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INTEGRATED MULTI CRITERIA DECISION ANALYSIS AND GIS FOR SITE SELECTION OF A 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. Landfills being the most sought out solution for municipal solid waste management, siting its location is an extremely complex task. Identification and selection of site for the same depends on many factors and strict regulations. In this study, an attempt was made to determine sites that are appropriate for landfill location by combining geographic information system (GIS) and multi-criteria decision making methods (MCDM) – Analytic Hierarchy Process (AHP).The various factors considered includes depth of ground water table, proximity to surface water sources, soil type, slope, elevation, land use and distance to sensitive sites. Weights were assigned to each criterion depending upon their relative importance and finally a landfill site suitability map was prepared showing the suitable sites taking Thiruvananthapuram as the study area.

I. INTRODUCTION

Urbanization and the rapid growth rates of the cities are posing challenges on the “environmental sustainability”. With the rising population and the associated unsustainable practices, there has been an enormous increase in the quantum as well as in diversity of the solid waste being generated. There are variety of methods for disposing solid waste which vary globally, includes methods like dumping in open space, sanitary landfilling, incineration, composting etc. Sanitary landfilling is prevalent in many developed countries, and are designed to greatly reduce or eliminate the risks that waste disposal may pose to the public health and environmental quality. They are usually placed in areas where land features act as natural buffers between the landfill and the environment. Siting decisions are governed by the pre existing land use dynamics of urban area as well as the nature of potential interactions of the landfill with environmental, geological, hydrological and socio economic parameters of the area.

A good design of a landfill site will prevent, or reduce as far as possible, the negative impacts on environment and equally important is selection of site for the same. The siting of a new landfill in a given urban matrix requires a multitude of considerations. Thus it is rather complex multi-criteria decision making process involving numerous stakeholders and public interest groups. 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 geographic data and preferences to arrive at uni-dimensional values of alternatives.

Objective

The present study focus on formulating a general methodology for selection of a suitable solid waste disposal site in Thiruvananthapuram district utilizing both Analytical Hierarchy Process and GIS for Thiruvananthapuram district.

II. STUDY AREA

The study area selected was Thiruvananthapuram district as shown in the figure.1. It is located between latitude of 8°17’N to 8°54’N and longitude 76°41’E to 77°17’E. Thiruvananthapuram is the densest district in Kerala with 1509 people per square kilometer.

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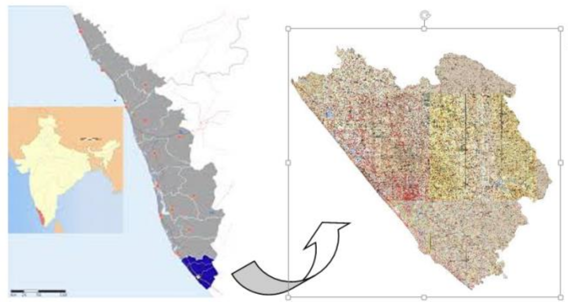

Figure :1 Map showing study area

III. METHODOLOGY

The set of key criteria influencing site selection for a sanitary landfill were identified from various literatures. In the present study all the criteria were assigned weights by pair-wise comparison matrix method based on AHP. Each pair of factors were examined at a time, in terms of their relative importance and a pairwise comparison matrix was formed in which $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$. The weight coefficients of the ranking criteria were calculated using maximum absolute eigenvalue (λmax). The grading values of all the criteria were normalized. The consistency of the judgment matrix was tested with calculation of the consistency index (CI) (Saaty,1980) and was found to be 0.05 (<0.1) and hence the judgements were said to be consistent.

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \qquad (1)$$

Where n is the order of comparison matrix
Consistency Ratio was determined by ;

$$\mathrm{CR} = \frac{CI}{RI} \qquad (2)$$

All the criteria were again sub divided into number of sub criteria, and each were assigned weightages based on previous studies. Analyses through weighted overlaying of various thematic criteria layers were then performed which was followed by the evaluation of the composite suitability index scores in the base map. Finally optimized sites for landfill were identified from composite landfill suitability map.

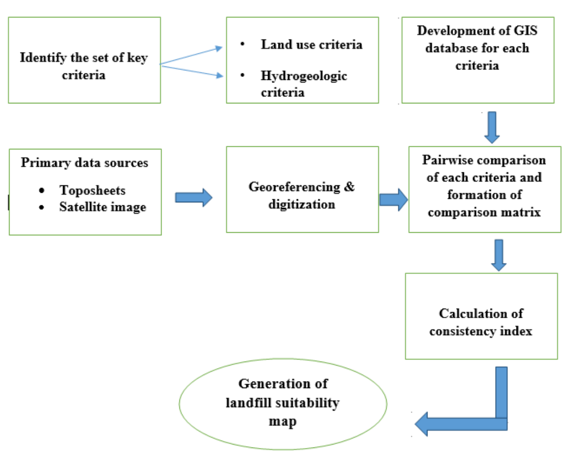

Figure 2: Methodology flow chart

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The flowchart of overall methodology is shown in figure 2

Table 1: Derivation of sub criteria weights

Criteria	Sub Criteria	Weights
Depth of Ground Water Table	0 – 5m 5 – 10m 10 – 15 15 – 20 >20	1 4 6 9 10
Distance to surface water sources	0 – 100m 100 – 500 500 – 1000 1000 – 3000 >3000	0 1 3 6 10
Land use	Water Built up Agriculture wasteland	0 1 5 10
Slope	0 – 4 4 – 8 8 – 12 12 – 16 >16	0 4 10 8 1
Distance from major roads	0 – 200m 200 -500 500 – 1000 1000 – 3000 >3000	0 3 5 8 10
Distance to Sensitive sites	0 – 500m 500 – 1000 1000 – 2000 2000 – 5000 >5000m	0 1 5 8 10
Elevation	0 – 10m 10 – 20 20 – 50 >50m	1 3 5 10

Thematic maps preparation and GIS analysis

The primary data sources for the study included the toposheets of Thiruvananthapuram district of the scale 1:50,000, which were used to prepare the base map for the study. Elevation and slope maps were derived from ASTER DEM using Arc GIS 10.1 interface. Soil, road network and groundwater table location details were collected from respective departments and subsequently digitized. The digitization and analysis of the thematic maps were performed within the framework of the well known desktop GIS software; Arc GIS Desktop 10.1. Data regarding depth of ground water table at various locations in Thiruvananthapuram district were collected from Central Ground Water Board, Thiruvananthapuram. Ground water table map was prepared by using IDW (Inverse Distance Weighing) interpolation method in Arc GIS 10.1 software. Soil association map of the study area was collected from Soil Survey and Conservation Department, and was scanned, georeferenced and digitized. A water body map indicating the ponds, lakes and rivers located in the Thiruvananthapuram district was prepared using image classisification technique in ERDAS Imagine software. The land use map was generated through the image

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interpretation and classification of the Indian Remote Sensing satellite Landsat7 imagery of Thiruvananthapuram using ERDAS Imagine software.

IV. RESULTS AND DISCUSSIONS

Thematic maps were prepared for each selected criteria layers and based on which final landfill site suitability map was created.

Base map
SOI Toposheets of Trivandrum district were collected, scanned and georeferenced to produce the base map of study area using ARC GIS Desktop 10.1

Groundwater table map
The depth of groundwater table is a significant parameter in determining the contamination risk of groundwater in order to limit potential contamination and hence a landfill site should not be located in areas with shallow ground water depth.

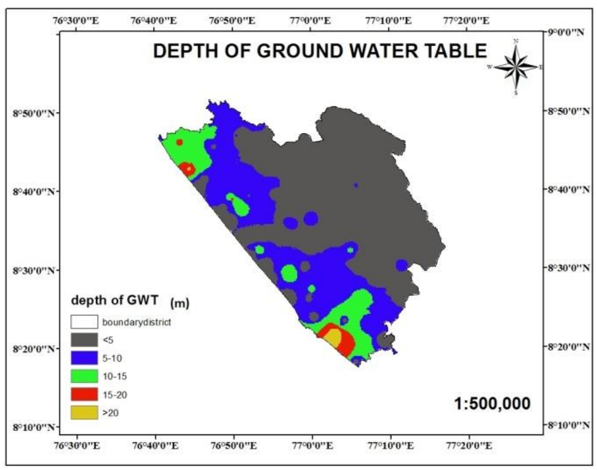

Figure 3: Depth of ground water table map

Distance to surface water sources
According to USEPA guidelines and Wetlands rules of Solid waste management, a protection zone should be given for surface streams, lakes, rivers, wells or wetlands since they create noxious gases and leachate which make them unsuitable to be in the proximity to water resources. (Figure:4)

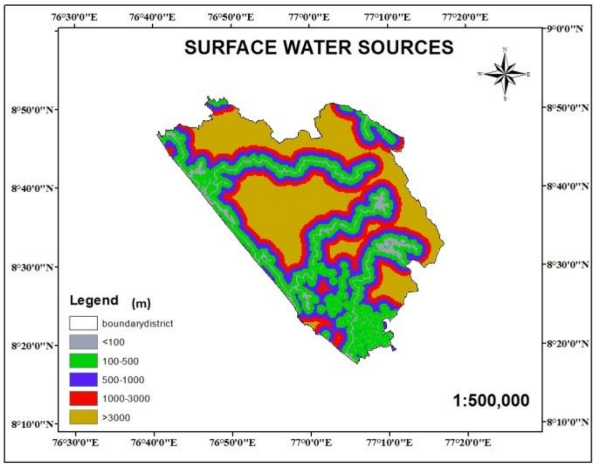

Figure 4: surface water sources map

Table 2 : Pair wise comparison matrix

Parameters	Ground water table	Surface water sources	Soil type	Land use	Distance from major roads	Slope	Elevation	Distance to Sensitive sites
Ground water table	1	1.28	1.73	0.59	4.39	0.88	1.43	0.38
Surface water sources	0.78	1	0.85	1.51	3.18	1.73	1.77	0.54
Soil type	0.46	1.17	1	1.58	4.10	2.58	1.83	1.20
Land use	1.68	0.66	0.63	1	2.90	2.00	1.18	0.36
Distance from major roads	0.22	0.31	0.24	0.34	1	0.82	1.46	0.51
Slope	1.14	0.57	0.38	0.49	1.20	1	1.20	0.30
Elevation	0.70	0.56	0.54	0.84	0.68	0.83	1	0.18
Distance to Sensitive sites	2.60	1.82	0.83	2.78	1.97	3.25	5.31	1

Soil type

Soil type affects the rate of infiltration into the water table. An optimal soil will have very low permeability, sufficient bearing capacity, pH of atleast 5, low erodibility potential and high cation exchange capacity. Soil map (Figure 5) of the study area is shown here

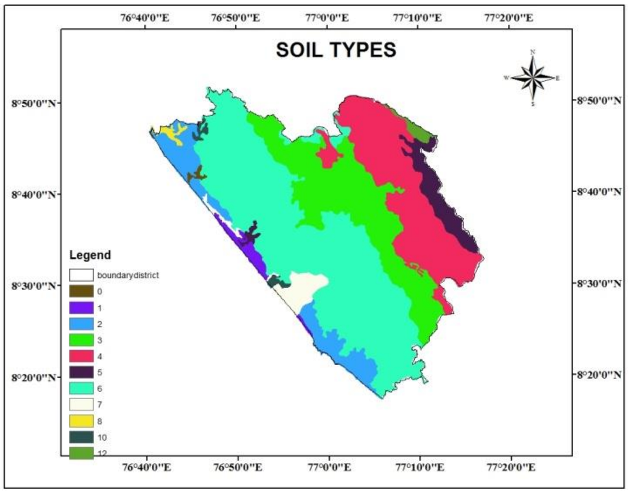

Figure 5: Soil type map

Landuse

The land use map (Figure; 6) displays the land utilized by the human and the natural cover in the Thiruvananthapuram district. It was developed by image interpretation and classification of the Landsat satellite imagery acquired on November 2014. The land use map indicates the areas of settlements, agriculture, waste land and water bodies

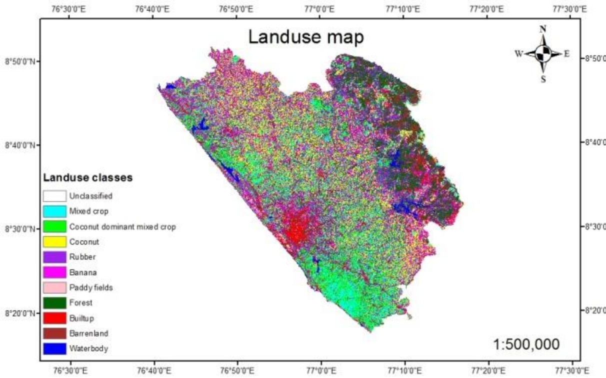

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Figure 6 : Landuse map

Distance to major roads

Solid wastes are daily delivered through one or more collection roads. Buffer zones of 500 m were created around roads. A distance to roads map was created where the less distance from a main road, the better the site. (Figure7)

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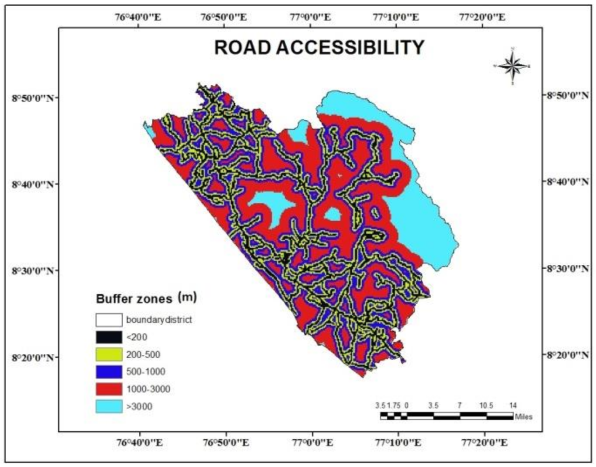

Figure 7: Map showing distance to major roads

Slope

Slope refers to the measures of the rate of change of elevation at a surface location and normally expressed in percent or degree slope. The slope of a land is considered an economic factor in construction of a landfill as high slope lands are more difficult to be managed and therefore will be more costly. The slope map (Figure 8) was prepared from ASTER DEM through Arc GIS Interface.

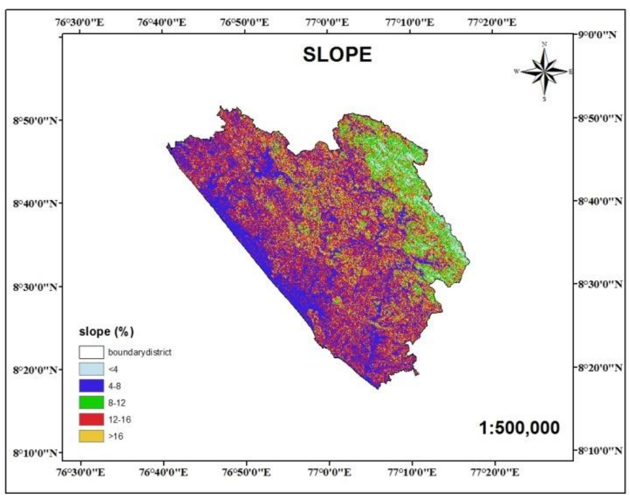

Figure 8: Slope map

Elevation

Elevation map (Figure 8) of the study area was prepared from ASTER DEM of 30m resolution

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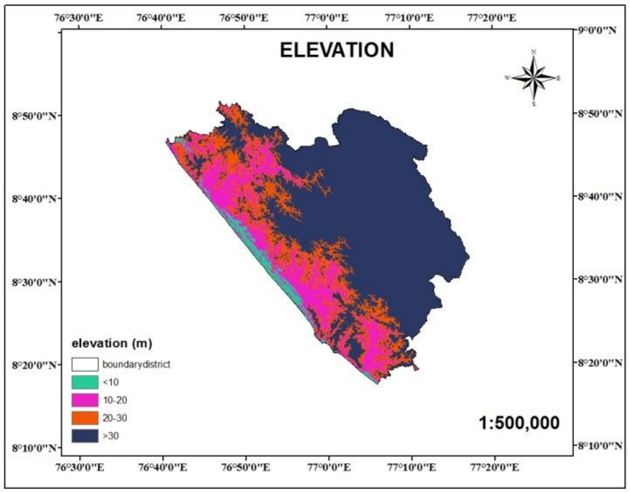

Figure 9: Elevation map

Distance to sensitive sites

A map showing sensitive sites (Figure 10) was developed by the digitization of the major cultural, archaeological and historical sites; where restrictions are there for the development of landfill.

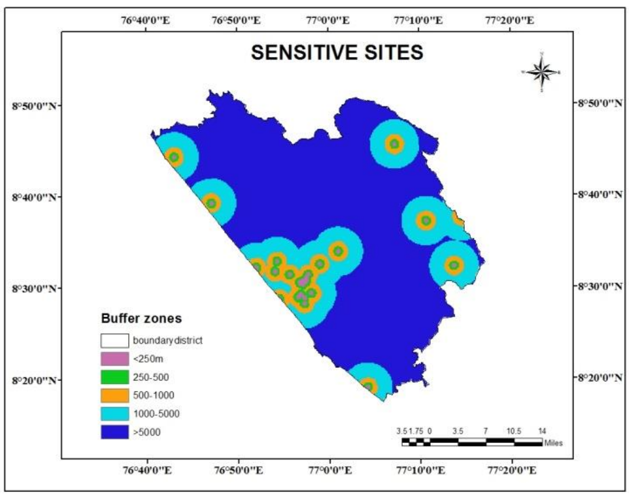

Figure 10 : Distance to sensitive sites

V. CONCLUSION

An optimum site for the construction of a landfill in a typically urbanizing city was identified using Analytical Hierarchy Process (AHP) along with GIS-based overlay analysis. The study was based upon a set of key criteria, which were selected based upon the previous studies in the area as well as the pre-existing local level factors of the study area.

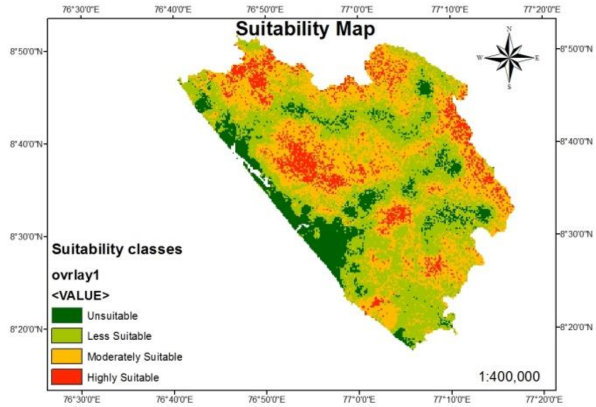

Figure 11: Landfill suitability map

The final suitability map (Figure 11) shows the areas that are suitable to locate a sanitary landfill. The suitability map was classified into four classes based on the suitability value, such as Unsuitable, Less suitable, Moderately suitable, Highly suitable. From the analysis Nedumangad, Kallara and Vithura were found to be the most suitable locations to site a landfill.

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