

Optimization of Waste Management Systems Using Graph Theory: A Case Study of Calabar Metropolis

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Received: : 07 June 2026/ Accepted: 16 September 2026/Published: 24 September 2026

<https://doi.org/10.4314/cps.v13i10.5>

Abstract: The increasing generation of municipal solid waste in Calabar Metropolis, Cross River State, Nigeria, has created challenges for efficient waste collection, transportation, and disposal. This study applied graph theory and vehicle routing principles to develop an optimized framework for municipal solid waste collection, with the Lemna dumpsite designated as the central disposal node. Global Positioning System (GPS) coordinates were obtained for 70 waste collection stations across Calabar Municipality and Calabar South. The collection network was represented as a weighted graph, with nodes representing collection stations and the dumpsite, and edge weights representing travel distances. Eight collection routes were proposed to organize waste collection and facilitate transportation to the dumpsite. Statistical analysis of the reported route-level distance values revealed a mean of 3.65 km, a median of 3.41 km, a minimum of 1.71 km, and a maximum of 6.53 km. The standard deviation was 1.51 km, while the coefficient of variation as 41.37%, indicating considerable variation in the reported distances across the routes. The proposed routes accounted for 65 of the 70 identified collection stations, representing 92.86% coverage, while five stations remained unassigned. These findings demonstrate the potential of graph-based modelling to support the spatial organization of waste collection activities and identify areas requiring further routing refinement. However, reductions in total travel distance, fuel consumption, and operational costs could not be statistically established because complete route-loop distances and comparable baseline measurements were unavailable. The study

recommends incorporating all identified stations, validating road-network distances, and considering vehicle capacity, waste generation, and operating conditions in subsequent optimization. The proposed framework provides a foundation for more systematic and data-driven municipal solid waste collection planning in Calabar Metropolis.

Keywords: Municipal solid waste; Route optimization; Geographic Information Systems (GIS); Vehicle routing problem (VRP); Calabar Metropolis

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1.0 Introduction

The management of municipal solid waste (MSW) has become a major environmental, public health, and operational challenge in rapidly urbanizing cities, particularly in developing countries where waste generation frequently increases faster than the capacity of

collection, transportation, and disposal infrastructure. Population growth, changing consumption patterns, commercial expansion, and increasing urban density contribute to the growing volume and complexity of municipal waste. Abdel-Shafy and Mansour (2018) observed that effective solid waste management requires technically feasible, economically sustainable, socially acceptable, and environmentally sound approaches to waste collection, transportation, treatment, and disposal. Similarly, Kaza et al. (2018) projected that global annual waste generation could increase from approximately 2.01 billion tonnes in 2016 to 3.40 billion tonnes by 2050, underscoring the need for more efficient and sustainable waste management systems. The challenges associated with waste management extend beyond the availability of disposal facilities to include the organization of collection services, the allocation of vehicles, the selection of transportation routes, and the efficient utilization of limited financial and logistical resources. Brunner and Rechberger (2015) further emphasized the importance of integrating appropriate waste management practices into broader environmental protection and resource conservation strategies.

Among the different stages of municipal solid waste management, collection and transportation constitute critical operational activities because their efficiency influences service coverage, fuel consumption, vehicle utilization, operating expenditure, and the frequency of waste evacuation. Poorly planned collection routes may result in unnecessary vehicle movement, repeated visits to the same locations, excessive travel distances, and delays in the removal of accumulated waste. These inefficiencies can increase operational costs and contribute to environmental problems associated with the prolonged accumulation of refuse. Gdowska (2021) highlighted the relevance of data-driven approaches to addressing operational inefficiencies in complex systems. In this context, the

optimization of municipal waste collection can be formulated as a mathematical and computational problem involving the selection of feasible routes that minimize travel costs while satisfying service requirements and operational constraints. Evidence-based waste management planning is also supported by the Waste Wise Cities Tool developed by the United Nations Human Settlements Programme (UN-Habitat, 2021), which provides a structured approach to assessing municipal waste generation, collection, and management performance. These considerations demonstrate the importance of developing quantitative methods that support efficient collection planning, particularly in cities experiencing increasing pressure on municipal infrastructure.

Calabar Metropolis, comprising Calabar Municipality and Calabar South in Cross River State, Nigeria, provides a relevant setting for investigating the application of mathematical optimization to municipal solid waste collection. The spatial distribution of waste collection stations, the configuration of the road network, traffic conditions, and the location of authorized disposal facilities collectively influence the distance and time required to complete collection operations. Where vehicle movements are determined largely by established routines or operational experience rather than systematic route analysis, opportunities may exist to improve the allocation of collection points to vehicles and the sequence in which those points are visited. Repeated journeys, inefficient sequencing of collection locations, and unnecessary movement toward disposal facilities can potentially increase fuel requirements and vehicle operating costs. Such challenges are particularly important where municipal authorities must provide adequate sanitation services with limited budgets, equipment, and personnel. Nevertheless, the magnitude of these operational problems in Calabar should be established using local



records, field observations, and measured route distances rather than assumed solely from evidence obtained in other cities.

The difficulties associated with municipal waste collection in developing urban environments have been examined in previous studies. Kinobe et al. (2015), in their investigation of waste collection and disposal in Kampala, Uganda, applied geographic information systems (GIS) to evaluate collection routes, transportation distances, collection time, and facility-location alternatives. Their findings demonstrated the practical value of integrating spatial information with optimization techniques to improve waste collection and disposal planning. In Nigeria, Olukanni et al. (2014) is cited in the original manuscript in connection with urban sanitation and infrastructure-related challenges; however, the precise bibliographic details and the extent to which that publication directly supports claims about drainage and waste collection should be verified against the original source. Similarly, Abba et al. (2020) is cited in the original manuscript to support the application of geospatial tools in municipal planning, while Sulemana et al. (2020) is cited in relation to the influence of disposal accessibility on waste management operations. These studies collectively motivate further investigation of spatially informed planning approaches, although their specific relevance to the Calabar collection network must be established through a careful comparison of their study areas, methods, and findings.

The development of mathematical models for transportation and collection systems provides a foundation for addressing these challenges. Graph theory represents a network as a collection of vertices and edges, making it possible to describe relationships among physical locations and the routes connecting them. In a municipal waste collection network, vertices may represent waste collection stations, vehicle depots, transfer points, and disposal facilities, while edges represent

connections between locations through the road network. A weighted graph can be expressed as $G=(V,E,W)$, where (V) is the set of vertices, (E) is the set of edges, and (W) is the set of associated edge weights. These weights may represent road distance, estimated travel time, or another measure of transportation cost. Bondy and Murty (2008) and West (2001) provide established mathematical foundations for the representation and analysis of graphs. For practical routing applications, however, the graph should reflect the actual road network as closely as the available data permit. One-way streets, restricted road access, turning limitations, and differences between travel directions may require a directed or asymmetric network rather than an undirected graph with identical weights in both directions. Different graph-theoretic and combinatorial optimization methods address different classes of routing problems. Dijkstra's (1959) shortest-path algorithm determines a minimum-distance path between specified vertices in a weighted network with non-negative edge weights. Although useful for calculating travel distances between pairs of locations, the shortest-path problem alone does not determine the best sequence for visiting multiple waste collection stations. Where a collection operation requires a vehicle to traverse specified streets or service road segments, an arc-routing formulation may be appropriate. The Chinese Postman Problem is one such formulation when the objective is to find a minimum-cost closed route that traverses every required edge of a network. Its suitability depends on whether the operational requirement concerns covering road segments rather than simply visiting designated collection points. The broader literature on routing problems, including the work discussed by Eiselt and Laporte (2022), provides a basis for distinguishing between these formulations. Golden et al. (2008) is retained as cited in the original manuscript, although the precise publication details and the specific proposition



attributed to that source should be checked before the manuscript is finalized.

Where the principal task involves visiting a specified set of waste collection stations, assigning them to vehicles, and transporting the collected waste to a disposal facility, the Vehicle Routing Problem (VRP) provides a more direct modelling framework. The classical formulation seeks to determine a set of routes that serves designated locations while minimizing a defined transportation cost. Dantzig and Ramser (1959) established an influential early formulation of the truck dispatching problem, which became a foundation for subsequent vehicle routing research. Laporte (2009) reviewed the development of the VRP and the progression of exact algorithms, mathematical programming techniques, and heuristic methods used to solve increasingly complex routing problems. Where collection vehicles have finite payload capacities, the problem can be formulated as a Capacitated Vehicle Routing Problem (CVRP). In this formulation, each required collection point is assigned to an appropriate route, the total demand allocated to a vehicle does not exceed its capacity, and the objective is to minimize the selected transportation cost. Toth and Vigo (2014) provide a comprehensive treatment of vehicle routing formulations, constraints, and solution methods.

The distinction between the CVRP and related routing problems is important for the present investigation. A node-based CVRP is appropriate when the 70 identified waste stations are treated as service locations and the model determines the order in which those stations are visited. In contrast, an arc-routing model would be required if the primary objective were to traverse specified streets or road segments for collection. The appropriate formulation therefore depends on the actual collection requirements, the availability of station-level waste quantities, vehicle capacities, and the manner in which the existing collection system operates. In

addition, GPS coordinates should not automatically be interpreted as road travel distances. Straight-line distances between coordinates may differ substantially from distances along accessible roads. A more realistic model should therefore use a road-network distance matrix, where available, or clearly identify and acknowledge the limitations of any coordinate-based distance approximation. These methodological considerations are essential for ensuring that the resulting routes are operationally feasible rather than merely geometrically short.

The solution of large vehicle routing problems can become computationally demanding as the number of collection stations, vehicles, and operational constraints increases. Laporte (2016) is cited in the original manuscript in relation to the use of heuristic and advanced optimization techniques for complex routing problems; the exact source and the specific claim should be verified before publication. More generally, the established routing literature recognizes the importance of heuristic and metaheuristic methods when exact optimization becomes computationally expensive (Laporte, 2009; Toth & Vigo, 2014). Such methods can generate feasible and comparatively efficient routes within practical computational limits. Their performance, however, depends on the problem formulation, the quality of the input data, the algorithm selected, and the criteria used to evaluate the resulting routes. Consequently, an optimization model should be assessed not only by whether it produces routes but also by whether those routes satisfy vehicle-capacity constraints and improve on an appropriately defined baseline. Previous research on waste management in Calabar has been described in the original manuscript as focusing mainly on institutional, socioeconomic, and waste-characterization issues. Bassey et al. (2006) is cited in this context in relation to institutional and operational challenges affecting waste management. The full publication details and



the exact findings attributed to this study should be confirmed from the original source. Research in other urban environments has demonstrated that spatial analysis and route optimization can provide practical support for waste collection planning. For example, Kinobe et al. (2015) investigated route and facility-location alternatives in Kampala, illustrating how spatial data can inform decisions about transportation distance, collection time, and fleet requirements. The original manuscript also cites Academe et al. (2026) as reporting the application of GIS and Dijkstra's algorithm to municipal waste collection planning in Ota Town, Ogun State, with an estimated reduction in vehicle travel distance of approximately 19%. This citation and the numerical result must be verified against the original publication before they are relied upon as evidence. Furthermore, because Dijkstra's algorithm solves shortest-path problems rather than the complete multi-vehicle routing problem, the precise relationship between the algorithm and the reported collection-route optimization should be clarified.

Although these studies provide a useful foundation, their findings cannot automatically be transferred to Calabar because urban road networks, collection-point distributions, vehicle capacities, disposal locations, and operational practices differ across cities. The specific research gap addressed by the present study is therefore the need to develop and evaluate a location-specific, graph-based routing framework using the identified waste collection stations in Calabar Municipality and Calabar South, with the Lemna dumpsite treated as the designated disposal destination. The literature reviewed for this study has not yet established whether an equivalent model covering these 70 stations, incorporating the relevant vehicle-capacity constraints, and evaluating the resulting routes against a clearly defined baseline has previously been implemented for Calabar Metropolis. This

statement represents the scope of the gap to be investigated and should be retained only after a sufficiently comprehensive literature search confirms that the claim is justified. Establishing this gap provides a basis for examining how spatial data and mathematical optimization can be combined to improve local collection planning.

Accordingly, the aim of this study is to apply graph theory and vehicle routing optimization to improve municipal solid waste collection routes in Calabar Metropolis, Cross River State, Nigeria. The specific objectives are to identify and georeference the selected 70 waste collection stations across Calabar Municipality and Calabar South; represent the collection network as a weighted graph using appropriate road-distance information; formulate the collection problem as a capacitated vehicle routing problem, subject to the availability of reliable station-demand and vehicle-capacity data; determine feasible collection routes terminating at or appropriately connecting with the designated Lemna dumpsite; and evaluate the optimized routes against the existing or baseline arrangement using total travel distance, route feasibility, and vehicle-capacity compliance. Where adequate operational data are available, the evaluation will also consider estimated fuel consumption and transportation costs. These objectives provide a direct link between the study's mathematical formulation, its data requirements, and the performance measures needed to assess the usefulness of the proposed routing framework.

The significance of the study lies in its potential to provide the Cross River State Waste Management Agency and other relevant municipal authorities with a quantitative basis for planning and evaluating waste collection operations. By identifying feasible routes and reducing avoidable travel where the model demonstrates such improvements, the proposed approach could support more efficient vehicle allocation, better use of available resources, and more systematic collection scheduling.



Improved collection efficiency may also contribute to more reliable waste evacuation and better environmental sanitation, although these wider benefits depend on implementation, collection frequency, vehicle availability, and other operational factors beyond route optimization alone. From a methodological perspective, the study demonstrates how GPS-derived location information, graph theory, and vehicle routing techniques can be integrated into a decision-support framework for urban waste management. Its findings may also provide a foundation for future research incorporating time-dependent traffic conditions, varying waste quantities, multiple disposal facilities, uncertain travel times, and additional operational constraints. In this way, the study seeks to contribute both a locally relevant analytical framework and practical evidence to support more efficient municipal waste collection planning in Calabar Metropolis.

2.0 Materials and Methods

The structural design of this study relies on a quantitative, field-empirical approach that translates real-world physical logistics infrastructure into an algebraic optimization model. Fieldwork was carried out across the urban extent of the Calabar Metropolis, which spans both Calabar Municipality and Calabar South local government areas. To capture the baseline geographic data required for the network graph, comprehensive spatial mapping was conducted using a handheld global positioning system (GPS) receiver. During this field survey, precise spatial coordinates were captured for 70 distinct municipal solid waste collection stations, predominantly community waste skips, urban bins, and localized collection points managed by public waste boards. Concurrently, the absolute geographic coordinates of the single authorized disposal destination, the Lemna road dumpsite, were recorded to establish the central sink of the network. Each unique waste station was

assigned an index $i = \{1, 2, 3, \dots, 70\}$, while the Lemna dumpsite was designated as the root or depot node, denoted as V_0 .

To transition from raw spatial points to a functional network configuration, these 70 GPS coordinates were used to model the municipal road infrastructure as a weighted, directed graph $G = (V, E)$. In this framework, the vertex set $V = \{V_0, V_1, V_2, \dots, V_{70}\}$ represents the collection nodes and the dumpsite, while the edge set $E = \{(V_i, V_j) : V_i, V_j \in V, i \neq j\}$ represents the physical road segments directly connecting any two locations. Because a simple straight-line Euclidean measurement does not account for real urban geometry, real driving distances were extracted between every pair of nodes. This structural data was compiled into a mathematical asymmetric distance matrix, denoted as an 71×71 matrix D :

$$D = \begin{pmatrix} d_{0,0} & d_{0,1} & \cdots & d_{0,70} \\ d_{1,0} & d_{1,1} & \cdots & d_{1,70} \\ \vdots & \vdots & \ddots & \vdots \\ d_{70,0} & d_{70,1} & \cdots & d_{70,70} \end{pmatrix} \quad (1)$$

where $d_{i,j}$ represents the exact shortest driving distance (measured in kilometers) from node i to node j . The matrix is explicitly modeled as asymmetric ($d_{i,j} \neq d_{j,i}$) to reflect real-world urban constraints within Calabar. This asymmetry directly accounts for one-way street regulations, particularly prevalent around dense commercial districts like Watt Market and parts of Calabar South, as well as traffic turning restrictions, variable elevation gradients, and localized traffic flow bottlenecks along major corridors like Marian Road and Murtala Mohammed Highway.

The logistical challenge of clearing all 70 waste points while minimizing total travel distance was formulated as a Capacitated Vehicle Routing Problem (CVRP). Let K represent the homogeneous fleet of municipal collection trucks deployed from the central depot V_0 . Each



vehicle $k \in K$ is bound by a strict, maximum physical payload capacity, denoted as Q (measured in metric tons or volumetric bin equivalents). Let q_i represent the daily waste accumulation demand at a given waste collection station V_i . The primary optimization objective is to minimize the total structural as:

$$x_{i,j}^k = \begin{cases} 1, & \text{if vehicle } k \text{ travels directly from node } i \text{ to node } j \\ 0, & \text{otherwise} \end{cases}$$

This minimization objective function is subject to a strict set of operational constraints. First, every individual waste collection station must be visited exactly once by a single vehicle, ensuring full spatial coverage across the metropolis:

$$\sum_{k \in K} \sum_{j=0}^{70} x_{i,j}^k = 1, \quad \forall i \in \{1, 2, \dots, 70\} \quad (3)$$

Second, standard flow conservation constraints dictate that if a vehicle enters a waste station node, it must leave that same node:

$$\sum_{i=0}^{70} x_{i,j}^k - \sum_{j=0}^{70} x_{j,i}^k = 0, \quad \forall j \in V, \forall k \in K \quad (4)$$

Third, the cumulative waste demand collected along any single vehicle loop cannot exceed the maximum payload capacity Q of the truck:

$$\sum_{i=0}^{70} q_i \left(\sum_{j=0}^{70} x_{i,j}^k \right) \leq Q, \quad \forall k \in K \quad (5)$$

Finally, strict subtour elimination constraints are integrated to mathematically prevent the formation of isolated loops that do not originate and terminate at the Lemna dumpsite (V_0). Given that an 71×71 CVRP grid is NP-hard and computationally prohibitive to solve using exact linear programming methods, a vehicle routing heuristic was applied to run the asymmetric distance matrix. This heuristic systematically groups the 70 points into highly dense, capacity-compliant collection loops. Each loop begins at the Lemna dumpsite, sequences through a designated subset of high-demand and low-demand waste stations without violating the capacity threshold Q , and

routing distance across the network, mathematically expressed as:

$$\text{Minimize } \sum_{i=0}^{70} \sum_{j=0}^{70} \sum_{k \in K} d_{i,j} x_{i,j}^k \quad (2)$$

where $x_{i,j}^k$ is a binary decision variable defined

returns directly to the dumpsite for waste evacuation.

3.0 Results and Discussion

3.1 Results of the Waste Collection Route Optimization

The graph-theoretic approach was applied to the spatially identified municipal solid waste collection stations in Calabar Metropolis, with the Lemna Road dumpsite designated as the central disposal destination. The routing framework was intended to organize the collection stations into geographically coherent routes that minimize travel distance while satisfying the operational requirements of the collection system. The resulting route schedule, as presented in Table 3.1, comprises eight proposed collection routes covering different geographical sectors of Calabar Municipality and Calabar South.

The route schedule identifies the Atimbo/Bypass Perimeter, IBB Road/Airport/Etagbor, Calabar South Core/Uwanse, Urban Core/Chamley/Slessor, Marian/State Housing/Ediba, Edeba/Olikamp/Ibom Layout, Parliamentary Extension, and Murtala Mohammed Highway/Lemna sectors. The reported number of stations assigned to each route ranges from seven to ten, while the reported mean distance to the Lemna Road dumpsite ranges from approximately 1.71 km to 6.53 km. These variations indicate differences in the reported proximity of the collection stations or station clusters to the disposal facility. However, the mean distance to the dumpsite should not be interpreted as the total distance of a collection



loop because a completed route also includes travel between collection stations and the return journey to the disposal facility.

3.2 Distribution of Collection Stations Across the Proposed Routes

Table 1 indicates that the proposed routes differ in the number of collection stations assigned to each sector. Route 5, covering the Marian/State Housing/Ediba axis, contains the largest reported number of stations, with ten collection points. Route 3, covering the Calabar South Core/Uwanse axis, and Route 8, covering the Murtala Mohammed Highway/Lemna sector, each contain nine stations. Routes 2 and 6 contain eight stations each, while Routes 1, 4, and 7 contain seven stations each.

The eight routes collectively account for 65 distinct stations, representing 92.86% of the 70 stations identified in the study. Five stations, corresponding to nodes 29–33, are not included in the displayed routing matrix. Consequently, the proposed routes cannot yet be regarded as a complete allocation of the 70-station network. These omitted nodes must be incorporated into the appropriate routes, or their exclusion must be explained, before the model can be evaluated as a complete municipal collection system.

The distribution of stations also demonstrates why route planning should consider both the number and geographical arrangement of collection points. A route serving ten closely located stations may require less travel than a route serving seven widely dispersed stations. Accordingly, the number of stations assigned to a route is not, by itself, a sufficient measure of route efficiency. The more appropriate indicators include total route distance, distance between successive collection points, distance travelled to and from the disposal facility, vehicle payload utilization, and the feasibility of servicing all assigned stations.

This interpretation is consistent with the broader vehicle-routing literature, which treats the assignment and sequencing of service locations as a joint optimization problem rather than simply dividing customers into groups of similar sizes (Laporte, 2009; Toth & Vigo, 2014). In the Calabar application, the proposed sector-based arrangement provides a practical structure for examining whether geographically related collection points can be served efficiently. Its operational effectiveness, however, depends on the actual road distances, waste quantities, vehicle capacities, and the final inclusion of all identified stations.

Table 1: Proposed Waste Collection Routing Matrix and Sector Logistics Schedule for Calabar Metropolis

Route ID	Neighbourhood cluster/sector	Collection-station sequence	Reported stations covered	Reported mean distance to Lemna (km)	Reported potential operational benefit*
1	Atimbo/Bypass Perimeter Axis	0 → 1 → 2 → 3 → 4 → 6 → 27 → 28 → 0	7	1.71	24% fuel saving
2	IBB Road/Airport/Etagbor Axis	0 → 5 → 7 → 8 → 9 → 10 → 11 → 12 → 13 → 0	8	2.39	21% efficiency gain
3	Calabar South Core/Uwanse Axis	0 → 14 → 15 → 16 → 17 →	9	5.06	18% lower fleet wear



		18 → 19 → 20 → 21 → 22 → 0			
4	Urban Core/Chamley/Slessor Axis	0 → 23 → 24 → 25 → 26 → 42 → 49 → 50 → 0	7	3.87	22% mileage saving
5	Marian/State Housing/Ediba Axis	0 → 34 → 35 → 36 → 37 → 38 → 39 → 40 → 41 → 51 → 52 → 0	10	2.75	26% cost reduction
6	Edeba/Olikamp/Ibom Layout Axis	0 → 43 → 44 → 45 → 46 → 47 → 48 → 53 → 54 → 0	8	2.95	20% energy optimization
7	Parliamentary Extension Axis	0 → 55 → 56 → 57 → 58 → 59 → 60 → 70 → 0	7	3.93	23% operational saving
8	Murtala Mohammed Highway/Lemna Sector	0 → 61 → 62 → 63 → 64 → 65 → 66 → 67 → 68 → 69 → 0	9	6.53	19% direct fuel saving

3.3 Analysis of Reported Distances to the Lemna Road Dumpsite

The reported mean distances to the Lemna Road dumpsite in Table 1 range from 1.71 km for Route 1 to 6.53 km for Route 8. Route 1, representing the Atimbo/Bypass Perimeter axis, has the smallest reported mean distance, whereas Route 8, representing the Murtala Mohammed Highway/Lemna sector, has the largest. Route 2 has a reported mean distance of 2.39 km, followed by Route 5 at 2.75 km and Route 6 at 2.95 km. Routes 4 and 7 have reported mean distances of 3.87 km and 3.93 km, respectively, while Route 3 has a reported mean distance of 5.06 km.

These figures provide a preliminary indication of differences in reported proximity to the disposal facility. Nevertheless, their interpretation requires clarification of how the mean distances were calculated. If they

represent the arithmetic mean of the individual distances from the collection stations assigned to each route to the dumpsite, they describe the spatial proximity of the stations to the disposal facility. If they represent another measure, the calculation should be explicitly defined.

In either case, the reported values do not establish the total distance travelled along the proposed routes. A collection vehicle must travel between successive stations and return to the dumpsite, and the distance associated with those movements depends on the order of visitation and the road network. Therefore, a route with a smaller mean station-to-dumpsite distance does not necessarily have the shortest complete collection loop.

For a rigorous comparison, the total distance of each route should be calculated by summing the road distances of all consecutive movements, including the initial departure



from the dumpsite and the final return. For route (r), this can be expressed as

$$D_r = \sum_{(i,j) \in r} d_{ij} \quad (6)$$

where D_r is the total travel distance for route r , and d_{ij} is the road distance from node (i) to node (j). The total distance for the proposed collection system is then

provided that all routes are feasible, every required station is covered, and the eight routes constitute the complete routing solution. Reporting these quantities would enable the performance of individual routes and the overall collection network to be evaluated using a consistent distance-based measure.

3.4 Interpretation of the Individual Collection Routes

3.4.1 Route 1: Atimbo/Bypass Perimeter Axis

Route 1 contains seven stations: nodes 1, 2, 3, 4, 6, 27, and 28. Its reported mean distance to the Lemna Road dumpsite is 1.71 km, the smallest value among the eight proposed routes. This suggests that the assigned stations may be relatively close to the disposal facility, subject to confirmation of the distance calculation and the actual road-network geometry.

A geographically coherent route in this sector could reduce unnecessary movement between collection points and the disposal facility. However, the presence of nodes 27 and 28 alongside nodes 1–6 should be assessed against their actual geographical coordinates and intervening road connections. Node numbering alone does not establish geographical proximity. The sequence should therefore be validated against the road network to ensure that it does not introduce unnecessary detours. The original schedule reports a potential fuel saving of 24% for this route. That figure cannot be confirmed from the reported mean distance alone. To establish the saving, the complete optimized route distance must be compared with the corresponding baseline distance under equivalent service conditions. Fuel

consumption data or a clearly specified distance-based fuel model would also be required to substantiate a fuel-saving estimate.

3.4.2 Route 2: IBB Road/Airport/Etagbor Axis
Route 2 contains eight collection stations, identified as nodes 5 and 7–13, and has a reported mean distance to the dumpsite of 2.39 km. The proposed grouping provides a basis for coordinating the collection points within the IBB Road/Airport/Etagbor sector.

The route may improve operational organization if the assigned stations are connected by feasible road movements and their sequence minimizes avoidable backtracking. The appropriate order of visitation should be determined from the weighted road-distance matrix rather than from the station numbers or neighbourhood labels alone. In addition, the model should account for any road restrictions represented in the underlying data.

The reported 21% efficiency gain requires a clearly defined performance indicator. Efficiency may refer to reduced travel distance, reduced collection time, increased waste collected per unit distance, or another operational measure. Until the indicator and its baseline are specified, the percentage should be treated as an unverified estimate rather than a demonstrated outcome.

3.4.3 Route 3: Calabar South Core/Uwanse Axis

Route 3 contains nine stations, nodes 14–22, and has a reported mean distance to the Lemna Road dumpsite of 5.06 km. This is the second-largest reported mean distance in Table 1. The figure suggests that the stations assigned to this route may be farther from the disposal facility than those assigned to Routes 1, 2, 5, and 6.

The sector-based grouping may facilitate coordinated collection within the Calabar South Core/Uwanse axis, particularly if the stations are geographically concentrated and accessible through connected roads. A suitable routing sequence can reduce unnecessary travel between service locations. Nevertheless, the



potential benefit depends on the actual road network, traffic conditions where modelled, and the order in which the stations are visited. The original schedule associates this route with an 18% reduction in fleet wear. Such a reduction cannot be inferred directly from the mean distance to the dumpsite. Vehicle wear depends on total distance, road surface conditions, stop-start driving, vehicle load, maintenance practices, and other operating factors. The claim would require baseline and optimized mileage data, together with an appropriate vehicle-maintenance or wear model. Without this evidence, the route's contribution should be discussed in terms of its proposed spatial organization rather than a quantified reduction in fleet wear.

3.4.4 Route 4: Urban Core/Chamley/Slessor Axis

Route 4 contains seven stations: nodes 23–26, 42, 49, and 50. Its reported mean distance to the dumpsite is 3.87 km. The route combines four consecutive node numbers, 23–26, with nodes 42, 49, and 50. This grouping should be checked against the recorded coordinates to determine whether the assigned stations form a coherent geographical cluster or whether the route introduces additional travel between separated locations.

The urban core may present complex routing conditions because of the distribution of commercial activities, intersections, parking restrictions, and other road-access considerations. If such constraints are accurately represented in the road-network data, the optimization model can use them to determine feasible movements between collection stations. However, the existence of congestion or backtracking cannot be established solely from the proposed route sequence; these conditions require supporting spatial, traffic, or operational evidence.

The original schedule reports a 22% mileage saving for Route 4. This estimate should be validated by comparing the total route distance before and after optimization. A defensible

evaluation would also establish that both arrangements cover the same collection stations and include equivalent depot-departure and return requirements. Such a comparison would determine whether the proposed sequence produces an actual reduction in mileage.

3.4.5 Route 5: Marian/State Housing/Ediba Axis

Route 5 contains ten stations, nodes 34–41, 51, and 52, making it the route with the largest reported number of collection points. Its reported mean distance to the Lemna Road dumpsite is 2.75 km. The combination of a relatively high station count and a comparatively small reported mean distance suggests that this route warrants further examination for potential operational efficiency.

The number of assigned stations does not, however, establish whether the route is feasible for a particular collection vehicle. A vehicle may be able to visit ten stations if the combined waste demand is within its payload capacity, whereas a route containing fewer stations may exceed capacity if its collection points generate larger quantities of waste. Consequently, the route should be evaluated using measured or defensibly estimated station-level demand and the payload capacity of the assigned vehicle.

The reported 26% cost reduction is the largest percentage in the original schedule. It is not yet possible to establish this saving from the distance information presented. Operational cost includes fuel, labour, maintenance, vehicle depreciation, disposal-related expenses, and other relevant expenditures. If the proposed route reduces travel distance, it may reduce the distance-related component of cost, but the overall percentage saving must be calculated using a documented baseline and a consistent cost model.

3.4.6 Route 6: Edeba/Olikamp/Ibom Layout Axis

Route 6 comprises eight stations, nodes 43–48, 53, and 54, and has a reported mean distance of



2.95 km to the dumpsite. This value is relatively close to the reported mean distances for Routes 2 and 5. The proposed sector grouping provides a basis for coordinating waste collection across the assigned locations. For the route to be operationally effective, the sequence must reflect feasible road connections and avoid unnecessary detours. Its performance should be evaluated using total route distance, payload utilization, and the number of trips required to complete the assigned collections. If the waste quantity exceeds vehicle capacity, the route would require additional trips, a different vehicle assignment, or an alternative route configuration.

The original schedule associates Route 6 with a 20% energy optimization benefit. This statement requires clarification because energy optimization is not a single, unambiguous performance indicator. If the intended measure is a reduction in fuel energy consumed during collection, the authors should specify the baseline fuel consumption, the optimized consumption, and the conversion method used. Until these data are available, the reported percentage cannot be interpreted as a verified energy saving.

3.4.7 Route 7: Parliamentary Extension Axis

Route 7 comprises seven stations, nodes 55–60 and 70, and has a reported mean distance to the dumpsite of 3.93 km. The proposed route provides a framework for organizing the identified collection points within the Parliamentary Extension sector.

Its operational value depends on the geographical relationships among the stations and the feasibility of the road connections used in the sequence. The inclusion of node 70 in this route should be checked against its recorded coordinates and the road-distance matrix to confirm that it is appropriately assigned to this sector.

The original schedule reports a 23% operational saving. However, the term “operational saving” is insufficiently defined to

permit a quantitative interpretation. It could refer to reduced distance, time, fuel expenditure, or total operating cost. The study should identify the intended measure and calculate the percentage from the corresponding baseline and optimized values. Without that comparison, the proposed route can be evaluated only in terms of its structure and reported distance characteristics.

3.4.8 Route 8: Murtala Mohammed Highway/Lemna Sector

Route 8 contains nine stations, nodes 61–69, and has the largest reported mean distance to the Lemna Road dumpsite at 6.53 km. This value is substantially higher than the reported means for Routes 1, 2, 5, and 6. If the values were calculated using a consistent method, the difference indicates that the stations assigned to Route 8 have greater average separation from the disposal facility than the stations in those four routes.

The result highlights the importance of accounting for disposal-facility proximity when planning municipal waste collection. Stations located farther from the dumpsite may require greater travel distances, increasing the contribution of transportation to operational requirements. Nevertheless, the total distance of Route 8 cannot be inferred from the mean station-to-dumpsite distance because the route also includes travel between the nine collection stations.

The original schedule reports a 19% direct fuel saving for this route. This claim requires a comparison of fuel consumption under the existing and optimized arrangements or a documented fuel model applied to comparable total route distances. The larger reported mean distance does not, by itself, establish either a fuel penalty or a fuel saving. The actual benefit depends on whether the proposed sequence reduces the total distance travelled relative to the baseline.

3.5 Assessment of Operational Efficiency and Resource Savings



The original routing schedule reports potential benefits ranging from 18% to 26%, covering fuel consumption, general efficiency, fleet wear, mileage, operating cost, energy use, and operational savings. These figures suggest that the original analysis intended to quantify the economic and operational implications of the proposed routes. However, the measures are heterogeneous and cannot be compared directly because they represent different outcomes and are not accompanied by the underlying calculations.

A reduction in travel distance may contribute to lower fuel consumption and transportation expenditure, but the relationship depends on vehicle characteristics, loading conditions, road conditions, driving behaviour, and other operating factors. Similarly, reduced mileage may contribute to lower maintenance requirements over time, but a percentage reduction in vehicle wear cannot be calculated from route distance alone. Each claimed benefit must therefore be linked to a defined performance measure and evaluated using the corresponding baseline and optimized data.

For total travel distance, the percentage reduction should be calculated using

$$R_D = \frac{D_b - D_0}{D_b} \times \frac{100}{1}$$

where D_b represents the total baseline distance and D_0 represents the total optimized distance. Both distances must cover the same collection stations and include comparable depot-departure, inter-station, and return journeys.

For fuel consumption, an equivalent comparison would use

$$R_D = \frac{D_b - D_0}{D_b} \times \frac{100}{1} \quad (7)$$

where D is the optimized fuel consumption over the same planning period. If fuel use is estimated from distance, the fuel-consumption model and its assumptions must be stated explicitly.

For operating cost, the corresponding calculation would be

$$R_D = \frac{F_b - F_0}{F_b} \times \frac{100}{1} \quad (8)$$

where F_b and F_0 represent baseline and optimized operating costs, respectively. The cost calculation should identify the cost components included and ensure that both scenarios are assessed over the same period and service requirements.

3.6 Discussion in Relation to Previous Studies

The proposed routing framework is consistent with the broader application of mathematical optimization to municipal waste collection. Kinobe et al. (2015) demonstrated the relevance of integrating geographic information systems with waste collection and disposal planning in Kampala, Uganda. Their work illustrates how spatial information can support the evaluation of collection routes and facility-location alternatives. The present study similarly uses geographically identified waste collection stations and a designated disposal facility to structure a routing problem for an urban waste management system.

The application of graph theory also provides a formal representation of the relationships between collection locations. By associating each permissible movement with a distance weight, the collection network can be evaluated systematically rather than relying exclusively on informal route selection. This approach is compatible with established vehicle-routing formulations discussed by Laporte (2009) and Toth and Vigo (2014), in which route selection and sequencing are treated as constrained optimization problems.

Nevertheless, the effectiveness of the Calabar model must be demonstrated using its own empirical results. The eight proposed routes provide an initial operational schedule, but a rigorous comparison with previous work requires numerical measures such as total baseline distance, optimized distance, the number of vehicles deployed, payload utilization, route feasibility, and the percentage change in the selected performance indicators. Without these results, the study can demonstrate the structure of the proposed routing framework but cannot establish the



magnitude of its improvement relative to existing practices.

The study also illustrates the importance of matching the mathematical formulation to the actual waste collection operation. A capacitated vehicle routing model is suitable when the principal task is to visit designated collection stations subject to vehicle payload limits. If collection demand is not available, the model cannot establish capacity compliance. Similarly, if the distance matrix is derived only from geographical coordinates without a road-network analysis, the resulting routes may not accurately represent feasible driving movements. These considerations affect the reliability of the optimization results and should be addressed explicitly in interpreting the findings.

3.7 Implications for Municipal Waste Management in Calabar

The proposed sector-based routing schedule has potential practical value for the Cross River State Waste Management Agency because it organizes the collection stations into identifiable geographical groups. Such an arrangement could support route assignment, collection scheduling, and the monitoring of vehicle movements if the routes are validated against actual road conditions, station demands, and available vehicle capacities.

The reported differences in mean distances to the Lemna Road dumpsite also suggest that route planning should account for the spatial relationship between collection locations and the disposal facility. However, the actual operational implications should be determined from complete route distances rather than mean proximity alone. The agency could use a validated routing model to compare alternative vehicle assignments, identify routes that require additional trips, and evaluate whether changes in collection sequences reduce unnecessary travel.

From an environmental perspective, reducing avoidable vehicle movement could contribute to lower fuel consumption and associated

emissions. Such benefits should be quantified only after the change in travel distance or fuel consumption has been established. Likewise, improvements in waste evacuation and environmental sanitation would require evidence that the optimized routes can be implemented without compromising collection frequency, service coverage, or the handling capacity of the disposal facility.

The practical contribution of the study therefore lies in developing a structured basis for route planning and in identifying the information required for evidence-based evaluation. Once the route matrix is completed, the road distances are validated, and the capacity and baseline data are incorporated, the proposed model can provide a stronger decision-support framework for municipal waste collection in Calabar Metropolis.

3.8 Limitations of the Results

Several limitations affect the interpretation of the current routing results. First, the displayed route schedule covers 65 of the 70 identified collection stations, leaving nodes 29–33 unassigned. The eight routes must be revised or supplemented before complete coverage can be claimed.

Second, the reported mean distances to the dumpsite do not establish the total distances of the completed collection loops. The total route distances must be calculated from the distance matrix using the complete sequence of road movements, including the return to the disposal facility.

Third, the reported percentages for fuel saving, cost reduction, fleet wear, mileage, energy optimization, and operational savings cannot be independently verified from the information provided. These claims require baseline and optimized measurements, together with clear definitions of the performance indicators and their calculation methods.

Fourth, the capacity compliance of the routes depends on the availability of station-level waste demand and vehicle payload capacities. If these data were not incorporated into the



optimization, the proposed routes should not be described as empirically verified capacity-compliant solutions.

Finally, the reported route sequences must be checked against the actual road network to establish connectivity and feasibility. These limitations do not eliminate the value of the graph-theoretic approach, but they define the evidence required to substantiate the study's conclusions.

Overall, the results provide a preliminary route organization for the 70-station waste collection network in Calabar Metropolis. The reported geographical groupings and mean distances offer a basis for further analysis, but the effectiveness of the model must be established through complete station coverage, verified road-network distances, documented vehicle-capacity constraints, and quantitative comparison with an existing or otherwise justified baseline. These steps are necessary before the proposed routes can be presented as a validated improvement in municipal waste collection efficiency.

3.9 Statistical Analysis of the Optimized Waste Collection Routes

The statistical evaluation of the proposed waste collection routes was undertaken to examine the distribution of collection stations, variation in reported distances to the Lemna dumpsite, and the overall coverage achieved by the routing arrangement. The results are presented in Table 2. The statistical measures were calculated from the eight proposed routes and their reported mean distances to the dumpsite. These measures provide an initial assessment of route distribution and geographical variation, although they do not independently

establish the statistical significance of the optimization or quantify improvements over the existing collection system.

As shown in Table 2, eight collection routes were proposed for the 70 identified waste collection stations in Calabar Metropolis. However, the listed routes account for only 65 stations, corresponding to a coverage rate of 92.86%. The remaining five stations, represented by nodes 29–33, were not included in the proposed route assignments. This finding indicates that the current routing arrangement requires further refinement before it can be considered a complete network-wide solution. The unassigned stations should be incorporated into the relevant routes or assigned to additional collection loops, with the resulting routes checked for connectivity, vehicle capacity, and feasibility.

The mean number of stations assigned to each listed route was approximately 8.13, indicating that the routes were organized to serve between seven and ten stations each. Route 5, covering Marian, State Housing, and Ediba, contained the largest number of assigned stations (10), whereas Routes 1, 4, and 7 each contained seven stations. Although these figures suggest a reasonably distributed allocation of collection points, station count alone is insufficient to determine whether workloads are balanced. A route serving fewer stations may require more time or fuel if the stations are widely separated, traffic conditions are difficult, or waste quantities are higher. Consequently, a more complete assessment should incorporate waste generation at each station, vehicle capacity, travel time, and collection-service duration.

Table 2. Statistical summary of the proposed waste collection routes in Calabar Metropolis

Statistical parameter	Value
Total number of collection stations identified	70
Number of routes proposed	8
Total stations assigned to the listed routes	65
Station coverage (%)	92.86



Stations not accounted for in the listed routes	5
Mean number of stations per route	8.13
Sum of the eight reported route-level distance values (km)	29.19
Mean of the reported route-level distance values (km)	3.65
Median route-level distance value (km)	3.41
Minimum reported route-level distance value (km)	1.71
Maximum reported route-level distance value (km)	6.53
Range of reported route-level distance values (km)	4.82
Sample standard deviation (km)	1.51
Coefficient of variation (%)	41.37
Statistically significant reduction in distance	Not determined
Statistically significant reduction in fuel consumption	Not determined

The eight reported route-level distance values had a mean of 3.65 km and a median of 3.41 km. The relatively small difference between these two measures suggests that the central values are reasonably close, although the longer-distance routes increase the arithmetic mean. The minimum reported value was 1.71 km for Route 1, while the maximum was 6.53 km for Route 8. The resulting range of 4.82 km demonstrates substantial variation in the reported distance values across the proposed collection areas.

The sample standard deviation of approximately 1.51 km and coefficient of variation of 41.37% further indicate considerable variation relative to the mean. This variation may reflect differences in the geographical distribution of collection stations and their proximity to the Lemna dumpsite. Route 1 had the lowest reported distance value, suggesting a comparatively short distance measure for its assigned stations, whereas Route 8 had the highest value. Nevertheless, the distance values should not be interpreted as the complete distances travelled by the collection vehicles unless the underlying calculations include travel from the dumpsite to the first station, movement between successive stations, and return to the dumpsite. Therefore, the results indicate differences in the reported route-level distances but do not, on their own, establish which route is the most efficient in terms of total operating distance.

Comparison with previous data and studies. The results are consistent with the general rationale of graph-theory-based waste collection optimization, in which collection stations are represented as network nodes and travel distances are used as edge weights to organize feasible collection routes. Previous research, including Kinobe et al. (2015), demonstrated the relevance of route optimization to urban waste collection planning, while Toth and Vigo (2014) discussed the broader vehicle-routing problem and the importance of distance, capacity, and route feasibility in designing efficient distribution systems. In comparison with these studies, the present analysis applies a network-based approach to collection stations in Calabar Metropolis and identifies eight proposed collection routes linked to the Lemna dumpsite. However, a numerical comparison of performance improvements with previous studies cannot be established from the current results alone. Such a comparison would require equivalent measures, including total travel distance before and after optimization, fuel consumption, operating costs, number of vehicles, and vehicle-capacity utilization. The reported percentages of fuel savings, operational savings, and efficiency gains associated with individual routes should therefore remain provisional until their calculations and baseline data are documented. This distinction is important because a route's



distance distribution does not directly establish the percentage reduction achieved by an optimization algorithm.

The statistical findings also differ from an inferential evaluation of the routing model. The mean, median, range, standard deviation, and coefficient of variation describe the distribution of the eight reported distance values; they do not demonstrate that the proposed routes are statistically superior to existing routes. Establishing such superiority would require matched observations of the existing and optimized routes, from which route-specific distance differences could be calculated and evaluated using an appropriate statistical test. Similar paired comparisons could be conducted for fuel consumption and operating costs if observations were collected under comparable vehicle, traffic, and waste-load conditions.

Overall, Table 2 provides a quantitative summary of the proposed route configuration and reveals two important findings: substantial variation in the reported route-level distance values and incomplete assignment of the 70 identified collection stations. These findings support further refinement of the routing network. Before final implementation, the five unassigned stations should be incorporated, complete road-network route distances should be calculated, and the capacity constraints of the collection vehicles should be verified. A comparison against the existing collection arrangement would then provide the evidence required to quantify distance reductions, fuel savings, and operational improvements.

4.0 Conclusion

This study examined the application of graph theory to the optimization of municipal solid waste collection routes in Calabar Metropolis, Cross River State, Nigeria. By representing the waste collection stations and Lemna dumpsite as nodes in a weighted graph, the study established a network-based framework for organizing collection activities and identifying potential routes that could improve the

movement of waste collection vehicles. The proposed routing arrangement comprised eight collection routes serving stations across Calabar Municipality and Calabar South, with route allocation informed by the geographical distribution of the collection points and their reported distances to the dumpsite.

The statistical analysis revealed a mean reported route-level distance of 3.65 km, a median of 3.41 km, and a range of 1.71–6.53 km. The sample standard deviation of 1.51 km and coefficient of variation of 41.37% indicated considerable variation in the reported distance values among the proposed routes. These findings suggest that the collection network contains routes with different geographical characteristics and that route-specific planning is important for improving operational coordination. However, the analysis also revealed that the eight proposed routes accounted for only 65 of the 70 identified collection stations, representing 92.86% coverage. The five unassigned stations, corresponding to nodes 29–33, must therefore be incorporated before the routing arrangement can be considered complete.

The study demonstrates the potential usefulness of graph theory and vehicle-routing principles for supporting waste collection planning in Calabar Metropolis. Nevertheless, the available results do not independently establish statistically significant reductions in total travel distance, fuel consumption, or operating costs because verified baseline measurements and complete route-loop distances were not available for comparison. Accordingly, the reported operational savings should be validated through a systematic comparison of the existing and proposed collection systems.

It is recommended that future implementation incorporate all 70 collection stations, verify road-network distances, account for waste quantities and vehicle-capacity constraints, and evaluate travel time, fuel consumption, and operating costs under comparable operating



conditions. Further analysis using an appropriate vehicle routing algorithm, supported by complete network data and field validation, would strengthen the reliability and practical applicability of the proposed system. Overall, the study provides a foundation for developing a more systematic, evidence-based, and geographically responsive waste collection framework for Calabar Metropolis, with potential relevance to other rapidly urbanizing Nigerian cities facing similar municipal solid waste management challenges.

Acknowledgements

We are grateful to the Institution Based Research, IBR of the Tertiary Education Trust Fund (TETFund) at the University of Cross River State for providing funding for this study.

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Declaration

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors, based on the information supplied.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical Consideration

Not applicable

Author Contributions

The authors developed a graph-based framework to optimize municipal solid waste collection in Calabar Metropolis. By collecting GPS coordinates for 70 waste stations and representing the network as a weighted graph, they proposed eight optimized collection routes anchored at the Lemna dumpsite. This work established a systematic, data-driven approach achieved 92.86% spatial coverage for waste collection planning.



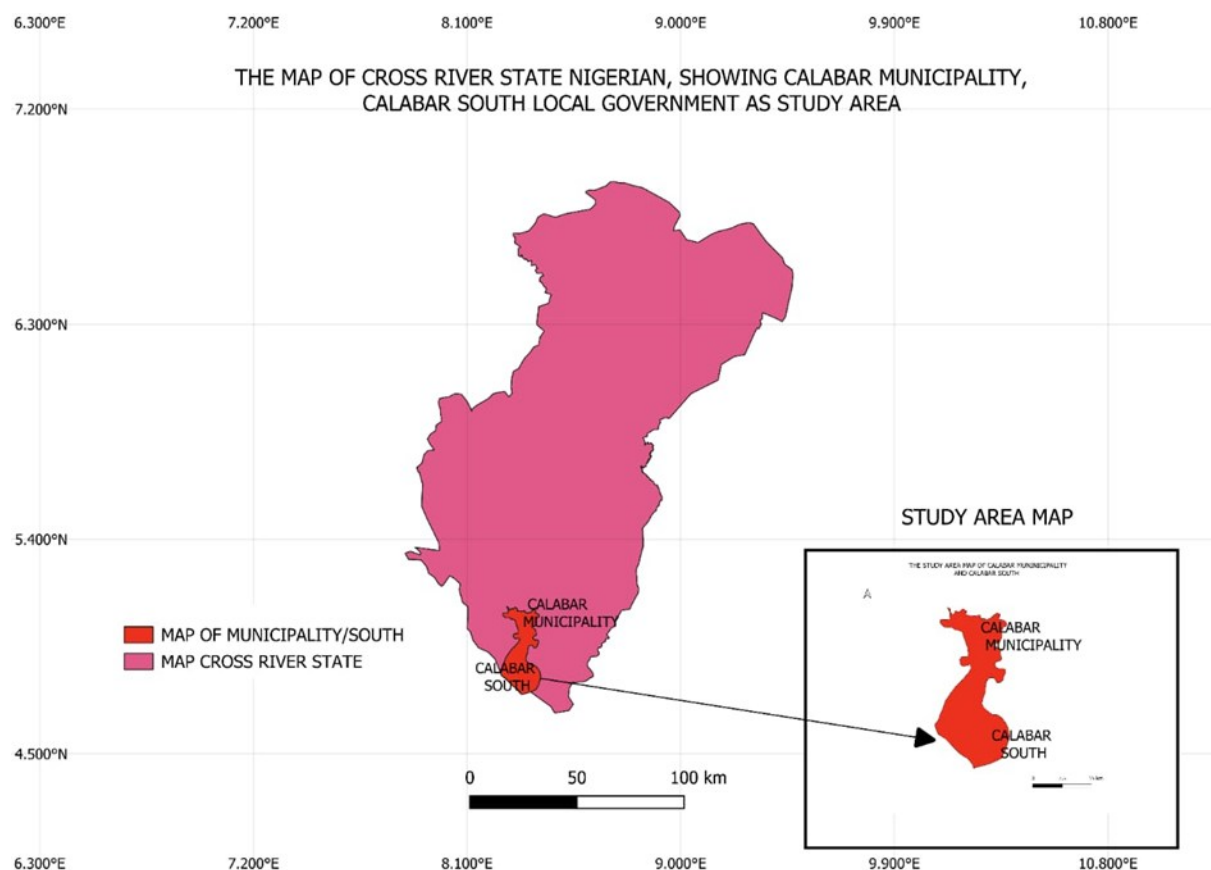
Appendix A: Geographic Coordinates and Dumpsite Proximities of Mapped Waste Stations

Node ID	Location Description/Axis	Longitude (°E)	Latitude (°N)	Distance to Lemna Dumpsite (m)
1	Atimbo by Orok Effim	8.357352	4.969894	692.64
2	Essien of Atimbo	8.354619	4.970325	969.60
3	Access Road off Atimbo	8.355861	4.973402	820.64
4	By Pass by DSS	8.351646	4.975524	1328.94
5	IBB Road by Airport	8.350866	4.971063	1369.14
6	Otuansa Lane beside Immigration	8.352294	4.968161	1284.91
7	IBB Road by Edimoto	8.349250	4.963101	1841.11
8	Babang Asana by Satellite Town	8.347981	4.960214	2141.70
9	Abang Asang by Etagbor	8.344381	4.961242	2408.70
10	IBB by Abang Asang	8.342179	4.962524	2560.29
11	Akim by Asitata	8.340620	4.961057	2786.06
12	Akim by Etagbor	8.341021	4.957629	2935.80
13	Etagbor by Tonimas Plaza	8.340499	4.956154	3075.36
14	Bateba by NTN	8.337897	4.951086	3645.74
15	Bateba by Marian Hill	8.332121	4.954517	3957.62
16	Mayne Avenue by Atu Field	8.331549	4.949478	4311.70
17	Uwanse Lane by Amikaitu	8.335177	4.947781	4112.24
18	Uwanse by Banner of Gods Grace Church	8.337808	4.941108	4439.71
19	Yellow Duke by Okoro Effim	8.330335	4.936804	5343.44
20	Epoabasi Junction	8.328131	4.931347	5956.09
21	Abitu Avenue off New Airport	8.317595	4.923439	7387.31
22	Mbukpa Market	8.316896	4.937486	6405.80
23	White House by Chamley	8.320335	4.952090	5242.65
24	Chamley by Victor Akan	8.322580	4.952925	4978.15
25	Bedwell by Nelson Mandela	8.321566	4.956832	4914.57
26	Mary Slessor Avenue by Zoo Garden	8.329168	4.957952	4084.57
27	Bypass by Garment Factory	8.360225	4.993796	2410.26
28	Bypass by Gospel City Church	8.367170	5.012456	4472.98
29	Akaifa by Orange Resort	8.357302	5.002966	3463.33
30	Akaifa by Assemblies of God	8.351975	4.999000	3212.39
31	Akaifa by Asariso Road	8.349668	4.996717	3096.46
32	Akaifa by Efute Junction	8.345585	4.993935	3094.39
33	Efute by MCC	8.344225	4.992161	3046.54
34	State Housing by Access Bank	8.343470	4.988922	2861.30
35	Marian by First Bank	8.343698	4.986163	2653.72
36	Marian by State Housing	8.342538	4.982661	2562.83
37	Marian by Atekong	8.341999	4.980779	2531.18
38	Atekong by Govt. Primary School	8.338391	4.980839	2908.04
39	State Housing by Internal Revenue	8.339291	4.982893	2899.01
40	State Housing by Jle Duke	8.335541	4.980438	3195.21
41	State Housing by Access Road	8.335700	4.983224	3279.88
42	Marian Market by Unity Bank	8.338856	4.975457	2718.96
43	Edeba by Workshop	8.336846	4.973709	2922.53
44	Edeba by Church of Christ	8.334521	4.972250	3175.57
45	Bikwo by Olkamp	8.333304	4.970955	3313.25
46	Olikamp by Ibom Layout	8.333307	4.968730	3332.24
47	Bikwo by Ndidem	8.335300	4.968732	3112.78
48	Marian by Olicamp	8.334452	4.968831	3204.82
49	Marian by Municipal	8.339393	4.970401	2642.80
50	Marian by Edeba	8.340382	4.974110	2534.64
51	Ediba Road by Biral Grand	8.341768	4.976817	2426.50
52	Edeba by St. Peters Catholic Church	8.344283	4.978303	2199.48
53	Asan Eso by The Bible Baptist Church	8.348779	4.983726	2041.75
54	Asan Eso by Efiete Roundabout	8.350297	4.990620	2486.89



55	Parliamentary by Ikot Eyo	8.345947	4.992778	2970.14
56	Parliamentary by NPA Branch	8.345186	4.995401	3248.70
57	Parliamentary by Ntufam Richard	8.345597	4.999006	3630.19
58	Parliamentary by Uddy King	8.345827	5.004492	4055.02
59	Parliamentary RCCG	8.347463	5.010410	4569.29
60	Parliamentary Axis	8.353950	5.017816	5145.85
61	Lemna by Northwest F.S.	8.359822	5.036529	7121.73
62	Lemna by Assemblies of God	8.363099	5.034325	6868.44
63	Ikot Efongha by Presbyterian	8.365130	5.033278	6756.17
64	Highway by NTA	8.355193	5.038370	7368.77
65	Highway by Fed. Housing	8.346184	5.034924	7185.54
66	Highway NDDC	8.340411	5.035054	7392.60
67	Highway by Zone 6	8.333827	5.015996	5833.09
68	Highway by INEC	8.334240	5.009664	5238.42
69	Highway by Ikotansa Bus Stop	8.334404	5.007303	5022.98
70	Ikot Ansa Area Bus Stop	8.338951	4.997475	3875.10

Appendix B: Map of Cross River State, Nigeria, Showing Calabar Municipality and Calabar South Local Governments, as Study Area



Appendix C: Map Showing Waste Points in Calabar Municipal and Calabar South Local Government Areas of Cross River State



