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Optimizing Municipal Solid Waste Collection for Environmental Sustainability: A GIS-Based Case Study of Mysuru City

Parinitha T Niranjan[1*], Sadashiva Murthy B M[2], D Istalingamurthy[3], Prashanth B[4]
[1]*Research Scholar, Environmental Engineering Department, JSS Science and Technology University, Mysuru, Karnataka, India, parinitha@sjce.ac.in
[2]Professor, Environmental Engineering Department, JSS Science and Technology University, Mysuru, Karnataka, India
[3]Professor, Environmental Engineering Department, JSS Science and Technology University, Mysuru, Karnataka, India
[4]Professor, Civil Engineering Department, Government Engineering College, K R Pete, Karnataka, India

Abstract
Rapid urban expansion and lifestyle changes have intensified challenges in municipal solid waste management, particularly in developing regions where inefficiencies in collection and disposal exacerbate environmental impacts. In Mysuru, Karnataka, approximately 450 tonnes of solid waste are produced daily across 65 wards, and the existing collection system is challenged by long collection routes, high fuel consumption, and the need to utilize landfills. This study aimed to assess current collection habits and subject them to Geographic Information System (GIS)-informed spatial optimization to minimize the travel on two levels: distance and fuel, while lowering emissions. ArcGIS Network Analyst was combined with high-resolution satellite imagery, municipal records, and GPS tracking data of collection vehicles to model and optimize routes in five wards. Outcomes showed significant gains in efficiency with travel distances minimized by 18.47% in Ward 6 (Gokulam), 19.95% in Ward 42 (K G Koppal), 27.01% in Ward 47 (Kuvempunagar), 27.9% in Ward 51 (Agrahara), and 42.11% in Ward 43 (T K Layout). Such gains equated to 1.2–1.7 liters of fuel savings daily and carbon dioxide decreases between 2.5 and 4.4 kg per ward. These results show that a GIS-based optimization can offer a quantitative process of attaining greater waste collection efficiencies and, at the same time, enable a path towards climate mitigation and sustainable urban governance. These results underline that route optimization is a climate mitigation approach that mitigates the use of fossil fuels, decreases greenhouse gas emissions, and ensures allied commitment to environmental sustainability objectives within the Sustainable Development Goals.
Keywords: *Municipal Solid Waste Management, Geographic Information System (GIS), Route Optimization, Environmental Sustainability, Carbon Emission Reduction, Climate Change Mitigation*

1. INTRODUCTION

The high rate of urbanization, increased living standards, and changing consumption patterns have enhanced the pressure of Municipal Solid Waste (MSW) management in nearly all parts of the world [1]. Developing cities are especially overloaded by the lack of proper collection systems, insufficient technical capabilities, resulting in inefficient collection systems, open dumping, and unsustainable disposal systems [2]. The problem of solid waste is not only an urban governance issue but an urgent environmental issue because of its direct and indirect effects on the ecosystems, the health of the population, and climate systems [3]. In uncontrolled cases, garbage builds up to contribute to air and water pollution, breed diseases caused by vectors, and cause greenhouse gases [4]. The United Nations has repeatedly noted that proper waste management is at the heart of attaining the Sustainable Development Goals (SDGs), especially those that focus on sustainable cities, responsible consumption, and climate action [5]. The problem has become even more severe in the past decades in the context of the Indian setting. The high population growth rate in towns, the industrialization process, and the change in lifestyles have contributed to a high rate of waste produced daily [6]. The issue that is facing municipalities in the country is the need to have effective waste collection and less environmental effects caused by landfill disposal [7,8]. Mysuru, which is the second largest in the state of Karnataka, is an example of this trend. Mysuru, with a population of about 128 square kilometers, is generating almost 450 tonnes of waste daily. Waste collection and disposal in Mysuru City Corporation (MCC) spans 65 wards and nine zones, with the corporation using a mix of door-to-door collection, community bins, and contracted, privately operated service. Despite efforts to maintain systematic collection and implement decentralized strategies, logistical inefficiencies remain [9, 10]. Vehicles often follow non-optimized routes, leading to excessive travel distances, increased fuel consumption, and higher emissions [11]. Such inefficiencies highlight the urgent need for data-driven strategies that integrate environmental considerations with operational efficiency [12]. Closely related to the priorities in environmental science, such strategies also relate to the route optimization as it lowers the amount of fuel consumed, enhances air quality, and helps to achieve relative climate resilience [13]. Efficiency in waste collection thus becomes a manageable intervention, not only logistically, but also in terms of reducing greenhouse gas emissions and furthering Sustainable Development Goals, SDG 11 (Sustainable Cities) and SDG 13 (Climate Action) [14]. Numerous investigations have demonstrated the potential of spatial technologies to transform municipal solid waste logistics. Geographic Information Systems (GIS) have emerged as a particularly powerful tool for optimizing collection routes, reducing travel distances and fuel consumption while simultaneously lowering operational costs and emissions [15]. Applications of GIS in different urban contexts have consistently shown that optimized routes can significantly improve cost-effectiveness and sustainability [16]. In several cities, GIS has been applied as a decision-support tool, underscoring its value for municipal planning and the integration of environmental priorities into waste governance. Evidence from urban centers indicates that systematic incorporation of geographic data into collection planning can substantially enhance transportation efficiency [17]. Beyond technical optimization, current perspectives emphasize the environmental implications of routing efficiency. Remote sensing and GIS are increasingly recognized as contributors not only to logistical improvements but also to holistic waste management systems, reducing energy demand and mitigating greenhouse gas emissions [18]. Such outcomes align with the broader objectives of environmental science, which regard waste governance as an essential component of sustainable resource management [19]. Collectively, the available evidence demonstrates that GIS-driven approaches act as critical enablers of both economic efficiency and ecological resilience [20]. However, the application of such methods at the ward level in medium-sized Indian cities remains limited, despite growing populations and substantial contributions to national waste generation [21].

Despite massive advancements in urban governance, the systematic efficiency of municipal solid waste collection in Mysuru remains a challenge. The collection vehicles repeatedly visit distant routes, which leads to fuel wasting, high operational costs, and an increased amount of carbon emissions that are unwarranted. Ward-level studies show that current travel distances for auto tippers are likely to be more than 25 kilometers a day in some zones, with great scope for savings through route optimization. For instance, in Ward 43 (T K Layout), the present collection routes take up to 13.09 kilometers, while the optimized routes cut down the distance to 7.58 kilometers, saving a 42.11% efficiency. Likewise, in Ward 51 (Agrahara), the routing optimization reduces the distance from 25.19 kilometers to 18.15 kilometers with a 27.9% decrease. These patterns evidence that the inefficiencies are not localized but diffuse in several wards. Such inefficiencies undermine both economic and environmental sustainability. Prolonged collection routes increase fossil fuel dependence, exacerbate air pollution, and intensify the ecological footprint of waste management systems. Furthermore, ineffective routing causes more pressure on the municipal budgets, as the funds are spent instead of being used to initiate other important services. The aggregate effect of these inefficient actions, without mitigation, will continue to increase with the increasing population and waste production in the city, resulting in an even more devastating effect on nature and creating a lack of resilience in the city [22].

The scope of the present study is to assess the practice of municipal solid waste management in Mysuru and specifically, the processes of collection and transportation. It aims to study the current waste collection system, such as the functional aspects of generation, collection, transfer, and disposal, and to analyze the data on the ward level in terms of population, waste generation, vehicle deployment, and workforce allocation to determine an area of inefficiency in the operations. With the application of Geographic Information System (GIS)-based spatial analysis, the study will also aim at maximizing waste collection paths within a few chosen wards, which will diminish the travel distance, fuel use, and operational cost. The analysis will also aim at estimating the environmental savings of optimized routing, specifically, the reduction of emissions and the efficiency of resources. The combination of technical optimization with the wider context of sustainability, and thus, the study helps to robustify the urban waste governance and shows the potential of GIS as a decision support tool to reach the environmentally sustainable management of municipal solid waste.

2. METHODOLOGY

2.1 Study Area

As the second-largest city of Karnataka after Bengaluru, Mysuru, with a greater population of over one million inhabitants, covers an area of 128 km^2, supported by service industries, tourism, and education. Such an increase has aggravated the city's solid waste problems handled by Mysuru City Corporation (MCC), covering 65 wards in nine zones. The city also produces approximately 450 tonnes of waste every day, most of which is of a household origin. The nature of wastes depends on the human population, land use, as well as business activity. The study area consisted of five wards (Gokulam, K G Koppal, T K Layout, Kuvempunagar, and Agrahara), which characterise different types of settlements, and are appropriate to assess the efficiency of the route optimisation.

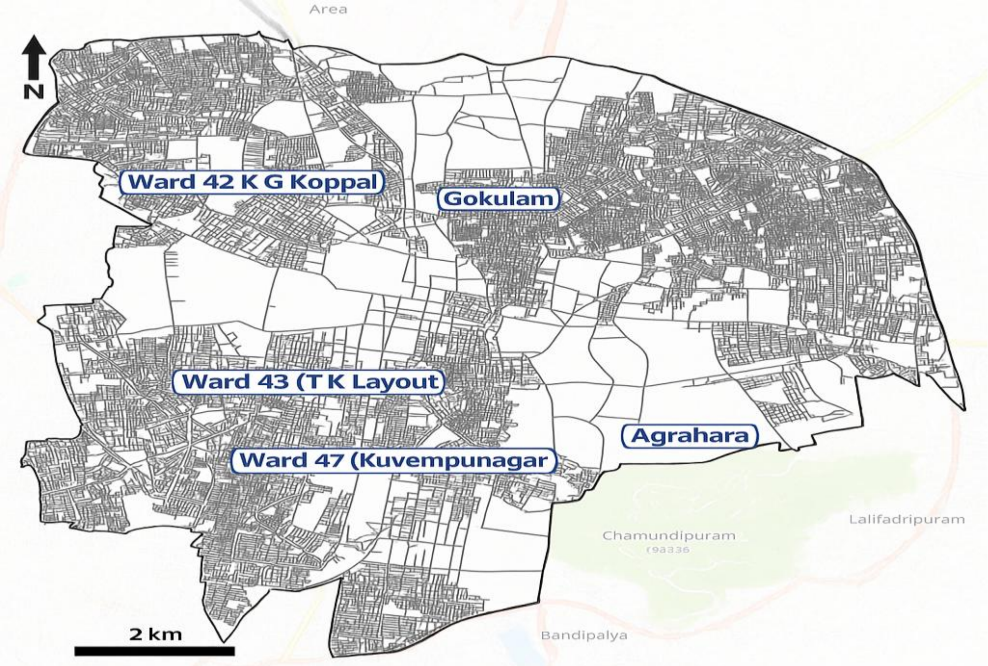

Figure 1. Map of Mysuru City showing the road network and the selected study wards (Ward 6: Gokulam; Ward 42: K G Koppal; Ward 43: T K Layout; Ward 47: Kuvempunagar and Ward 51: Agrahara).

Mysuru City, Karnataka, comprises 65 municipal wards. For GIS-based route optimization, five wards were selected: K G Koppal (42), T K Layout (43), and Kuvempunagar (47) Gokulam, Agrahara. Figure 1 presents the city boundary and road network with the study wards highlighted.

2.2 Data Sources

The analysis of municipal solid waste collection in Mysuru utilized diverse data sources. High-resolution satellite imagery provided details on land use, roads, and open spaces, while GPS data from collection vehicles mapped current routes and inefficiencies. Demographic and ward-level waste generation statistics, along with vehicle deployment data for autos, tractors, and tippers, were obtained from Mysuru City Corporation records. Road network information was verified through Google Earth and municipal maps. Additional spatial inputs included bin locations, community collection points, and the Vidyaranyapuram landfill. Collectively, these datasets formed a comprehensive spatial database that enabled accurate and efficient route optimization.

2.3 GIS Methodology

The analytical framework used ArcGIS 10.1 and the network analyst extension to model the transportation networks and optimize routes of waste collection. A spatial database was constructed, which included road networks, the location of waste bins, and land-use patterns at the residential, commercial, and industrial sites. The attributes in the digitalization of roads included hierarchy and connectivity, whereas bins and points of transfer were geo-referenced to wards. The task was divided into two parts: first is mapping and validating the available GPS-trace routes, and then, finally, the second part was optimization of the most efficient and shortest paths. Products included ward-based mapping and distance summaries, and allowed quantifying the possible distance, fuel, and time savings.

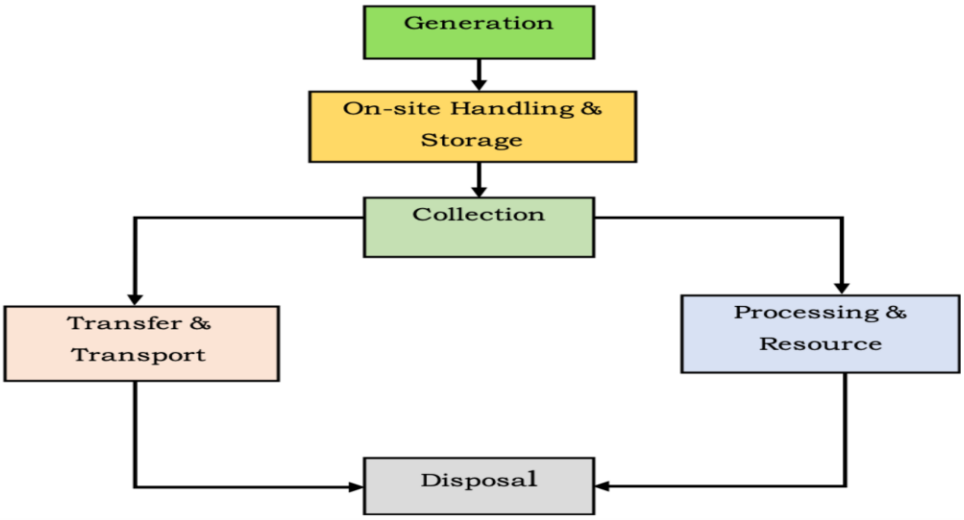

Figure 2. Municipal solid waste handling sequence used in this study.

The figure 2 shows the chronological path of MSW from Generation to final Disposal. Waste is first handled and stored on-site (household/community containers), then collected. From Collection, flows branch to Transfer & Transport (haulage to facilities) and Processing & Resource Recovery (MRFs, composting/biogas). Rejects/residuals from both branches proceed to Disposal at the landfill. The Collection and Transfer & Transport stages are the main targets of the GIS-based route optimization in this work.

2.4 Evaluation Metrics

The effectiveness of the routing system was determined by the performance indicators of operational and environmental aspects. The measure used was mainly travel distance, and savings were directly related to the amount of fuel saved, depending on the distance covered by auto tippers and tractors in an urban setting. Cost saving associated with fuel was estimated based on the current prices of diesel, and efficiency improvement was presented as a percentage reduction in the route length. As an example, in Ward 43, the distance was optimized by 42.11 %; that is, 13.09 km became 7.58 km. Avoided carbon dioxide emissions were assessed as an environmental benefit with standard diesel emission factors, which incorporate the efficiency with sustainability results.

2.5 Limitations

While the methodology provides valuable insights, several limitations should be acknowledged. The optimization was conducted under the assumption of static traffic and uniform road conditions. Variability due to traffic congestion, seasonal weather changes, or road maintenance activities was not incorporated into the model, which may influence real-world performance. Furthermore, the analysis primarily emphasized route distance and did not include time-window constraints, which are critical in operational planning where waste must be collected within defined hours. The scope of environmental assessment was limited to fuel-related emissions, without extending to life-cycle impacts of waste treatment and disposal. Despite these constraints, the methodology establishes a robust baseline for integrating GIS tools into municipal waste management planning, with significant potential for refinement through dynamic modelling, real-time vehicle tracking, and incorporation of socio-behavioural data in future studies.

3. RESULT

3.1 Municipal Solid Waste Management Practices in Mysuru

Mysuru City Corporation (MCC) manages approximately 450 Tonnes Per Day (TPD) of municipal solid waste generated across 65 wards. The city employs 2,879 bins, 22 tractor-trailers, 24 lorries (by contractors), 20 dumper placer containers, and several auto tippers for primary collection. Still, even with a relatively well-organized system, inefficiencies exist due to the unsegregated landfill, lack of regularity, and dependence on the landfill at Vidyaranyapuram, which is a 34-acre area. Table 1 shows the level of activity (450 TPD, 2,879 bins, 22 tractor-trailers) and identifies problems like poor segregation and the use of landfill.

Table 1: Quantitative Overview of Municipal Solid Waste Management Practices in Mysuru **Source:** [23], [24]

Functional Element	Quantitative Data (Mysuru)	Key Challenges Identified
Waste Generation	~450 TPD across 65 wards (2,06,370 households)	Rising volumes due to urban growth
Storage & Handling	2,879 household/community bins; RCC & brick containers	Limited segregation at source
Collection (Primary)	~2879 bins serviced; 6–7 autos per ward on average	Irregular coverage, operational delays
Transfer & Transport	22 tractor trailers, 1 tipper, 2 dumper placers, 24 lorries (contractors)	Long routes, high fuel consumption
Material Recovery	Minimal formal recovery; limited composting & recycling	Dominance of the informal sector; low efficiency
Disposal	34-acre landfill at Vidyaranyapuram (open dumping)	Leachate, odors, and vector breeding

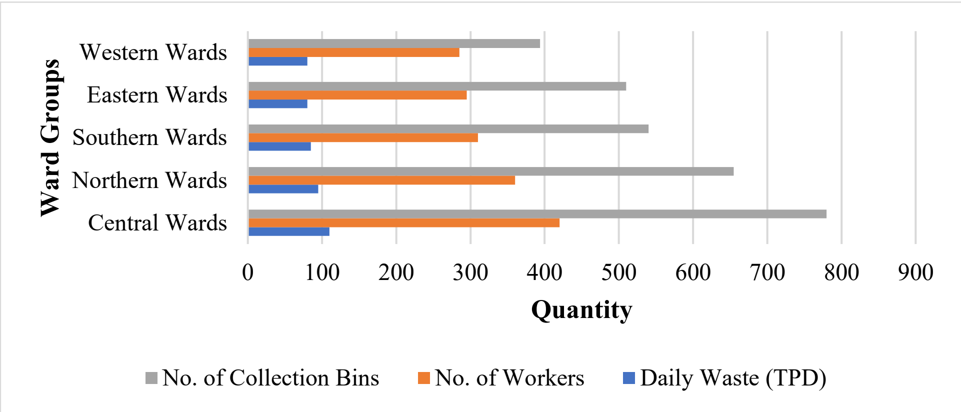

Figure 3: Waste Generation, Workforce, and Collection Infrastructure in Different Wards of Mysuru

Figure 3 shows daily waste generation, the number of workers, and the collection bins across Mysuru's ward groups. Central wards record the highest values, while western wards show the lowest, indicating spatial variation in waste load and resources.

3.2 Existing Waste Collection Routes

The available routes were traced through GPS and city records. Ward-level analysis uncovered significant inefficiencies with distances far over operating needs. For instance, Ward 6 (Gokulam) recorded 27.44 km of route per day for auto tippers, and Ward 51 (Agrahara) registered 25.19 km. The demographic and operational information of some wards has been presented in Table 2, such as the population, households, generation of waste, and route lengths for auto tippers and tractors. The information reveals extreme inefficiencies, with current routes varying between 13.09 km in Ward 43 and 27.44 km in Ward 6.

Table 2: Existing Route Details in Selected Wards

Ward	Population	Waste Generated (TPD)	Households	Existing Route Distance (km)	Vehicles Used
6 (Gokulam)	15,562	8.0	4,005	27.44	6 autos + 1 tractor
42 (K G Koppal)	19,260	5.8	4,140	19.40	5 autos + 1 tipper
43 (T K Layout)	13,846	4.2	4,860	13.09	3 autos + 1 tipper
47 (Kuvempunagar)	15,075	4.5	4,060	26.40	5 autos + 1 tipper

51 (Agrahara)	8,800	6.5–7.0	2,411	25.19	5 autos + 2 tractors

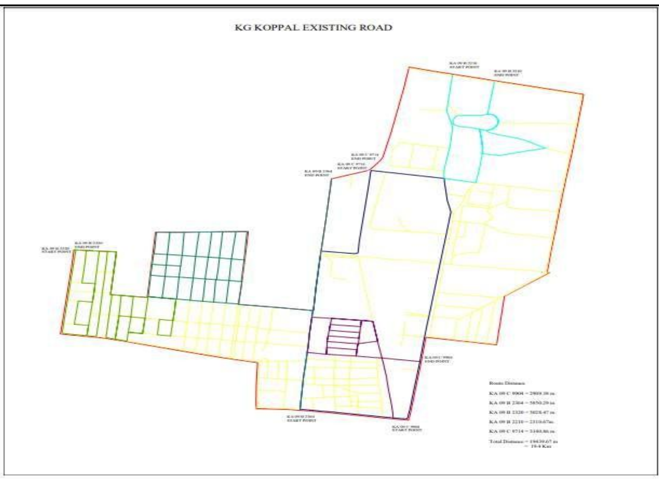

Figure 4: Existing waste collection route of ward number 42- KG Koppal

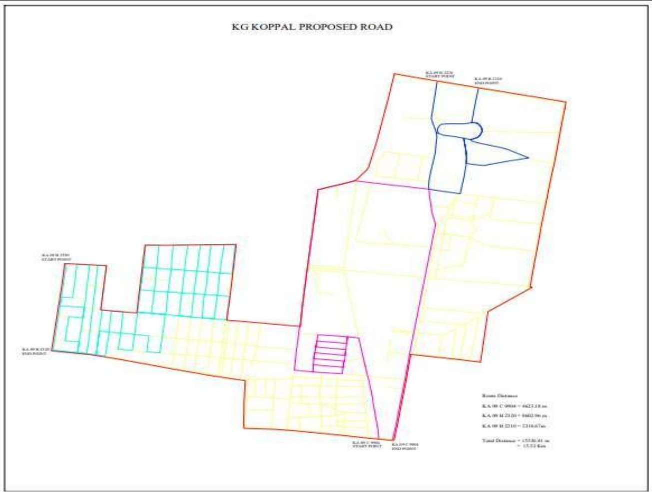

Figure 7: Optimized waste collection route of ward number 42- KG Koppal

Figure 5: Existing waste collection route of ward number 43-T K Layout

Figure 8: Optimized waste collection route of ward number 43-T K Layout

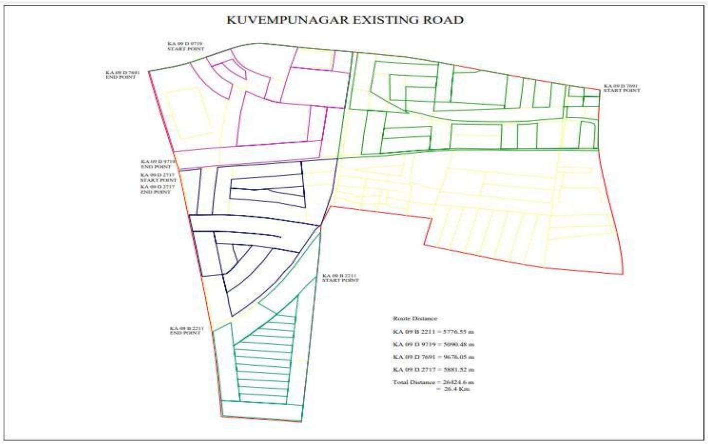

Figure 6: Existing waste collection route of ward number 47- Kuvempunagar

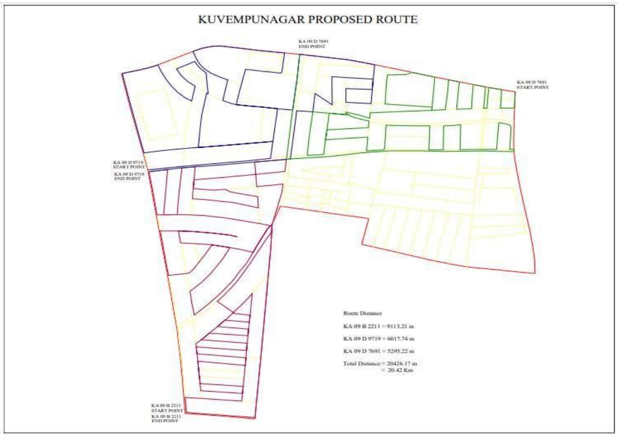

Figure 9: Optimized waste collection route of ward number 47- Kuvempunagar

Figure 4 shows the existing collection route in Ward 42 extending nearly 19 km, highlighting overlaps in coverage and longer travel than required for the waste generated. Figure 5 shows the collection route in Ward 43 that goes through 13 km daily, which indicates rural placements of collection sites and unintelligent routes. Figure 6 shows the current waste collection system in Ward 47, where vehicles travel 26 km per day, underscoring operational inefficiency relative to the ward's waste load.

Figure 7 – 9 shows the optimized waste collection routes of wards number 42, 43, and 47, which showed a significant decrease in travel distance.

3.3 Optimized Waste Collection Routes

Use of ArcGIS Network Analyst slashed travel distances by considerable amounts. The biggest efficiency was found in Ward 43, where the distances were cut by more than 42%, and Ward 47 had 27% savings. The results are a testament to the ability of GIS-based methods to minimize cost and environmental impacts. Table 3 shows the optimized distance for waste collection trucks in the five wards as computed using ArcGIS Network Analyst. The savings are significant, from 18% in Ward 6 to more than 42% in Ward 43, illustrating the efficiency potential of GIS-based optimization.

Table 3: Optimized Route Distances in Selected Wards

Ward	Optimized Route Distance (km)	% Reduction from Existing	Efficiency Gain
6 (Gokulam)	22.37	18.47	Moderate
42 (K G Koppal)	15.53	19.95	Moderate
43 (T K Layout)	7.58	42.11	High
47 (Kuvempunagar)	20.42	27.01	High
51 (Agrahara)	18.15	27.90	High

3.4 Comparative Analysis of Existing and Optimized Routes

The comparative evaluation reflects uniform decreases in travel distance in all the wards. Ward 43 recorded the maximum improvement in efficiency (42.11%), while Wards 51 and 47 recorded almost a 28% decline. This study confirms that systematic routing optimization can significantly reduce operational costs while reducing emissions. Table 4 shows ward-wise comparison of existing and optimized routes, showing uniform decreases in travel distance. Gains in efficiency range between 18% and 42%, with a maximum gain for Ward 43 and a minimum gain for Ward 6.

Table 4: Comparative Summary of Existing vs Optimized Routes

Ward	Existing Distance (km)	Optimized Distance (km)	% Reduction	Waste Generated (TPD)
6 (Gokulam)	27.44	22.37	18.47	8.0
42 (K G Koppal)	19.40	15.53	19.95	5.8
43 (T K Layout)	13.09	7.58	42.11	4.2
47 (Kuvempunagar)	26.40	20.42	27.01	4.5
51 (Agrahara)	25.19	18.15	27.90	6.5–7.0

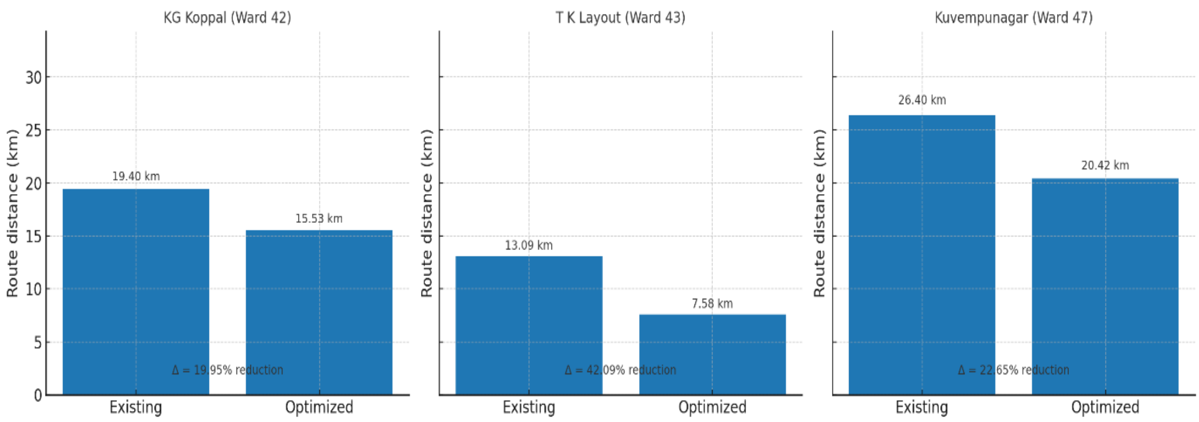

Figure 10. Existing vs optimized route distances in the three study wards of Mysuru: (a) KG Koppal (Ward 42), (b) T K Layout (Ward 43), and (c) Kuvempunagar (Ward 47).

Figure 10 compares existing versus optimized route distances for the three study wards using small-multiple panels. In KG Koppal (Ward 42), the route length falls from 19.40 km to 15.53 km (−19.95%).

In T K Layout (Ward 43), it drops from 13.09 km to 7.58 km (−42.11%), the largest improvement. In Kuvempunagar (Ward 47), distance reduces from 26.40 km to 20.42 km (−27.01%). Identical scales across panels enable direct, like-for-like comparison, making the magnitude of reductions immediately visible. Overall, Figure 8 shows consistent distance savings after GIS-based optimization, with T K Layout exhibiting the strongest efficiency gain.

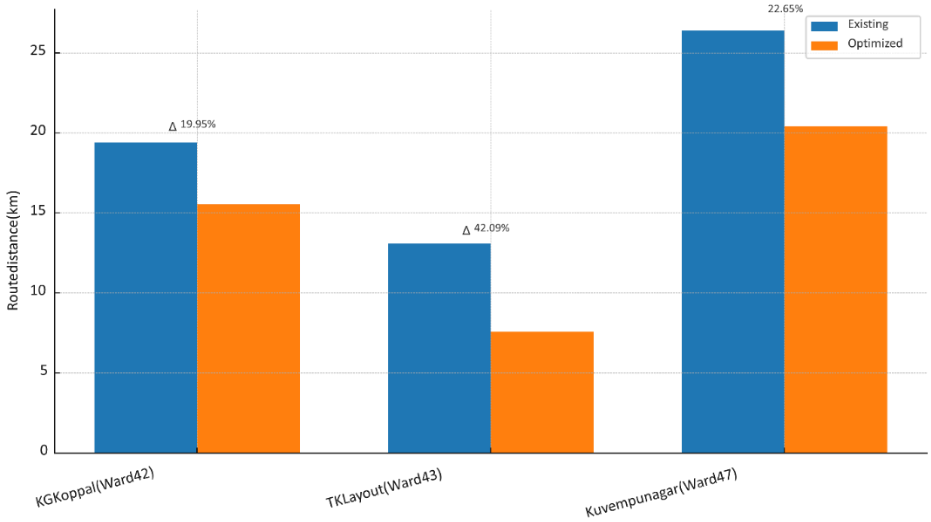

Figure 11. Grouped comparison of existing vs optimized route distances across the three study wards. Labels above bars indicate the percentage reduction relative to the existing distance.

Figure 11 presents a grouped bar chart that consolidates existing and optimized distances across the three wards, highlighting percentage reductions above each pair. The chart makes the ranking of gains clear: T K Layout (Ward 43) shows the greatest improvement (−42.11%), followed by Kuvempunagar (Ward 47) (−27.01%) and KG Koppal (Ward 42) (−19.95%). By placing wards side-by-side, Figure 4-9 provides a quick comparative overview and reinforces the ward-level panels. The visual summary underscores how optimized routing consistently shortens travel distances, implying proportional savings in fuel use and CO_2 emissions across the study area.

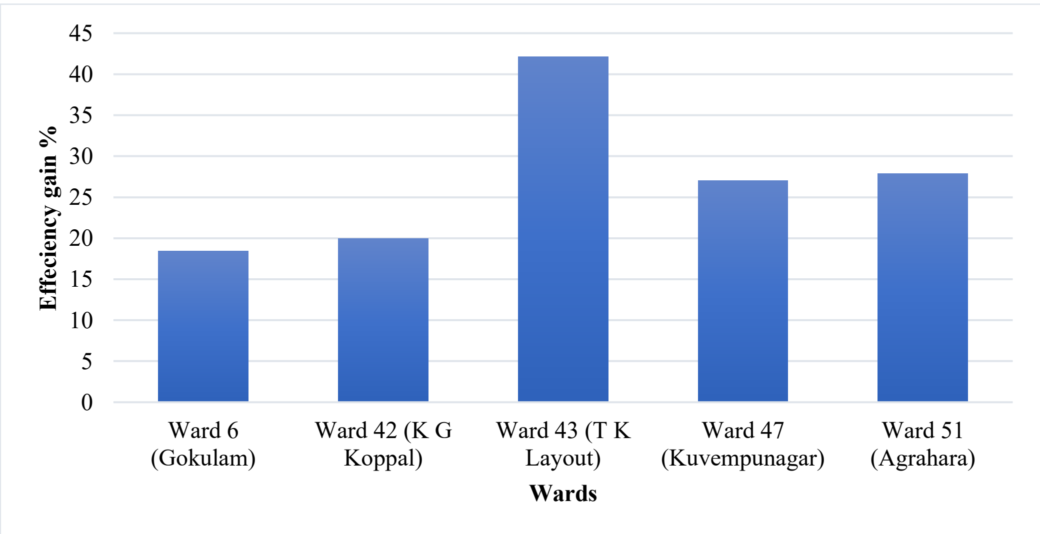

Figure 12: Efficiency Gains in Waste Collection Routes Across Wards

Figure 12 shows the percentage of travel distance reduced in five wards of Mysuru after route optimization. Ward 43 (T K Layout) showed the maximum efficiency gain of more than 42 %, whereas Ward 6 (Gokulam) experienced the least gain of about 18 %.

3.5 Environmental and Operational Implications

The distance reduction has a direct relationship with fuel and emission reduction. Shorter routes reduce the use of diesel, subsequently lowering carbon dioxide emissions. The example of the minimization of approximately 5.5 km per trip in Ward 6 translates into quantifiable reductions in the use of fossil fuels, while the 42% reduction in Ward 43 exemplifies significant environmental benefits. These reductions are additions to climate mitigation targets and align with SDGs that address sustainable cities and climate action. Table 5 shows the environmental benefits accrued through the shortening of distances, including fuel savings and carbon dioxide emission reductions per day. Optimization in all wards adds to economic efficiency as well as minimizing the ecological footprint.

Table 5: Estimated Environmental Benefits of Route Optimization

Ward	Distance Saved (km)	Estimated Fuel Saved (litres/day)	Approx. CO_2 Reduction (kg/day)
6 (Gokulam)	5.07	~1.2	~3.2
42 (K G Koppal)	3.87	~0.9	~2.5
43 (T K Layout)	5.51	~1.3	~3.5
47 (Kuvempunagar)	5.98	~1.4	~3.8
51 (Agrahara)	7.04	~1.7	~4.4

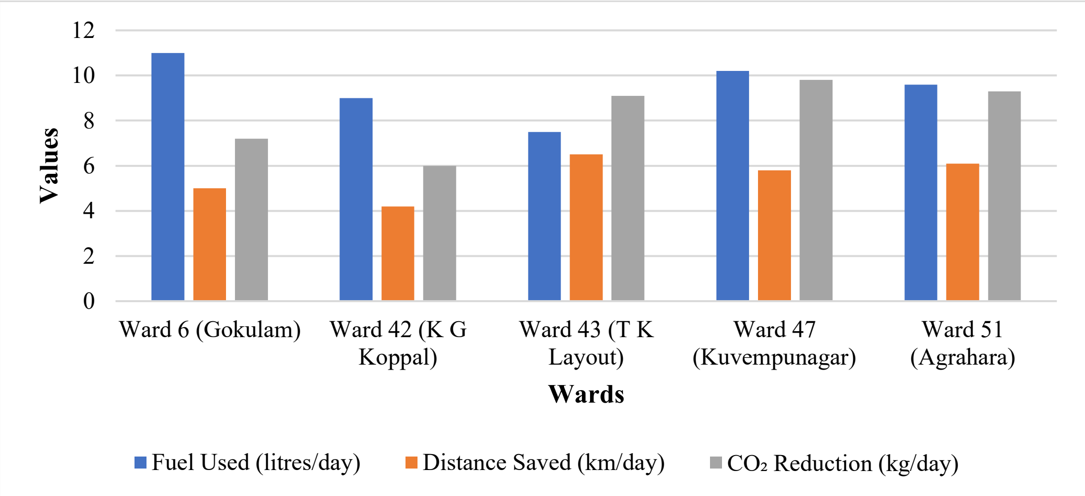

Figure 13: Fuel Use, Distance Saved, and CO_2 Reduction Across Selected Wards of Mysuru

Figure 13 shows fuel consumption, saved distance, and reduction in CO_2 by ward. Ward 43 saved 6.5 km with 9.1 kg CO_2 saved, with Ward 6 consuming the most at 11 litres/day, with an efficiency gap observed.

4. DISCUSSION

Results show that current municipal solid waste collection routes in Mysuru are marked with high inefficiencies. Daily travel distances varied between 13.09 km in Ward 43 (T K Layout) and 27.44 km in Ward 6 (Gokulam), frequently higher than operational needs. GIS-based optimization resulted in uniform decreases in all wards, with increases in efficiency varying between 18.47% in Ward 6 and 42.11% in Ward 43. These savings translated directly to environmental advantages. For example, Ward 51 (Agrahara) saved 7.04 km per day, which corresponds to an estimated 1.7 liters/day fuel save and 4.4 kg/day reduction in CO_2 emissions. Even the lowest reduction, in Ward 6, was equal to a daily fuel saving of ~1.2 liters and 3.2 kg of CO_2 emissions. Together, the study discloses that optimization not only minimizes operating distances but also brings quantifiable ecological benefits through decreased reliance on fuel and greenhouse gas. These results validate the perspective that route optimization represents a practical method in environmental science, once tied to municipal operations with corresponding decreased emissions, enhanced air quality, and enhancements in ecological resilience.
These results have two implications. One is that it leads to economic advantages for the municipal budgets. Less travel/shorter routes decrease fuel utilization and vehicle wear, creating a lower cost of operation. Second, the cuts on fuel consumption offer direct environmental benefits to climate-related action. Efficiency gains in all of the wards were consistently above 18% after moving through the wards, indicating that even modest gains at the ward level can add up to significant citywide savings. In addition, the implementation of route planning with the help of GIS in the work of municipalities will increase the institutional capacity, ensuring the long-term sustainability of waste governance.

The results are consistent with more general evidence from urban waste collection study, which repeatedly suggests the efficacy of spatial optimization in minimising fuel consumption, operating costs, and environmental impacts [25]. Comparable studies in different urban settings have shown that optimized routing regularly yields reductions in travelling distance of 15–45%, putting Mysuru's findings in a similar range [26]. The magnitude of efficiency improvements seen here—especially the 42% savings in Ward 43—bolsters the finding that Indian medium-sized cities can attain environmental and operating gains comparable to those published globally. Furthermore, the established connection between route optimization and CO_2 savings is part of a larger global pattern of internalizing environmental sustainability in municipal waste logistics [27].
Although the present analysis showed high potential for efficiency gains, new improvements can still be made. Further work can be done on the integration of the future real-time traffic data, dynamic routing models, and time-window constraints to more accurately represent the applicability of the optimized routes with real operating conditions. Including areas that receive the waste, such as transfer stations, recycling facilities, and treatment plants, could produce a unified waste management plan that generates the least impact on the entire chain of waste treatment. Moreover, the association of GIS-based routing with digital monitoring systems and citizen engagement platforms would enhance accountability, participation in the process of waste segregation, and further de-rely on landfills.

CONCLUSION

Municipal solid waste collection in Mysuru can be made substantially more efficient through GIS-based route optimization. The assessment shows that baseline routes were longer than operationally necessary, driving avoidable fuel use, costs, and greenhouse-gas emissions. After optimization, travel distances decreased consistently across the study area—ranging from about one-fifth to over two-fifths reduction—demonstrating strong technical feasibility and immediate operational value. These distance cuts translate into measurable environmental benefits in daily operations, including fuel savings on the order of about 1–2 liters per ward per day and CO_2 reductions reaching roughly 4 kg per day in some cases. Beyond the direct savings, the results underscore how integrating spatial data, service demand, and infrastructure constraints into routing decisions strengthens municipal capacity, improves service reliability, and supports broader sustainability goals. Methodologically, presenting outcomes in a compact, comparative format (contrasting existing and optimized results across representative wards) makes the efficiency gains transparent and decision-relevant, while avoiding redundant ward-by-ward route panels. In line with the author's guidance, route maps for Gokulam and Agrahara are not included; the emphasis remains on a clear comparison that highlights the magnitude and distribution of gains without overloading the reader with repetitive visuals. Strategically, these findings indicate that similar medium-sized Indian cities can adopt GIS-supported routing to curb fuel expenditure, extend vehicle life, and contribute to climate objectives through routine, scalable operational changes. Future work should incorporate time-window constraints, updated vehicle capacities, and dynamic traffic conditions to further align optimized routes with real-world variability. Extending the analysis to the full logistics chain (transfer stations, processing facilities, and disposal sites) and linking routing with digital monitoring and citizen engagement can amplify benefits. Overall, GIS-driven route optimization emerges as a practical lever for cost control, emissions reduction, and resilient, sustainable urban services.

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