves many factors and strict regulations. For proper identification and selection of appropriate sites for landfills careful and systematic procedures need to be adopted and followed. Wrong siting of landfill may result in environmental degradation and often time public opposition. Geographic Information System (GIS) technology provides an advanced modelling framework for decision makers in order to analyse and simulate various spatial waste management problems, including landfill site selection.
Key Words: waste, GIS, landfill, site selection.

Introduction. Waste management issues are coming to the forefront of the global environmental agenda at an increasing frequency, as population and consumption growth result in increasing quantities of waste. Moreover, technological development often results in consumer products of complex composition, including hazardous compounds, which pose extra challenges to the waste management systems and environmental protection at the end of their useful life, which may often be fairly short (e.g. cell-phones and electronic gadgets). These end-of-pipe challenges are coupled with the deepening understanding that the Earth's natural resources are finite by nature and their current exploitation rate unsustainable, even within a midterm perspective.

In the context of the above mentioned challenge a New Paradigm for waste management has emerged, shifting attention to resources efficiency and minimisation of environmental impacts throughout the life cycle of waste management, from waste prevention to safe disposal. This is best expressed, but not confined, in the relevant EU policy and legislation (e.g. the Thematic Strategy on the prevention and recycling of waste, the Thematic Strategy on the Sustainable Use of Natural Resources and the revised Waste Framework Directive, WFD-2008/98/EC). Especially the latter is of particular interest as it has a legally binding nature for all EU member states. The WFD reaffirms the need to move waste management higher in the so called "waste hierarchy", preferring, in this order, prevention, reuse, recycling and energy recovery over disposal.

About GIS. Geographic Information Systems (GIS) are one of the most sophisticated modern technologies to capture, store, manipulate, analyse and display spatial data. These data are usually organised into thematic layers in the form of digital maps. The combined use of GIS with advanced related technologies (e.g. Global Positioning System – GPS and Remote Sensing - RS) assists in the recording of spatial data and the direct use of these data for analysis and cartographic representation. GIS have been successfully used in a wide variety of applications, such as urban utilities planning, transportation, natural resources protection and management, health sciences, forestry, geology, natural disasters prevention and relief, and various aspects of environmental modelling and engineering.

In a Geographic Information System we can represent real world and objects in formats that can be stored, handled and displayed in a computer. The two most commonly used formats for representing the real world objects are vector and raster data models.

There are some main areas involving waste management and GIS: recording and representing the existing status, proposing suitable areas for implementation of waste management strategies (e.g. new waste disposal areas), optimisation of waste collection and transport, a.s.o. GIS can be used to store data concerning waste producers, amounts and types of waste produced. Data sets and layers of environmental characteristics such as land use, topography, hydrographic network, environmental protection zones, soil types, geologic features etc., combined with aero photographs and satellite images can give a good illustration of the current status. Digital Elevation Models can be used to represent the topography of the examined region in 3 dimensions.

GIS and waste management. Over the last three decades, advances in computer science have led to the creation of GIS, initially based on basic map layering concept. GIS combines spatial data (maps, aerial photographs, and satellite images) with quantitative, qualitative, and descriptive information databases, which can support a wide range of spatial queries. All of these factors have made GIS an indispensable tool for location studies (Church 2002), particularly for landfill siting.

Processing such data with conventional drawing and calculation tools is generally time-consuming. GIS, however, converts georeferenced data into computerized maps, while GIS map analysis tools also make it possible to efficiently manipulate maps with a computer. The advantages of using GIS for waste disposal and landfill site selection have been demonstrated by various researchers. Jensen & Christensen (1986) demonstrate the use of GIS in the selection of solid and hazardous waste disposal sites. GIS was subsequently used for the site selection of an industrial waste facility (Fatta et al 1998). In another research a method that identifies and ranks potential landfill areas for preliminary site assessment was presented (Siddiqui 1996). This method combines GIS with a decision-making method based on the analytic hierarchy process (AHP). Lin & Kado (1998) developed a mixed-integer programming model to obtain a site with optimal compactness. The compactness model was further extended to include multiple siting factors with weights that were determined by the GIS map layer analysis function.

GIS can be used to combine various demographic, geological, land use and census tract maps to apply landfill criteria, and find suitable areas to place a landfill (Michaels 1991). It was developed a prototype network GIS to increase the efficiency of complex solidwaste landfill siting (Kao et al 1996). Furthermore, this system makes site-related information available to the general public; assists local environmental protection agencies in maintaining a GIS; and helps the central environmental protection agency to manage, instruct, and evaluate the local siting process. It was described a spatial method that integrates multiple criteria analysis, GIS, spatial analysis, and spatial statistics with a view to evaluating a region for landfill siting (Kontos et al 2005).

The main steps of a typical GIS – based landfill allocation model are as following (Chalkias & Lasaridi 2011):

- conceptualisation of the evaluation criteria and the hierarchy of the landfill allocation problem. This step is dedicated to the selection of the criteria related to the problem under investigation;
- creation of the spatial database. Here, the development of GIS layers for the modelling is implemented. These layers correspond to the primary variables;
- construction of the criteria – layers within the GIS environment. Criteria maps are primary or secondary variables;
- standardisation of the criteria – layers. This step includes reclassification of the layers in order to use a common scale of measurement. Most often, the ordinal scale is used;
- estimation of the relative importance for the criteria. This estimation is implemented by weighting, e.g. with the use of Analytic Hierarchy Process (AHP) and pair wise comparison between variables;
- calculation of the suitability index. A standard procedure for this step is the weighted overlay of the standardised criteria/layers;

- zoning of the area under investigation is the next phase of the modelling. This classification action is based on the suitability index and reveals the most suitable areas for the application;

- sensitivity analysis and validation of the model;

- final selection – land evaluation.

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

- to ensure that the most environmentally suitable site is selected, in terms of technical criteria, including impact on humans, flora, fauna, soil, water, air, climate and landscape;

- to integrate the site selection into an overall programme of regional development taking into account economic factors in siting the landfill;

- 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 (e.g. 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).

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.;

- climatic - local microclimate, rainfall, wind velocity etc.;

- geotechnical - foundation characteristics, side slope stability relations, site design and operation requirements; mitigation of risks;

- social - 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 scale of hierarchies, 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.

Siting a landfill requires an extensive evaluation process in order to identify the optimum available disposal location. This location must comply with the requirements of the existing governmental regulations and at the same time must minimize economic, environmental, health and social costs.

GIS has been found to play a significant role in the domain of siting of waste disposal sites. Many factors must be incorporated into landfill siting decisions and GIS is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. The integration of GIS and Analytical Hierarchy Process (AHP) is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and AHP supplies consistent ranking of the potential landfill areas based on a variety of criteria. AHP is a systematic decision approach first developed by Saaty (1980). This technique provides a means of decomposing the problem into a hierarchy of sub-problems that can be more easily comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values that are ranked on a numerical scale (Bhushan & Rai 2004).

GIS modelling for the optimisation of waste collection and transport. The optimisation of the routing system for collection and transport of municipal solid waste is a crucial factor of an environmentally friendly and cost effective solid waste management system. The development of optimal routing scenarios is a very complex task, based on various selection criteria, most of which are spatial in nature. The problem of vehicle routing is a common one: each vehicle must travel in the study area and visit all the waste bins, in a way that minimises the total travel cost: most often defined on the basis of distance or time but also fuel consumption, CO_2 emissions etc.

Conclusion. GIS technology supports the optimisation of municipal solid waste management as it provides an efficient context for data capture, analysis and presentation. Two main categories of GIS-based waste management applications can be identified in the international literature. In the first, GIS is used for the selection of waste disposal landfills, and to a smaller extent, other waste treatment facilities. Most of these applications benefit from map overlay GIS functions and spatial allocation modelling methods. The final output of an application of that type is the suitability map of the area under investigation. This map could be the core of a spatial decision support system for a landfill site / waste treatment facility selection problem.

The second, more complex category of GIS supported waste management applications is related to waste collection. There are several applications for route optimisation, reallocation of waste bins and complete redesign of the collection sectors. The main aim of these applications is to reduce the collection distance and/or time of the collection vehicle fleet. The optimisation of routing has a direct positive impact on cost savings (reduction of fuel consumption and maintenance costs) as well as significant environmental impacts due to the lower levels of sound pollution within the urban environment and the reduction of greenhouse gases emissions.

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 must 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.

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