GIS BASED LEAST COST PATH ROUTING MODEL FOR MUNICIPAL SOLID WASTE: CASE STUDY IN KUMBAKONAM, TAMILNADU

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Abstract— The purpose of the study area is to identify the shortest route for solid waste disposing.GIS technology can be used to find out optimal collection routes by corresponding real world travel conditions and patterns. To accomplish appropriate route by least cost path (LCP) method using Geographic Information System (GIS) software. Since solid waste transportation is one part of waste management. In addition to that to active the objective of this research, seven very important factors have been used such are: master plan of the city, land use/land cover, road type, slope, aspect, source date sate and destination point using the method of Network analyst for all selected factors in GIS software. This research work is focal point on use of GIS model for current and proposed collection patterns using GIS Network Analyst. The GIS was used to determine optimal routes for small collection groups and outlines the workflow and best practices for future analysis throughout the Kumbakonam city.

Index Terms— GIS, LCP, solid waste, master plan, slope, aspect, Network Analyst

1 INTRODUCTION

The worsening solid waste disposal situation in Kumbakonam has attracted attention among the populace. High profile government officials including Ministers of State, and even the presidency have expressed concern about the deplorable solid waste situation in Kumbakonam.Uncontrolled open dumps are reservoirs of high public health hazards because of improper site management which directly endanger the health of the people living near to, or on the site. The public may be affected by the contamination of their drinking water, by soil contamination passed on to the aquatic and terrestrial food chain and through the spreading of diseases. People living near or on the site are often subject to direct transfer of contamination from hand to mouth and through inhalation of dangerous volatile compounds and aerosols. Waste generation is inevitable and we need to find a way to curb this problem of solid waste in the environment because it contributes to global warming. Open dumping is the least financial cost solution for dealing with waste disposal, it is apparent that continued open dumping is not suitable for practical, social and environmental consider-ations..

The typical municipal garbage tipper lorry travels approximately 27,000 km annually, gets less than three kilometer per gallon, and uses around 7,240 gallons of fuel per year. A large part of a city sanitation budget goes towards fuel, maintenance, reduces overall costs. The city was not sure how to plan improved travel routes to develop efficiency, as it is a complex problem in and labor for its fleet of sanitation collection Vehicles. The City of Kumbakonam required using GIS Technology to help out volving many factors, including the location of waste bins, type of waste, collection details, number of workers, operational hours, driving direction, type of vehicle, travel impedances, and integrity of road network being traversed. The city wanted to know the best approach and configurations using a GIS to help optimize sanitation collection routing. Geographic problems often require the analysis of many different factors for laying a new route, such as land use cost and slope cost [1].

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2 REVIEW OF LITTRRATURE

The various authors are discussed about the use of GIS for optimized route plan in different countries. [2] Developed a simulation model DOWOR (Design on weekly optimum route) to de-termine optimized refuse collection vehicle routes for individual vehicles. The various authors [3] and [4] discussed about optimal collection routing model for municipal solid waste in different cities studied a multi objective programming model for vehicle routing and scheduling to analyze the optimal route between a given origin and destination in a waste collection network using GIS.

Arc GIS's Model Builder has been used to automatically perform all processes necessary to calculate cost distances and paths between the stations of source and final suitable site; [1].The road network raster modeling used the term "accumulated" implies that there is a building up of numbers or values, and this is exactly what happens [5].The cost for a cell in an accumulated surface is a value that represents a cumulative cost from the target. [6].developed a simulation model DOWOR (Design on weekly optimum route) to determine optimized refuse collection vehicle routes for individual vehicles. The model may be adopted to accommodate either daily or weekly route method of scheduling

Vehicles. [3] Determined the optimal path for transfer of waste from specified waste bins to the disposing station in Haridwar using network analysis.

[7] developed an algorithm to solve the vehicle routing problem in a collection area of 80 nodes and 153 links (Streets) for a uni directed network. Highway route location using GIS had been carried out by Satheesh (1996).[8] studied a multi objective programming model for vehicle routing and scheduling to analyse the optimal route between a given origin and destination in a waste collection network using GIS.In this context, optimization seeks to minimize total collection distance, costs and time. The use of Geographic Information System in vehicle route planning offers a number of advantages over traditional methods [9] [10] have employed GIS to analyze the spatial; relationships between various geologic, hydrologic, and geographical characteristics necessary for the identification of suitable landfill sites.GIS have often been employed for the siting and placement of facilities [11] [12] developed a method to quantify the relationship between the demand and supply of suitable land for waste disposal over time using a geographic information system and modeling techniques. Based on projections of population growth, urban sprawl and waste generation the method can allow policy and decision makers to measure the dimension of the problem of shortage of land into the future. Geographic information system is one of the most powerful tools in planning and decision-making today [13] [14] [15] .

The purpose of this study was to examine the solid waste situation in Kumbakonam municipality with the aim of enhancing understandings of the problem and the key issues affecting urban solid waste disposal in the town, and also to identify possible solutions to the problem. In other words, this research was an attempt to answer the question 'why are urban authorities in Kumbakonam unable to organize adequate and equitable waste management within their jurisdictions?' In line with this, the specific objectives that guided the study were:

The aim of this work was to develop an objective for the optimization of the waste Collection system, based on GIS technology.

- ✓ To describe the urban solid waste situation in Kumbakonam town
- ✓ To inventory and analyze the spatial patterns of waste dump sites in Kumbakonam Municipality
- ✓ To shrink the overall distance of kilometers drive to collect and transport solid waste bins.

Waste management system optimization through the selection of waste collection and transportation route.

3 DESCRIPTION OF THE STUDY AREA AND MATERIALS

Kumbakonam is one of the important religious towns in South India. Kumbakonam is a special grade municipal town and the

Second biggest in terms of administrative status in Thanjavur district. Kumbakonam town extends from 10°51' North to 11°4' North latitudinal and from 79°17' East to 79 °31' East longitudinally It is located 313 km from Chennai on the South, 90 km from

Trichy on the East, and 40 km from Thanjavur on the Northeast. It is one of the first grade municipalities in Tamil Nadu with a population of 1, 41,814 in 2011.The town is famous for Mahamagam festival, which is celebrated once in 12 years. It is a deltaic plain with smooth rolling surface towards to east coast and attitudinally its elevation is between 22 meters to 36 meters from mean sea level. The location of the study area map is shown in Figure..1

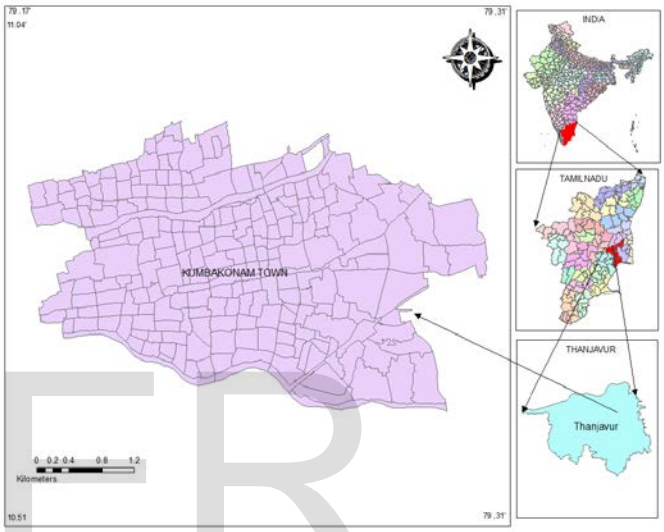

Figure.1.Location Map

4. POPULATION AND RATE OF WASTE GENERATION

The ever increasing population in Kumbakonam has resulted in the generation of solid waste due to the adoption to modern life style, thus resulting into contamination of air, water and land resources. Domestic solid wastes, commonly known as trash or garbage, are the solid waste generated from different sectors of the urban local bodies. The uncontrolled and unscientific dumping of such wastes has brought rising number of incidents on hazards to human health. The following section deals with the Solid Waste Management of the Kumbakonam city and how it is trying to mitigate the potential risks and hazards. Similar to any other Indian city, solid waste is generated by residents, commercial establishments, industrial establishments, hospitals and nursing homes, hotels and restaurants, slaughter houses in Kumbakonam.As per CPHEEO Guidelines, the per capita combined waste generated would be between 0.2 to 0.6 kg/capita/day in area with population between 0.1 million to greater than 5 million (Figure.2).It has also been estimated that the per capita combined waste generated would be no more than 0.405 kg/capita/day in with population density less than 20000/sq.km.The following table shows the approximate waste generated from the various establishments .For projection purposes, the per capita waste generation is projected to increase by 1.4% annually. Following table

shows the projection for the years 2021, 2031 and 2045 respectively.

4.1. Secondary collection / transpor-tation of MSW

Cumulative Average Waste Collected by ULB and Private Party is 70 MT per day. (Further details on Waste classifications are required to calculate the actual amount of waste generated in the city).For transportation of the collected waste to the dumping yard, 7 Twin Bins(4 by ULB,3 by Private Party)2 Single Bins (Both by ULB),1 Compactor(By ULB 1,8 Tipper Lorry (6 by ULB, 2 by Private Party),4 Mini Trucks(3 by ULB, 1 by Private party) have been apportioned. Following is the list of vehicles used for Primary Collection of Waste

No	Vehicle Type	Availability	Capacity
1	Green & White Bins	38000	10 kg
2	Push carts with four Bins	86	50 litre
3	Tricycles old	17	60 kg
4	Tricycles new	100	65 kg
5	250 litre Plastic Containers	623	2009
6	TATA Ace	4	300 kg

Table.1.Vehicle Inventory for Primary Collection

No	Types of Vehicles	Availability	Capacity
1	Tipper lorry	9	3 Tons
2	Dumper placer Lorry Twin Bins	7	1 Ton
3	Dumper placer Lorry Single Bin	2	0.5 Ton
4	Compactor	1	6.50 Tons
5	Dumper placer Bins	78	2.5 m^3
6	Compactor Bins	40	1.1 m^3

Table.2.Vehicle Inventory for Primary Collection

Following is the list of vehicles used for Secondary Collection of Waste Only 90% of the waste collected Successfully compared to the ideal 100% waste to be collected. Additional burden on the periphery of the municipal limit due to over-utilization of bins by the citizens residing outside the boundary limit, posing a threat from sustainability point of view. The the number of vehicles used for solid waste collection is shown in table.1 &2.

Figure.2.Dust Bins within Kumbakonam city

4.2. Present status of disposal of MSW

There is no availability of Secured Landfill site for disposal. No complaint management system exists in the municipality. Wide gap in required staff and available staff for carrying out day to day activities. Lack of availability of Solid Waste Management Bye-Laws. The aerial view of landfill area (Karikulam) shows that the vicinity was normal, less solid waste coverage and large empty places in 2002.In contrary, the landfill site has owned one building and six segregation units, eastern side there are trace of incineration and heaps of solid wastes were noticed in 2009.Similarly,(Figure.3) two segregation units were noticed in the northern margins of landfill area and huge heap of solid waste dumping were found in a linear pattern along the southern side this site in 2012.In 2014, larger areas were under heaps of solid waste and few places were incinerated. Behind the western side of the land fill area were change of greeneries in to vacant/absence of greeneries due to this landfill site when compare to the year 2002. In the same location there were plots/land area are ready for sale for the purpose of building constructions.

Figure.3.Solid waste dumping Site at Kumbakonam

The land use land cover map of kumbakonam town was prepared and shown in figure.4.

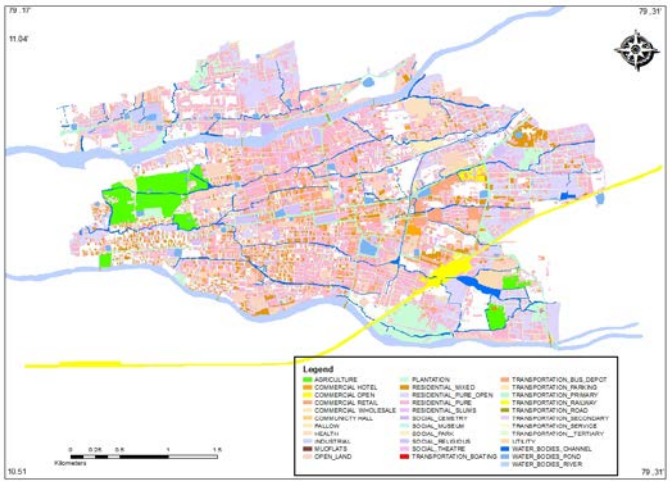

Figure.4.Land use/ Land cover Kumbakonam city

5 METHODOLOGY

The methodology includes the collection of information about the waste management situations in these municipalities and preparing a database about the waste situations of the project area. Analysis of the present waste situation and recognizes the problems faced in the system. On the basis of the present situation analysis, the data availability of the project area and the study analysis, the framing of guidelines for the work to be proposed in dealing with waste management planning for the project area was carried out. In the proposed model the waste management issues are considered to solve some of the present situation problems like proper allocation of dumper bins and check for unsuitability and proximity convenience by primary collection. Finally collection route is optimized based on analysis of bin locations which there by results in the reduction of fuel consumption and proper waste management.

5.1 Data Collection

The city Kumbakonam was constituted as municipality in the year 1866 and was subsequently constituted as a city municipal corporation from 1.5.1981.It has a population of 20 lakhs (2010 census) and has an extent of 105.50sq km..The city is divided in to 72 wards and these wards are grouped in to 4 zonal committees. Ward (42) was taken to find the Shortest Route from the collection points to the transfer stations. Solid waste from these three transfer stations is again transferred to another site location at vellallore composting yard. Proceedings of vellallore yard were observed and various snaps were taken. This ward belongs to south zone. we have met major officials of municipal corporation council like town planning officer, sanitary inspector, Deputy Commissioner, commissioner etc for getting the ward. After getting the permission from the commissioner we proceeded. The specific data required for this study were collected (table 3.) from primary and secondary sources. Primary data of this study were field survey data's with hand GPS of the ground truth and secondary data has obtained from the local government Authority. Analogue map of the study area has obtained from the Municipality of Kumbakonam. A field visit has paid in order to determine the names of features on the analogue map in the attribute field of the digitized copy. The data and their sources used to generate land-use layer, road layer, the least cost path analysis in case of Kumbakonam town by using GIS with the integration of Multi-Criteria Evaluation(MCE).

Data Types	Sources	Use of the data
Master plan Of the town	Kumbakonam Municipality	Use to create required layers such as ward map, which is done by digitization
Land Use /Land cover	Google images	Digitization of current Land use
Elevation/ slope/aspect	Kumbakonam Municipality	To create TIN and DEM for further analysis of the study.
Road	OSM data	Used to analyze proximity zone
Dust bin locations	GPS survey	To locate sources data set and distention point
Population, Transportation	Kumbakonam Municipality	Solid waste generation and accesability

Table 3. Data and their sources

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5.2 Digitization

The ward map is digitized, geo-referenced and the collection bins are attributed from the Global Positioning System (GPS) data using GIS.The network module of ArcGIS software is used to find the shortest or minimum impedance path through a network. Thus the shortest route for collecting the MSW is determined. In this analysis, the collection frequencies are proposed for the collection of degradable and recyclable wastes based on the size of the bin and the quantity of wastes generated.

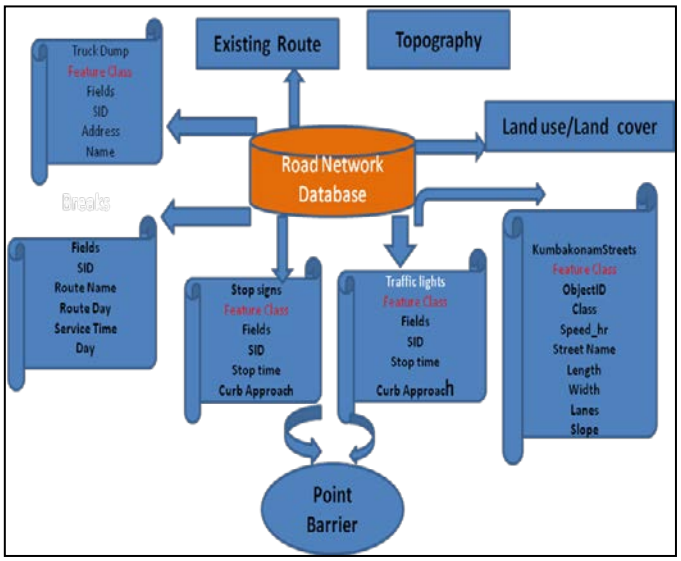

Figure.5. Structure of the developed model showing its component modules and the spatial database

5.3 Least cost path analysis

GIS is useful tools for locating the least cost path from starting point of solid waste to ending point solid waste disposal site. The least cost path route identification is used for ArcGIS network analyst, which relies on a route system, such a road network is a vector based method. A second method is cost distance/cost path, which is a raster based method and does not use road networks but can be constrained to do so. Based on this, the study has worked with the least cost path method to achieve the objectives and to answer the study questions. To find a least cost path between a starting point or sources data set, a destination point in a given gridded Digital Elevation Model (DEM) have generated in Arc GIS environment, there are two major steps. The first step is to create an accumulated cost surface with respect to all relevant cost factors, which has derived from slope and land use factor and shortest path algorithm is widely used to create a path on an accumulated cost surface for cost identification. The second step is to construct the least-cost path with slope-tracing lines on the accumulated cost surface. It has designed for tracing the shortest path in a network with nodes connected by weighted links[5].To use this algorithm in a GIS grid data layer, a virtual network has constructed fewer than two conditions:

1. The centers of each grid cell serve as the nodes in the network.

2. The connections between the neighboring cell centers act as the links of the network.

The value of each cell represents the cost per unit distance of crossing that cell in the unit of meter, which does not include the existing road [11]Generally, the costs based on following variables: land use, slope based on a digital elevation model and source data set, which is the location of solid waste collectors. And over all analysis and network analysis carried out for shortest route for solid waste collection.

6. RESULTS AND DISCUSSIONS

A GIS can be effectively used fot the new route identification with the help of various GIS layers to identify a shortest route which will cover less distance and covers maximum waste bin locations with a less overlaps. GIS provides a solution to choose shortest route for collection of waste. The new suggested route will be cheaper by upto 50% of the old route [6].This is due to lesser generation of recyclable wastes than the degradable wastes. Thus the total collection distance of 46 % is saved due to the optimization of collection route. Table 4.briefs the total running and maintenance cost of the vehicle for the present system of collection of MSW and optimized route for the collection of both the wastes. From the above table, it is known that benefit in the running and maintenance expenditure for the vehicle is 86.7% due to the optimization of collection routes.

A GIS be able to successfully used for the new route detection with the assist of different GIS layers to recognize a shortest route which will cover less distance and covers maximum waste bin locations with a less overlaps. On the basis of GIS analysis the various factors like road condition, slope and other land use pattern determine fuel cost savings. In addition to the calculated route and fuel cost shown in table. The model output shows current MSW collection routing for one year fuel consuming 52079.28 INR at the rate of INR 65.76/ litre.whereas in optimized routing fuel consuming 45555.89 INR at the rate of INR 65.76/ litre. GIS provides a solution to choose shortest route for collection of waste. The new suggested route will be cheaper by up to 35 % of the old route (6).This is due to lesser generation of recyclable wastes than the degradable wastes. Thus the total collection distance of 46 % is saved due to the optimization of collection route.

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Route	Distance (km/year)	Fuel used (lires/year)	Cost of fuel (INR/year)	Depreciation Cost per year (INR)
Current Route	46.23/ trip x52 weeks =2403.96	15.23/ trip x52 weeks =791.96	791.96 litres / year x INR 65.76 / litre =52079.28	2403.96 /100 km xINR 1300/ 100 km =31251.48
Optimized Route	34.25/ trip x52 weeks =1781	13.32/ trip x52 weeks =692.64	692.64 litres /year x INR 65.76 / litre =45555.89	1781/100 km x INR 1300/ 100 km =23153

Table.4. Cost benefit analysis in Kumbakonam

7. CONCLUSION

GIS can be effectively used in the management of solid waste and waste bin management. To avoid open dump of waste, waste bins must be allocated by finding proximity distance convenient to the people. Bin size should be decided in consideration with the generation of amount of waste and collection frequency to avoid overflow of bins. On the basis of type of waste generat-ed in particular area, type of bin can be decided. GIS can be effectively used in waste collection to decide collection routes, which will reduce the collection cost. This model also helps in finding the intermediate nodes form which shortest path is otained.User can simply figure out the route from where shortest path can be obtained. This model is valid for one way, two way and also for there is no way between the nodes.The complexity of the problem is more when there is one way from one node to another node. This model can be used for effective management of solid waste collection and disposal, and help in reducing time taken to collect and dispose solid waste among various nodes.In addition, this process has a great environmental impact due to fuel combustion.Total distance traveled, in many ways, defines the amount of fuel consumed and associated pollutantsemission. This paper presented methodology for vehicle routing optimization in the process of waste collection and transport. With such optimization tool, it was possible to achieve savings of 2714.4 kilometers per year, by optimization of one route.

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