Optimization of Solid Waste Management using Geographic Information System (GIS) for Zone A under Pimpri Chinchwad Municipal Corporation (PCMC)

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Abstract: ***Rapid urbanization, surging population numbers, limitations of funding, emerging limitations of both energy and raw materials coupled with increasing industrial, commercial and economic development in Pimpri-Chinchwad area has given rise to an increased generation of various types of wastes. Among these wastes, managing of solid waste is a major problem faced by the city. Maintaining daily logs of collection and transport of solid waste is time consuming and difficult as it involves huge data and statistics. 80% of the total cost of solid waste management is being spent on collection and transportation so there is a need of proper monitoring of the system. This paper attempts to analyze the existing status of location of municipal bins along with the various secondary routes followed for the solid waste collection of Zone A under PCMC. Then using Arc GIS 3.2 a, a GIS based urban solid waste management system is proposed for the study area by proper optimizing the waste transportation routes and reallocating the bins f or efficiency in distance travelled and time taken. Thus Geographical Information System model would reduce the complications in waste management system to some extent and exhibit remedies for the same in the study area.***

Keywords: Geographic Information System, municipal bins, optimization, reallocation, Solid waste management system

1. Introduction

Solid waste management is one of the major increasing problem faced by today's world. With the increase in socio economic and industrialization development, solid waste generation has also increased.[8]. Higher the percentage of urban population, the greater amount of solid waste produced[12]. 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. Each city produces tones of solid waste daily from the household, hospitals, industries, agricultural fields, market centres etc. The management of this enormous waste in terms of collection, handling and disposal with conventional methods has become increasingly difficult [10]. Currently, collection and transport of municipal solid waste is responsible for a large portion of the total waste management costs, in the range of 70-100%. Therefore, the cost effective collection system and finding the appropriate number and location of collection bins can be confronted with applying the sophisticated technology like Geographical Information System (GIS) computerized tool [9].

Geographic Information Systems (GIS) have been successfully used in a wide variety of applications, such as urban utilities planning, transportation, natural resources protection and management, health sciences, forestry, geology, natural disasters prevention and relief, and various aspects of environmental modelling and engineering. Among them, the study of complex waste management systems, in particular sitting waste management and disposal facilities and optimising Waste Collection &Transportation (WC&T) have been a preferential field of GIS applications, from the early onset of the technology [4]. The problem of vehicle routing is a common one: each vehicle must travel in the study area and visit all the waste bins, in a way that minimises the total travel cost: most often distance and time. As the success of the decision making process depends largely on the quantity and quality of information that is made available to the decision makers, the use of GIS modelling as a support tool has grown in recent years, due to both technology maturation and increase of the quantity and complexity of spatial information handled[10]. Optimization of WC&T making use of the novel tools offered by spatial modelling techniques and GIS may provide large economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions.

The aim of this work is to develop a methodology for the optimisation of the waste collection system, based on GIS technology. The methodology was applied to the zone A of Pimpri Chinchwad Municipal Corporation (PCMC), based on real field data. The strategy consisted of

1) Analyzing the existing status of waste collection bins with their locations for zone A under PCMC.
2) Analyzing the existing status of secondary transportation routes A1, A2, A3, A4, A5, A7, A8, A9, A11, A12, A13 and A15 followed for waste collection.
3) Optimization of the above waste collection routes in terms of minimum time and distance taken using Network Analyst of Arc GIS 3.2a
4) Reallocating of the waste collection bins through field survey as well as rescheduling waste collection routes via GIS routing optimisation.
5) Comparison the above three scenarios in terms of time and distance taken

6) The benefits of the proposed strategy were assessed in terms of quantity of waste collected and minimising collection time and distance travelled

2. About the City

2.1 City Profile

Pimpri Chinchwad is a modern twin city, situated South-East of Mumbai and in the North-West quadrant of Pune. Pimpri-Chinchwad also happens to be the fifth-most populated city of Maharashtra.

The twin city (Pimpri Chinchwad) is governed by the Pimpri Chinchwad Municipal Corporation (PCMC). The city is located on the Deccan Plateau and is surrounded by hills. It is situated 530 m above the mean sea level. Pavna River traverses the city, while the Indrayani River flows through the north-western outskirts and Mula River on south side, forms a boundary of Pune and Pimpri Chinchwad Cities. Various particulars of the city are given in the table below.

The PCMC was earlier divided into 4 Zones, namely A, B , C & D. Just recently, these 64 wards are now divided into 6 zones, namely A, B, C, D, E & F. Zone 'A' consists of main places like Nigadi, Akurdi, Bhakti-Shakti, Dattawadi, Kalbhor Nagar, Chikhali, Talawade, Akurdi station, Talawade road, Dehu-Alandi road, NH-4 etc .In the present study, old zone A under Pimpri Chinchwad Municipal Corporation (PCMC) has been chosen for efficient management of MSW.

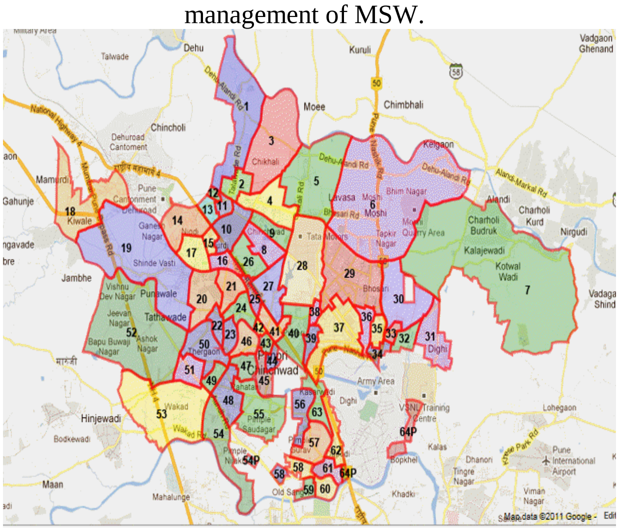


Figure 1: Different Wards of PCMC

Table 1: Area under each Ward

Ward no.	*Ward name*	*Area under ward*
8	Vidyanagar	Vidyanagar,Dattanagar, Ramnagar part, MIDC part
10	TuljaiVasti - Ajanthanagar	Ajanthanagar,Durganagar Ambedkarnagar,Sharadnar,Slum, Bajaj Auto Company and Colony, Force Motors Companyan and Colony, Akurdi, Bhaji Mandai Area,Vivrknagar part, Tuljai Vasti
14	Bhakti Shakti Udyan	Sector 26, Sector 24, Sector 23 (Transport Nagar)
15	Dattawadi	Sent Ursula School Area, Dattawadi, Akurdi part, Telco Kapur Colony, Nirupam Society, Rupesh Colony
16	Akurdi Gaonthan	Akurdi Gaonthan, Sector 28 part, Jai Ganesh Vision, Shubhashree Building
17	Sant Tukaram Udyan	Raigad, Tornagad, Sharad Society, Sector-27 Part, Sector-28 Part, Sector - 27 A,,Mhalsakant College Area ,Gadh Area, Ayurvedik College Area
18	Kiwale	Mamurdi part. Kiwale part, Vikasnagar, Bapdeonagar, Taras Vasti, M.B. Camp etc.
19	Walhekarwadi	Atharva Society, Shinde Vasti, Sector 29, Sector 32 A, Gurudwara, Rajanigandha Society, Vikasnagar part, Kiwale part, Rawet, Walhekarwadi, Shevantiban etc.
25	Chinchwad Station-Anandnagar	Anantnagar slum, Empire Estate, Chinchwad Station etc.
26	Kalbhornagar	Kalbhornagar ,Mohannagar, Ramnagar Part
27	Morwadi	Telephone Employee Colony, MIDC Office , Annasaheb Magar Slum, Indiranagar, Morwadi Slum, Mhada (Dnyaneshwarnagar) Laltopinagar, Amruteshwar Colony, Autocluster etc.

Table 2: Population and Waste generated in each Ward of Zone A

Ward no.	*Population*	*Waste generated in TPD*
8	48303	17
10	35566	13
14	30098	11
15	28149	10
16	20554	7
17	27663	10
18	36227	13
19	53834	19
25	25392	9
26	31553	11
27	22397	8

Table 3: Summary of Zone A

Area (sq.km)	36.18
Population	359735
Waste forecast in TPD	128
Roads Length in km	491.83
Road density (length of road in km/sq.km)	13.59

2.2 Demography

- Location of the area

  The PCMC area is situated to the Northwest of Pune on the Mumbai Punt National Highway. The Mumbai - Pune rail link also traverses through the Corporation area dividing it into two halves. The total area of PCMC is 177.3 sq.km.

- Increase in waste generation

  The annual increase in the quantity of waste generation is about 8.4%, which can be accepted as a normal increase in the quantity of waste generated considering the rise in population. The quantities of waste increases on two counts:-

- Population growth
  Per capita increase in waste generation due to change in life style due to more and more use of packing materials. This has been assumed at 1.3% per year

Table 4: Summary of Waste Generation

Year	*Waste in Metric Tonne per day*
2014	764
2021	1126
2031	1792
2041	2608

3. Data Collection and Description

For efficient management of the municipal solid waste system, detailed spatial information is required. This information is related to the geographical background of the area under investigation as well as to spatial data related to the waste collection procedure.

In co-operation with the Pimpri Chinchwad Municipal Corporation, a large database of waste management data has been collected and statistically analysed like population, waste generation, number, type and positions of waste bins; the road network and the related traffic; the current routing system of the collection vehicles; and, the geographic borders. Thus, for the reallocation of bins and optimisation of the collection routes the following data were generated (data source in the bracket):

- Study area boundary (PCMC Corporation)
- Land use of the study area (toposheet)
- Satellite image of the area (Google Earth)
- Road network of the study area (toposheet)
- Road class information (official toposheet plan, PCMC Corporation, field work)
- Location of waste bins (PCMC Corporation, field work)
- Capacities of bins (PCMC Corporation, field work)
- Time schedule for the collection process (PCMC Corporation, field work)
- Existing collection routes (PCMC Corporation, field work)

Figure 2: Toposheet of Study area

For this project, out of the total 18 secondary routes of waste collection in old zone A of PCMC area, 12 routes viz; route A1, A2, A3, A4, A5, A7, A8, A9, A11, A12, A13 and A15 are being chosen for route optimization by GIS, the capacity of the bins picked up by the secondary routes being 4.5 cu.m and 1.1 cu.m

Table 5: Number of bins along the secondary routes of zone A

A zone Wards	*Number of Bins*
A1	12
A2	6
A3	14
A4	7
A5	8
A7	11
A8	7
A9	14
A11	12
A12	21
A13	8
A15	9

For the project a spatial geo database was designed and implemented using standard commercial GIS software (ESRI, Arc GIS 3.2a). Background spatial data for road network, existing routes, bins and geographical boundary were obtained from Pimpri Chinchwad Municipal Corporation. These data were updated with field work and other non spatial data such as road name, road type, vehicle average speed, travel time, bin number, bin type/capacity, bin collection time are added. Furthermore, spatial attributes of road network were registered. These attributes included traffic rules, traffic marks, and special restrictions (e.g. turn restrictions) in order to model efficiently the real world road network conditions.

Table 6: The Spatial Database- Type of Data and the corresponding Geometry

Spatial Data	*Type*	*Geometry*
Zone boundary	Vector	Polygon
Road network	Vector	Line
Waste bins	Vector	Point
Existing run routes	Vector	Line
Road networks attributes/ restriction	Tabular	-
Waste bins attribute	Tabular	-
Population data	Tabular	-
Satellite image	Raster	-

4. Methodology

4.1 Spatial Database Development

In order to analyse the spatial data for the optimisation of the waste collection scheme, a spatial database (SDB), within a GIS framework, was constructed. The main sources of the SDB are (a) toposheet, (b) maps digitized in Autodesk 2004 (c) data derived from field work.

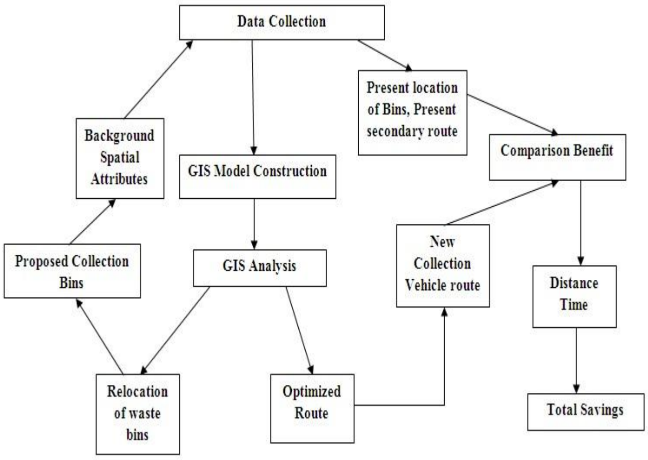


Figure 3: Proposed Methodology

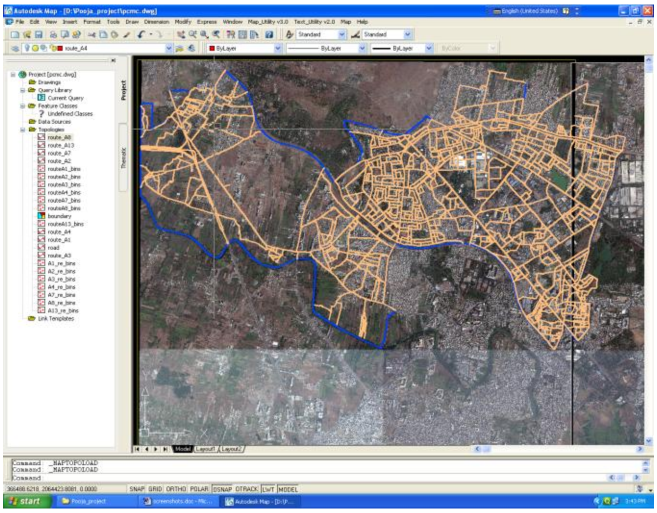


Figure 4: Road Networks of zone A

4.2 Reallocation of waste collection bins

The next phase of the proposed methodology is related to reallocation of waste collection bins wherever required. This analysis is implemented in a GIS environment with the use of sophisticated spatial analysis functions. The placement of the waste collection bins in their newly proposed positions is based on the following criteria:

First, the number of present bins is determined by field study and data from PCMC. Next, the reallocation of these bins in the study area is performed according to the following rules:

1) Allocate bins wherever open dumps are found
2) Allocate bins on the road network (intersections are preferable);
3) Install new bins near existing bin locations and
4) Allow the placement of more than one bin at the same intersection. The number of the bins sharing the same intersection point is related to the surrounding land use and the population of the covered area.

4.3 Routing- Network Analysis

For the purpose of optimization of routes, the Arc GIS 3.2 a Network Analyst modelling is used. To use it within the context of real transportation data, Network Analyst model includes real problem restrictions, such as one-way roads, prohibited turns (e.g. U-turns), demand at intersections (nodes) and along the roads ,etc. These points correspond to pairs of vehicle stops (waste bins). The total travel time for the optimal route is the sum of the travel time for each road segment plus the collection time for the waste collection bins. The final output is an optimal solution in terms of distance and time criteria.

5. Results and Discussion

The method described above was applied to analyse the waste collection scheme for zone A of PCMC area. Two different optimisation approaches were considered:

1) Optimization of secondary routes A1, A2, A3, A4, A5, A7, A8, A9, A11, A12, A13 and A15 of zone A with the developed GIS model; and,

2) Reallocation of waste collection bins for the above routes and finding the optimal waste collection routes using Arc GIS 3.2 a Comparison of the above two approaches with the existing collection routes with respect to time taken and distance travelled. The reallocation of bins is mainly dependent on population of the area, waste generated and open dumps. A higher priority for the reallocation of the new bins is given to locations of bins in the existing system and to crossroads in order to facilitate social acceptance and collection vehicle travel.

Based on various criteria and restrictions adopted in Arc GIS Network Analyst, different routing solutions were created. In order to evaluate the outputs of the proposed methodology two different waste collection scenarios were examined and their results were compared with the measured data of the existing collection scheme.
Scenario 0: The current existing waste collection scheme.
Scenario 1 (routing optimisation on S0): A waste collection scheme using route optimisation for the existing waste collection bins.
Scenario 2 (reallocation of bins and routing optimisation): A waste collection scheme introducing reallocation of bins with route optimisation.
Finally the comparison between the above two scenarios was made in terms of benefit in time and distance travelled.

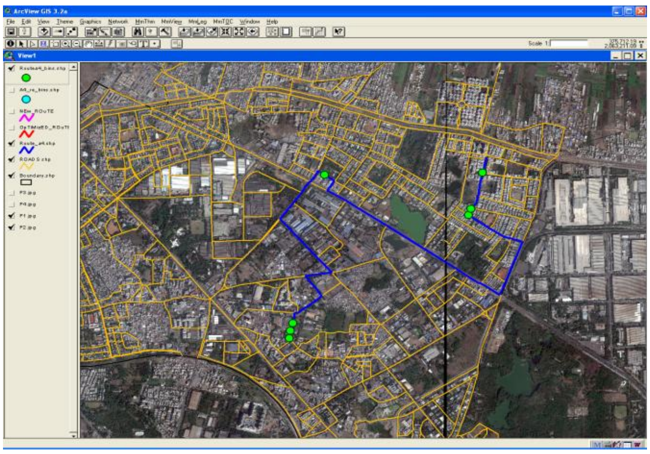


Figure 5: Present route for route A4

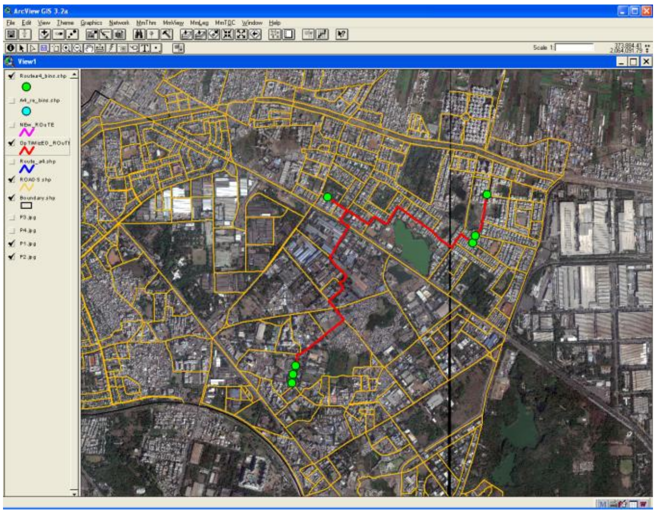


Figure 6: Optmized route for route A4

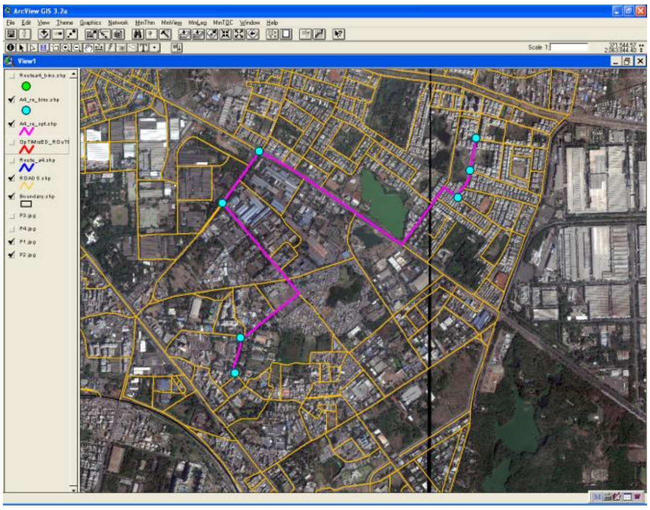


Figure 7: Optimized route for route A4 after reallocating bins

The time needed during waste collection has three distinct components: 1) time for hauling; this is not taken into consideration in this study, as it is not affected by the proposed system re-organisation for each individual collection trip; 2) time for driving during collection; and 3) time for emptying the bins. In this study only component 2 and 3 were considered. Model tuning was based on real data provided by the PCMC and verified by field study. According to these, the time for emptying the bins (bin loading, emptying and unloading – component 3) is 3 mins for bins with capacity 1.1m^3 and 5 mins for bins with capacity 4.5m^3. The time for driving during collection (component 2) is determined by the average speed of the collection vehicle in the travel between stops and the total distance travelled in the collection segment of the route. The average speed is 15km/hr and 10km/hr for 1-way and 2-way roads, respectively.

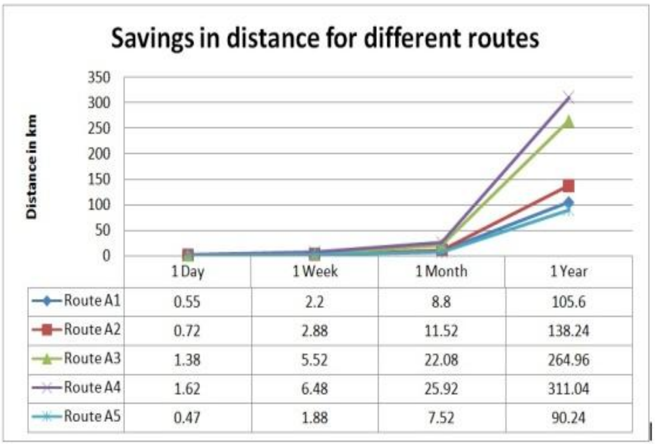
Table 7: Comparitive Results of Secondary Routes for Collection of 4.5 cu.m bins

Secondary Route	*Scenario*	*Route distance (km)*	*Route time (min)*	*Improvement from existing route % Distance (time)*
A1	Existing route (S0)	10.97	48.88	
	Routing on S0 (S1)	10.42	46.68	5 (4.34)
	Reallocation and routing (S2)	13.31	58.24	-
A2	Existing route (S0)	5.98	28.92	
	Routing on S0 (S1)	5.26	26.04	12 (9.95)
	Reallocation and routing (S2)	5.67	27.68	5.18 (4.28)
	Existing route (S0)	10.22	45.88	
A3	Routing on S0 (S1)	8.84	40.36	13.5 (12.03)
	Reallocation and routing (S2)	9.34	42.36	8.61 (4.72)
A4	Existing route (S0)	6.19	29.76	
	Routing on S0 (S1)	4.57	23.28	26.17 (21.77)
	Reallocation and routing (S2)	4.3	22.2	30.53 (25.40)
A5	Existing route (S0)	3.39	18.56	
	Routing on S0 (S1)	2.92	16.68	13.86 (10.12)
	Reallocation and routing (S2)	2.95	16.8	12.97 (9.48)
A7	Existing route (S0)	3.96	20.84	
	Routing on S0 (S1)	3.91	20.64	1.26 (0.95)
	Reallocation and routing (S2)	4.13	21.52	-
A8	Existing route (S0)	2.35	99.32	
	Routing on S0 (S1)	2.08	88.44	11.48 (10.95)
	Reallocation and routing (S2)	2.35	99.32	0
A13	Existing route (S0)	4.19	21.76	
	Routing on S0 (S1)	3.78	20.12	9.78 (7.53)
	Reallocation and routing (S2)	4.38	22.52	-
A15	Existing route (S0)	10.1	45.4	
	Routing on S0 (S1)	10.1	45.4	0
	Reallocation and routing (S2)	5.75	23	43.06 (49.33)

Table 8: Comparative Results of Secondary Routes for Collection of 1.1 cu.m bins

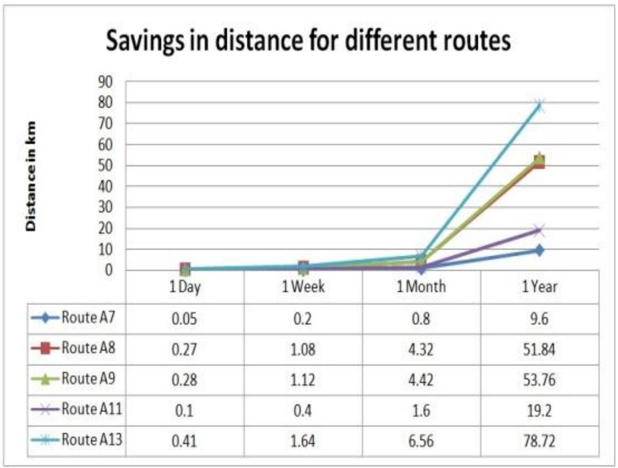
Secondary Route	*Scenario*	*Route distance (km)*	*Route time (min)*	*Improvement from existing route % Distance (time)*
A9	Existing route (S0)	6.74	31.96	
	Routing on S0 (S1)	6.46	30.84	4.15 (3.50)
A11	Existing route (S0)	8.70	39.8	
	Routing on S0 (S1)	8.60	39.4	1.15 (1.0)
A12	Existing route (S0)	5.32	26.31	
	Routing on S0 (S1)	5.32	26.31	0

The optimal solution route S1 for route A1, A2, A3, A4, A5, A7, A8, A13, A9 and A11 corresponds to 5%, 12%, 13.5%, 26.17%, 13.86%, 1.26%, 11.48%, 9.78%, 3.5% and 1.15% improvement when compared to the existing route S0. Similarly, the optimal solution route S2 after reallocation of bins for route A2, A3, A4, A5, and A15 corresponds to 5.18%, 8.61%, 30.53% , 12.97% and 43.06 % improvement when compared to the existing route S0. The improvement is more emphatic in terms of the total travel time in the optimal route, defined as the runtime of the collection vehicle plus collection time for the waste bins. Route distance and time savings become all more important when considered on a weekly basis. Waste is collected 4 times per week for secondary route A4, resulting to a total of 4 collection trips per week. Thus a large amount of time and distance is saved by the optimized routes.



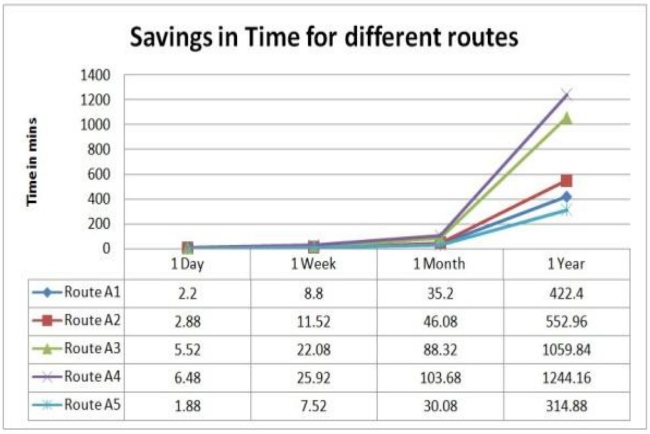
	1 Day	1 Week	1 Month	1 Year
Route A1	0.55	2.2	8.8	105.6
Route A2	0.72	2.88	11.52	138.24
Route A3	1.38	5.52	22.08	264.96
Route A4	1.62	6.48	25.92	311.04
Route A5	0.47	1.88	7.52	90.24

Figure 8: Savings in Distance (kms) for routes A1, A2, A3, A4 and A5



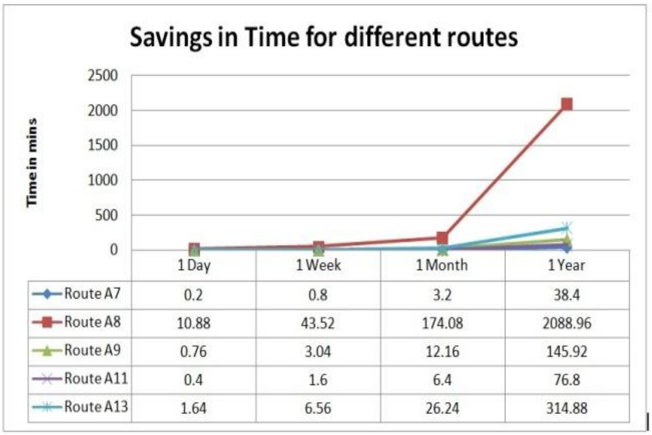
	1 Day	1 Week	1 Month	1 Year
Route A7	0.05	0.2	0.8	9.6
Route A8	0.27	1.08	4.32	51.84
Route A9	0.28	1.12	4.42	53.76
Route A11	0.1	0.4	1.6	19.2
Route A13	0.41	1.64	6.56	78.72

Figure 9: Savings in Distance (kms) for routes A7, A8, A9, A11 and A13



	1 Day	1 Week	1 Month	1 Year
Route A1	2.2	8.8	35.2	422.4
Route A2	2.88	11.52	46.08	552.96
Route A3	5.52	22.08	88.32	1059.84
Route A4	6.48	25.92	103.68	1244.16
Route A5	1.88	7.52	30.08	314.88

Figure 10: Savings in Time (mins) for routes A1, A2, A3, A4 and A5



	1 Day	1 Week	1 Month	1 Year
Route A7	0.2	0.8	3.2	38.4
Route A8	10.88	43.52	174.08	2088.96
Route A9	0.76	3.04	12.16	145.92
Route A11	0.4	1.6	6.4	76.8
Route A13	1.64	6.56	26.24	314.88

Figure 11: Savings in Time (mins) for routes A7, A8, A9, A11 and A13

6. Conclusion

In this project GIS technology was used for the development of a methodology, reallocation of waste bins of zone A and for the optimisation of MSW collection secondary routes. The method uses various geographical data (road network, location of waste bins, land uses etc) in co-operation with advanced spatial analysis GIS tools. The model was applied to examine routing optimisation of the existing scenario (S0) and its improvement through route optimization (S1) and route optimization after reallocation of bins (S2). Results indicate that the optimal scenario (S1) is more efficient in terms of collection time and distance travelled. The project aims at an efficient designing and developing of a proper storage, collection and disposal system plan for zone A under Pimpri Chinchwad Municipal Corporation, India. A GIS optimal routing model is developed by considering the parameter like population density, waste generation capacity, road network and transporting waste routes. This model will help to find minimum cost/distance , efficient collection pattern for transportation of solid waste. Pimpri Chinchwad Municipal Corporation (PCMC) can use this model as decision support tool for efficient management of moving the solid waste, fuel consumption and work schedule for the worker and vehicle in daily route of life.

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