Review

GIS-based approach for optimized siting of municipal solid waste landfill

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Abstract

The exponential rise in the urban population of the developing countries in the past few decades and the resulting accelerated urbanization phenomenon has brought to the fore the necessity to develop environmentally sustainable and efficient waste management systems. Sanitary landfill constitutes one of the primary methods of municipal solid waste disposal. Optimized siting decisions have gained considerable importance in order to ensure minimum damage to the various environmental sub-components as well as reduce the stigma associated with the residents living in its vicinity, thereby enhancing the overall sustainability associated with the life cycle of a landfill.

This paper addresses the siting of a new landfill using a multi-criteria decision analysis (MCDA) and overlay analysis using a geographic information system (GIS). The proposed system can accommodate new information on the landfill site selection by updating its knowledge base. Several factors are considered in the siting process including geology, water supply resources, land use, sensitive sites, air quality and groundwater quality. Weightings were assigned to each criterion depending upon their relative importance and ratings in accordance with the relative magnitude of impact. The results from testing the system using different sites show the effectiveness of the system in the selection process.

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1. Introduction

In developing countries, the ever increasing human population and the associated anthropogenic activities have accelerated the phenomenon of urbanization in the past decade. In India, the rate of increase of urban population shot from 11% in 1901 to about 26% in 2001. The census of 2001 indicates the fact that presently 25.73% of the total population resides in the urban centers, which has been forecast to rise to 33% in the next 15 years. The rapid growth rates of the cities, combined with their huge population base, has left many Indian cities lacking in basic infrastructure services like water supply, sanitation and sewerage, and solid waste management. With the rising population and the associated unsustainable practices, there has been an enormous increase in the quantum as well as the diversity of the solid waste being generated. The problem of solid waste has assumed significant dimension especially in the urban centers. Domestic, industrial and other wastes, whether these are of low or medium level, have become a perennial problem as they continue to cause environmental pollution and degradation. Poor waste management systems coupled with hot climatic conditions results in increasing environmental problems with significant local as well as global dimensions. The need of the hour is to devise an efficient solid waste management system wherein decision-makers and waste management planners can deal with the increase in complexity, uncertainty, multi-objectivity, and subjectivity associated with this problem.

In spite of the increasing stress towards the waste reduction at the source, as well as recovery and recycling of the solid waste, disposal of solid waste by landfilling remain the most commonly employed method. Landfill incorporates an engineered method of disposal of solid waste on land in a manner that minimizes environmental hazards by spreading the solid waste in thin layers, compacting the solid waste to the smallest practical volume and applying a cover at the end of the operating day. However, with the increased population density and urban infrastructure, several key considerations are required to be taken into account to ensure its overall sustainability, especially those associated with its economics, optimized siting and operation. The development of a municipal solid waste landfill requires the acquisition of large tracts of land and its suitable siting in a pre-existing urban matrix comprised of diverse competing land uses. Siting decisions are governed by the pre-existing land use dynamics of the urban area as well as the nature of potential interactions of the landfill with the pre-existing environmental, geologic, hydrological, and socio-economic parameters of the area. In the domain of the science of solid waste management, identification of landfill sites for solid waste disposal remains a critical management issue wherein the selection should be based on a number of considerations (Dipanjan et al., 1997; CPCB, 1999). Siting a sanitary landfill requires an extensive evaluation process in order to identify the best available disposal location. This location must comply with the requirements of governmental regulations and at the same time must minimize economic, environmental, health and social costs. The site selection procedure, however, should make maximum use of the available information and ensure that the outcome of the process is acceptable by most stakeholders. Therefore, landfill siting generally requires processing of a variety of spatial data.

The present study focuses on an optimized land use site selection based on multi-criteria decision analysis and geographic information system based (GIS) overlay analysis. The most appropriate landfill site has been identified for Pondicherry, a typical urbanizing city of India. Several important factors and criteria were considered to arrive at the optimum siting decision including the pre-existing land use, location of sensitive sites, infiltration, water bodies, water supply sources, groundwater quality, air quality, fault line and geology. Thematic maps of the selected criteria were developed within the paradigm of standard GIS software. Subsequently, weightings were assigned to each criterion depending upon their relative importance, and ratings in accordance with the relative magnitude of impact. A GIS-based overlay analysis was performed to identify the optimum site for the landfill, one which fulfilled all of the desired attributes.

2. Landfill siting and the potential application of GIS

The evaluation of a new waste disposal site is a complicated process as it requires considerable expertise in diverse social and environmental fields, such as soil science, engineering, hydro-geology, topography, land use, sociology, and economics. Methods of evaluating new landfill sites take into consideration parameters such as distance to roads, habitation, key infrastructure elements and the pro-
pensity of soil to leach contaminants. Therefore, the siting of a solid waste landfill must also involve processing of a significant amount of spatial data, regulations and acceptance criteria, as well as an efficient correlation between them. Some of the promising methods for landfill siting evaluation have been discussed by Gebhardt and Jankowski (1987), Swallow et al. (1992), Chen and Kao (1997) and Sasao (2004).

In recent years, GIS has emerged as a very important tool for land use suitability analysis. GIS can recognize, correlate and analyze the spatial relationship between mapped phenomena, thereby enabling policy-makers to link disparate sources of information, perform sophisticated analysis, visualize trends, project outcomes and strategize long-term planning goals (Malczewski, 2004). GIS has often been employed for the siting and placement of facilities (Church, 2002). The pioneering work in this field was initiated by McHarg (1969) who enunciated the basic mapping ideas for site suitability analysis; especially those that involve delineating the best route connecting two points or identifying the best location for a specific function. His idea involved the preparation of thematic maps and superimposing them on top of one another to view the composite configuration so as to decide upon the most suitable location in relation to the pre-existing set of interacting factors. With the evolution of GIS and the subsequent developments in the field of location science, considerable focus was placed upon its potential application for optimized siting. The earliest application of GIS in this direction included the analysis conducted in the 1970s, especially those by Kiefer and Robbins (1973), Durfee (1974), Voelker (1976) and Dobson (1979). At about the same time, Clark (1970), Helms and Clark (1971) and Esmaili (1972) generated models to determine facility locations, capacities and expansion patterns. Several realistic solid waste management models were formulated by applying and refining various optimization techniques. Fuertes (1974) included social equity issues in choosing the site for the facilities. The landfill selection problems have often been tackled using MCDA.

GIS has been found to play a significant role in the domain of siting of waste disposal sites. The potential advantage of a GIS-based approach for siting arises from the fact that it not only reduces time and cost of site selection, but also provides a digital data bank for long-term monitoring of the site. GIS may also play a key role in maintaining account data to facilitate collection operation and provide customer service, analyzing optimal locations for transfer stations, planning routes for vehicles transporting waste to transfer stations and from transfer stations to landfills, as well as long-term monitoring of landfills. Other advantages of applying GIS in the landfill siting process may include:

- Selection of objective zone exclusion process according to the set of provided screening criteria.
- Zoning and buffering.

- Performing ‘what if’ data analysis and investigating different potential scenarios related to population growth and area development, as well as checking the importance of the various influencing factors etc.
- Handling and correlating large amounts of complex geographical data
- Visualization of the results through graphical representation.


Along with the proliferation of GIS technology, ever since the 1950s, multiple criteria decision making methods (MCDA) have evolved as a major tool to assist decision makers with analyzing and solving multiple criteria decision problems. MCDA methods have been developed to assist decision makers in either ranking a known set of alternatives for a problem or making a choice among this set while considering the conflicting criteria. Generally, the alternatives are compared against each other based on how they perform relative to each criterion. Similarly, some methods require comparison of the criteria to arrive at the relative importance of each criterion. Thereafter, MCDA methods utilize this information to assign ranks to the alternatives. Some of the important methods of MCDA have been summarized by Keeney and Raiffa (1976), Zeleny (1982), Yoon and Hwang (1995), Gal et al. (1999) and Figueira et al. (2005). In recent years, the integration of MCDA techniques with GIS has considerably advanced the map overlay approaches to sit suitability analysis (Carver, 1991; Banai, 1993; Eastman, 1997; Malczewski, 1999). A GIS-based MCDA integrates and transforms spatial and aspatial data into a decision. It involves the utilization of geographical data, the decision maker’s preferences and the manipulation of data and preferences to arrive at uni-dimensional values of alternatives.

The siting of a new landfill in a given urban matrix requires a multitude of considerations. Consequently, it may be considered as a rather complex multi-criteria decision making process involving numerous stakeholders and public interest groups. Hipel (1982) proposed an earlier version of multi-criteria modeling incorporating fuzzy set theory to solve solid waste disposal problems in Canada. MCDA have primarily been employed to solve site selection problems in solid waste management (Vuk et al., 1991; Pereira and Duckstein, 1993; Hokkanen and Salminen, 1994, 1997). Kontos et al. (2005) described a methodology which comprises several methods from different scientific fields such as multiple criteria analysis, geographic information systems, spatial analysis and spatial statistics to evaluate the suitability of the study region in order to optimally site a landfill. Padmaja et al. (2006) identified a solid waste disposal site in Hyderabad city using an analytical hierarchy process and GIS.
An integrated approach incorporating the application of GIS and MCDA methods have been employed for the suitability analysis of landfills in an urban matrix (Minor and Jacobs, 1994; Kao and Lin, 1996; Siddiqui et al., 1996; Lin and Kao, 1998; Allen et al., 2002; Kontos et al., 2005).

3. Geographical extent and background information about the study

The Union Territory of Pondicherry comprises of four interspersed geographical entities namely Pondicherry, Karaikal, Mahe and Yanam, having a total area of 492 km², located in southern India. The study area is the district of Pondicherry which is the first largest among the four regions. It has an area of 293 km² located between latitudes 11° 46' N and 12° 03' N and longitudes 79° 36' and 79° 53' E. It is located along the Coramandal coast of India, being limited on its east by the Bay of Bengal and on the other three sides by the Cuddalore district of Tamil Nadu State (Fig. 1). As per the census of India, 2001, the total population of the Pondicherry is 735,004 and it is rising at an annual rate of 2% (PPCC, 2005). It is one of the fast growing urbanizing regions of southern India with increasing investments being made for the industrial and tourism sector. The urban population stands at 505,715 which is 68.8% of the total population.

The built-up area of Pondicherry has shown a considerable growth in the past decade. The core urban area constituting the city occupies an area of 25.5 km². Settlements comprising of housing, towns, villages currently occupy 5.37%, while with plantations it occupies 21.30% of the total geographical area. The areas occupied by industries have also shown an increasing trend rising from 0.22 km² in 1990 to 0.34 km² in 1998 and 0.70 km² in the year 2002. The region has shown all the potential attributes to develop in to a major urban centre in the next few years.

A closer look at the scenario of municipal solid waste generation indicates that major generation sources in Pondicherry are households, markets, bus stands, hotels, restaurants, marriage halls, Government offices, parks, cattle and hospitals. The total quantity of waste generated in Pondicherry averages 300 tons/day. Average per capita solid waste generation in Pondicherry averages approximately 450 g/day. A qualitative analysis indicates that the solid waste generated in Pondicherry contains a fairly high percentage of organic matter, as high as 70–80% dry weight, and has a low calorific value ranges between 1900 and 2600 kJ/kg. Currently, the management of solid waste is being looked after by Local Administration Department through municipalities. However, any organized method of waste disposal is yet to be practiced; solid waste is disposed of by open dumping. The present system of primary collection of garbage is through bins; about 500 dust bins are kept in residential areas for the collection of wastes. However, no systematically organized method of waste disposal is being practiced in the district.

In recent years, there has been consensus amongst the decision makers and town planners towards the evolution of mechanisms to reorganize the primary and secondary waste collection system at Pondicherry, as well as to the establishment of a centralized landfill at an appropriate location to cater to the needs of the entire district. The present study has been an effort towards this direction, primarily focusing towards the selection of an optimized land use site for the municipal solid waste landfill. Multi-criteria decision analysis has been employed to identify the key...
governing factors affecting landfill siting and subsequently operating within the paradigm of GIS, an optimized site was identified through an overlay analysis of the map layers characterizing the thematic factors.

4. Site selection criteria

Siting a sanitary 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 (Siddiqui et al., 1996). In assessing a site as a possible location for solid waste landfilling, many factors could be considered (Savage et al., 1998; UNEP, 1994). These factors may be presented in many ways; however, the most useful way is the one that may be easily understood by the community (Tchobanoglous et al., 1993).

In the present study, the guidelines of Central Pollution Control Board, India (CPCB, 2003) and that of Central Public Health and Environmental Engineering Organization (CPHEEO, 2000) were considered for landfill site identification. The selection of disposal sites was carried out through a multi-level screening process. Subsequently, a GIS-based constraint mapping was employed to eliminate the environmentally unsuitable sites and to narrow down the number of sites for further consideration. The list of factors considered for selecting the disposal sites (Sumathi, 2006) are as indicated:

- lake and ponds,
- rivers,
- water supply sources,
- groundwater table,
- groundwater quality,
- infiltration,
- air quality index,
- geology,
- fault line,
- elevation,
- land use,
- habitation,
- highways,
- sensitive sites.

4.1. Thematic maps preparation and GIS analysis

The primary data sources for the study included the toposheets of Pondicherry viz., 58 M/13, 58 M/9, 57 P/16 and 57 P/12 of the scale 1:50,000, which were used to prepare the base map for the study. Water bodies, road network and elevation maps were prepared based on the Survey of India map by digitization. Geology, soil, fault line, water supply sources, and groundwater maps were collected from departments and subsequently digitized. The land use map was generated through the image interpretation and classification of the Indian Remote Sensing satellite IRS1D imagery of Pondicherry of 22.8 m resolution. Subsequently, the thematic maps of habitation, sensitive sites and waste lands were derived from land use map using standard procedures. Secondary data was collected by ground truth and surveys conducted at the concerned sites. The digitization and analysis of the thematic maps were performed within the framework of the well known desktop GIS software; Arc GIS Desktop 9.0 available at the Department of Civil Engineering, Anna University. Digital thematic maps were generated by employing the following procedures:

- Scanning of the available primary paper maps.
- Geo referencing the scanned maps to earth coordinates.
- On screen digitizing of the primary maps, thereby generating the digital thematic maps, each characterizing the influencing factor for landfill site selection.
- Locating the GPS coordinates and entering in the data base as latitude and longitude.
- Conversion of the latitude and longitude data into the point data using the software.
- Addition of the attribute data to the locations.

The air quality index map was generated from the air quality data collected by the Department of Science, Technology and Environment, Pondicherry. Thereafter, the air quality index (AQI) was computed and classified based on the model prepared by Tiwari and Manzoor (1987). The geometric mean of ‘n’ no. of parameters was taken as air quality index and then AQI was categorized into different classes as shown in Table 1.

\[
\text{AQI} = \left[ \left( \frac{\text{Obs}}{\text{Std}} \right)_{\text{SO}_2} \times \left( \frac{\text{Obs}}{\text{Std}} \right)_{\text{NO}_2} \times \left( \frac{\text{Obs}}{\text{Std}} \right)_{\text{SPM}} \right]^{1/3} \times 100
\]

Buffer maps indicating regions encompassing appropriate areas from lakes, ponds, rivers, water supply sources, habitation, highways and fault line were also generated to act as ‘areas of constraints’, i.e., where a landfill can not be sited.

4.1.1. Water bodies map

A water bodies map (Fig. 2) indicating the ponds, lakes and rivers located in the Pondicherry region was prepared
through digitization of the Survey of India map. There are two major lakes, viz. Bahour and Ousteri, which are used for agriculture. The region is also drained by two rivers, namely Sankaraparani and Pennaiyar, which along with their tributaries drain into the Bay of Bengal.

4.1.2. Road network map

The road network map (Fig. 3) delineating the national highways and other major roads in the Pondicherry region was prepared. There are three NH 45 A and one NH 66 highways in the Pondicherry region.

4.1.3. Land use map

The land use map (Fig. 4) displays the land utilized by the human and the natural cover in the Pondicherry region. It is the basic map of the study and helps in generating many thematic maps required for overlay analysis. It was developed by image interpretation and classification of the IRS satellite imagery. The land use map indicates the areas of settlements, double crop land, single crop land, waste land, water bodies and rivers. The majority of the regions occupied by double crops include cultivation of paddy and groundnut while single crops include mainly sugar cane and tapioca. Waste lands are scattered more towards the northern part of the region. The majority of the settlement areas occur along the coast.

4.1.4. Sensitive sites map

A sensitive sites map (Fig. 5) was developed by the digitization of the major cultural, archaeological and histori-
cal sites; these sites are restricted from the development of landfill. About 280 years of French rule had left a unique urban form within Boulevard town; the invaluable heritage needs to be conserved in its special ambience and therefore the Boulevard area has been identified as a heritage zone. The Archaeological Survey of India has identified the following four temples in the Pondicherry region as national monuments:

- Sri Moolanathar Swami Temple at Bahour,
- Sri Panchadeeshwara Swami Temple at Thiruvandarkoil,
- Sri Varadharaja Perumal Temple at Thirubhuvanai and
- Sri Thirukandeshwara Temple at Nallur.

Arikkamedu, an historical place and an ancient excavated site, is situated on the southern bank of the river Ariyankuppam and has also been included as a sensitive site. The site was a port during the Chola and Pallava period and trade flourished during that time with Greeks and Romans.

4.1.5. Infiltration map

An infiltration map (Fig. 6) was also developed by taking into account the key soil types and their properties. The infiltration rate plays an important role in determining potential risk of contamination of the groundwater and hence is a key criterion for the development of a landfill at a particular site. Depending on the infiltration rate, the region has been divided into high/medium/low zones. The coastal area has been shown to possess a high infiltration rate. The central and southern part of the region has thick clayey soils with predominantly low infiltration rate.
4.1.6. Geology map

The geology map (Fig. 7) shows that major part of the region is alluvium. Thick alluvial deposits are built up along the course of Penniar and Gingee rivers covering three-fourths of the Pondicherry region. The thickness of alluvium varies from 10 m to 55 m at different places. Other geological structures viz., Basement, Cuddalore sandstone, Limestone, Ottai clay and Vanur sandstone are present in the northern part of the region.

4.1.7. Elevation map

Near the coastal side, the elevation is less than 10 m and in the northern part of the region it ranges between 40 m and 50 m (Fig. 8).

4.1.8. Waste land map

The waste land map (Fig. 9) depicts patches of land spread throughout the entire region which are not under productive use, owing to some natural and external causes such as water logging, very high erosion, deposition of salts etc. Such land can be prospective sites for a sanitary landfill.

4.1.9. Groundwater table map

The depth of the groundwater table plays an important role in determining the contamination risk of groundwater. It was found that the groundwater table is shallow (<5 m) in the areas nearer to the coastal stretch. In the northwestern part of the region, the groundwater table ranges between 5 m and 15 m and in the remaining part of the region the groundwater table occurs at depths greater than 15 m.

4.1.10. Groundwater quality map

The groundwater quality map determines the extent of pollution in the resources. To assess the groundwater quality, TDS was considered. The total dissolved solids concentration is less than 500 mg/l (Fig. 10) in most of the region.
Fig. 8. Elevation map.

Fig. 9. Waste land map.

Fig. 10. Groundwater quality map.
In the southern part of the region nearer to the coast, total dissolved solids are above 2500 mg/l.

4.1.11. Air quality index map

Assessment of air quality reveals that in the major portion of the study area, SO\textsubscript{2} concentration is less than 50 mg/m\textsuperscript{3} and in very few patches the concentration is between 50 and 80 mg/m\textsuperscript{3}. NO\textsubscript{x} concentration in the Pondicherry region is less than 50 mg/m\textsuperscript{3}. Except for a small area in the northern part, where SPM concentration >200 mg/m\textsuperscript{3}, the majority of the study area has an SPM concentration in the range between 100 and 200 mg/m\textsuperscript{3}. A composite air quality index map was developed (Fig. 11) and it shows that the Boulevard area is comprised of polluted, moderately polluted, heavily polluted and severely polluted areas.

4.1.12. Buffer maps

Maps with buffer zones for ponds, rivers, roads, habitation, water supply sources and fault lines exhibit the permissible distance beyond which the landfill can be sited for various criteria using the buffer option in ArcGIS, i.e., the areas within the buffer are unsuitable for landfill development for solid waste disposal. They were generated on the basis of pre-existing published landfill criteria, existing standards and regulatory requirements, as well as the prevailing local conditions. For example, to generate the buffer for rivers, the three rivers in the study area viz., Penniar, Chunnambar and Ariankuppam, were considered and a buffer distance of 100 m was applied around each of them. Similarly, buffer zones for ponds, rivers, roads, habitation, water supply source and fault lines were created at a distance of 200 m, 100 m, 200 m, 500 m, 500 m and 500 m, respectively.

4.2. Importance ranking and rating for each criterion and the governing algorithm

After the preparation of thematic maps characterizing the influencing factors and the preparation of the GIS database for landfill siting, the next step involved the identification, importance ranking of each of the influencing factors, and the preparation of a relative rating scheme for each influencing factor based on the relative magnitude of impact. In the present study, the technique of Delphi was employed for identifying the key governing criteria for landfill site selection. A set of questionnaires was prepared and sent to the policy makers of key government departments of Pondicherry.

Based upon the inputs of the key policy makers of the different sections of the local government, guidelines of Central Pollution Control Board, India (CPCB, 2003) and that of the Central Public Health and Environmental Engineering Organization (CPHEEO, 2000), as well as the review of the scientific literature on previous work conducted, four categories of criteria were identified, namely, the land use criteria, hydro-geologic criteria, air quality criteria and the constraint parameterization. Each category was further divided into sub-categories. A sequential hierarchy of the multi-criteria problem was developed; analytic hierarchy process was employed wherein a consistent weight set was extracted through the pair-wise comparison by decision makers in their consideration of each factor against one another. Feedback from a team with expertise in multi-disciplinary fields of local environmental management of the Pondicherry was sought in the process. Associated with each thematic map (TM) characterizing a given criteria, once the importance weighting ($W_c$) of the criteria, as well as the ratings ($R_c$), were associated with each criterion depending on their relative magnitude, a sub-index score ($I_{sub}$) for that particular criteria was evaluated. The same process was followed for each of the sets of sub-categories of criteria. A weighted sum aggregation function was employed to arrive at a Composite Suitability Index (CSI).

$$CSI = \sum_{c=1}^{n} (I_{sub})_{TM} = \sum_{c=1}^{n} (W_c \cdot R_c)_{TM}$$

Fig. 11. Air quality index map.
The process of employing weights and ratings to each set of criteria has been indicated in Fig. 12.

The Analytic Hierarchy Process (AHP) developed by Saaty (1980) has been employed to derive the relative importance weighting of each criterion. Pairwise comparisons were conducted among the criteria to determine the relative importance of each criterion among others. A comparison matrix among the criteria was developed, which was subsequently used to compute an eigen vector, which ultimately represented the ranking of the criteria. For the calculation of ratings associated with each criterion, a pairwise comparison of alternatives on the basis of each criterion was conducted. An intensity of importance was associated for all possible alternatives and a comparison matrix arrived at by repeating the process for each criterion. Using the comparison matrix among the alternatives and the information on the ranking of the criteria, AHP generated an overall ranking of the solutions. The alternative with the highest eigenvector value was considered to be the first choice.

4.3. Identification of optimum site for landfill localization

The overall algorithms employed for the optimized siting of a landfill site has been indicated in Fig. 13. Firstly, key sets of criteria which govern the siting of a landfill are identified. They have been broadly categorized into land use criteria, hydro-geologic criteria and air quality criteria. Another important factor is the constraint parameterization indicating the areas of constraint in the given land use configuration where a landfill cannot be developed. This is based on a set of buffer zones constituted on the basis of some key influencing factors. The buffers were set in ArcGIS based upon the existing scientific knowledge of the cause-impact relationship of a specific influencing factor upon a receptor. The next step involves the development of a GIS database for the above mentioned governing criteria. Separate thematic maps characterizing each sub-criteria are developed and the attribute data associated. In the study, the land use map constitutes the base map. In the next step, all of the buffer maps are overlaid on the base map and the regions of constraint where a landfill cannot be constructed are identified. Subsequently, each of the thematic maps characterizing a governing criterion is overlaid on the base map. For each pixel of the base map, the cumulative suitability index (CSI) for landfill siting is evaluated through the aggregation of the sub-index values calculated from each of the overlaid thematic maps characterizing a governing criterion. The multi-criteria analysis was performed using the Spatial Modeler of ArcGIS. Thereafter, the algorithm performs a GIS-based constraint mapping technique to eliminate the potentially unsuitable sites. The algorithm thus ends with a final map indicating the best suitable sites for the development of a municipal solid waste landfill, based on a set of identified key criteria.
Identify the set of key criteria for landfill siting

Hydro-geologic criteria
- Level of infiltration
- Geologic strata
- Degree of slope and elevation
- Depth of the groundwater table
- Nature of groundwater quality (TDS conc.)

Air quality criteria
- Nature of ambient air quality

Constraints Parameterization
- 200 m buffer for ponds
- 100 m buffer for rivers
- 200 m buffer for major highways
- 500 m buffer for areas of habitation
- 500 m buffer for water supply sources
- 500 m buffer for major fault lines

Land use criteria:
- Distance to a surface water body (ponds, rivers)
- Distance to a road network
- Distance to agricultural land
- Distance to settlement
- Distance to wasteland
- Distance to sensitive sites

On-screen digitization & generation of thematic maps characterizing the identified criteria

Primary data sources
- Toposheets
- Available paper maps

Primary data sources
- IRS 1D satellite image

Scanning

Geo-referencing to earth coordinates system

Secondary data sources
- Ground truth studies
- Locating coordinates

Image interpretation, classification and generation of the primary land use map

Secondary data sources
- Groundwater table map layer
- Groundwater quality map layer
- Air quality index layer

Development of a GIS database for municipal landfill siting comprising of following layers:
- Land use layer (base map)
- Road network map layer
- Water bodies map layer
- Sensitive sites map layer
- Waste land map layer
- Infiltration map layer
- Geologic map layer
- Elevation map layer

GIS analysis through overlaying of the various thematic layers characterizing a set of identified criteria

For each thematic map (TM) characterizing an identified criterion 'c':
- Associate Importance Weighting based on the significance of the criterion ($W_c$)
- Decide upon the Rating Score based on the range of magnitude of the parameter value ($R_c$)
- Aggregate the sub-index score by simple additive weighing
  $$ I_{sub} = (W_c \times R_c)_{TM0} $$

Development of GIS database for municipal landfill siting comprising of following layers:
- Land use layer (base map)
- Road network map layer
- Water bodies map layer
- Sensitive sites map layer
- Waste land map layer
- Infiltration map layer
- Geologic map layer
- Elevation map layer
- Groundwater table map layer
- Groundwater quality map layer
- Air quality index layer
- Set of layers indicating the various constraints (Buffer layer)

Overlay the generated buffer maps to identify the sites where the constraints parameterization may be employed – sites where the siting of landfill is ‘not permissible’

For each pixel (i, j) of the base map, calculate the sub-index scores associated with each thematic criteria and thereby evaluate the Composite Suitability Index of that pixel
  $$ CSU = \sum (W_c \times R_c)_{TM} $$

Identify the set of key criteria for landfill siting

GIS-based multi-criteria analysis for optimized landfill site selection

Stop

GIS-based constraint mapping approach to eliminate the environmentally unsuitable sites

Evaluate the Composite Suitability Index scores for all of the pixels in the base map

Fig. 13. Algorithm for the identification of the optimized landfill site in an urban location.
In this study, the Pondicherry region has been taken as the study area. The thematic maps were generated, overlaid upon one another and the above proposed algorithm was run on them and GIS based analysis performed. The GIS-based constraint mapping technique was employed for the entire study area and subsequently 17 potential sites were identified for landfill development on the basis of the selected criteria. Thereafter, the immediate local conditions prevailing at the present moment were assessed and the 17 potential sites were further screened to 3 sites that were the most optimum ones. Most of the sites were eliminated due to their proximity to high tension power lines, location in dip zone, location near upcoming habitation areas, a school zone and away from the municipal boundary. The 3 most optimum sites have been indicated in Fig. 14.

5. Results and conclusion

This paper examines an approach for identifying the optimum site for the construction of a landfill in a typically urbanizing city. A multi-criteria approach was employed in conjunction with GIS-based overlay analysis to identify the most suitable site for landfill development in the Pondicherry region. The study was based upon a set of key criteria, which were selected based upon the already available knowledge from research literature as well as the pre-existing local level factors of the area. A set of 17 potential sites were identified (Table 2) in the first level of analysis while subsequent screening and refinement on the basis of existing microscopic factors led to optimized selection of the 3 most suitable sites for landfill construction. The sites were ranked on the basis of area availability. Sites 1, 5, and 13 covering areas of 0.36 km², 0.11 km² and 0.06 km², respectively, were chosen as the most suitable for landfill construction. They are located in areas comprised of wasteland, the physicochemical characteristic of the soil are optimum, and they also fulfill all of the selected criteria.

### Table 2

<table>
<thead>
<tr>
<th>Site no.</th>
<th>Rank</th>
<th>Description of the site</th>
<th>Area in km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Waste land, large area and soil suitability</td>
<td>0.36</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Area located in the path of HT power lines</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Land located in the dip zone of main water source of Pondicherry</td>
<td>0.14</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Land situated around the new habitation area</td>
<td>0.12</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Waste land and soil suitability</td>
<td>0.11</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Site not recommended by the geologists due to sandy soil</td>
<td>0.09</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Land situated around the new school zone</td>
<td>0.08</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Land located in the dip zone of main water source of Pondicherry</td>
<td>0.08</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Located 10 km or more away from the municipal boundary</td>
<td>0.08</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>Land situated around the new habitation area</td>
<td>0.07</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>Located 10 km or more away from the municipal boundary</td>
<td>0.06</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>Land located in the dip zone of main water source of Pondicherry</td>
<td>0.06</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>Waste land and soil suitability</td>
<td>0.06</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>Small single site</td>
<td>0.05</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>Land located in the dip zone of main water source of Pondicherry</td>
<td>0.05</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>Land situated around the new habitation area</td>
<td>0.04</td>
</tr>
<tr>
<td>17</td>
<td>17</td>
<td>Located 10 km or more away from the municipal boundary</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Site 2 was eliminated from consideration, as it is located in the path of high-tension power lines. Sites 3, 8, 12 and 15 were also eliminated, as they are located in the dip zone of main water source of Pondicherry. Although sites 4, 10 and 16 satisfied the selected criteria, they were also screened out as they are located where new habitation areas have been proposed according to the Pondicherry Master Plan. Site 6 has sandy soil and a high infiltration rate, while
site 7 is located in the school zone; hence neither was considered suitable. Sites 9, 11 and 17 were also eliminated as they are located too far from the Pondicherry municipal boundary (more than 10 km).

The superiority of the proposed approach stems from its inherent flexibility in its application to different sites with diverse local conditions. Although the basic factors to be assessed for a landfill development are universally the same, different sites may have different sets of local conditions. Hence the sets of important criteria, as well as the important ranking and weighting values, have to be optimized on the basis of site-specific conditions. The governing algorithm was suitably calibrated for the Pondicherry region through the iterations of the weightings and ratings in AHP based on inputs from local policy makers. Expert opinions from key local government policy makers were gathered through Delphi for inputs to the model.

Furthermore, the uniqueness of the present approach stems from the fact that the environmental factors were deemed as the primary governing factors in the study. It has been identified that the impacts produced to the neighboring environment as a result of development of a sanitary landfill causes secondary impacts upon the health and socio-economic conditions. A detailed study of the pre-existing groundwater and air quality was conducted in this regard. In addition, pre-existing land uses and demographics was also given due importance.

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References


