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Site Selection and Route Optimization for Solid Waste Disposal for Tiruchirappalli Corporation using GIS

Aarthi Priyadharshini. M [1]
Department of Civil Engineering
PSG College of Technology
Coimbatore- 04

Francina. J [2]
Department of Civil Engineering
St Joseph College of Engineering
and Technology Thanjavur

***Abstract*—Collection of municipal solid waste (MSW) is an important problem in every waste management program. The various problems are overflow of waste containers, ground dumping at collection sites, and open / indiscriminate dumping at unauthorized places. However the manual analysis of solid waste management is very tedious as it involves a huge data and statistics. Geographical Information System (GIS) is a tool introduced to overcome these limitations and make waste management planning to be more efficient and also can be quickly implemented. It will reduce the waste management work load to a great extent.The present study aims at selecting suitable sites for solid waste in Tiruchirappalli city. Also route optimization need to be done to dump the waste in an optimum way. Hence GIS has been used to achieve these aims. Integration of Geographic Information Systems (GIS) and Global Positioning Systems (GPS) present a platform to capture , map, and analyse such spatial issues. Aerial extent of Tiruchirappalli is 167.23 Sq. Km with a population of 9.27 lakhs. At present solid waste is being dumped at Ariyamangalam dump yard. The current routing for dumping waste is being done in an irregular manner by the truck drivers.**

The various data like Road map, land use /land cover map, contour map, route chart details and bin locations were collected. They were digitized using GIS and weighted overlay was carried out to find suitable sites for dumping solid waste. In addition, network analysis was also done to optimize the various routes. The major contribution in this present study is the simple optimal routing model planned to achieve the minimum cost/distance/time efficient collection and transport path for solid waste management in Tiruchirappalli Corporation.

Keywords: Solid waste management, Waste collection, Geographic information system, Site selection, Route optimization.

I. INTRODUCTION

Our Environment is facing potential threat from unsustainable waste disposal practices prevailing in almost all the urban centers in the country. Vast quantities of waste generation by the cities are one of the serious outcomes of unplanned development. Due to the increasing population and industrialization, large quantities of wastes are being generated in different forms such as solid, liquid and gases. The most common problems associated with improper disposal of solid waste include diseases transmission, fire hazards, odor nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses. The technique of getting rid of these wastes in an economic and environmentally friendly approach is called Solid waste disposal. Hence waste disposing is an important part of waste management system, which requires much attention to avoid environmental pollution.

Landfill site selection is a complex process involving social, environmental and technical parameters as well as government regulations which requires the processing of a massive amount of spatial data. Waste management issues should be confronted in a more generalized manner, which means that new strategies need to be designed considering diverse and variable urban models. In addition, site selection of new landfills for municipal solid waste disposal is a great concern for the urban government as old landfill sites are being filled-up and demand for new sites is increasing. This demonstrates the necessity of developing integrated, computerized systems for obtaining more generalized and optimal solutions for the management of urban solid waste planning. It is a tool that allows users to analyze spatial information, edit data, maps, and present the results of any spatial and non-spatial based analysis.

A. STUDY AREA

Tiruchirappalli, also called Tiruchi or Trichy, is a city in the Indian state of Tamil Nadu and the administrative headquarters of Tiruchirappalli District. It is the fourth largest municipal corporation and the fourth largest urban agglomeration in the state. Located 322 kilometers (200 mi) south of Chennai and 379 kilometers (235 mi) north of Kanyakumari, The Kaveri Delta begins 16 kilometers (9.9 mi) west of the city where the Kaveri river splits into two, forming the island of Srirangam, which is now incorporated into the Tiruchirappalli City Municipal Corporation. Occupying 167.23 square kilometers (64.57 sq. mi), the city was home to 916,857 people in 2011. The city has been divided into four zones namely, north, south, east, and west with a total of 65 wards. In addition to these commercial complexes, hospitals and industries are established in and around the city which add up to solid waste generation. The figure 1 shows the study area.

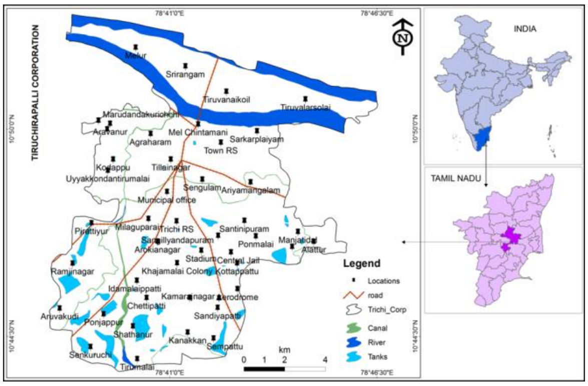


Figure 1.1: Study area

B. *GIS IN SOLID WASTE MANAGEMENT*

Geographic Information System (GIS) is a computer tool for capturing, storing, querying, analyzing and displaying spatial data from the real world for a particular set of purposes. This technique is used to generate optimal route for collecting solid waste. GIS is a tool that not only reduces time and cost of the site selection, but also provides a digital data bank for future monitoring program of the site. Therefore, objectives of the present study are to estimate the ward wise per capita solid waste generation and to prepare a distribution map of waste generation in the urban limit of Tiruchirappalli.

II. LITERATURE REVIEW

Karthiheyan P.N and Yeshodha,2016 [1] deals with determination of suitable site for the disposal of waste generated from Krishnagiri district where the greatest protection for environment is provided using Remote Sensing and GIS techniques.Urban solid waste management is considered as one of the most serious environmental problems confronting municipal authorities in developing countries.The problem associated with the solid waste disposal site in today's society is complex because of the quantity and diverse nature of the wastes. Hence potential sites will have to be managed by technologies and methods that support sustainable communities and environment. This study that has been carried out involved analyzing the existing solid waste disposal site initially and later land use land cover, geology, geomorphology, soil, road network and drainage mapping was done using on screen visual interpretation of the IRS P6 LISS-IV satellite imagery for identifying the sites for solid waste dumping. All thematic vector layers created were analyzed by the theme wise suitability of different classes in the study area by giving them weightage scores using spatial analyst tool in Q-GIS to target the potential sites for waste disposal.

Ankitverma and BhondeB.K,2014 [2] proposes a GIS based urban solid waste management (SWM) system to implement the developed model to study area to solve some of the present situation problems like proper allocation of waste bins, optimizing waste transportation routes and planning location of waste disposal facility. This paper portrays Geographical Information System as a decision support tool for Municipal solid waste management. This model will help to get rid of solid waste as per the study area. Amendment in the system through based Geographical Information System model would reduce the waste management workload to some extent and exhibit remedies for some of the Solid waste management problems.

III. METHODOLOGY

The following flow charts explain the methodology that has been followed in this paper. Since the objectives are site selection and route optimization for finding the shortest route, two different methodologies were adopted for respective cases. Figure 3.1 shows the methodology for site selection for solid waste disposal and the figure 3.2 shows the methodology for route optimization of the trucks carrying the waste to the disposal site.

Figure 3.1:Methodology for site selection

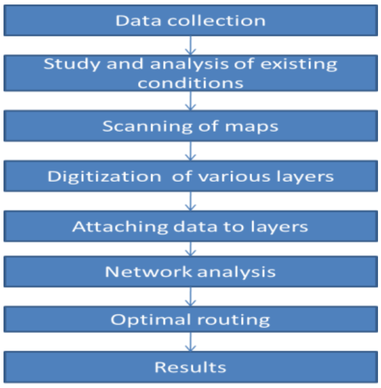


Figure 3.2: Methodology for Route Optimization

A. *DESCRIPTION OF DATA COLLECTION*

To efficiently manage the municipal solid waste system, detailed spatial information is required. It contains study area boundary, population density, satellite image, ward map, land use / land cover map, contour map, road network, location of bins, capacity of bins , route chart details.

DATA	SOURCE
Study area boundary	Trichy corporation
Population density	Census 2011
Satellite image	Google earth
Ward map	Trichy corporation
Land use / land cover map	Trichy corporation
Contour map	Survey of India , Chennai
Road map	Trichy corporation
Location of bins	Trichy corporation
Route chart	Trichy corporation

Table 3.1: Data collection and their source

B. COLLECTION OF WASTE

Collection of solid waste is carried out by using suitable vehicles. The type of vehicle to be used depends on the type of collection bin and width of the road. Hence, three types of vehicles are used for the three types of bins. All of the mechanized vehicles are chosen to reduce the pickup time of bins at different locations and thus to reduce the number of vehicle requirements. The three types of vehicles designed for managing the solid waste are as follows:

- Vehicle type-A: It is a skipper type of vehicle having a length of 4.5 m. It lifts only A-type bins and travels only on major roads. It can carry only one bin at a time.
- Vehicle type –B: It is a lifter type of vehicle with a front loading mechanism and lifts B-type bins and travels both on major and minor roads.
- Vehicle type –C: It is an auto-rickshaw type of vehicle and is used for the collection of waste from the congested areas. It can collect wastes from C-type bins and unload it into the nearest A-type bin.
-

IV. RESULTS AND DISCUSSION

A. EXISTING SOLID WASTE DISPOSAL SITE

The estimated MSW generation in Trichy city is about 400 to 600 tons per day, which is facilitated by an open dumping yard namely Ariyamangalam garbage ground. The dumping site is positioned at 10˚48'N and 78˚43'E. Inappropriate disposal of solid waste can be manifested by soil contamination through direct waste contact, air pollution by burning of wastes, spreading of diseases by different vectors like birds, insects and rodents, or uncontrolled release of methane by anaerobic decomposition of waste. The unscientific landfill may reduce the quality of the drinking water by contamination of surface and ground water through leachate and causes diseases like jaundice, nausea, asthma. Therefore, locating proper sites for solid waste disposal and selecting appropriate landfill site far from residential areas, environmental resources and settlement is very important for the management of solid waste. The present condition of the dumping site in Trichy district is shown in Figure 4.1.

Figure 4.1: Present condition of dumping site

B. THEMATIC MAPS GENERATED

The thematic maps such as land use land cover, slope, geology, road network and river buffer zones were created using ARC-GIS software.

a. LAND USE/ LAND COVER MAP AND GEOLOGY MAP

The dumping site should not be selected close to the built up area to avoid adversely affecting land value and future development and to protect human being from environmental hazards created from dumping sites. It should be selected at a suitable distance farther from the residential area. Scrub land and barren land are most suitable for the dumping site. Rivers and lakes, canals, built-up, vegetation, agricultural land, scrub land and fallow land are major land use/land cover classes in the present study. Geological structures have great importance in ground investigation. The geology of the study area has homblende biotite gneiss that covers the major portion of the study area.The Figure 4.2 & 4.3 represents land use / land cover map and geology map respectively.

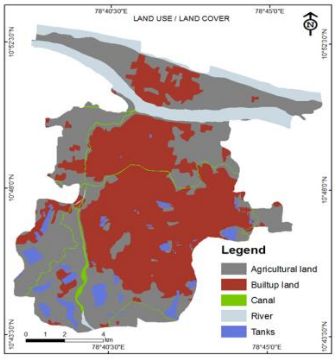


Figure 4.2: land use/ land cover map

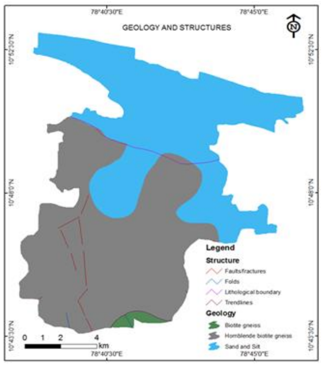


Figure 4.3: geology map

b. SLOPE MAP

Elevation is an important parameter in the identification of landfill site. In the method used here, the land morphology was evaluated using the grading of the slope and specified in degrees format. The areas with high slopes are not ideal for solid waste disposal and flat areas are not ideal either. Figure 4.4 shows the details of slope.

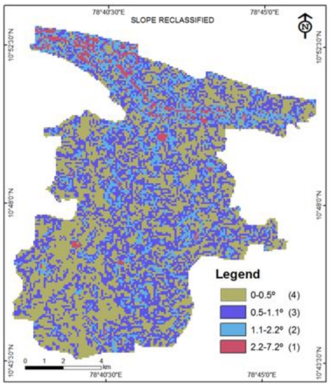


Figure 4.4: slope map

c. ROAD NETWORK BUFFER ZONES AND RIVER BUFFER ZONES

The road network comprises of the railway network, national highway, state highway and other local roads that almost link all the towns and villages of the district. The buffer zones were created for both roads and rivers. The Figure 4.5 & 4.6 represents the buffer zones of road networks and rivers respectively.

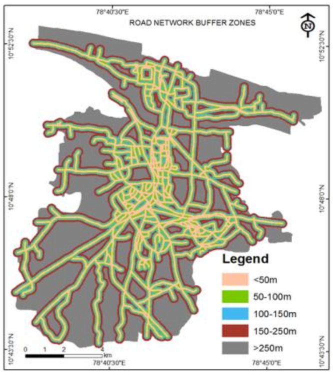


Figure 4.5: Road network buffer zone

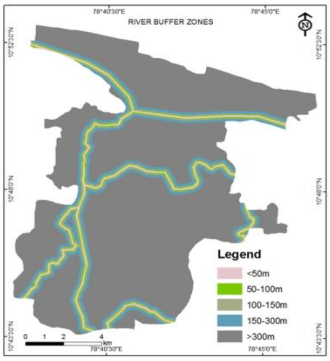


Figure 4.6: River buffer zone

Weights have been assigned to each class of all thematic maps for GIS analysis. Weights range from 1 to 4 in which 1 stands for unsuitable while 4 stands for suitable.The Table 4.1 represents the summary of rankings and suitability level used in selection of site.

S.No	Criteria	Sub-Criteria	Ranking	Weights	Level of suitability
1	Slope	0-0.5º	4	15	Highly suitable
		0.5-1.1º	3		Moderately suitable
		1.1-2.2º	2		Less suitable
		2.2-7.2º	1		Unsuitable
2	Geology	Biotite gneiss	2	15	Less suitable
		Hornblende biotite gneiss	4		Highly suitable
		Sand and silt	1		Unsuitable
3	Land use / land cover	Agricultural land/Fallow land	4	30	Highly suitable
		Built-up land	2		Less suitable
		Canal	1		Unsuitable
		River	1		Unsuitable
		Tanks	1		Unsuitable
4	Distance from road	<50m	1	20	Unsuitable
		50-100m	1		Unsuitable
		100-150m	2		Less suitable
		150-250m	3		Moderately suitable
		>250	4		Highly suitable
5	Distance from main river	<50m	1	20	Unsuitable
		50-100m	1		Unsuitable
		100-150m	2		Less suitable
		150-300m	3		Moderately suitable
		>300m	4		Highly suitable
Total				100	

Table 4.1 Summary of Rankings and Suitability Level used in Selection of Dumping Site

Based on the above weightages, final suitability map has been created to find the suitable site for waste disposal. Figure 4.7 shows the final suitability map for site selection.

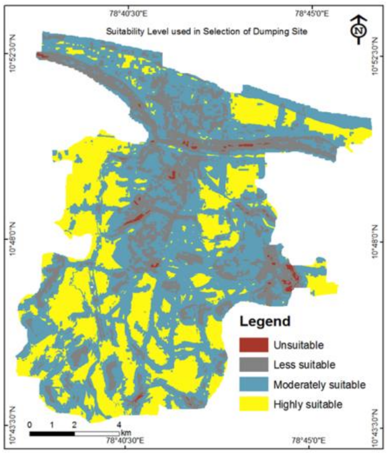
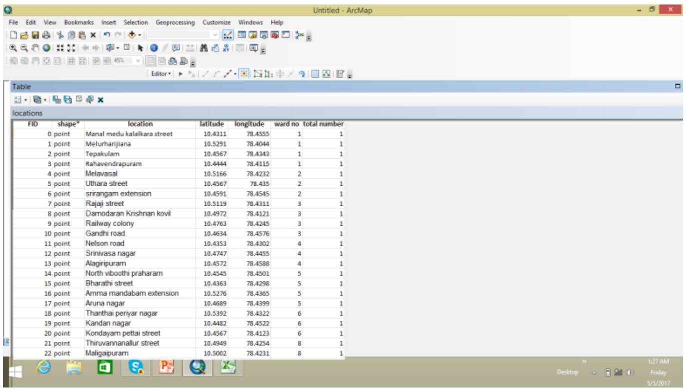


Figure 4.7: final suitability map

C. ROUTE OPTIMIZATION

Arc View Network Analyst extension module allows the user to solve three categories of network analysis problems: Find best route, Find closest facility and Find service area. Based on this network analysis shortest path for various bin locations is being calculated. Actual traveling distance from the location of bins to the dumping yards has been calculated using GPS application in mobile within the corporation. Using network analyst in GIS best route between those two points are measured and the difference between those two values will give the path difference. With these four zones bins located in different wards in each zone are taken and a model was created. This random manner of optimization will give reduced travelling distance and based on the result for further bins the same procedure is being carried out. Bin locations are converted as geo referenced point using latitude and longitude using GPS. Table 4.2 shows the bin locations entered in attribute table and Figure 4.8 shows the roads along with bins.



FID	shape*	location	latitude	longitude	ward no	total number
0	point	Manal medu kalalkara street	10.4311	78.4555	1	1
1	point	Melurharijiana	10.5291	78.4044	1	1
2	point	Tepakulam	10.4567	78.4343	1	1
3	point	Rahavendrapuram	10.4444	78.4115	1	1
4	point	Melavasal	10.5166	78.4232	2	1
5	point	Uthara street	10.4567	78.435	2	1
6	point	srirangam extension	10.4591	78.4545	2	1
7	point	Rajaji street	10.5119	78.4311	3	1
8	point	Damodaran Krishnan kovil	10.4972	78.4121	3	1
9	point	Railway colony	10.4763	78.4245	3	1
10	point	Gandhi road	10.4634	78.4576	3	1
11	point	Nelson road	10.4353	78.4302	4	1
12	point	Srinivasa nagar	10.4747	78.4455	4	1
13	point	Alagiripuram	10.4572	78.4588	4	1
14	point	North viboothi praharam	10.4545	78.4501	5	1
15	point	Bharathi street	10.4363	78.4298	5	1
16	point	Amma mandabam extension	10.5276	78.4365	5	1
17	point	Aruna nagar	10.4689	78.4399	5	1
18	point	Thanthai periyar nagar	10.5392	78.4322	6	1
19	point	Kandan nagar	10.4482	78.4522	6	1
20	point	Kondayam pettai street	10.4567	78.4123	6	1
21	point	Thiruvannanallur street	10.4949	78.4254	8	1
22	point	Maligaipuram	10.5002	78.4231	8	1

Table 4.2: Bin locations in attribute table

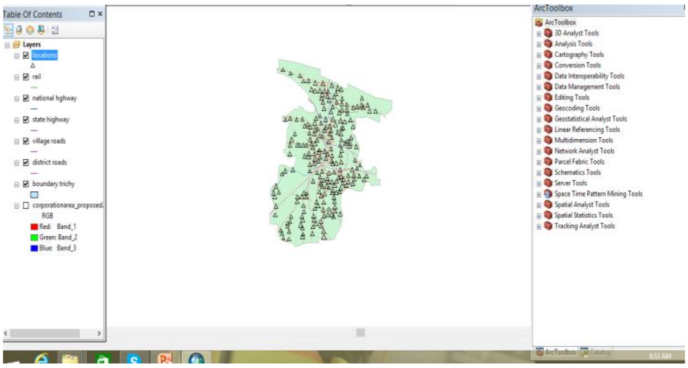


Figure 4.8: Roads along with bin locations

Steps to be followed:

- Creating a network dataset
- Creating a multimodal network dataset
- Finding the best route using a network dataset
- Creating a model for route analysis
- Finding best routes to service a set of paired orders
- Choosing optimal routes

i. CREATING NETWORK DATABASE

A Network Dataset was created from the feature sources that participated in the network. It incorporates an advanced connectivity model that can represent complex scenarios, such as multimodal transportation networks. It also possesses a rich network attribute model that helps model impedances, restrictions, and hierarchy for the network.

Arc-GIS-NA is an extension that provides network-based spatial analysis including routing, travel directions, closest facility and service area analysis. The NA is able to find efficient travel routes for the trucks during solid waste collection. In order to solve the route optimization, distance criteria and collection time by the truck (regardless to time spent in traffic) were considered and generated. By considering speed formula (v = ¨d/¨t) duration taken for each truck travelled throughout solid waste collection was obtained. The final output was an optimal solution in terms of distance criteria.

ii. SERVICE DESIGN (DEFINITION OF THE ROUTES

Best possible routes for solid waste collection were identified based on the information obtained with the help of the GIS regarding the possible routes, and having taken into account the restrictions to the road conditions and topography. The routes were chosen in a way that the resources used for the collection, the length of the route and the time taken to complete the collection is minimized.

iii. FINDING SHORTEST ROUTE

The Figure 4.9 shows that, the SOLVE tool in network analyst has been used to find the shortest route between Tepakulam extension which is situated in Srirangam zone to Ariyamangalam dump yard. The same procedure is carried out for rest of the locations also. This optimization using GIS gives the shortest route compared to actual distance travelled by the truck, so that the time and fuel consumption by the vehicles can also be saved.

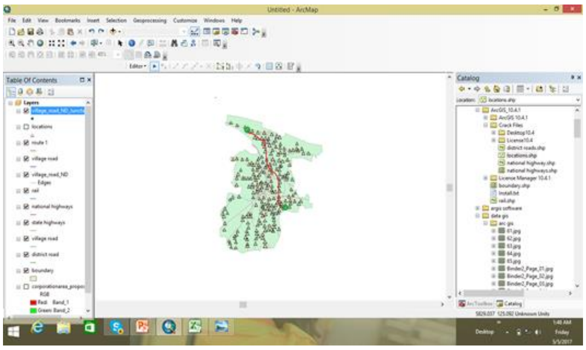


Figure 4.9: Shortest route between the location of bin and dump yard

Then using the application of network analyst, optimization of route was carried out considering 3 areas in each zone and it is created as model. The total distance being reduced in these areas is nearly more than 5 kms.The table 4.3 shows the Short path analysis.

Bin location	Actual path (km)	Short path (km)	Path difference (km)
Manalmedu kalalkara street	9.3	8.91	0.39
Melurharijana street	8.7	8.43	0.27
Tepakulam extension	7.5	7.21	0.29
Alangananthapuram	6.5	6.13	0.37
Hirudayapuram	5.4	4.89	0.51
TVS street	4.8	4.49	0.31
Thangeshwari nagar	10.3	9.87	0.43
Raja veethi	9.9	9.36	0.53
Mannarpuram	8.5	8.22	0.28
Ashok nagar	9.2	8.76	0.44
Gandhiyadigal street	11.1	10.75	0.35
Viruppachipuram agraharam	8.7	8.43	0.27

Table 4.3: Short path analysis

V. CONCLUSION

Solid wastes consist of highly heterogeneous mass of discarded materials from residential, commercial and industrial activities. Selection of disposal sites for solid wastes generated in the urban area has always remained a big task as the selected site should not affect the environment negatively. The methodology employed in this study described the GIS and weighted index process techniques for the selection of suitable sites for the disposal of municipal solid wastes in Tiruchirappalli district. The study shows the ability of GIS as an authentic tool for decision support. The techniques considered a number of siting criteria ranging from accessibility, land use to natural factors which are very important in identifying sites which possess minimum or no risk to the environment. Finally, the suitable site was selected for the management of solid waste in the study area which was identified to be the ideal and the most accessible site. The site that has been selected is located at Ponmalai zone covering an area of 42 acres of land. The study also demonstrated the efficacy of GIS in the optimization of collection routes. It also states an efficient designing and developing of a proper storage, collection and disposal system plan for Tiruchirappalli Corporation. A GIS optimal routing model has been developed by considering parameters like population density, waste generation capacity, road network and types of road, storage bins and collection vehicle etc. This model helps to find minimum cost/distance efficient collection pattern for transportation of solid waste to landfill. Thus the reduction in the travelling distance of the truck will reduce the transportation cost.

VI. ACKNOWLEDGEMENT

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