Solid waste disposal site selection by data analysis using GIS and Remote sensing tools: A case study in Thiruvananthapuram corporation area

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ABSTRACT

The major environmental issue faced by urbanization and industrialization is generation of large quantity of solid waste. Effective solid waste management is required for proper disposal of this waste produced. The major problem they are facing is to find a suitable site for waste disposal by overcoming major constrains such as political, economic and environmental pressures for execution of a suitable site. In this paper we focus on the strategies to be followed while selecting a solid waste disposal site for decentralized system, using Geographic Information System (GIS), the Analytical Hierarchy Process (AHP) and the remote sensing method focusing on highly populated Thiruvananthapuram, capital Kerala, located on the west coast of India. Being on the basin of Killiyar and Karamana River, the waste managements must be regulated with the water body. The different physical criteria considered are slope, drainage, waterbodies and residential area with sub criteria like population distance from road, waterbodies and residential area are examined in relation to land fill site selection. Each criterion was identified and weighted by AHP score and mapped using GIS technique and suitable map is prepared by overlay analysis. The result indicates that 12% area is suitable and 6% area moderately acceptable and % not suitable.

Keyword: Geographic Information System, Analytical Hierarchy Process, solid waste disposal, site selection, remote sensing

1. Introduction

Site selection for waste disposal is meant for a long period of time so it should be done in a scientific procedure without disturbing the environmental factors. A centralized system of waste treatment is not applicable to big town and cities, so we should targeted for small decentralized systems of waste disposal sites, which is more economical and long lasting. In the present study we have selected Thiruvananthapuram Corporation as model study area for decentralized solid waste disposal site selection and it was attempted with geoinformatic approach using GIS and RS analysis tool. Identification of suitable site by GIS technique or sieve mapping is reported as a highly efficient tool. In initial phase, screening by GIS overlay technique with the help of exclusionary criteria to eliminate sites with legal restrictions, physical impracticalities, potential threats to public water supply and environmentally sensitive areas, proximity to residential areas, and overlying geological fault zones etc. In this process reclamation of abandoned landfill sites should also be considered (Khan and Samadder 2014). This is followed by ranking of potential sites using multi-criteria decision analysis (MCDA) algorithms and non-exclusionary data such as soil suitability, habitat effect, flood resistance, property costs, distance from population center, and transportation distance. Sensitivity analyses can be performed rapidly to assess how assigned weights affect the
outcome. The results of the MCDA and the decision-making process can be demonstrated and displayed with GIS to diminish environmental effect (Rajan et al. 2014). Remote sensing provides a synoptic view of large area and it has a multispectral capability of providing appropriate contrast between various natural features, and its repetitive coverage provides information on the dynamic changes taking place over the earth surface and the natural environment (Choudhury and Das 2012, Rajan et al. 2014). The data obtained from RS helps in identification and locating such landfill sites by monitoring the changes in land-use within and near hazardous waste and sanitary landfill. Technological development in computer science has introduced GIS as an innovative tool in site selection process. Attention should be focused on identification of suitable new sanitary landfill sites to isolate waste from human society and the ecosystem and monitoring of the existing landfill sites for environmental impact assessment.

1.1 Geo environmental Setting of Study area

Thiruvananthapuram capital of Kerala state and the District headquarters is located at Lat: 8°30’25”N, Log: 76°57’25”E and Altitude – 10m (36 feet). The Thiruvananthapuram Corporation covers an area of 214.86 km² with total Population (Census 2011) - 957730 inhabitants and Density - 4,457/km². The average elevation of the city is 16 ft (4.9 m) above sea level. It lies on the shores of Killiyar and Karamana rivers and there are Vellayani, Thirvallam and Aakulam backwaters in the corporation area, so the waste disposal site selection should be done by considering these water bodies. The major soil types of the corporation region are Sandy, clayey and gravelly clay. Major landuse type reported in the study area are Built up area, agricultural, mixed vegetation and crops, water bodies and settlement. Daily Corporation collects an average of 250 tons/day of solid waste (CPCB 2010-2011) of which only 25-30% (50-60tons) of the waste is converted to manure through treatment and the rest (≈180tons) is piled up as open dumps (Asha and Latha. 2013).

2. Material and method

The methodology adopted for the present study is shown as flow diagram (Figure.1). LISS IV image of IRS P6 satellite was acquired and geo corrected in ERDAS image package using UTM Projection and WGS84 datum and coregistered with Survey of India Topographical map (58D/14, 58d/15, 58h/2, 58h/3 on a 1:50,000 scale) of study area using Ground Control Points (GCP,s).

![Flow Diagram of methodology adopted for the this study](image-url)
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SRTM derived Digital Elevation Model, LISS IV derived thematic maps and secondary data were integrated in GIS domain. Other important transportation network (main roads and sub road) throughout the corporation area is plotted from Google Earth. The successful use of GIS depends on the accessibility of data of adequate quantity and quality, representing various layers used to recreate the relevant real world conditions. The availability and accuracy of data can significantly affect the results of any analysis. Therefore, significant effort should be made to complete and frequently study the necessary datasets that should be used in GIS. The methodology is divided into two sub methodologies: creation of land use/cover maps and site selection criteria using Weighted Linear Combination (WLC) and GIS. The entire region was evaluated based on certain evaluation criteria for analysis of land fill site suitability and theses criteria is classified into two category (Table. 1) (Ozeair and Mohesn 2009). Subcriteria used are slope, drainage, population and distance from major roads, residential areas and drainages. Analytical Hierarchy method (AHP) is an important tool in multi-criteria decision making and it is used in the site selection for suitable land fill. It is flexible, powerful and easy to use decision making when decision criteria are different and contradictory and selection between options is difficult. The main feature of this method is based on pair –wise criteria comparison. Main feature this based on pair-wise criteria comparison weightage where given to the factors and entered in the GIS software then were overlaid, Coefficients used ranged from one (minimum) to five (maximum) (Sener et al.2010).

Table 1: Criteria and Sub criteria used for the analysis

<table>
<thead>
<tr>
<th>Physical criteria</th>
<th>Slope</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Drainage</td>
</tr>
<tr>
<td></td>
<td>Water bodies</td>
</tr>
<tr>
<td></td>
<td>Residential area</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social Economic Criteria</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distance from major roads</td>
</tr>
<tr>
<td></td>
<td>Distances from drainage</td>
</tr>
<tr>
<td></td>
<td>Distance from Water bodies</td>
</tr>
<tr>
<td></td>
<td>Distance from residential Areas</td>
</tr>
</tbody>
</table>

3. Site selection criteria using WLC and GIS

A number of possible selections examined for setting a suitable site by taking into consideration multiple criteria and contradictory objectives in a GIS based MCE technique, using WLC analysis (Al-Ansari et al. 2012, Chang et al. 2008). Data were obtained from different sources and stored in GIS system and used for site selection studies. To apply the WLC analysis practically, ArcGIS software package and its extensions were used.

3.1 Weightage to geomorphology

Geomorphology of the surface should be give importance during site selection particularly for solid waste disposal. The suitable score given to the geomorphology of Thiruvananthapuram corporation region is well explained in Table. 2 based on the topological importance.

3.2 Weightage to drainage

The landfill site should not be placed within surface water or water resources protection areas to protect surface water from contamination by leachate. Safe distances from meandering and
non-meandering rivers should be achieved to prevent waste from eroding into rivers and major streams. The potential landfill location with the lowest groundwater or river level is more suitable for a landfill. Table: 3. illustrates the suitable score given to distances from drainage.

**Table 2: Suitable score given to Geomorphology**

<table>
<thead>
<tr>
<th>Geomorphology</th>
<th>Suitability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pediplain</td>
<td>10</td>
</tr>
<tr>
<td>Plateau</td>
<td>8</td>
</tr>
<tr>
<td>Coastal area</td>
<td>6</td>
</tr>
<tr>
<td>Residual hill</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 3: Suitable score given to distances from drainage**

<table>
<thead>
<tr>
<th>Drainage distances in meter</th>
<th>Suitability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-228.5</td>
<td>2</td>
</tr>
<tr>
<td>228.5-526.2</td>
<td>4</td>
</tr>
<tr>
<td>526.2-950.7</td>
<td>6</td>
</tr>
<tr>
<td>950.7-1536.8</td>
<td>8</td>
</tr>
<tr>
<td>1536.8-2665.7</td>
<td>10</td>
</tr>
</tbody>
</table>

**3.3 Weightage to road**

Road is an important factor when we consider the human settlement and transportation of the waste. The site should not be too near to the road or too far from the road then only the conveyance of waste should be smooth and more economical and the weightage is given accordingly and suitable score given to the distances is explained in Table 4.

**Table 4: Suitable score given to distances from road**

<table>
<thead>
<tr>
<th>Road distances in meter</th>
<th>Suitability Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-160</td>
<td>2</td>
</tr>
<tr>
<td>160-435</td>
<td>8</td>
</tr>
<tr>
<td>435-761</td>
<td>10</td>
</tr>
<tr>
<td>761-1291</td>
<td>6</td>
</tr>
<tr>
<td>1291-2365</td>
<td>4</td>
</tr>
</tbody>
</table>

**3.4 Weightage to landuse**

Landuse type ie. due to anthropogenic activity. The landuse type is classified in five open lands, which is given highest suitability score. Mixed vegetation is given second priority then to region with plantation and final built up area or human settlement. Water body is not given any score such region should be avoided. The suitable score given to land use type based on its importance is illustrated in Table 5.

**Table 5: Suitable score given to Landuse**

<table>
<thead>
<tr>
<th>Landuse</th>
<th>Suitability Scores</th>
</tr>
</thead>
<tbody>
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<td></td>
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</table>
4. Results and discussion

GIS desktop software package ArcGIS 9.3 and its extensions were used as the GIS tools; it is able to perform suitability analysis using MCE. In multi-criteria evaluation a number of possible selections were taken into consideration and conflicting objectives to solve a location problem. In order to use GIS for site selection, the available information for the study area was collected and stored in the GIS. All digital maps of the study area including topographical maps were registered to UTM coordinate system, zone 43N, WGS84 datum. Present study designed to evaluate Thiruvananthapuram corporation area for selecting a suitable site for Solid waste disposal for decentralized system of solid waste treatment plant construction.

Figure 2: A. Thiruvananthapuram Corporation area (study area-yellow), B. Base Map of study area Important places, National Highway, Southern Railway, major water bodies - Akulam, Vellayani Kayai), Major River-Karamanayar and Killiyar, C. Drainage Map (A to C- Sources SOI toposheet), D. Transportation Network Map (Sources SOI toposheet and Google earth), E. Geomorphology Map, F. Geology Map (E,F- Sources: Landuse Body)
Figure 2A. gives an insight to Thiruvananthapuram district inlaid with corporation area of 214.86 Sq km. Base map preparation with administrative boundaries done in ArcGIS 9.3 software (Figure 2B). The SOI Toposheet No: 58D/14, 58d/15, 58h/2, 58h/3 geo-referenced with the help of ArcGIS 9.3. The drainage map of corporation area was illustrated in Figure 2C, and the transportation network in Figure 2D, the sources of these data is plotted from Google earth. Corporation area is served by a network of NH, SH, DR, pucca (metalled), semi-pucca and kutch (unmetalled) roads. The geomorphology of the study was illustrated in Figure 2E and major parts of study are plateau as per data available from Landuse body Trivandrum. The geology of the study area shown in Figure 2F and the major rock type of this study area is Khondolite rock (Sreejith et al. 2010).

**Figure 3:** Landuse Map of Thiruvananthapuram Corporation area (Study area) (Sources: LISS IV image) (Blank white area inside the study area where image is not available)

The LISS IV image (Figure.3) is georeferenced in ERDAS 9.2 software and after Georeferencing the area of interest (AOI) has been extracted in ERDAS 9.2 software. The land use map display the land utilization of Corporation area. It is the basic map of the study area 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 LISS IV image was classified in ERDAS 9.2 to 5 classes. The landuse map indicated areas of- Open land, built up area, mixed vegetation, plantation and water body and the image is extracted using ArcGIS and illustrated. The blank white area in the image indicated where the swath data (RS data) is not available. The majority of the regions occupied by mixed vegetation include coconut plants mango trees and other plants. Small patches of open land are visible in some part of the region of the region.

The SRTM data used to prepare the SRTM map of Corporation area (Figure4A), from this the contour at 20m elevation prepared (Figure4B) and the using 3-D analyst the DEM Map prepared (Figure 4C) The DEM data is used to prepare the slope map (Figure4D). Among most conventional method contour is captured from SOI toposheet are the base for DEM. In SOI topsheet 1:50,000 scale, generally the contour interval is 20m. The contour and spot height data captured from topological maps along with the height values are used to prepare Triangulate Irregular Network (TIN) model. The TIN model is a network of triangles at
randomly located terrain points. It is converted to grid for creating a smooth surface of the terrain where each pixel on the raster DEM file corresponds to its heights. Five suitability criteria (distance from roads, drainage, Geomorphology, landuse and urban areas maps) were used in this study and were partly based on international practices that account for environmental, economic, social, and technical factors. A map was created for each suitability criterion and a final composite map was produced by simple overlaying of the individual maps. The weights were evaluated by taking into account the possibility of modifying the natural conditions of the sites by appropriate engineering interventions, so as to increase their suitability (Delgado et al. 2008). In practice, it is usually unsuitable to give equal importance to each of the criteria being combined. Factors need to be weighted depending on their relative significance.

**Figure 4:** A- SRTM Map showing the elevation of Corporation area (Sources: SRTM – Data from NASA/USA), B- Contour map derived from SRTM Map illustrating the contour interval at 20m, C- Digital Elevation Model (DEM) derived from Contour map showing the elevation, D- Slope Map derived from DEM showing the slope of Thiruvananthapuram Corporation area (Study area) in degrees

Hence, each location will be evaluated according to weighted criteria, resulting in a ranking on a suitability scale, rather than simply presence/absence. This method is known as index overlay. In this method, each factor map will be assigned ranks, as well as the maps themselves receive different weights. All scored maps will be assigned to a common scale (e.g., ranging between 0 to 10, where a score of 0 indicates no constraint and a score of 10...
indicates a total constraint). Weights are generally assigned to these maps to express the relative importance. In order for the output map to be meaningful and consistent, map weights have to add up to 100% and the attribute scores have to be chosen using a scheme that is the same for each map (Issa and AL Shehhi 2010). Each criterion was reclassified, and then given ranking, to comply with a specific scheme. For this the vector maps have to be converted to raster map using converter tool in spatial analyst tool in tool bar. Then, a final composite map was produced using WLC. The weights and scores were assigned based on previous knowledge of the study area.

4.1 Geomorphology weightage map

Relevance of geomorphology in regional and local decision making has to be given importance. Geomorphology plays significant role in the land and water management related planning processes. The topography of an area is an important factor on site selection, structural integrity, and the flow of fluids surrounding a landfill site because it has important implications for landfill capacity, drainage, ultimate land use, surface and groundwater pollution control, site access and related operations. Deciding the type of landfill design (area, trench, and depression-type landfills) is directly related to topography of a site. Flat and gently rolling hills that are not subjected to flooding are the best sites for area and trench type landfills. The digitized map of geomorphology is converted to raster map and weightage is given to each by reclassifying the data with giving suitable score as explained in Table 2. as in methodology and illustrated in Figure 5.

A landfill should be designed and located accordingly to meet the essential conditions for preventing pollution of the soil, surface water, groundwater and ensuring efficient collection of leachate. Equally, a landfill site should be kept as far away as possible from population density, for reducing pollution impact on public health. But a decentralized solid waste treatment system can be in near vicinity of inhabitants, because it is meant for local community for this type of treatment public participation is very important. And this type of system can be installed based on requirement. It is also important that, the landfill site should be placed as close as possible to existing roads for saving road development, transportation, and collection costs but should not be very near to road. In addition, difficult or steep terrains are not appropriate for hosting landfills. Based on these criteria weightage is given to each features. The WLC analysis was applied using the following equation:

\[ S = \sum w_i x_i \]

Where \( S \) is the suitability, \( w_i \) is a weighting of factor \( i \), and \( x_i \) is the criterion score of factor \( i \).

4.2 Drainage density, distance and weightage map

Density map is most likely a useful aid as a visual support for finding areas with relatively high concentrations of drain. The dark region indicated densest region of drainage (Figure 6.) It also indicated the distribution of drainage in the region. Drainage density is most useful where a high concentration of drainage is problematic for a waste disposal site. A landfill must not be located near drainage channels, wells, wetlands or coastlines, should not be located within 100 feet (30.48 m) of any non-meandering stream or river, and at least 300 feet (91.44 m) from any meandering stream or river (Lunkapis, 2010; Despotakis, 2007). Large ponds, lakes, and reservoirs should have a buffer zone of land to prevent blown debris and runoff from harming aquatic habitats. Large bodies of water (greater than 20 acres (80937.45 m2) of surface area) should be at least 100 feet (30.48 m) from any landfill site. Since major
rivers have a higher discharge and greater downstream influence, no landfill should be sited within the floodplains of major rivers (Bagchi, 1994).

Figure 5: Geomorphology Weightage Map of Thiruvananthapuram Corporation area (Study area) Score (0-10) is given to each features based on importance of topology for site selection. Dark red indicates very high potential regions

If the regional drinking water is supplied by surface water impoundments, it may be necessary to exclude the entire watershed that drains into the reservoir from landfill sites (Bagchi, 1994). The construction of a landfill within the 100-year flood stage of a minor river or stream is not safe. A high groundwater level or a nearby high river level will cause more risk to pollute the groundwater or river water.

So the estimation of drainage distances is important and illustrated in Figure 6B. SW treatment plant or landfill should not be located near to water bodies the leachate from the treatment site or landfill should ooze into the water catchment and contaminate the surface as well as the groundwater table. A weighting of 10 is then applied if < 100 m away and 0 for > 100 m away. In this study, distance 1536 -2665m given a score of 10 and 0-228.5m given 2 as explained in Table 3. in methodology and Figure 6C illustrates the result of weight given to distance from drainage.

Road density maps can be created for a specific area by using an Arc Macro Language program (AML) like the moving windows type. It can be also used in combination with other layers. It is a visual aid for finding areas with relatively high concentrations of roads. Road density is most useful where a high concentration of roads is problem for suitable site for landfill or SWTP. The road density is explained in Figure 7A and dark region indicates dense region.

Road density is a simple indicator of the concentration of roads in an area. The road density can be determined for road segments that have characteristics that are attributed, like road segments within a 100-meter buffer of stream channels.
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4.3 Road density, distance and weightage maps

Most of the roads are in good condition except those which are kutchta and semipucca. The single lane pucca roads are narrow, with un-surfaced kutchta shoulders and insufficient or no space for parking and pedestrian movement. Open roadside drain creates environmental problems for pedestrians.

For this study only NH, SH, MC road and district roads are considered as in Figure 1D, no other sub-roads where considered. There is no specific rule of what should be the best distance to place the landfill site. Most studies suggested that the landfill site should be located within a 1 km buffer from the roads (Chang, et al. 2008). The road distance is considered for site selection and it is explained in Figure 7B. However, planners may prefer to give an aesthetic concern when deciding a location of a landfill site. Also, the landfill sites should not be placed too far from the roads to decrease the cost of transportations. The road
network in the study area was prepared as GIS vector format and then converts to raster format. Using GIS spatial analysis, the road distances is reclassified as mentioned in Methodology Table 4. Considering the cost of transportation, it was decided to give a score of 0 to the distance ranges from 435-761m, while distances of less 0-160m given 2 as score. The Drainage distance weightage was illustrated in Figure 7C.

**4.4 Landuse weightage map**

The land availability for landfill or SWTP is very less in Thiruvananthapuram corporation area so it is important consider the landuse data and it is prepared from Remote sensing image (LISS IV) classified in ERDAS tool. The weightage of land use was explained in Table.5. Open land is given higher score and built up is given the least consideration score of 2 and the map is illustrated in Figure 8.

![Landuse weightage Map](image)

**Figure 8:** Landuse weightage Map of study area, Score 10 given to open land which is selected potential region indicated in red color.

**4.5 Urban areas weightage map**

The landfill site should not be placed near a residential or an urban area, to protect the general public from possible environmental hazards released from landfill sites. If the site is near it will adversely affecting land value and future development. In the same time, it should not be located too far to avoid extra transportation costs and environmental pollution. The landfill or decentralized system is best location would be within 10 km of an urban area. However landfill shall not be located within 1,000 m of an urban area (Nas et al. 2010).

**4.6 Suitability assessment**

After partial valuation and identification of the relative importance of each criterion in the site selection process, the next step is to obtain the suitability of each pixel (point). After projection and topology creation all feature classes like geomorphology, drainage, landuse, population and road were converted to raster files and separate datasets were created using weightage and rank. For the analysis all the raster datasets for different layers having different score were overlayed and the scores of each composite class were added using raster calculator tool of spatial analyst extension of Arc Map. The final scores were reclassified to
generate the output map showing various classes of suitable site for waste dumping and illustrated in Figure 9A. Most potential site was shown in Figure 9B.

![Image of map showing various classes of suitable site for waste dumping](image)

**Figure 9:** A. Geomorphology, landuse, drainage and Road Network weightage Map where overlaid and given equal weightage to find potential region Corporation area. 9B. Suitability Map sites selected in Corporation area (Study area). Red colour indicates most potential regions.

Most potential site was shown in Figure 9B. To find most suitable site for land fill in the Lake Beysehir catchment area AHP combined with GIS used for examining the criteria like geology/hydrogeology, landuse, slope, height, aspects and distance from settlements, surface waters, roads and protected area (ecologic, scientific or historic and result 73.70% area studied was found to be completely unsuitable for land fill site (Sener et al. 2010).

### 5. Conclusion

Thiruvananthapuram Corporation have a population density of about 4,457/km$^2$ and generates about 250 tons waste/day. Solid waste management and disposal in Thiruvananthapuram Corporation at its present status does not fulfill the required conditions. Furthermore, high rate of population growth will inevitably make problems more sever. In spite of these facts the disposal sites had been found fulfilling the conditions set by the international community, other conditions concerning the management process should be further evaluated. It has been established beyond every reasonable doubt that GIS is a very important tool for determining the most appropriate locations for setting disposal sites and it also helps to find the least-cost travel routes for waste transportation and disposal. Therefore, the projected disposal sites should be measured as suitable waste disposal/landfill sites and further studies should be done. Locating disposal/landfill sites should not be arbitrary and its management should be deliberately planned and consistent to ensure a continuous and efficient waste management program. Transport routes to these sites can be designed using GIS tool and it should be short to allow for multiple trips, efficiency in waste collection and transportation and cost-effectiveness. The findings of this work can be useful to planners and researchers since this work serves as a guide for further development and research in this area.
Further studies have to be done related to Ground truth, which is not performed due to time limit. Detail study of the biotic and abiotic factors of the region is highly recommended before implementation of the project.

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