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GIS-based solid waste management – A case study of Nagercoil Municipality, Tamil Nadu †

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Abstract: Cities and towns are growing rapidly because of the increasing population, which is not always contributing to the growth and prosperity of cities and towns, but also contributing to their associated problems, like waste generation and its management. Several processes are involved in the management of solid waste, like siting, monitoring, collection, transportation, processing and disposing of. However, foremost after the collection of solid waste, a site is required for disposal and processing. The present study attempts to use Remote Sensing and GIS coupled with the AHP method for analyzing and identifying a dumping Site for solid waste disposal in Nagercoil Municipality in Tamil Nadu. The different physical criteria: LU/LC, geomorphology, soil texture, settlement, road, surface water bodies, lineaments, groundwater depth, NDVI and slope are considered and are examined in relation to landfill site selection. Each criterion was identified and weighted by AHP score and mapped using the GIS technique and a suitable map is prepared by overlay analysis. The result indicates that a barren land of 57.8891 sq. km which is also in proximity to Nagercoil city is the best site for the disposal of solid waste.

Keywords: Landfill, Analytical Hierarchy Process, Relative Importance Weightages, Suitability Index

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1. Introduction

Due to rapid industrial growth and the migration of people from villages to cities, the urban population is increasing rapidly. Waste generation has been observed to increase annually in proportion to the rise in population and urbanization. Improved lifestyle and social status of the populations in urban areas result in a tremendous increase in per capita generation of Municipal Solid Waste (MSW). Solid waste management is now a major global concern that is increasing daily. Of the various techniques of solid waste management, solid waste dumping/landfilling is the most popular and widely prevalent technique in India. Selection of a solid waste dumping/landfilling site for the disposal of solid wastes requires processing and evaluation of a significant amount of spatial data concerning various parameters governing the suitability of a site [1]. A disposal site must consider all the socio-economic, environmental, and land use factors within the city.

Several researchers worked with GIS as a tool to identify a suitable landfill site [2-4]. The most common approach is the spatial method that integrates Multiple Criteria Decision Analysis (MCDA), GIS provides efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential solid waste dump/landfill areas based on a variety of criteria [5,6]. The efficiency of the analysis depends on the choice of the variables used for the analysis. The most common layers for suitability analysis are Land use/ Land cover (LULC), Slope, distance from the water body and Road [7-9]. The choice of variables depends on the study area and this study aimed to integrate every aspect of influence in deciding a suitable landfill site including geomorphology, lineaments and groundwater depth. Thus, the main aim of this study is to select a suitable site for solid waste disposal using GIS and Remote Sensing, with the view to protecting the environment and public health.

2. Study area

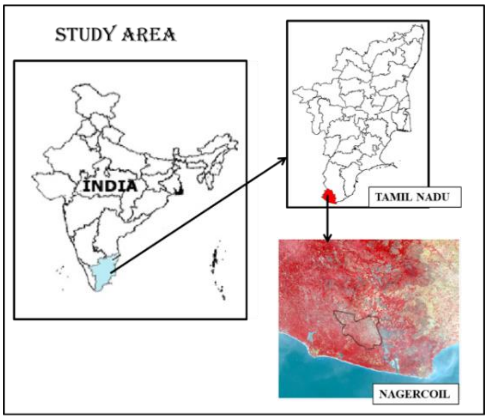

Figure 1. Location Map of Study Area

Located in the Kanyakumari district of the state, Nagercoil is one of the important towns of Tamil Nadu. The town is situated at a distance of 20 km to the North-West of Kanyakumari and the intersection of 77 o 29' East Longitude and 8 o 11' North latitude. About 20 to 40 percent of solid waste out of 62 tons produced in the town was being dumped into the degraded water sources regularly. Hence, the district administration should take immediate steps to prevent the dumping of waste in water resources. Through field visits to existing landfill/ solid waste disposal sites, little information was gathered. There is no cover over the spread of waste to inhibit the ingress of surface water, minimize litter blow and odor, and to reduce the presence of vermin and insects in all the existing landfilling sites. There is no proper compaction of waste in the existing sites. The runoff during the monsoon season flows over and beside the landfill sites, since there are no specific arrangements to prevent the flow of water into and out of solid waste dump/landfill sites, the diffusion of contaminants/odor may release during the degradation of wastes. Hence, there is a need to take immediate steps to prevent the dumping of waste in a less suitable area. To undertake this study of identifying suitable solid waste dumping sites, a buffered region of 15 km south and 20 km in north, east, and west directions from the center of Nagercoil city was considered as shown in figure 1.

3. Methodology

The below diagram gives the general methodology of the study to identify a suitable solid waste disposal site for Nagercoil Municipality (figure 2).

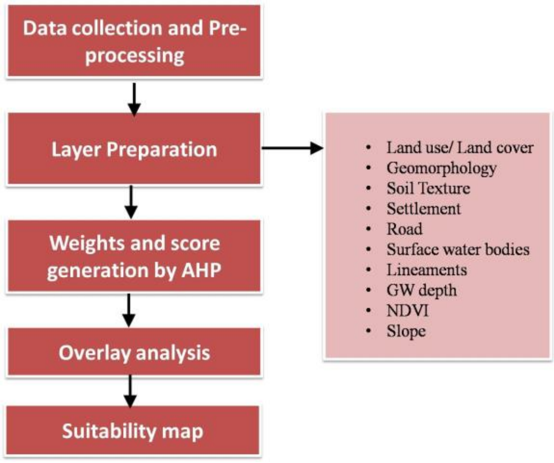

Figure 1. Methodology Flowchart

3.1. Layer preparation

The Landsat 8 data was used to prepare Land use/ land cover (LU/LC) dataset comprising classes namely Agricultural Land, Barren Land, Built-up, Forest, and Water Body. Manual digitization is performed since it was expected to give more accuracy than other methods. From the LU/LC prepared, built-up/settlements, Water bodies were separately extracted and multiple ring buffer operation was performed accordingly. From the Bhuvan website, the web map service for Lineaments was imported to ArcGIS online and the feature was digitized manually. Similarly, the geomorphology layer was prepared using the data available on the Bhuvan website. The soil Map downloaded was georeferenced to the study area shapefile and rectified. Then the soil classes with ID for polygon were digitized and attributed. Using the NBSS manual, the corresponding soil textures were attributed to the polygons. The ASTER DEM data was projected to the study area UTM zone and the slope was derived and classified as needed for the study. Road data downloaded from NUIS was also projected and then multiple ring buffer operation was performed. Using Landsat 8 NIR and red bands, NDVI was calculated with a raster calculator and classified into classes as needed for the study. Groundwater data was downloaded from India WRIS data was downloaded in excel format. This data was used to create point data. This point layer was further used to divide the study area into polygons using the Thiessen polygon tool. All the layers thus prepared were checked for extent and projection information to proceed further.

3.2. Calculation of weights using AHP

The AHP divides the decision problems into understandable parts; each of these parts is analyzed separately and integrated in a logical manner as suggested by Saaty [10]. Structurally, the hierarchy is broken down into a series of pair comparison matrices, and the participants are asked to evaluate the off-diagonal relationship in one half of each matrix. The 9-point scale used in typical analytic hierarchy studies is ranging from 1(indifference or equal importance) to 9 (extreme preference or absolute importance). A pair-wise comparison matrix is formed. The weight coefficients of the ranking criteria and the decision sub criteria are calculated

3.3. Overlay analysis

Once the weights for criteria and sub criteria were derived, the geoformula is used to generate the overall score of the alternatives in the GIS environment, and the suitability index (LSI) was calculated by means of multiplication of each criteria weight with each sub criteria weight as follows

$$\boldsymbol{A_i} = \sum\nolimits_{\boldsymbol{j=1}}^{\boldsymbol{n}} \boldsymbol{W_j} \times \boldsymbol{C_{ij}}$$

where, *Ai* is the suitability index for area i, Wj is the relative importance weight of criterion, Cij the grading value of area i under criterion j and n is the total number of criteria. All the layers were intersected and the suitability index was calculated. Based on the index values, the study area was classified for suitability.

4. Results & Discussions

4.1. Mapping the variables

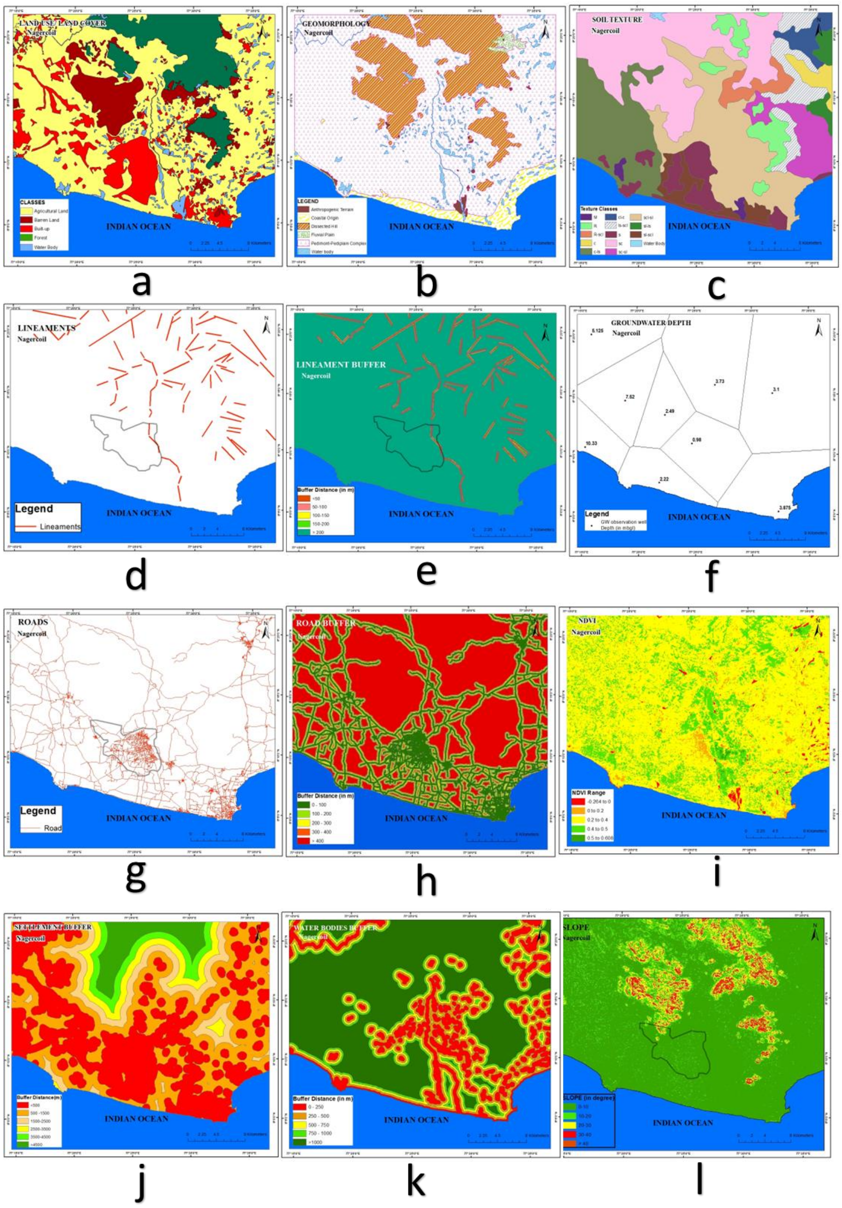

Figure 3: Maps showing a) LULC b) Geomorphology c) Soil texture d) Lineaments e) Lineaments buffer f) Groundwater depth g) Road h) Road buffer i) NDVI j) Settlement buffer k) Water bodies buffer l) Slope.

The various land use and land cover types in the study area were identified and classified by visual digital interpretation, presented in the form of a map (figure 3.a.). Major geomorphologic features units found in the study area are mapped as shown in figure 3. b to decide on the favorable landfill site. Soil texture expresses the porous nature of the land and is hence mapped to use for overlay analysis (figure 3.c.). All the lineaments were buffered by a distance varying from 0 to 200 m, and each buffer zone was weighted by AHP. According to the calculations, the areas that are 0–50 m away from the lineaments have the lowest weight values, but those > 200 m from the lineaments have the highest weight values (figure 3.d, 3. e).

A landfill site should be in an area having low groundwater. In this study, 9 observations well data were collected for the study area, pre and post-monsoon. The area in which groundwater is deep has the highest weight value because of the lowest groundwater pollution risk. The spatial results of the groundwater depth of the basin are represented in figure 3.f. The roads are buffered by a distance varying from 0 to 400 m according to the related literatures (figure 3. g, 3. h). The zones that are at a distance of 0–100 m from roads have the highest weight values. The normalized difference vegetation index (NDVI) is a simple graphical indicator that can be used to assess whether the target being observed contains live green vegetation or not. Low NDVI range values were given high weightages and vice versa (figure 3. i). The use of NDVI is to include the sparse vegetative cover as suitable area when it is completely discarded in LULC layer as not suitable.

Considering the health issue, odour and aesthetics, the dumping site should be placed away from settlements. The buffers for settlements ranging from o to 4500m was classified into 6 categories and mapped (figure 3.j.). The farther buffer zone was given high weightages. One of the most faced problems in the city of Nagercoil is the dumping of waste near surface water bodies. In this study this problem was regarded with significant importance. The water bodies were buffered into 5 categories (figure 3. k,) and zone with distance greater than 1000m was given highest weightage. For the current study, slope is considered as it affects construction of landfill and must be taken into account in site selection. High regions such as hill and mount have the lowest weight values. Flat zones whose slopes are between 0◦–10◦ were identified as most suitable areas for solid waste disposal. The study area is classified to five categories and mapped as shown in (figure 3. l.)

4.2. Suitability analysis

Table 1. Weights and ranks for the variables derived from AHP analysis.

LAYER	WEIGHTAGES	CLASSES	RANKS
LULC	0.112	Agricultural land	0.163
		Forest	0.297
		Barren Land	0.54
		Builtup	0
		Water body	0
Geomorphology	0.06	Anthropogenic Terrain	0.062
		Dissected Hills	0.097
		Coastal Origin	0.16
		Fluvial Plain	0.263
		Pedimont-Pediplain Complex	0.419
		Sea	0
		Waterbody	0

Soil Texture	0.203	s	0.024
		ls-scl	0.033
		sl-ls, sl-scl	0.048
		scl-sl	0.071
		cl-c	0.106
		sc, sc-sl	0.158
		c, c-ls	0.231
		R-scl, R, M	0.329
		Water Body, Sea	0
Lineament buffer	0.149	0 to 50 m	0.05
		50 to 100	0.081
		100 to 150	0.149
		150 to 200	0.269
		> 200	0.45
Groundwater depth (m)	0.024	>5	0.095
		3 to 5	0.25
		0 to 3	0.655
Road buffer (m)	0.045	> 400	0.051
		300 to 400	0.086
		200 to 300	0.15
		100-200	0.261
		0-100	0.451
NDVI	0.018	0.5 to 0.608	0.055
		0.4 to 0.5	0.09
		0.2 to 0.4	0.154
		0 to 0.2	0.265
		-0.264 to 0	0.437
Settlement buffer	0.033	<500	0.039
		500 to 1500	0.061
		1500 to 2500	0.098
		2500 to 3500	0.156
		3500 to 4500	0.252
		>4500	0.394
Water body buffer	0.273	0 to 250	0.059
		250 to 500	0.096
		500 to 750	0.158
		750 to 1000	0.26
		> 1000	0.427
Slope	0.083	0 to 10	0.062
		10 to 20	0.097
		20 to 30	0.16
		30 to 40	0.263

> 40	0.419

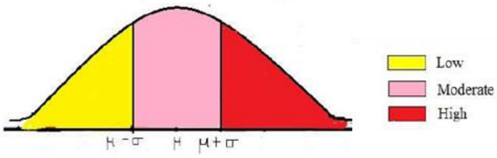

Figure 4 Levels of Suitability

Post preparation of layers, the weights and ranks were decided by performing AHP analysis (Table 1), which is further used in computing the suitability index. Based on the mean and standard deviation of the computed index value the entire study area was classified into three suitability classes namely: Highly suitable, Moderately suitable and Less suitable (figure 4). Not suitable class includes water bodies and the Indian ocean. From the derived classes, the best site was decided and is shown in blue border in figure 5. and area of each classe is given in table 2. At the end of the analyses, a suitability map was created using the ten criteria layers in the GIS environment. The three suitability classes were analyzed with the LU/LC layer and it was found that the highly suitable areas cover barren land, Forest and few built-up areas. This is because other factors in forest and those built-up are favourable for solid waste disposal. With the consideration for availability and best land use, the barren land covering suitable is suggested for solid waste disposal, which covers an area of 57.8891 sq. km.

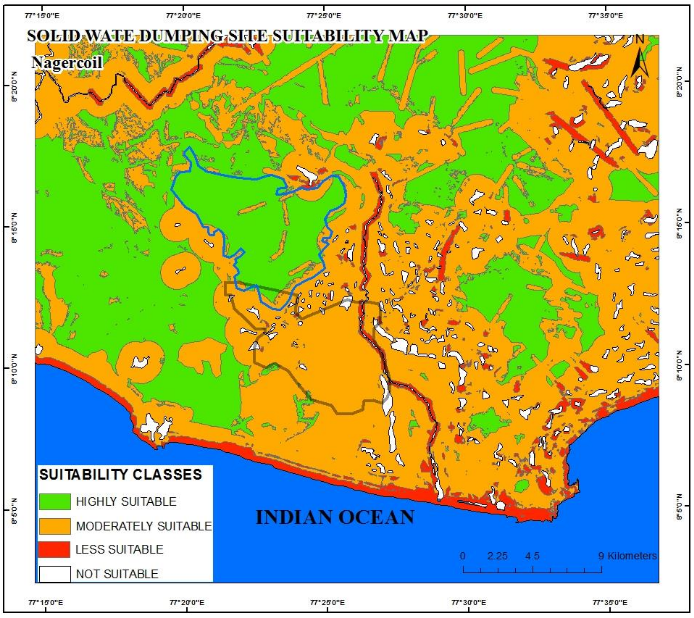

Figure 1. Solid waste dumping site suitability map

Table 1. Suitability classes and their area

Classes	Index values		Area (sq. km)
Highly suitable	> μ+σ	> 0.274	393.552
Moderately suitable	μ-σ to μ+σ	0.154 to 0.274	59.201
Less suitable	< μ-σ	< 0.154	629.736
Not suitable	Waterbody, sea		368.315

5. Conclusion

In many countries, MSW management focuses on waste collection. While collection helps to remove waste from the generator, the collected waste is often disposed of in open dumps without concern for environmental degradation. In general, there is a lack of organization and planning in waste management due to insufficient information regarding regulations and financial restrictions endured by developing countries, such as India. Landfills/ Solid Waste Dumping Sites have been used as the most common method for the disposal of solid waste generated by different communities for many years. The selection of landfill sites has targeted areas that are financially efficient and minimize hazards to environmental and public health. Site selection of waste disposal and waste management for developing countries always pose major problems. The establishment of a national strategy is very important both for the protection of natural resources and the prevention of environmental pollution. Solid waste disposal site selection should be performed for Nagercoil city, but it is very difficult and expensive. Therefore, GIS and remote sensing techniques are becoming powerful tools for this kind of preliminary study due to their ability to manage large volumes of spatial data from a variety of sources. Additionally, the AHP method is used to deal with the difficulties that decision-makers encounter in handling large amounts of the complex. The integration of GIS and AHP is a powerful tool to solve landfill site selection problems. However, besides offering all the advantages of the above-mentioned techniques, an important contribution has been achieved through the application of the order weights, on a pixel-by-pixel basis, which offers full control over the level of risk and trade-off desired. This kind of GIS and AHP integrations allow the decision maker to perform decision analysis functions such as ranking the alternatives to select the best option, specifically the best landfill site.

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