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Identification of Suitable Landfill Site Alternatives using GIS – A Case Study

Trupti Lokhande[1], Sachin Mane[2]
ME Student[1], Assistant Professor[2]
Department of Civil Engineering
D. Y. Patil College of Engineering, Akurdi, Pune, India

Abstract:
Rapid growth of industrialisation has made the solid waste management a challenging issue. The inadequacy of old landfill sites to handle this huge quantities of solid waste, the statutory laws and the public opposition has necessitated the need to identify new landfill sites. Landfill siting is a complex and time consuming process requiring evaluation of various environmental, social and economic criteria. The methodology adopted in this article is used to identify suitable landfill site alternatives for Nagpur city, Maharashtra using Geographical Information System (GIS). The site assessment is based on six location criteria: rivers, lakes, airport, habitation, parks, and Highways, accordingly to Solid Waste Management Rules, 2016. The paper analyses the effect of location criteria restrictions on the available suitable area. The spatial analysis results obtained using GIS provided 224.75 Sq.km total suitable area and seven potential landfill site alternatives for waste disposal.

Keywords: GIS, Landfill, Solid Waste Management.

I. INTRODUCTION

In India, landfilling is the most common method used for municipal solid waste disposal. Despite of advances in waste processing techniques for waste minimization, landfill has remained as an integral part of any solid waste management system of the city (Al-Jarrah et al., 2006). Various statutory regulations are formulated for selection of landfill site. Also, many different parameters are required to be considered in the process of landfill site selection. This is essential for prevention of contamination of natural resources, to minimize nuisances to the society and to optimize the cost associated with landfill site. Thus making landfill site selection a time consuming and complex process (Chang et al., 2008). The traditional method for landfill site selection in India is manual, costly and time consuming. Moreover, no proper disposal site or scientific landfill is provided in small villages and towns, ultimately resulting in open dumps. The landfill site selection is also influenced by land availability and opposition by community resulting in selection of improper landfill site. Selection of improper landfill site results in contamination of groundwater, soil, surface waters, ultimately causing impact on health of community in the vicinity of landfill site. Thus, it is essential to consider various parameters such as topology, natural resources, transportation cost, landuse, and others, to avoid contamination and health impact. Processing such a huge data manually may provide faulty results. Thus, an advance technology is required to accurately process this data to select an appropriate landfill site. Geographical Information System (GIS) is one such advanced technique for processing massive amount of spatial data for selecting suitable landfill site. It is cost effective and less time consuming process.

Study Area

The Nagpur is the center of India and a prime city in eastern part of Maharashtra. It is located between 78°30" to 79°30" East and 20°30" to 21°45" North latitude. It is situated at an altitude 310.5 m above mean sea level. The study area considered for disposal of municipal solid waste of Nagpur city comprises of Nagpur city administrative boundary and adjacent towns and villages in the range of 10 kilometers from the administrative boundary. The Nagpur Municipal Co-operation administrative area is 225.08 sq. km. The population of the city is 2,405,665 (Census, 2011). The municipal solid waste generation in Nagpur city is 1000 MT/day (MSW, 2016).

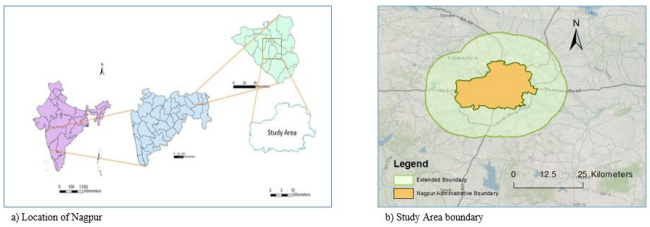

Figure.1. Location of study area

II. MATERIALS AND METHODS

In the present article, ArcGIS® 10.2, desktop GIS software is used for geo-processing and suitability analysis (ESRI, 1969). The available data for the study area was digitized and stored in GIS environment.

The topographical map of scale 1:250,000 is digitized with Geographical Co-ordinate System GCS_WGS_1984. Data extraction for various criteria related to environment, socio-culture and economy are carried out using maps obtained from Survey of India. The satellite images with projected co-ordinate system WGS_1984 were used. The technique used for obtaining suitable landfill site is Boolean logic (Delgado et al., 2008; Effat et al., 2012). The Model Builder and Raster Calculator available in ArcGIS® are used to create constraint maps for suitability analysis.

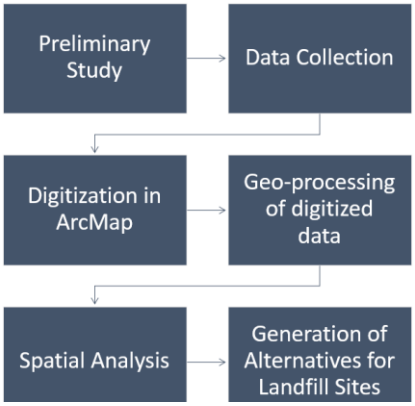

Figure. 2. Methodology flowchart

A. Preliminary Study and Data Collection

The Solid waste management (SWM) is an integral part of sustainable development of the city. Nagpur city has a well-established SWM system with door-to-door collection system, transportation and transfer of municipal solid waste to transfer station and disposal site. Out of 1000 tons waste generated daily, only 170 tons/day waste is taken for composting and remaining waste is landfilled (MSW, 2016). The transfer station is located at Budhwar Bazar Road, Sakkardara. The Bhandewadi landfill site is about 10 km from the center of the city and is in operation from 1967. The distance from transfer station to landfill is approximately 8 kms. At present, 10.13 acres area is available for landfilling. This available area may not prove sufficient for disposal of estimated waste generated after 10 years. Moreover, old landfill sites pose a serious environmental risk and thus, capping of old landfill sites is recommended after operating period of 20-25 years (SWM, 2016).

B. Digitization process

The study area under consideration for landfill site for solid waste disposal of Nagpur city is extended to 10 km around the city boundary. The search area is delineated on map by taking a range of 5 km around the city boundary and enlarging it if required (MSWM, 2000). The rivers, lakes, residential area, airport location, road network is digitized by using satellite images.

C. Geo-processing and Spatial analysis

Model Builder available under Geo-processing functionality provides an interface to create restriction model of all the criteria under consideration. The 'Analysis tool' is used to generate restriction maps. The buffer required for particular criteria is applied during this process (Dikshit et al., 2001). The 'Conversion tool' is used to convert vector dataset to raster dataset which is required for spatial analysis. 'Con' conditional processing is carried out on raster to assign values 0 and 1 for suitable and unsuitable area respectively. 'Raster calculator' is used to get final suitability map with landfill site alternatives.

D. Location Criteria for Landfill site

The landfill site should be located such that it does not create nuisance in the surrounding premises of the site. It does not contaminate the groundwater and surface water like rivers and lakes and the landfill site area is sufficient enough to fulfill the projected area requirement for waste disposal. It should not be located in the buffer zones specified for landfill site location. Table I provides the buffer requirement that should be applied to various criteria for creating restriction area for landfill site.

Table.1. Location criteria for landfill

Sr. No.	Criteria	Restriction (Distance)
1	Surface water - Rivers	100 m
2	Surface water – Lakes and Ponds	200 m
3	Highways	200 m
4	Landuse – Habitations , parks	200 m
5	Airports	20 km (NOC for within 10-12km)

III. RESULTS AND DISCUSSIONS

This case study illustrates the process of identifying suitable alternatives for landfill sites for Nagpur city. The screening process is based on the location criteria for landfill sites (MSWM, 2000). The alternatives are further screened on the basis of area requirement and transportation distance. Since, the method takes into consideration the operational period and estimated area requirement, it is practical for real-world planning.

A. Area Requirement

The waste generation of the Nagpur city is 1000 tons per day. For design life of 10 years with closure and post closure period of 25 years, the estimated area requirement for landfill site is 0.194 sq. km (MSWM, 2000).

Table.2. Available Area under Various Criteria Restrictions

Sr. No.	Constraints	Abbreviations	Suitable Area (Sq. km)
1	Airport	A	290.42
2	Highways	Hi	1486.62
3	River	R	1550.80
4	Parks	P	1605.49
5	Lakes	L	1576.76
6	Habitation	Ha	1408.61
7	Airport-Highway	A-Hi	267.14
8	Airport-River	A-R	272.84
9	Airport-Habitation	A-Ha	257.71
10	Airport-Parks	A-P	290.42
11	Airport-Lakes	A-L	290.42
12	Airport-Highway-River	A-Hi-R	249.98
13	Airport-Highway-Park	A-Hi-P	267.14
14	Airport-Highway-Lake	A-Hi-L	267.14
15	Airport-Highway-River-Habitation	A-Hi-R-Ha	224.75
16	Airport-Highway-Rivers-Lake-Park	A-Hi-R-L-P	249.98
17	Airport-Highway-Habitation-Rivers-Lakes-Parks	A-Hi-Ha-R-L-P	224.75

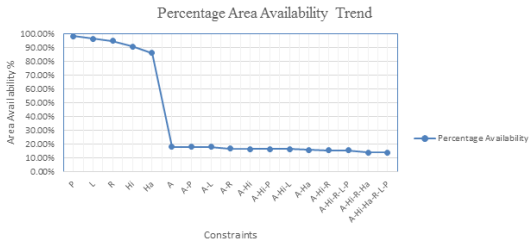

Figure. 3. Percentage Area Availability Trend

B. Constraint maps

Appropriate buffer distances are applied to each criterion as mentioned in Table I. These results are the constraint maps for landfill sites. The suitable areas available for landfill siting are tabulated in Table II. Majority of land becomes unsuitable for landfill site within and around the city due to airport location criteria. The suitable area for landfill sites decreases with increase in number of criteria restrictions. The area available for landfill sites after overlaying all the constraint maps is 224.75 sq. km. The land availability can be increased by obtaining NOC for landfill siting within 10-12 km from airport. The area available under each criteria (Table II) can be further useful for identifying suitable landfill site alternatives in case any particular criteria is given priority over another. The Park restriction of 200 meters provides largest suitable area for landfill site. 98.23% of total study area is available. The Airport restriction of 20 kilometers provides smallest suitable area, with 17.77% of total study area as suitable land for landfill siting. River constraints give 94.89% as suitable land whereas Habitation constraints give 86.19% as suitable land. Habitation constraint may get neglected in the process of decision making if environmental criteria is considered to be more significant parameter than the social criteria. In this instance, the suitable land available for landfill site becomes 94.89% of total area. With equal importance to all the criteria constraints, the suitable area available for landfill site is 13.75% of the total area.

C. Suitable alternatives for landfill site

The Raster Calculator provides the final suitability map with all considered restrictions for the study area. The total suitable area available for landfill siting is detailed in Table II. Figure 5a shows the final suitability map obtained by Raster Calculator. The map shows North-Eastern region outside the Nagpur city has majority of suitable land area for landfill siting. The result provides approximate locations of the landfill site. For primary ranking process, accessibility to landfill site and distance from transfer station is considered in this paper. It is found that all the potential sites have road accessibility and available area greater than 0.194 sq.km. The potential landfill sites in the eastern region, Bhanegaon, Juni Kamptee, Kamptee, Gada, Sihora, Palsad, Titur, are closer to transfer station. The distance of these potential sites is tabulated in Table III.

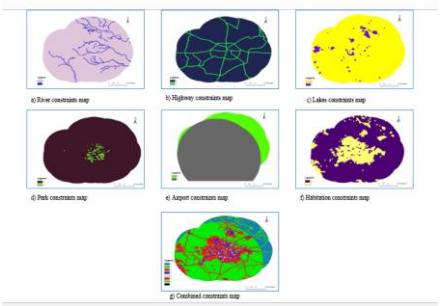

Figure.4. Constraint maps

Table.3. Distance between transfer station and potential landfill sites

Sr. No.	Potential Sites	Distance (Km)	Rank
1	Kamptee	15.0	**1**
2	Gada	16.4	**2**
3	Bhanegaon	17.0	**3**
4	Juni Kamptee	17.4	**4**
5	Sihora	18.2	**5**
6	Titur	18.3	**6**
7	Palsad	18.6	**7**

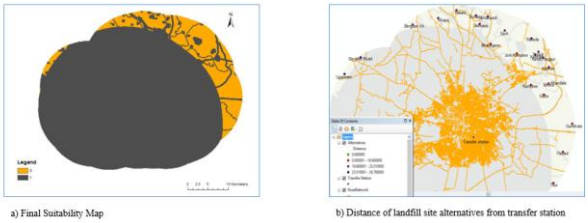

Figure. 5. Potential Landfill site alternatives

For the final site selection, the criteria under evaluation are required to be expanded. Limiting the criteria compromises the accuracy of the proposed approach. The use of multiple-criteria decision analysis (MCDA) methods for importance weighting of various environmental criteria, socio-cultural criteria and economic criteria will increase the accuracy of ranking of the potential sites. Integrating GIS and MCDA can prove to be very helpful in tackling the real-world problem of landfill site selection (Al-Jarrah et al., 2006; Chang et al., 2008; Delgado et al., 2008; Effat et al., 2012). The study requires further site investigation of the potential landfill site alternatives to incorporate public opinion.

IV. CONCLUSION

The case study demonstrated in this paper show that GIS has the potential to identify suitable landfill site alternatives. Total suitable area for landfill siting obtained is 13.75% of the study area. Seven potential landfill sites are identified for the waste disposal of Nagpur city. Kamptee, situated in the eastern region of study area, has been identified as the most suitable landfill site on the basis of distance for waste transportation. Landfill siting is a real-world problem. Thus, further site investigations are required to implement the results of the study. Additionally, it is essential to incorporate the opinion of experts, regulatory bodies and the residents of the identified landfill site region in the study.

V. ACKNOWLEDGEMENTS

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