GIS in Municipal Solid Waste Management

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Abstract*:* Solid Waste Management (SWM) is an integral part of public health and environmental control. Improper handling of Solid waste leads to both economical and environmental sufferings. SWM includes control of generation, storage, collection, transfer/transport, processing and disposal of waste. Almost all factors related to SWM has both spatial and non-spatial components, thus, traditional ways of storing and analyzing data keeps data in isolated form, which results in inefficient management system. This paper reviews the use of Geographic Information System (GIS) in the field of SWM. GIS in areas related to SWM increases system efficiency, reduce workload, save time and cost, and helps in decision support system.

Key words: Geographical Information System (GIS), Landfill, Solid Waste Management (SWM), Waste collection and transport

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).

SOLID WASTE MANAGEMENT

Solid waste is composed of garbage or refuse, a broad array of materials discarded by households, businesses, industries, and agriculture. Solid waste can be discarded as food waste, paper, plastic, glass, rubber, wood, textile, metals, stones, rocks, and ceramics. The major sources of the solid waste are residential, institutional and commercial waste and City Corporation or municipal services (street sweeping) wastes [1].

Municipal Solid Waste (MSW) disposal has been enormous concern in developing countries due to poverty, population growth, urbanization and ineffectual fund (UNDP, 2004). MSW management is a big challenge due to number of problems including; inadequate management, lack of technology and human resources, shortage of collection and transport vehicles, and insufficient funding. Waste disposing is another important part of waste management system, which requires much attention to avoid environmental pollution. The most common problems associated with improper dumping includes; diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses. The effectiveness of solid waste disposal depends upon the selection of proper site and current global trend of waste management problems stems from unsustainable methods of waste disposal, which is ultimately a result of inadequate planning [2].

GIS

GIS is a computer system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data related to positions on the Earth's surface. Typically, a Geographical Information System is used for handling maps of one kind or another. These might be represented as several different layers where each layer holds data about a particular kind of feature. Each feature is linked to a position on the graphical image on a map and a record in an attribute table. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps you answer questions and solve problems by looking at your data in a way that is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework.

USES OF GIS IN SOLID WASTE MANAGEMENT

Solid waste management comprises several phases, starting from the stage where the waste is generated till it reaches its final destination or at a stage where it is no more a threat to the environment. It is observed that solid waste management can be bifurcated into mainly two phases. One is the waste management in the area where it is generated and second is the management of waste at dumping grounds."The development of Geographic Information System (GIS) and its use throughout the world has contributed a lot in improving waste management systems. GIS helps to manipulate data in the computer to simulate alternatives and to take the most effective decisions. GIS can add value to waste management applications by providing outputs for decision support and analysis in a wide spectrum of projects such as route planning for waste collection, site selection exercises for transfer stations, landfills or waste collection points. GIS provides a flexible platform which integrates and analyses maps and waste management databases.

GIS allows us to create and store as many layers of data or maps as we want and provides various possibilities to integrate tremendous amounts of data and map overlays into a single output to aid in decision making [3].

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Sarptas et al. [4] studied the use GIS in solid waste management in coastal areas as a decision support system with a case study on landfill site selection. The results of the study are that GIS is becoming a powerful tool in SWM. However there are still some drawbacks and deficiencies in applying the method extensively [4].

Since routing models make extensive use of spatial data, GIS can provide effective handling, displaying and manipulation of such geographical and spatial information. For example, Ghose et al. (2006) proposed a model for the system of Municipal Solid Waste (MSW) collection that provides planning for distribution of collection bins, load balancing of vehicles and generation of optimal routing based on GIS[5].

According to Reddy et al, traditional and static approaches are no longer adequate for analyzing network flows and conducting minimum cost routing. Reddy et al. attempted to develop a decision support system for generating an optimum route for solid waste disposal in Hyderabad City and hence to reduce the distance ran by the collection vehicle using GIS. GIS tool provides an effective decision support through its database management capabilities, graphical user interfaces and cartographic visualization. The system developed by Reddy et al. used the Network Analyst module available in Arcview, which is a path-finding program used to model the movement of resources between two points or more.

Chatila (2008) developed a GIS system for natural resources management and recycling of solid waste in the village of Marjeyoun in Southern Lebanon. A GIS map was prepared to serve as a zone management plan along with an environmental assessment that identifies cumulative pressures and impacts of some human activities on the village and the environment. A recycling program was developed based on solid waste sampling and analysis of collection systems.

In a study carried out by Bergeron et al., 3D visualization and GIS were used to produce a digital city model for the Star City, West Virginia to allow government officials and managers to manage assets and perform day-to-day operations, develop sustainable planning initiatives, and management of solid waste assets and facilities, planning for solid waste and recycling facilities and drop-offs, mapping and planning efficient waste hauler routes and identifying issues such a underserved populations and illegal dumping. However, building and using a GIS requires expert knowledge, and can often prevent such systems from being used to their full capability by local officials. In addition, local government is often comprised of mature citizens who are committed to serving their community but may be wary of new technologies that are unfamiliar to them.

There has been a significant increase in solid waste generation in India over the years from 100 gm per person per day in small towns to 500 grams per persons per day in large towns. Presently most of the municipal solid waste in India is being disposed unscientifically. Generally municipal solid waste is collected and deposited in sanitary landfill, such unscientific disposal attract birds, rodents and fleas to the waste dumping site and create unhygienic conditions (Suchitra, et al). The degradation of the solid waste results in the emission of carbon dioxide (CO_2), methane (CH_4) and other trace gases. Municipal solid waste management is one of the major problems that city planners face all over the world. The problem is especially severe in most developing country cities where increased urbanization, poor planning and lack of adequate resources contribute to the poor state of municipal solid waste management.

The environment is heading towards a potential risk due to unsustainable waste disposal. It is a sensitive issue, which concerns about serious environmental problems in today's world.

Local authorities (LAs) constitute worldwide the main providers of municipal solid waste (MSW) management services, either directly or indirectly through subcontracting part or all of these services. Especially waste collection and transport (WC&T) are typically provided at the local municipality level and constitute the main interface between the waste generator and the waste management system. Assessing the different components of the solid waste management costs is a complex, poly-parametric issue, governed by a multitude of geographic, economic, organisational and technology selection factors [6]. However, in all cases WC&T costs constitute a significant component of the overall waste management costs, which may approach 100% in cases where waste is simply dumped. For modern waste management systems WC&T costs vary in the range of 50-75% of the total, which overall is significantly higher, as advanced treatment and safe disposal take their own, large share of the total costs.

Therefore, the sector of WC&T attracts particular interest regarding its potential for service optimisation as (a) waste management systems with more recyclables' streams usually require more transport[7] and (b) this sector, even for commingled waste services only, already absorbs a large fraction of the municipal budget available to waste management[6]. Optimisation of WC&T making use of the novel tools offered by spatial modelling techniques and geographic information systems (GIS) may offer large savings, as it is analysed further here next.

GIS-BASED MODELLING FOR LANDFILL SELECTION

The primary idea of superimposition of various thematic maps in order to define the most suitable location according to the properties of the complex spatial units derived. The allocation of a landfill is a difficult task as it requires the integration of various environmental and socioeconomic data and evolves complicated technical and legal parameters. During this process the challenge is to make an environmentally friendly and financially sound selection. For this purpose, in the last few decades, many studies for landfill site evaluation have been carried out using GIS and multicriteria decision analysis[7]; GIS in combination with analytic hierarchy process]8] – AHP[3], GIS and fuzzy systems [3]; GIS and factor spatial analysis [9], as well as GIS-based integrated methods [10].

A large fraction of these applications produce binary outputs while most recent ones aim at evaluating a "suitability index" as a tool for ranking of the most suitable areas [11]. The main steps of a typical GIS – based landfill allocation model (Fig.1) are as following.

a. 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.

b. Creation of the spatial database. Here, the development of GIS layers for the modeling 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.

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d. 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.

e. 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.

f. Calculation of the suitability index. A standard procedure for this step is the weighted overlay of the standardised criteria/layers.

g. 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.

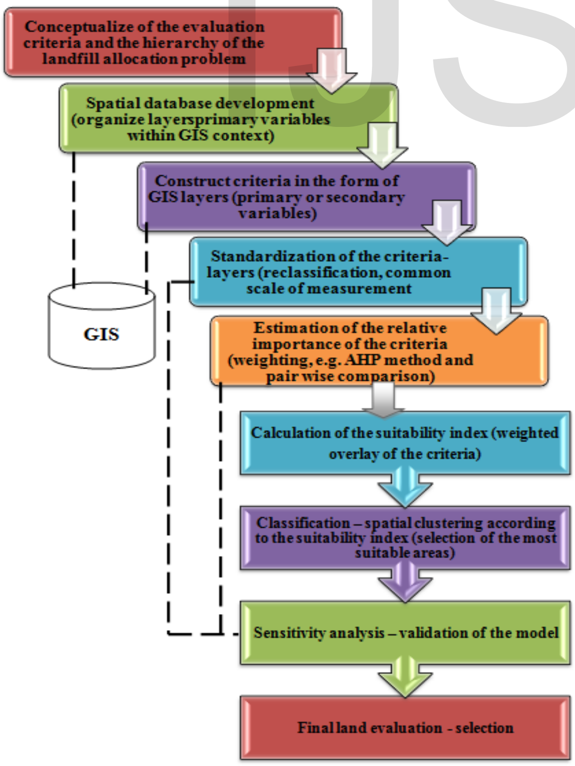

Fig. 1 Landfill site selections - A GIS approach (Source: [22]

h. Sensitivity analysis and validation of the model.
i. Final selection – land evaluation.

It should be noticed that for most of the aforementioned functions the geographic background (in digital format) of the area under investigation is required. Figure 1 demonstrates the data flow of the adopted procedure. Additionally, the incorporation of various spatial analysis methods, such as geostatistics, analytical hierarchy process, fuzzy logic modelling and many others, constitutes a major advantage of a GIS-based modelling approach. Finally, a particularly useful option of a GISbased decision making model is the combination of experts knowledge with the opinions of citizens and stakeholders[7].

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. This is very similar to the classic Travelling Salesman Problem (TSP) [12]. However, the problem of optimising routing of solid waste collection networks is an asymmetric TSP (ATSP) due to road network restrictions; therefore adaptations to the classic TSP algorithm are required, making the problem more complex.

As the success of the decision making process depends largely on the quantity and quality of information that is made available to the decision makers, the use of GIS modelling as a support tool has grown in recent years, due to both technology maturation and increase of the quantity and complexity of spatial information handled (Santos et al., 2008). In this context, several authors have investigated route optimisation, regarding both waste collection in urban and rural environments and transport minimisation, through improved siting of transfer stations , landfills [14] and treatment installations for integrated regional waste management [13] Optimisation of WC&T making use of the novel tools offered by spatial modeling techniques and GIS may provide significant economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions[15]. These systems are particularly rare in Greek local authorities, where WC&T is typically organised empirically and in some cases irrationally, under public pressures.

According to Tavares et al. (2008) "effective decision making in the field of management systems requires the implementation of vehicle routing techniques capable of taking advantage of new technologies such as the geographic information systems"[16].

Sahoo et al. (2005) presented a comprehensive route-management system, the Waste Route for the optimal management of nearly 26000 collection and transfer vehicles that collect over 80 million tons of garbage every year for more than 48 states of USA [17].

Alvarez et al. (2008) presented a methodology for the design of routes for the “bin to bin” collection of paper and cardboard waste in five shopping areas of the city of Leganés (Community of Madrid, Spain). Their proposed system was based on GIS technology and optimised urban routes according to different restrictions. From the comparison of their system with the previous situation they concluded that the proposed “bin to bin” system improved the quality of the paper and cardboard in the containers, avoiding overflow and reducing the percentage of rejected material [18].

Teixeira et al. (2004) applied heuristic techniques to solve a collection model in order to define the geographic zones served by the vehicles, as well as the collection routes for recyclable waste collection of the centre-littoral region of Portugal. The study indicated that proper modelling of the collection procedure can provide cost effective solutions[19].

Nuortio el al. (2006) developed a GIS-based method for the optimisation of waste collection routes in Eastern Finland. They estimated an average route improvement in comparison with the existing practice of about 12%. Moreover they proposed a combination of routing and rescheduling optimisation. This combination in some cases introduced extremely significant savings (~40%). They concluded that by allowing rescheduling it is possible to significantly increase the improvement rate [20].

Karadimas & Loumos (2008) proposed a method for the estimation of municipal solid waste generation, optimal waste collection and calculation of the optimal number of waste bins and their allocation. This method uses a spatial Geodatabase, integrated in a GIS environment and was tested in a part of the municipality of Athens, Greece. After the reallocation of the waste bins, their total number was reduced by more than 30%. This reduction had a direct positive impact on collection time and distance [21].

Chalkias & Lasaridi (2009) developed a model in ArcGIS Network Analyst in order to improve the efficiency of waste collection and transport in the Municipality of Nikea, Athens, Greece, via the reallocation of waste collection bins and the optimisation of vehicle routing in terms of distance and time travelled. First results demonstrated that all the examined scenarios provided savings compared to the existing empirical collection organisation, in terms of both collection time (savings of 3.0% -17.0%) and travel distance(savings of 5.5% - 12.5%)[22].

Apaydin & Gonullu (2006) developed an integrated system with the combination of GIS and GPS technology in order to optimise the routing of MSW collection in Trabzon city, northeast Turkey. The comparison of the proposed optimised routes with the existing ones revealed savings of 4–59% in terms of distance and 14-65% in terms of time, with a benefit of 24% in total cost[23]. Finally, Kanchanabhan et al. (2008) attempted to design and develop an appropriate storage, collection and routing system for Tambaram Municipality in South Chennai, India using GIS. The optimal routing was investigated, based on population density, waste generation capacity, road network, storage bins and collection vehicles. They roughly estimated 30% cost-savings with this approach [24].

Benefits of GIS:

GIS environmental management solutions enable organizations to

• Ensure accurate reporting with improved data collection.

• Improve decision making.

• Increase productivity with streamlined work processes.

• Provide better data analysis and presentation options.

• Model dynamic environmental phenomena.

• Create predictive scenarios for environmental impact studies.

• Automate regulatory compliance processes.

• Disseminate maps and share map data across the Internet.

Application of GIS:

- Wild Land Analysis
- Emergency Services like Fire Prevention
- Hazard Mitigation and Future planning
- Air pollution & control
- Disaster Management
- Forest Fires Management
- Managing Natural Resources
- Waste Water Management
- Oil Spills and its remedial actions
- Sea Water – Fresh water interface Studies
- Coal Mine Fires

CONCLUSIONS

GIS technology supports the optimisation of municipal solid waste management as it provides an efficient context for data capture, analysis and presentation. 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.

GIS supported waste management applications are 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 implementation of GIS-based modelling for waste collection optimisation in many countries with different socioeconomic conditions and technological background shows that significant savings could be achieved in most setups. 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.

REFERENCES

[1] Afroz, R. ‘Sustainable household waste management improvement in Dhaka City,Bangladesh’, *Int. J. Environment and Sustainable Development* , Vol. 10, No. 4, pp.433–448, 2011

[2] Abbas, I.I., Nai’ya, R. and Arigbede, Y.A. . Use of remote sensing and GIS in effective and efficient solid management planning: A case study of Samara, Zaria, Nigeria. Res. J. Earth Planet. Stud., 2, 46-52, 2011.

[3] Chang, N.B.; Parvathinathan, G. & Breeden, J.B. Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management, Vol. 87, pp. 139-153, ISSN 0301-4797, 2008

[4] Sarptas, H., Alpaslan, M. N., Dolgen, D. GIS supported solid waste management in coastal areas. Water Science and Technology, Vol. 51, No. 11, 2005, pp. 213–220, ISSN:0273-1223

[5] Ghose, M.K.; Dikshit, A.K. & Sharma S..K. . A GIS based transportation model for solid waste disposal - a case study of Asansol Municipality. Waste Management, Vol.26, pp. -257-168, 2006.

[6] Lasaridi, K. Implementing the landfill directive in Greece: problems, perspectives and lessons to be learned. Geographical Journal, Vol. 175, No.4, December 2009, pp. 261-273, 2009

[7] Geneletti, D. Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Waste Management, Vol. 30,, pp. 328-337, ISSN 0956-053X, 2010.

[8] Saaty, T. L. The analytic hierarchy process, (p. 287), ISBN: ISBN 0-07-054371-2, New York: McGraw-Hill, 1980

[9] Biotto, G.; Silvestri, S.; Gobbo, L.; Furlan, E.; Valenti, S. & Rosselli, R. GIS, multicriteria and multi-factor spatial analysis for the probability assessment of the existence of illegal landfills. International Journal of Geographical Information Science, Vol. 23, No.10, pp. 1233-1244, 2009.

[10] Zamorano, M., Molero E., Hurtado A., Grindlay A., Ramos, A. Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology. Journal of Hazardous Materials, Vol. 160, No. 30, December 2008, pp. 473-481,, 2008.

[11] Kontos, T.D.; Komilis, D.P. & Halvadakis, C.P. Siting MSW landfills with a spatial multiple criteria analysis methodology. Waste Management, Vol. 25, pp. 818– 832, ISSN 0956-053X, 2005

[12] Dantzig, G.B; Fulkerson, D.R. & Johnson, S.M. Solution of a large-scale travelling salesman problem. Operations Research, Vol.2, pp. 393-410, ISSN 0030-364X, 1954.

[13] Adamides, E.D.; Mitropoulos, P.; Giannikos, I. & Mitropoulos, I. A multimethodological approach to the development of a regional solid waste management system. Journal of the Operational Research Society, Vol. 60, pp. 758-770, 2009

[14]Despotakis, V.K. & Economopoulos, A.P. A GIS model for landfill siting. Global NEST Journal, Vol. 9, No.1, pp. 29-34, ISSN 1790-7632, 2007

[15] Johansson, O.M. The effect of dynamic scheduling and routing in a solid waste management system. Waste Management, Vol. 26, pp. 875-885, ISSN 0956-053X, 2006.

[16] Tavares, G., Zsigraiova, Z., Semiao, V., Carvalho, M. A case study of fuel savings through optimization of MSW transportation routes. Management of Environmental Quality, Vol.19, No.4, pp. 444-454, ISSN: 1477-7835, 2008.

[17] Sahoo, S., Kim, S., Kim, B-I., Kraas, B., Popov, A.. Routing Optimization for Waste Management. Interfaces, Vol. 35, No. 1, January 2005, pp. 24-36, ISSN: 0092-2102, 2005.

[18] Alvarez, J.V.L.; Larrucea, M.A.; Quero, S.F-C. & Del Valle, A.J. Optimizing the collection of used paper from small businesses through GIS techniques: The Leganés case (Madrid, Spain). Waste Management, Vol. 28, pp. 282-293, ISSN 0956- 053X, 2008.

[19] Teixeira, J., Antunes, A., P., de Sousa, J., P. Recyclable waste collection planning–a case study. European Journal of Operational Research, Vol. 158, No. 3, November 2004, pp. 543-554, ISSN: 0377-2217, 2004.

[20] Nuortio T., Kytöjokib J., Niska H., Bräysy O. Improved route planning and scheduling of waste collection and transport. Expert Systems with Applications, Vol. 30, No. 2, February 2006, pp. 223-232, 2006.

[21] Karadimas, N.V.& Loumos, V.G. GIS-based modeling for the estimation of municipal solid waste generation and collection. Waste Management & Research, Vol. 26, pp. 337-346, 2008.

[22] Chalkias, C. & Lasaridi, K. . A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. WSEAS Transactions on Environment and Development, Vol. 5, No. 10, pp. 640-650, 2009.

[23] Apaydin, O. & Gonullu, M.T. . Route optimization for solid waste collection: Trabzon (Turkey) case study. Global NEST Journal, Vol. 9, No.1, pp. 6-11, ISSN 1790-7632, 2007.

[24] Kanchanabhan, T.E.; Abbas Mohaideen, J.; Srinivasan, S. & Lenin Kalyana Sundaram, V. . Optimum municipal solid waste collection using geographical information system (GIS) and vehicle tracking for Pallavapuram municipality. Waste Management & Research, Vol. 29, pp. 323-339, 2011.

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