Application of the On-the-Fly-Shortest-Path Plugin for Optimizing Waste Collection Routes

Karuppaiyan Kalaiyarasan and Jayaprakash Santhosh*
Department of Civil Engineering, Periyar Maniammai Institute of Science & Technology (Deemed to be University), Thanjavur-613403, Tamil Nadu, INDIA
*santhoshj@pmu.edu

Abstract
Municipal solid waste (MSW) management poses a critical challenge for rapidly urbanizing cities where inefficient collection and transportation contribute to high fuel consumption and uneven service delivery. To overcome the constraints of transporting solid waste from urban areas to disposal sites, a plan is underway to develop the shortest possible route using geospatial techniques. This study applies geospatial techniques to optimize municipal solid waste (MSW) collection in Thanjavur City, Tamil Nadu. It utilizes road network data from Open Street Map and ward boundaries from the Ministry of Housing and Urban Affairs. The data were processed in the software QGIS 3.34.10 and ArcMap 10.7.1. Ward centroids and the Srinivasapuram dumping yard were designated as the origin and destination points.

Optimized routes were computed using the Dijkstra algorithm through the "On-the-Fly-Shortest-Path" plugin in QGIS for all 51 wards. The existing collection network covered 168.43 km while optimized paths reduced this to 157.93 km, yielding a 10.5 km (6.2%) reduction. Peripheral wards achieved notable distance savings whereas central wards exhibited minimal changes. Division-based analysis revealed cumulative connectivity of 65.84 km. The obtained results in the decrease of travel distances provide a replicable framework for sustainable MSW management.

Keywords: Route Optimization, Geospatial Analysis, Municipal Solid Waste, Dijkstra's Algorithm, Sustainable Urban Development.

Introduction

Efficient waste collection is a vital component of urban infrastructure, ensuring environmental cleanliness and protecting public health. In rapidly urbanizing cities, the demand for optimized vehicle routing systems has increased. Most of the cities in India face the constraints in collection and conveyance of waste. In addition to that, the fluctuating waste generation, changing consumption patterns and growing population densities influence more challenges in collection and transportation of the waste[3,7]. MSW collection and transportation contribute significantly to greenhouse gas (GHG) emissions and account for 50–75% of total MSW management costs in developed countries[6,12]. These operations are energy-intensive and represent environmental hotspots due to high CO_2 emissions. Improving collection efficiency is therefore critical in achieving sustainability targets outlined in smart city frameworks[4,6].

In many developing countries, waste collection systems remain fragmented and poorly coordinated. Subburaj et al[10] observed that sanitation workers in Indian cities often determine routes independently, disregarding bin status or real-time road conditions. This unstructured planning leads to excessive fuel consumption, delays and inefficiencies, further worsened by traffic congestion, narrow streets and inadequate infrastructure. The absence of real-time communication among sanitation personnel, traffic authorities and the public amplifies these challenges, highlighting the need for integrated and intelligent routing solutions.

Several empirical studies demonstrated the benefits of route optimization. Das et al[1] achieved a 9.4% reduction in travel distance for waste collection vehicles in Khulna City using GPS tracking, field surveys and driver feedback. Similarly, Nematollahi et al[5] applied optimization algorithms in a smart waste collection system, reducing vehicle kilometers travelled by 52%. These interventions lowered fuel use and GHG emissions while improving air quality, reducing land requirements and promoting sustainability through the integration of electric vehicles and renewable energy sources.

Yazdani et al[13] developed a hybrid model combining long short-term memory (LSTM) neural networks with differential Evolution (DE) algorithms to optimize waste collection in disaster-affected regions. Their approach emphasized linking waste logistics with emergency supply systems and applied exact optimization methods such as branch-and-bound to improve efficiency.

For high-risk waste streams, Rattanawai et al[9] addressed the vehicle routing problem (VRP) for infectious waste. They proposed a heuristic method, MDE-2, which outperformed conventional DE approaches in both improved result and computational efficiency.

Geospatial technologies, particularly Geographic Information Systems (GIS), are indispensable for waste route optimization. Paul et al[8] developed a GIS-based routing framework that incorporated waste generation volumes, road hierarchy, traffic conditions, bin capacity and service time windows. Using time-impedance shortest-path algorithms, their model provided data-driven insights that enhanced operational efficiency.

In this context, the present study focuses on optimizing waste collection routes within Thanjavur Municipal Corporation (TMC), a historically significant city in Tamil Nadu, India. The study employs the On-the-Fly-Shortest-Path plugin in QGIS, which uses the Dijkstra algorithm to calculate real-time shortest paths without creating new layers[2,11]. It is well known that the Plugin is being practiced for the laying of fibre optic network routing. Considering the Urban logistics and Waste management, this kind of Plugin is further focused towards the identification of optimum routing for the collection and conveyance of MSW. Using a road network shapefile in QGIS, the model analyzes travel paths between municipal wards and the central dumping site.

Through spatial analysis, the study aims to minimize travel distances and evaluate the effectiveness of the On-the-Fly-Shortest-Path plugin in optimizing routes within TMC. The focus is specifically on distance reduction rather than fuel consumption or traffic conditions.

Material and Methods

Data Collection and Software: The OSM shapefile was obtained from Geofabrik's Open Street Map Data Extracts and it was utilized for the identification of road layer in this study. The municipal corporation boundary shape file was sourced from the Ministry of Housing and Urban Affairs, Government of India, using the dataset titled 'Corporation_Wards_Thanjavur_30-06-2020. Spatial analyses were conducted using QGIS Desktop 3.34.10 and ArcMap 10.7.1. In addition, supplementary data on the existing waste management practices was collected through field visits and consultations with the waste collection manager and supervisors during the first week of August 2025.

Existing Scenario: The Thanjavur Municipal Corporation (TMC) currently manages solid waste collection using a fleet comprising of 48 battery-operated vehicles (BOVs), 48 light carrying vehicles (LCVs), 9 heavy carrying vehicles (HCVs) and 2 compactors. Fuel consumption ranges from 12–18 liters per week per LCV and 25–40 liters per week per HCV. On average, 70–100 waste transportation trips are made daily to the Srinivasapuram dumping yard, with each vehicle primarily LCVs and HCVs making 2 to 4 trips per day.

An analysis of waste collection across the city's 14 divisions (51 wards) over a three-day period revealed distinct spatial variations in collection frequency. While most wards required a single trip per day, certain wards, including 17, 38, 40, 47 and 50, consistently required up to four trips, indicating comparatively higher waste generation and/or population density. On a single day, division 4 recorded the highest waste volume (16,325 kg), predominantly comprising wet and mixed waste. Divisions 9 and 14 followed with 11,515 kg, including the largest share of construction and demolition (C and D) waste (2,000 kg). Divisions 12 and 2 also generated substantial quantities, primarily wet and mixed waste. Moderate volumes were reported in divisions 5 to 8, with notable sanitary waste in division 6 and compacted waste in division 08.

E-waste and hazardous waste were recorded across all divisions, with division 13 registering the highest quantities (19 kg and 108 kg respectively). Vehicle trips per division ranged from 1 to 4, depending on waste load, with divisions 1 and 4 reporting the maximum number of trips. Overall, the waste stream was dominated by wet and mixed waste, followed by dry and non-recyclable fractions, while C and D waste was concentrated in limited zones. These findings emphasized an uneven distribution of waste volume and type, stressing the need for division-specific operational strategies, resource optimization and route planning to improve overall waste management efficiency and sustainability in the city.

Data Analysis Procedure

- ❖ The centroid points for all 51 wards, as well as for the Srinivasapuram dumping yard, were generated using the Feature to Point tool in ArcMap. Manual adjustments were made, wherever necessary, to ensure that the points remained within their respective ward boundaries.
- ❖ The road network shape file was clipped using the Thanjavur Municipal Corporation (TMC) boundary layer with the Clip Multiple Layers plugin in QGIS. The clipped TMC road network was subsequently used as the input line network for the shortest path analysis. The centroid of the first ward was designated as the origin while the centroid of the Srinivasapuram dumping yard served as the destination.
- ❖ The On-the-Fly-Shortest-Path plugin in QGIS was employed to compute the shortest route and corresponding distance between the selected points. The resulting paths were stored as line feature shapefiles along with their associated attribute tables.
- ❖ This procedure was systematically carried out for all 51 ward centroids to determine their respective shortest paths to the Srinivasapuram dumping yard.
- ❖ The same methodology was also applied on a division-wise basis. For each division, up to four wards were directly connected to the dumping yard, while the remaining wards were categorized as "missing wards" and were listed separately.

Results and Discussion

Optimizing municipal solid waste (MSW) collection routes presents a noteworthy challenge for the Thanjavur Municipal Corporation (TMC), facing the complexity of urban infrastructure and spatial constraints. However, the application of geospatial techniques significantly enhances the efficiency, accuracy and operational sustainability of this process.

In this study, key spatial datasets namely the road network shapefile, ward boundary map, ward centroid points and the location of the existing dumpsite at Srinivasapuram were integrated within a Geographic Information System (GIS) environment. On the other hand, the 'On-the-Fly-Shortest-Path' plugin in QGIS was utilized for the determination of the shortest route from each of the 51 ward centroids to the central dumping yard. In the same way, the shortest path was also identified from each division of the city to the same dumping yard.

Shortest Path Analysis: The shortest path distances between each ward centroid and the Srinivasapuram disposal facility were computed using the Dijkstra algorithm as implemented in the 'On-the-Fly-Shortest-Path' QGIS plugin. These distances, recorded in meters, are tabulated in table 1.

The results provided a baseline information for evaluating the spatial efficiency of waste collection routes. Shortest route was illustrated in figure 1 through 51 wards represented in green color line.

Comparative Analysis of Existing route and Shortest Path Distances: Table 1 presents the ward-based analysis of existing route distances and optimized shortest paths from various wards to the central dumping yard. The existing routes collectively account for a total distance of 168.43 km whereas the shortest path optimization reduces the cumulative travel distance to 157.93 km, reflecting a net saving of approximately 10.5 km. This reduction, although varying across wards, indicates the efficiency gained through optimized routing.

For instance, ward 1 shows a significant reduction from 5.40 km to 4.67 km and ward 4 shows a reduction from 6.20 km to 5.78 km, highlighting notable improvements. Likewise, the wards 8, 9, 10 and 15 also displayed considerable distance savings and each contributed to the overall reduction.

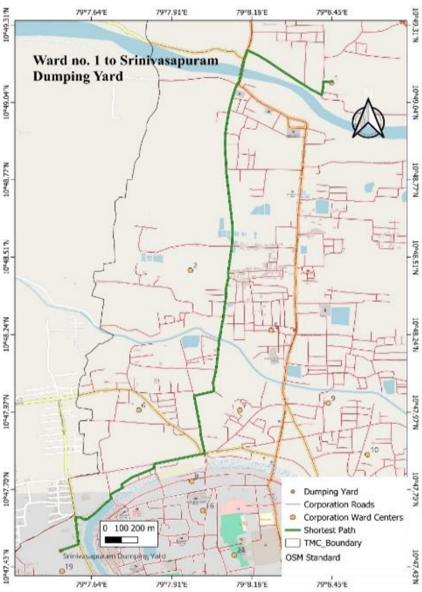

Figure 1: Ward 1 to Dumping Yard

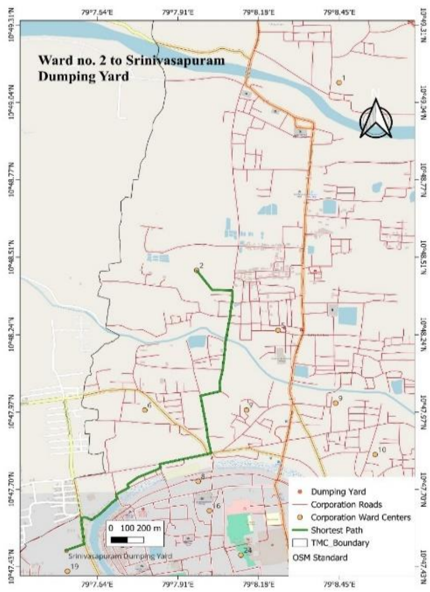

Figure 2: Ward 2 to Dumping Yard

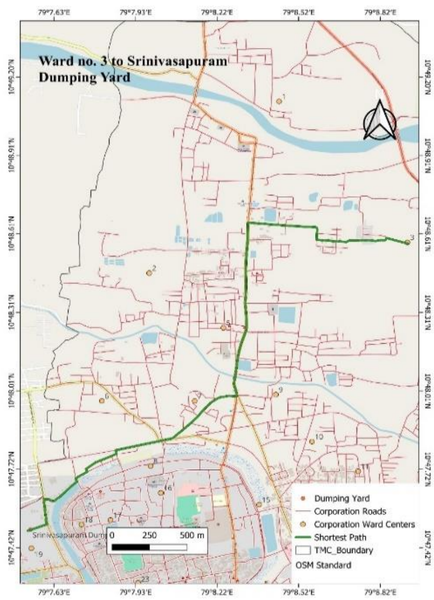

Figure 3: Ward 3 to Dumping Yard

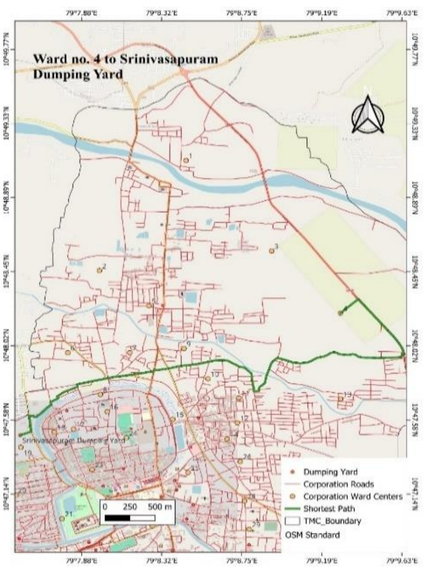

Figure 4: Ward 4 to Dumping Yard

Figure 5: Ward 5 to Dumping Yard

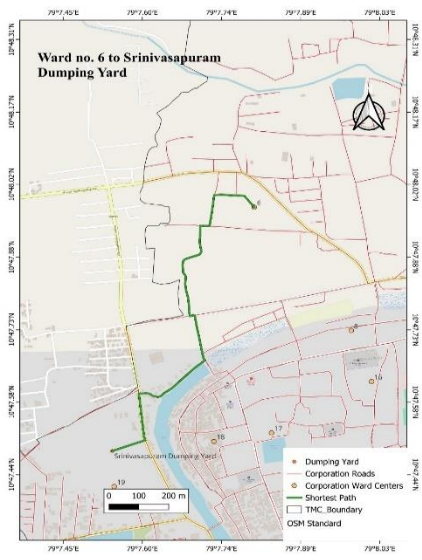

Figure 6: Ward 6 to Dumping Yard

Figure 7: Ward 7 to Dumping Yard

Figure 8: Ward 8 to Dumping Yard

Figure 9: Ward 9 to Dumping Yard

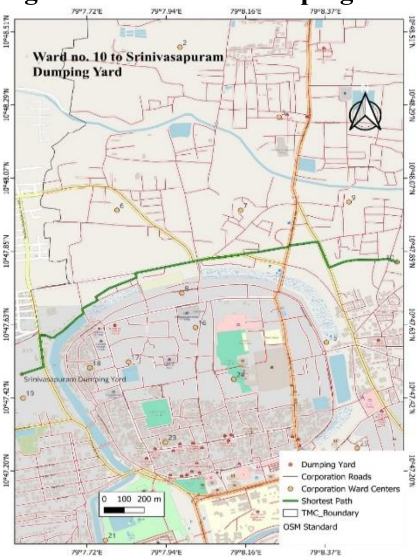

Figure 10: Ward 10 to Dumping Yard

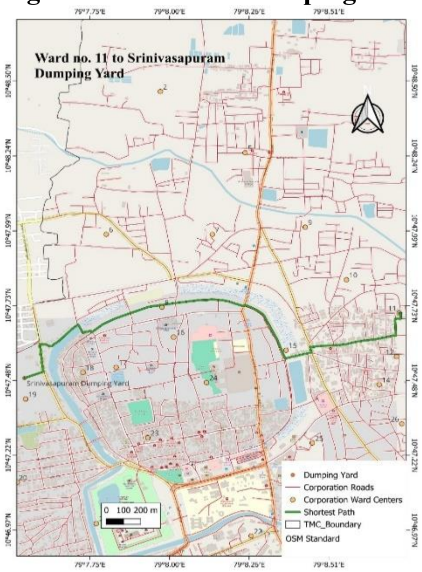

Figure 11: Ward 11 to Dumping Yard

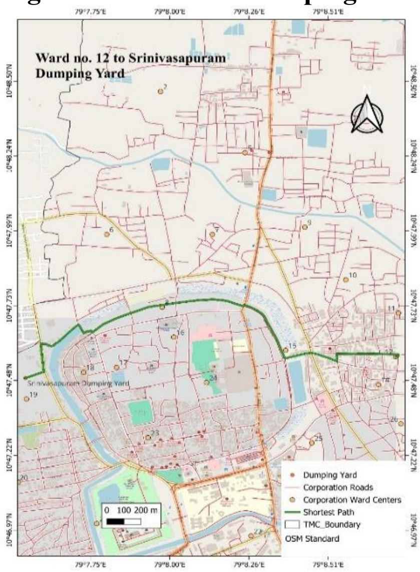

Figure 12: Ward 12 to Dumping Yard

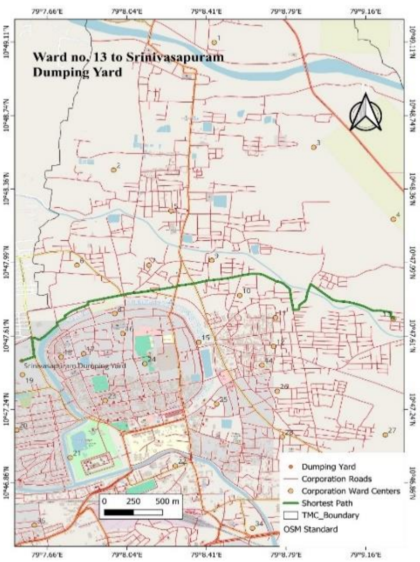

Figure 13: Ward 13 to Dumping Yard

Figure 14: Ward 14 to Dumping Yard

Figure 15: Ward 15 to Dumping Yard

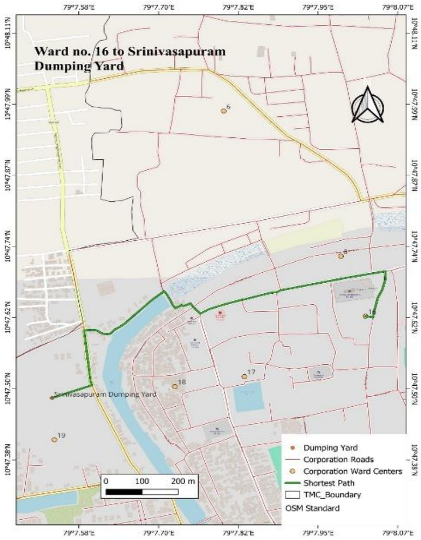

Figure 16: Ward 16 to Dumping Yard

Figure 17: Ward 17 to Dumping Yard

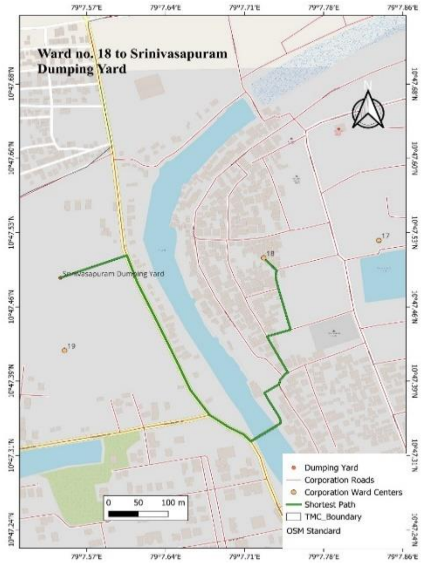

Figure 18: Ward 18 to Dumping Yard

Figure 19: Ward 19 to Dumping Yard

Figure 20: Ward 20 to Dumping Yard

Figure 21: Ward 21 to Dumping Yard

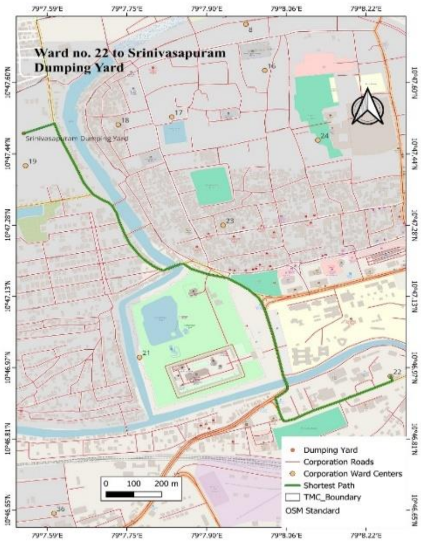

Figure 22: Ward 22 to Dumping Yard

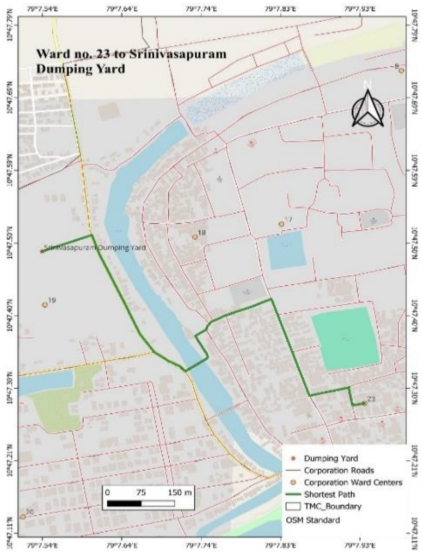

Figure 23: Ward 23 to Dumping Yard

Figure 24: Ward 24 to Dumping Yard

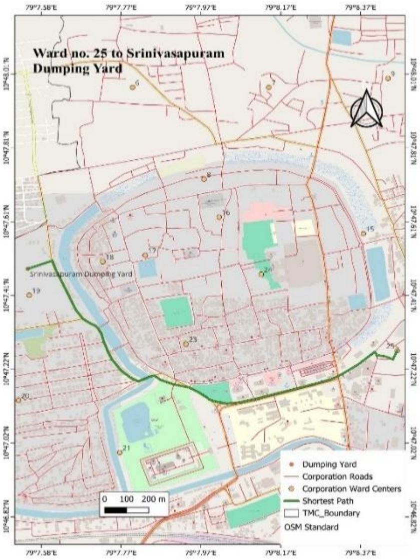

Figure 25: Ward 25 to Dumping Yard

Figure 26: Ward 26 to Dumping Yard

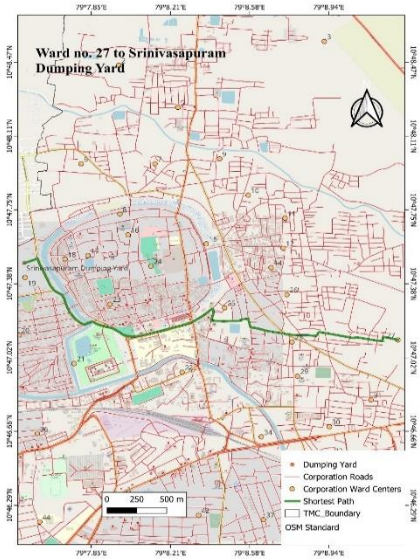

Figure 27: Ward 27 to Dumping Yard

Figure 28: Ward 28 to Dumping Yard

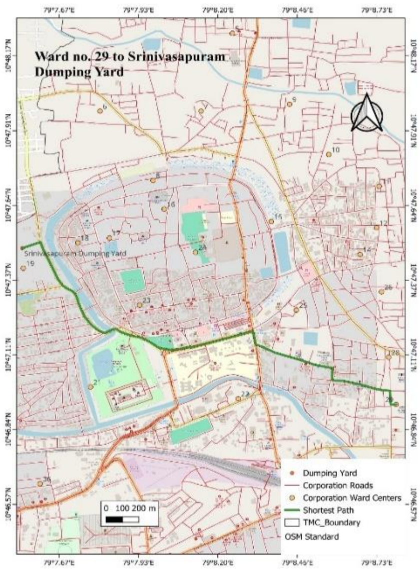

Figure 29: Ward 29 to Dumping Yard

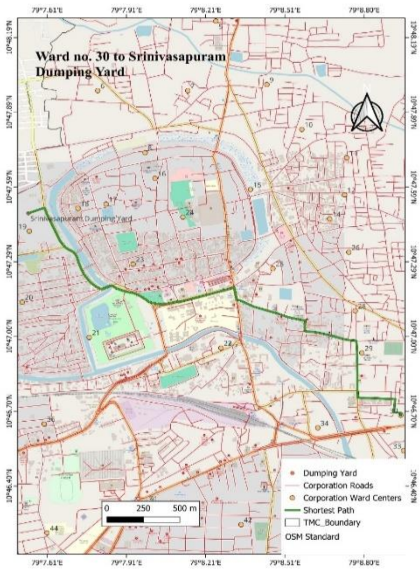

Figure 30: Ward 30 to Dumping Yard

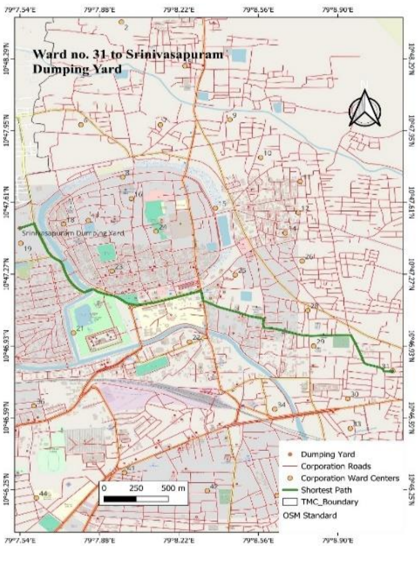

Figure 31: Ward 31 to Dumping Yard

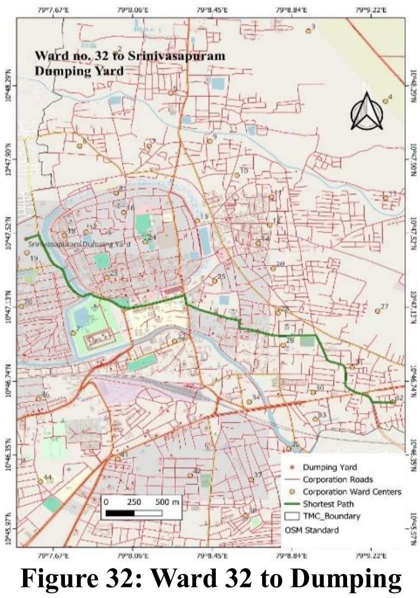

Figure 32: Ward 32 to Dumping Yard

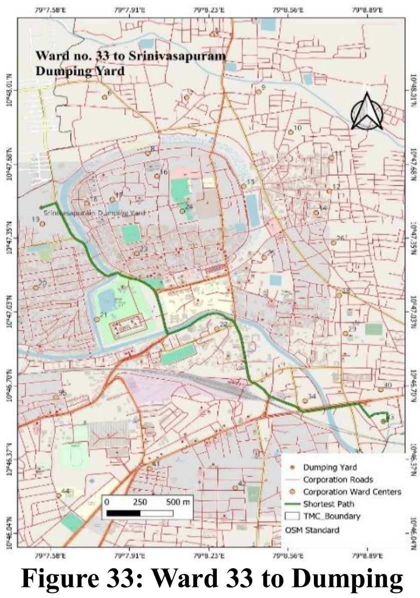

Figure 33: Ward 33 to Dumping Yard

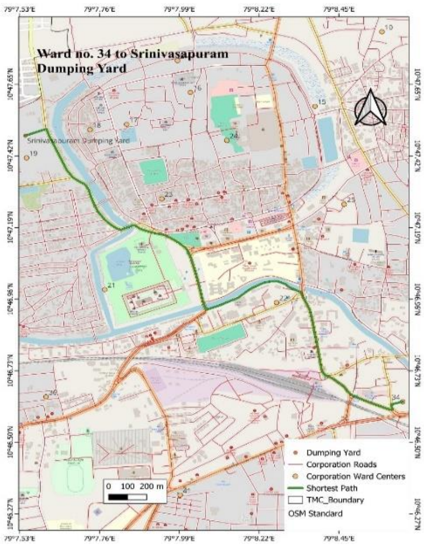

Figure 34: Ward 34 to Dumping Yard

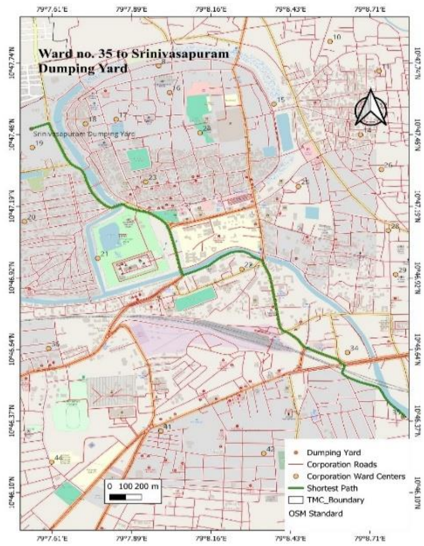

Figure 35: Ward 35 to Dumping Yard

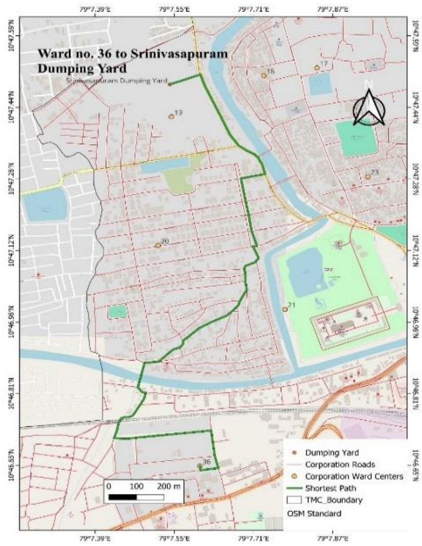

Figure 36: Ward 36 to Dumping Yard

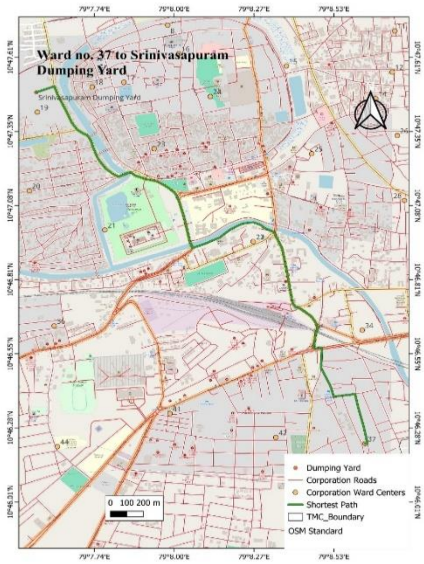

Figure 37: Ward 37 to Dumping Yard

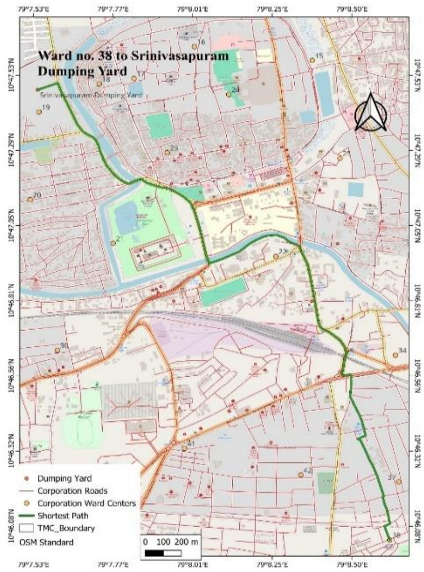

Figure 38: Ward 38 to Dumping Yard

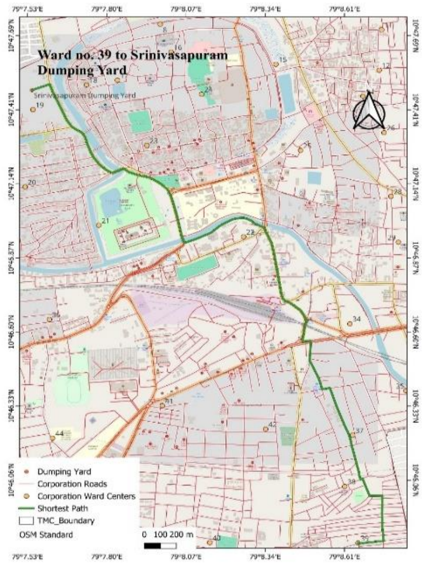

Figure 39: Ward 39 to Dumping Yard

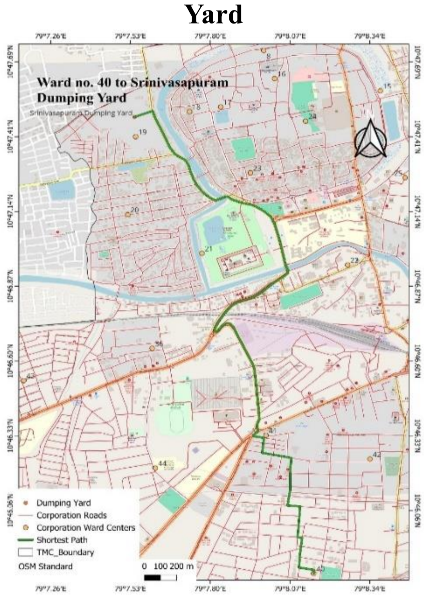

Figure 40: Ward 40 to Dumping Yard

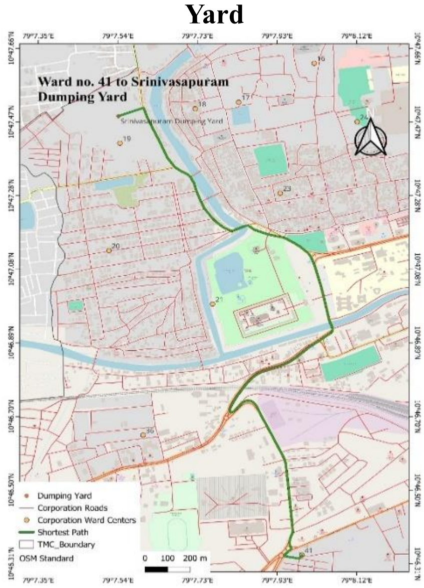

Figure 41: Ward 41 to Dumping Yard

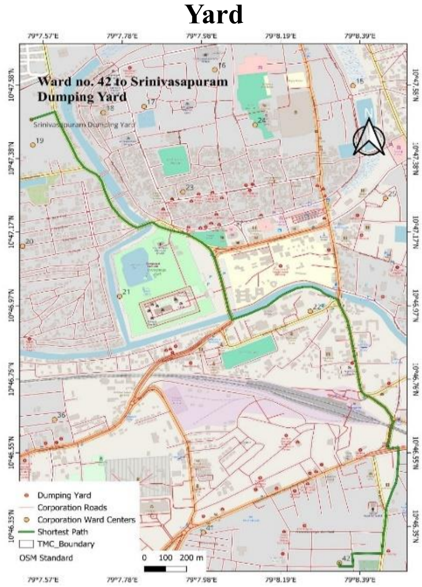

Figure 42: Ward 42 to Dumping Yard

Figure 43: Ward 43 to Dumping Yard

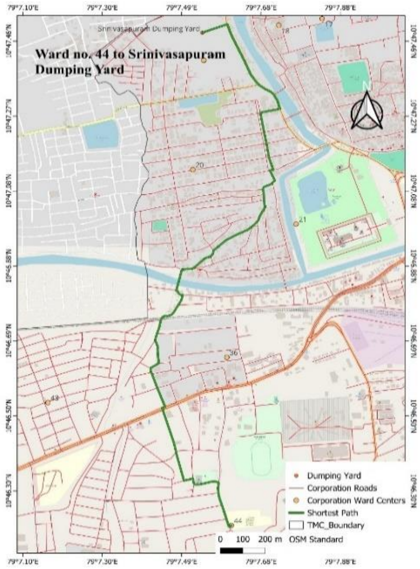

Figure 44: Ward 44 to Dumping Yard

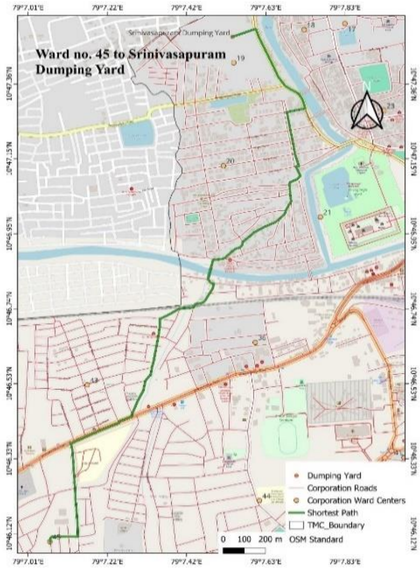

Figure 45: Ward 45 to Dumping Yard

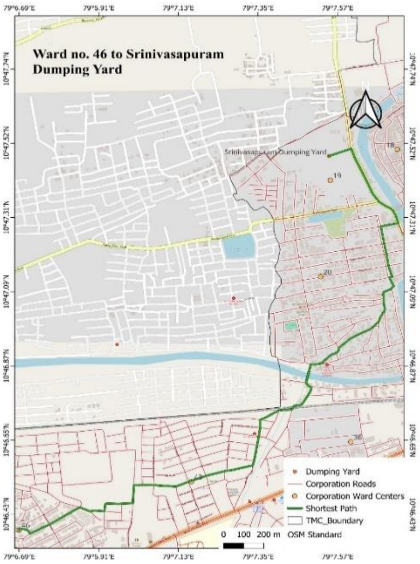

Figure 46: Ward 46 to Dumping Yard

Figure 47: Ward 47 to Dumping Yard

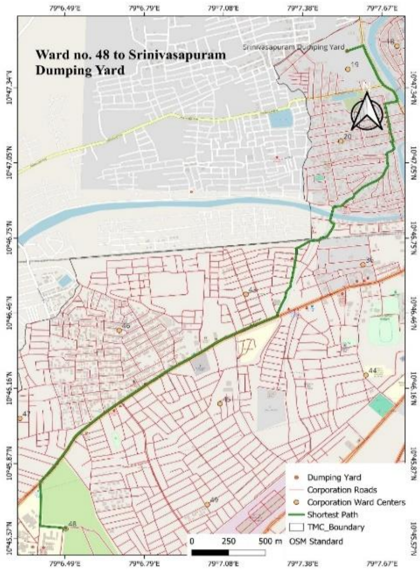

Figure 48: Ward 48 to Dumping Yard

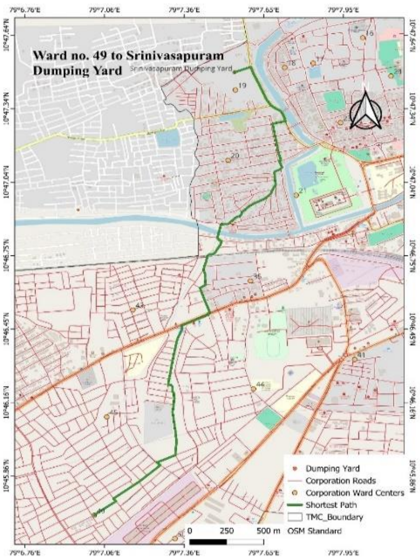

Figure 49: Ward 49 to Dumping Yard

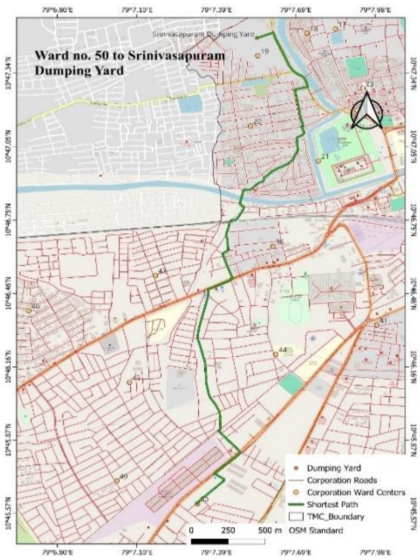

Figure 50: Ward 50 to Dumping Yard

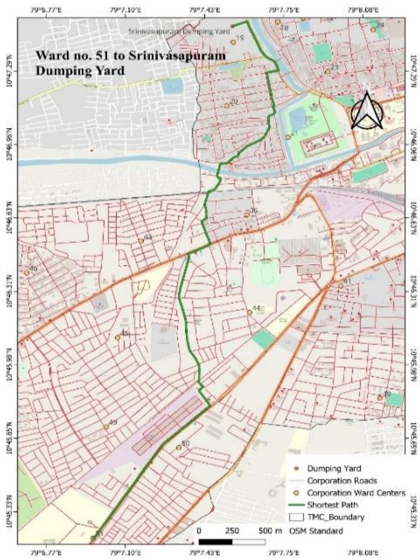

Figure 51: Ward 51 to Dumping Yard

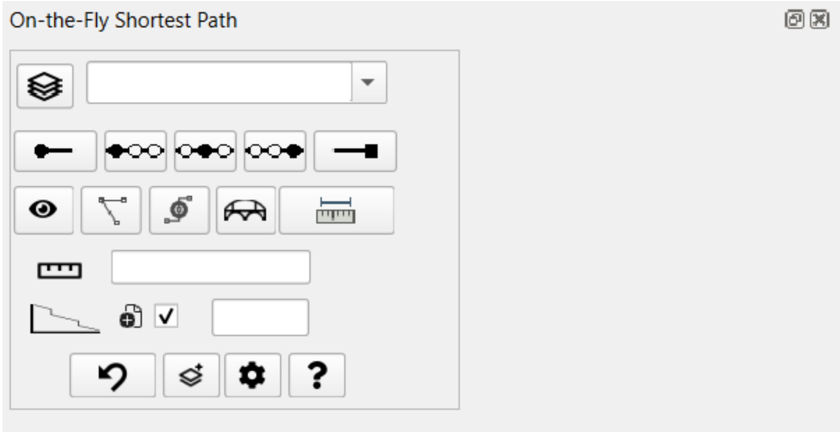

Figure 52: On-the-Fly-Shortest-Path Plugin

In some cases, however, the optimized shortest paths are nearly equal to or slightly greater than the existing routes, as seen in wards 2, 19, 20, 36, 43, 45, 49 and 50, where deviations range from 0.002 km to 0.3 km, suggesting that the existing routes were already close to optimal. Despite these minor exceptions, the majority of wards were benefited from reduced travel distances. The highest reductions were observed in the peripheral wards such as 38 and 39 where distances decreased from 5.20 km to 4.19 km and 5.60 km to 4.83 km respectively.

Comparative Analysis of Division-Based Shortest Path Connectivity and Missing Wards: Table 2 presents the shortest path analysis across the divisions reveals significant variation in connectivity efficiency and the presence of missing wards. In division 1, comprising five wards, the optimal path covers four wards (3, 1, 2 and 5), leaving ward 4 unconnected, with a total distance of 7.990 km, which is the highest among the missing-ward divisions. Similarly, division 2 (wards 6–10) excludes ward 6, while the path through 10, 9, 7 and 8 spans 3.130 km, indicating a relatively compact cluster compared to division 1. Division 3 also experiences a missing ward (13), with the remaining four wards connected in 3.463 km whereas division 4 leaves out ward 25, maintaining connectivity among the rest within 2.693 km, the shortest distance recorded in missing-ward divisions. Division 11, however, shows a missing ward (42) and a higher distance of 6.788 km, suggesting a more dispersed arrangement.

By contrast, several divisions achieved complete connectivity without leaving any ward excluded. Division 5, though smaller with only two wards (22 and 28), covers 3.677 km while division 6, with four wards, establishes a longer path of 5.968 km. Division 7 connects its four wards within 5.640 km, while division 8, covering four wards as well, records a relatively longer 7.676 km, reflecting a wider spread. Division 9 maintains connectivity across three wards in 4.028 km whereas division 10 efficiently links its two wards in 5.094 km. Division 12, with three wards, covers 5.126 km, while division 13 connects its two wards with a relatively higher distance of 5.611 km, showing that shorter ward numbers do not always correspond to shorter distances. Division 14 has the lowest distance overall, with just 1.931 km connecting wards 18 and 19.

Comparative Analysis of Ward-wise and Division-wise Routes: The comparative analysis of table 1 and table 2 provides distinct yet complementary insights into route optimization for waste collection. Table 1 presents a ward-level perspective by examining the existing route distance and the optimized shortest path distance for all 51 wards to the dumping yard. This granular analysis, supported by geospatial coordinates, highlighted a significant reduction in overall travel distance from 168.430 km to 157.929 km, reflecting a saving of approximately 10.501 km (6.2%). The findings indicate that most wards benefit from reduced travel distances, with notable efficiency gains observed in wards 1, 38 and 39, while a few wards exhibit marginally longer shortest paths due to network topology and routing constraints.

In contrast, table 2 adopts a division-level perspective, wherein wards are clustered into 14 divisions to evaluate intra-division connectivity and collective shortest paths. The division-based optimization reveals a cumulative distance of 65.835 km, though this represents internal connectivity rather than total ward-to-dumping yard travel. Importantly, the table identifies missing wards in specific divisions (e.g. divisions 1, 3 and 11), suggesting potential routing inefficiencies and the need for supplementary linkages. However, the software has the limitation to utilize only maximum of four wards of the cluster. Henceforth, for the missing wards (4, 6, 13, 25, 42), the shortest path can be taken from the individual ward wise shortest path analysis. Together, the two tables reinforce the necessity of a multi-scalar approach.

Table 1 addresses micro-level efficiency by optimizing individual ward-to-destination routes while table 2 underscores macro-level efficiency through coordinated division-based clustering. Integrating these perspectives provides a robust framework for designing sustainable and cost-effective waste collection systems, balancing localized operational efficiency with broader network-wide optimization.

Table 1
Ward-Based Existing Route Distance and Shortest Path

Ward No.	Starting point (ward)		Ending point (dumping yard)		Existing Route	Shortest Path
	Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	Distance In km	Distance In km
1	10.818584	79.140839	10.791451	79.125663	5.400	4.668
2	10.807667	79.132923	10.791464	79.125671	2.700	2.704
3	10.809541	79.148666	10.791358	79.125530	4.800	4.308
4	10.803490	79.154910	10.791442	79.125693	6.200	5.778
5	10.804210	79.137442	10.791442	79.125693	2.700	2.447
6	10.799584	79.130042	10.791442	79.125693	1.700	1.432
7	10.799582	79.135692	10.791442	79.125693	1.900	1.722
8	10.795464	79.133008	10.791442	79.125693	1.500	1.150
9	10.799990	79.140637	10.791442	79.125693	2.500	2.198
10	10.797010	79.142875	10.791442	79.125693	2.900	2.408
11	10.795123	79.145641	10.791442	79.125693	3.100	2.941
12	10.792664	79.145504	10.791442	79.125693	3.200	2.818
13	10.795023	79.154932	10.791442	79.125693	4.500	4.139
14	10.791069	79.144579	10.791442	79.125693	3.100	2.732
15	10.793021	79.139613	10.791442	79.125693	2.500	2.039
16	10.793764	79.133629	10.791442	79.125693	1.800	1.422
17	10.792051	79.130568	10.791442	79.125693	1.300	1.047
18	10.791764	79.128804	10.791442	79.125693	1.100	0.957
19	10.790256	79.125754	10.791442	79.125693	0.130	0.998
20	10.785541	79.125307	10.791442	79.125693	0.900	1.243
21	10.783200	79.129510	10.791442	79.125693	1.500	1.327
22	10.782501	79.137764	10.791442	79.125693	2.300	2.232
23	10.788066	79.132255	10.791442	79.125693	1.300	1.256
24	10.791194	79.135376	10.791442	79.125693	1.500	1.464
25	10.787769	79.141015	10.791442	79.125693	2.200	2.170
26	10.788854	79.145778	10.791442	79.125693	3.000	2.857
27	10.785140	79.154272	10.791442	79.125693	4.100	3.844
28	10.784968	79.146173	10.791442	79.125693	3.100	2.935
29	10.782166	79.146593	10.791442	79.125693	3.700	2.979
30	10.778023	79.149026	10.791442	79.125693	3.700	3.693
31	10.780219	79.152213	10.791442	79.125693	4.100	3.694
32	10.777163	79.155482	10.791442	79.125693	4.600	4.275
33	10.775677	79.149202	10.791442	79.125693	4.100	3.975
34	10.777195	79.143830	10.791442	79.125693	3.500	3.211
35	10.773106	79.147026	10.791442	79.125693	4.100	3.752
36	10.777456	79.126690	10.791442	79.125693	2.400	2.653
37	10.770395	79.143988	10.791442	79.125693	4.000	3.921
38	10.767265	79.143534	10.791442	79.125693	5.200	4.195
39	10.763827	79.144295	10.791442	79.125693	5.600	4.826
40	10.763845	79.135841	10.791442	79.125693	4.700	4.488
41	10.772193	79.133133	10.791442	79.125693	3.500	3.275
42	10.770766	79.139026	10.791442	79.125693	4.200	3.948
43	10.775507	79.119412	10.791442	79.125693	2.400	2.744
44	10.770216	79.126871	10.791442	79.125693	3.500	3.227
45	10.768338	79.117800	10.791442	79.125693	3.400	3.643
46	10.773147	79.111545	10.791442	79.125693	4.500	3.794
47	10.767378	79.105376	10.791442	79.125693	4.800	4.777
48	10.760153	79.108212	10.791442	79.125693	5.600	5.230
49	10.761732	79.117015	10.791442	79.125693	4.400	4.456
50	10.760180	79.122017	10.791442	79.125693	4.400	4.537
51	10.753466	79.116102	10.791442	79.125693	5.100	5.400
			Total		168.430	157.929

Table 2
Division-Based Shortest Path Connectivity and Missing Wards

Division No.	Number of Wards	Wards	Covered Wards	Shortest Path Distance	Missing Ward
				In km	
1	5	1, 2, 3, 4, 5	3, 1, 2, 5	7.990	4
2	5	6, 7, 8, 9, 10	10, 9, 7, 8	3.130	6
3	5	11, 12, 13, 14, 15	11, 12, 14, 15	3.463	13
4	5	16, 17, 23, 24, 25	23, 24, 16, 17	2.693	25
5	2	22, 28	28, 22	3.677	Nil
6	4	26, 27, 29, 30	30, 29, 27, 26	5.968	Nil
7	4	31, 32, 33, 34	32, 31, 33, 34	5.640	Nil
8	4	35, 36, 40, 41	35, 40, 41, 36	7.676	Nil
9	3	20, 21, 44	44, 21, 20	4.028	Nil
10	2	46, 47	47, 46	5.094	Nil
11	5	42, 43, 45, 48, 49	48, 49, 45, 43	6.788	42
12	3	37, 38, 39	39, 38, 37	5.126	Nil
13	2	50, 51	51, 50	5.611	Nil
14	2	18, 19	18, 19	1.931	Nil

Conclusion

This study demonstrates the effectiveness of geospatial techniques in optimizing municipal solid waste (MSW) collection routes in the Thanjavur Municipal Corporation (TMC). By integrating ward boundaries, road networks and the central dumping yard location into a GIS environment, ward-wise shortest paths were systematically computed and compared with existing routes. The analysis revealed a cumulative reduction of 10.5 km (6.2%) in travel distance, underscoring the potential for operational efficiency and cost savings. Notable improvements were observed in peripheral wards while certain central wards showed minimal or negligible changes, indicating that existing routes in those areas were already close to optimal.

At the division level, clustering analysis provided complementary insights into connectivity efficiency and revealed missing-ward gaps in certain divisions such as divisions 1, 2, 3, 4 and 11, which may create plugin inefficiencies. Meanwhile, divisions with complete connectivity demonstrated more balanced spatial arrangements. Moreover, field-based observations further highlighted uneven waste generation across the city, with divisions 4, 9 and 12 requiring more frequent trips due to higher waste volumes. The waste stream was dominated by wet and mixed fractions, followed by C and D, sanitary, e-waste and hazardous waste, reflecting both population density and socio-economic activity patterns.

Comparing ward-level shortest path optimization with division-level clustering can significantly enhance the sustainability and efficiency of MSW operations. By reducing vehicle kilometers traveled, optimizing fuel consumption and ensuring equitable allocation of collection resources, this approach provides a strong framework for waste management planning. Moreover, the methodology demonstrated it as scalable and adaptable, offering practical implications for other urban centers facing similar challenges. Future efforts may focus on integrating dynamic datasets such as real-time traffic, seasonal waste generation trends and community-level participation to further strengthen the resilience and efficiency of urban waste management systems.

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