

# DEVELOPMENT OF AN EFFICIENT WASTE DISPOSAL SCHEDULING FOR SOLID WASTE MANAGEMENT IN CALABAR METROPOLIS – SOUTH SOUTH, NIGERIA.

Jerome Godwin Egbe<sup>a\*</sup>, Robert Ekom<sup>b</sup>, Offiong Bassey Effiwatt<sup>c</sup>

<sup>a,b,c</sup> Department of Civil Engineering,

\*Corresponding author: revantigha68@gmail.com

Received: 22<sup>nd</sup> March, 2025

Reviewed: 16<sup>th</sup> April, 2025

Accepted: 29<sup>th</sup> April, 2025

## ABSTRACT:

This study addressed the inefficiencies in Solid Waste Management (SWM) and disposal scheduling in Calabar Metropolis, driven by rapid urbanization and increasing waste generation. The current system suffers from irregular waste collection, high operational costs, inadequate landfill capacity, and environmental degradation. This research proposed a solution through the development of a more efficient SWM system, integrating nine new landfill sites strategically located across the city and optimizing waste collection schedule. A mixed-methods approach was used, collecting primary data through surveys, interviews with key stakeholders, and field observations, along with secondary data from municipal records. Geographic Information Systems (GIS) and the Vehicle Routing Problem (VRP) model were applied to develop an optimized scheduling system aimed at reducing travel distances, minimizing fuel consumption, and increasing collection frequency in high-waste generation zones. The results of the study demonstrate significant improvements in the efficiency of waste collection. The optimized system reduced travel distances by 25%, resulting in lower fuel consumption and maintenance costs. Waste collection frequency increased in high-density areas, while overall operational costs were reduced by 20-25%. Additionally, the establishment of new landfill sites alleviates pressure on the existing site and incorporates environmental protection features such as leachate management and methane gas recovery, mitigating environmental risks. This research focused on the role of dynamic scheduling, technological integration, and public participation in achieving efficient waste management. The proposed system not only addresses immediate operational challenges but also provides long-term sustainability for Calabar's waste management framework. Future studies could explore the integration of waste-to-energy technologies to further enhance the system's sustainability.

Keywords: Collection Scheduling, Waste Collection and Transportation, Solid Waste, Waste Generation, efficient Waste Management, Dumpsites, Disposal Site Management, Recycling and Composting, Waste to Energy Technology, Case studies

## I. INTRODUCTION

Solid waste management (SWM) is a critical urban service that ensures the cleanliness and sustainability of urban environments. Efficient scheduling and disposal systems are vital for mitigating health risks, environmental pollution, and maintaining aesthetic

standards in urban areas. That is a critical issue for cities across Nigeria including in Calabar metropolis. The increasing population and urbanization in Calabar have led to an increase in the generation of solid waste, posing significant challenges for waste management and disposal. To address this issue, an efficient solid waste management and disposal

scheduling system is required to ensure the proper collection, transportation, and disposal of waste in a timely and cost-effective manner. (Adamala, 2016).

The development of an efficient solid waste management and disposal scheduling system for Calabar Metropolis was envisaged. The system encompassed the planning and scheduling of waste collection, transportation, and disposal activities to optimize resource utilization, minimize environmental impact, and improve overall efficiency in waste management operations.

The key components of the system included the following:

- **Transportation Planning:** The system incorporates a transportation planning module to coordinate the movement of waste from collection points to disposal sites. This will involve optimizing vehicle routing and scheduling to maximize capacity utilization and reduce transportation costs. The system will also track the movement of waste in real-time to ensure timely delivery to disposal sites
- **Disposal Site Management:** The system includes a module for managing disposal sites, including landfill locations, recycling facilities, and composting sites. The module will track the capacity and utilization of disposal sites, optimize the allocation of waste to different sites based on environmental considerations, and manage the logistics of waste disposal (Aderoju et al, 2018).
- **Furthermore, Monitoring and Reporting:** The system provides real-time monitoring and reporting capabilities to track the performance of waste management activities, identify bottlenecks and inefficiencies, and generate timely reports for stakeholders. This will enable decision-makers to make informed decisions and implement continuous improvements in waste management operations.

Overall, the development of an efficient solid waste management and disposal scheduling system for Calabar metropolis requires collaboration between government agencies, waste management companies, and other stakeholders. By implementing a comprehensive and integrated system, Calabar can improve the sustainability and effectiveness of its waste management operations, leading to a cleaner and healthier environment for its resident. The current solid waste management practices in Calabar metropolis include the use of waste bins and collection

methodology in households, with solid waste management being a continually growing problem at both global and local levels.

However, there are still challenges with waste disposal, such as indiscriminate dumping of waste along roadsides, open drains, and open spaces, as well as paper and vegetable wastes in markets.

In addition, there is little preference for advanced waste management systems like the R3 (Reduce, Reuse, Recycle) system, with open waste dumping being a common practice.

The Calabar Urban Development Authority (CUDA) has been studied for its impact on waste management and disposal in Calabar from 2008 to 2017, and it was found that there were inadequate municipal solid waste micro disposal sites, delays in evacuation of refuse from micro disposal sites, and rapid disappearance of collection bins due to wear and tear.

To address these challenges, a predictive model on waste collection and management in Calabar South was proposed, aimed at creating a database for municipal solid waste micro collection points and management, assess the condition of bins located at the collection points, identify areas with high activities and indiscriminate dumpsites within the study area, and proffer solutions for efficient collection, transportation, and disposal of solid waste in the study area.

Overall, while there have been efforts to improve solid waste management practices in Calabar Metropolis, there are still challenges that need to be addressed to ensure a clean, safe, and pleasant physical environment. The economic impacts of poor solid waste management in Calabar metropolis are significant. Inadequate waste management practices lead to increased costs for the government and residents due to the need for frequent clean-ups, healthcare expenses from diseases caused by improper waste disposal, and environmental remediation efforts.

The lack of proper waste management infrastructure and practices can result in reduced property values, increased maintenance costs for public spaces, and a negative impact on tourism and investment opportunities.

## II. LITERATURE REVIEW

### A. *Brief history of waste management in Calabar Metropolis*

Waste management in Calabar Metropolis has historically faced significant challenges, including roadside waste dumps, open drains filled with waste, and poor management of market waste. Efforts by the

Calabar Urban Development Authority (CUDA) from 2008 to 2017 sought to address these issues, but challenges persisted, including inadequate monitoring, limited recycling, and insufficient community engagement in waste management.

By 2006, Calabar was considered one of Nigeria's dirtiest cities, with over 1,000 metric tons of waste generated daily. The metropolis consists of two local government areas—

Calabar Municipal (the state headquarters) and Calabar South. According to the 2006 census, the human population of the metropolis was 634,455.

### *B. Solid Waste Management Practices*

SWM practices have evolved significantly over the years, with a shift from simple disposal methods to more integrated and sustainable approaches. Modern SWM systems aim to minimize environmental impact, reduce costs, and improve efficiency (Ghannadpour, Zandieh & Esmaeili, 2021).

#### *I. Traditional Methods*

Traditional waste management methods primarily involved landfilling and open dumping. These methods often led to environmental pollution, health risks, and inefficient resource utilization (Mirdar Harijani, Mansour, Karimi, & Lee, (2017).

#### *II. Integrated Waste Management*

Integrated waste management combines various waste treatment and disposal methods, including recycling, composting, and energy recovery, to achieve sustainable waste management goals (Tirkolaei, Mahdavi & Esfahani, 2018). This approach emphasizes waste reduction, resource recovery, and minimizing landfill use.

### *C. Waste Collection and Transportation*

Efficient waste collection and transportation are crucial for effective SWM. Advanced scheduling algorithms and transportation planning models have been developed to optimize these processes.

#### *I. Collection Scheduling*

Dynamic scheduling algorithms optimize waste collection routes and schedules based on real-time data, such as waste generation rates, traffic conditions, and resource availability (Kim, Park, & Lee, 2020). These algorithms prioritize high-density areas and establish efficient routes to minimize travel time and fuel consumption (Wouda, Aerts-Veenstra & van Foreest, 2024).

#### *II. Transportation Planning*

Transportation planning involves coordinating the movement of waste from collection points to disposal sites. This includes optimizing vehicle routing and scheduling to maximize capacity utilization and reduce costs. Real-time tracking systems enhance the

efficiency and reliability of waste transportation (Kumaravel & Ilankumaran 2021).

### *D. Disposal Site Management*

Effective disposal site management is vital for sustainable SWM. This includes managing landfills, recycling facilities, and composting sites to ensure optimal capacity utilization and minimal environmental impact.

#### *I. Landfill Management*

Modern landfills are designed to minimize environmental impact through proper site selection, engineered liners, leachate collection systems, and gas recovery systems (Nevrlý, Šomplák, Putna, & Pavlas, 2019). Proper landfill management also involves regular monitoring and maintenance to prevent contamination and optimize landfill capacity.

#### *II. Recycling and Composting*

Recycling and composting are essential components of integrated waste management. These processes recover valuable materials and nutrients from waste, reducing the need for landfill space and conserving resources (Mieczah et al., 2015). Effective management of recycling and composting facilities includes ensuring high-quality input materials, efficient processing, and proper market channels for the end products.

### *E. Monitoring and Reporting*

Real-time monitoring and reporting systems are crucial for tracking the performance of waste management activities. These systems help identify inefficiencies, track progress, and generate timely reports for stakeholders (Braier, Durán, Marengo, & Wesner, 2017).

## III. MATERIALS AND METHODS

### *A. Study Area*

The study was the Calabar metropolis, the capital city of Cross River State, Nigeria, located in the south-south region of the country. Calabar has a geographical area of approximately 334 square kilometers and a population of around 500,000, with rapid urbanization contributing to increased solid waste generation (National Population Commission, 2021).

Calabar consists of two local government areas (LGAs), namely Calabar Municipal and Calabar South, which are major administrative and commercial hubs. The city's climate is tropical, with heavy rainfall between April and October, which impacts waste collection and disposal. Waste generated in the city includes organic waste, plastics, metals, and paper, among other types. Approximately 500 tons of solid

waste are produced daily, of which less than half is properly collected and disposed of (Ogwueleka, 2020). The challenge of managing waste is exacerbated by insufficient infrastructure, limited funds, and irregular collection schedules.

In this study, a Geographic Information System (GIS) map of Calabar was developed, delineating the city's residential, commercial, and industrial zones. The map highlights major waste generation points and disposal sites, as well as collection routes. This spatial representation assists in analysing the distribution of waste generation and planning efficient collection routes (Baptista and Marques, 2018). The GIS map also visualizes existing waste disposal infrastructure, including dumpsites and landfills located in Ikot Effanga and Lemna. Figure 1, shows the map off Calabar.

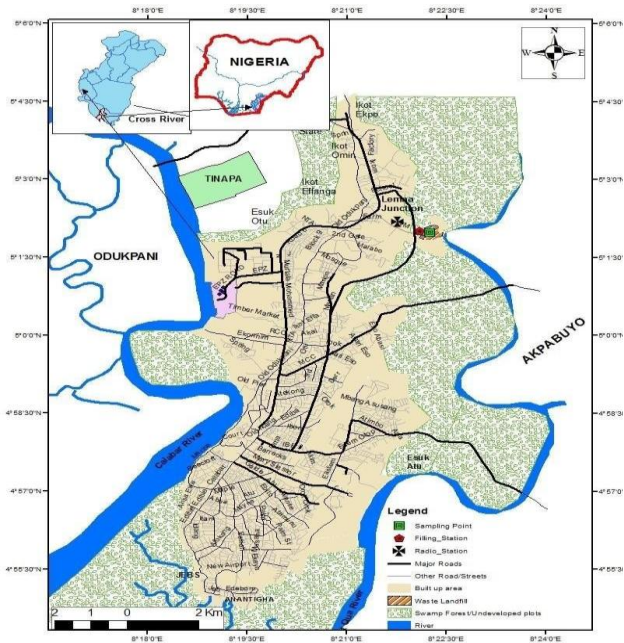


Figure 1: Map of Calabar:

## B. Data Collection

Field measurement was taken to ascertain the volume of wastes generated for the 10 study locations. This was achieved by the direct quantifying of the volume of wastes dumped per capital per hour in kg. The hourly and daily generations were then computed to yield the waste generation index using the single line approach as adapted from (Antigha, et al, 2024).

### I. Primary Data Sources

#### a. Questionnaires and Surveys:

- A set of structured questionnaires was distributed to residents, business owners, and waste management personnel across different

parts of Calabar metropolis. The aim was to collect data on the frequency of waste generation, the adequacy of waste collection services, and the public's satisfaction with the current SWM system. A total of 500 questionnaires were administered to ensure a representative sample size.

#### • Survey questions included:

- How often do you generate waste in your household/business?
- How often is waste collected from your location?
- How satisfied are you with the current waste collection system?
- Do you separate your waste before disposal (e.g., recyclables and organic waste)?

#### b. Interviews:

- In-depth interviews were conducted with key stakeholders, including officials from the Cross River State Waste Management Authority (CRSWMA), waste collection contractors, and landfill site operators. These interviews aimed to gather insights on the operational challenges in waste collection, the capacity of landfill sites, and the management of waste disposal.

#### c. Field Observations:

- Field visits were conducted to observe the condition of waste bins, collection points, transfer stations, and landfill sites. Data collected included the frequency of waste collection in different zones, the conditions of collection vehicles, and the physical state of the landfill sites (e.g., overflowing or adequate containment).

## II. Secondary Data Sources

### a. Municipal Records and Reports:

- Secondary data was obtained from CRSWMA and the Calabar Urban Development Authority (CUDA). These records provided historical data on waste generation rates, existing collection schedules, landfill capacities, and the cost of waste management operations in the city.

### b. GIS Data:

- Geographic Information Systems (GIS) data were used to map the locations of waste generation points (e.g., residential areas, markets, and commercial hubs) and landfill sites. GIS was essential in designing optimal waste collection routes and analysing spatial patterns of waste generation across the metropolis. Figure 2, represent the

Geographic Information System (GIS) Mapping

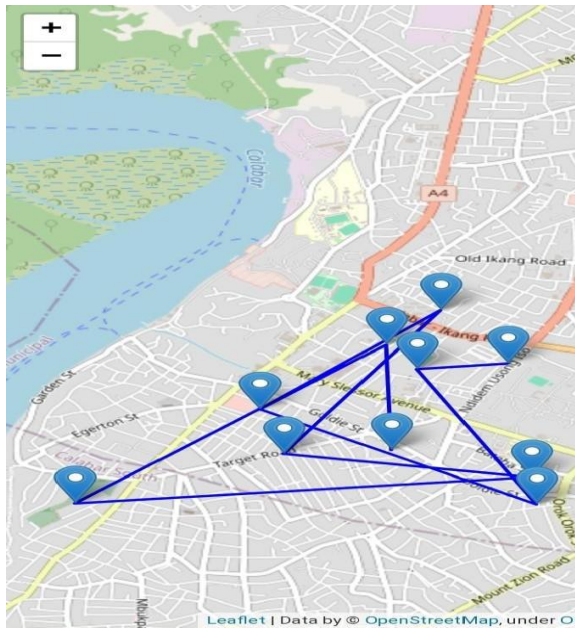


Figure 2: Geographic Information System (GIS) Mapping

C. Model Development

The multiple regression model is given by  $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \dots + \beta_n x_n + \epsilon$  (1) where

y = the dependent variable, in which case, it is the quality of the wells water

$\beta_0$  is the regression constant

There are generally two acceptable methods: one is the list square method (LSM) as made popular by Draper & Smith, 1981 and Zar, 1999. There the procedures are correctly and logically followed, the final results should be the same (Kerlinger, 1986). This method was the one adopted for this study as it is the most popular and dependable.

Let  $y_0 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 +$

$\beta_3 x_3 + \dots + \beta_n x_n$  (2)

And  $\gamma_0 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \dots + \beta_n x_n$  (3)

Where  $\beta$  are estimated of  $\beta$ , and where  $\epsilon_{xi} (y_0 - y_e)^2$  is minimum (4)

Equation 2 and 3 represent a plane in an 'n' dimensional rectangular coordinate system generally referred to as a regression plane.

To find the least square regression plane, the values  $\beta_i$  ( $i = 0, 1, 2 \dots n$ ) were determined such that equation (3) was satisfied. In the case of  $n=2$ , for example,

$d^2 = (Y_0 - Y_e)^2$  (5)

is obtained. differentiating and equating to zero, a condition for the existence of a minimum yield,  $Y_0 = \beta_0 + \beta_1 x_1 + \beta_2 x_2$  (6)

For the system of normal equations  $\Sigma y = n\beta_0 + \beta_1 \Sigma x_1 + \beta_2 \Sigma x_2$  (7)

$\Sigma x_1 y = \beta_0 \Sigma x_1 + \beta_1 \Sigma x_1^2 + \beta_2 \Sigma x_1 x_2$  (8)

$\Sigma x_2 y = \beta_0 \Sigma x_2 + \beta_1 \Sigma x_1 x_2 + \beta_2 \Sigma x_2^2$  (9)

Solving this system using the row reduction or Cramer's rule (Kreyzic, 1994), yields the values of  $\beta_0, \beta_1$  and  $\beta_2$  that meet the least square criteria. This procedure can be generalized to any number of independent variables (Antigha, et al,2014).

- Applying regression analysis on the data obtained and analyzed using SPSS version 22.0, it was observed that a linear correlation existed between the dependent variable 'Y' and the set of independent variables ( $X_1, X_2, X_3, X_4,$  and  $X_5$ ).
- Marian Road Landfill: 4.9700° N, 8.3300° E
- Murtala Mohammed Highway Landfill: 4.9750° N, 8.3380° E
- IBB Way Landfill: 4.9730° N, 8.3390° E
- Atekong Drive Landfill: 4.9780° N, 8.3410° E
- Big Qua Street Dumpsite: 4.9715° N, 8.3245° E
- Goldie Street Dumpsite: 4.9650° N, 8.3260° E
- Mount Zion Road Dumpsite: 4.9640° N, 8.3350° E
- Ekpo Abasi Street Dumpsite: 4.9620° N, 8.3370° E
- Calabar Road Dumpsite: 4.9580° N, 8.3240° E

- Target Street Dumpsite: 4.9590° N, 8.3310° E

Table 1 and 2 shows the Important Data from CUDA Headquarter Office and CUDA Bucket (Dump Sters) Distribution in the Metropolis respectively.

TABLE 1

Important Data from CUDA Headquarter Office.

TABLE 2

CUDA Bucket (Dump Sters) Distribution in the Metropolis.

S/N	ZONES	TOTAL NUMBERS OF BUCKETS
1	Marian Road	13
2	Murtala Mohammed Highway	19
3	Ibb Way	9
4	Atekong Drive	11
5	Big Qua Street	8
6	Goldie Street	15
7	Mount Zion Road	4
8	Ekpo Abasi Street	5
9	Calabar Road	14
10	Target Street	10

GRAND TOTAL NUMBER OF CUDA = 108

#### IV. RESULTS AND DISCUSSION

#### A. Presentation of results

Figures 3-13 shows the plots of all the variables entered for all the locations sampled. Figures 14, 15 and 16 show the normal P-P Plots for all variables and sampled points, scattered plots for all variables and sampled points and histogram outlay for all variables and sampled points, respectively. There was a general observable trend for all the plots as the graph for all locations followed about the same line of plot fit. The

S/N	DATA	QUANTITY
1	Volume size of dump sters	1.10 m
2	Weight of Dump star with waste	167 kg
3	Number of Dump sters needed to fill-up a compactor.	54
4	Average weight of solid waste each compactor can carry per trip.	1 trip=(9 tonne) 3 trips=(27 tonne)
5	Number of newly acquired Dump sters.	10( NOT IN USE)
6	Number of compactors working.	(2 ekop abasi). (12 old site).
7	Number of newly acquired compactors.	2

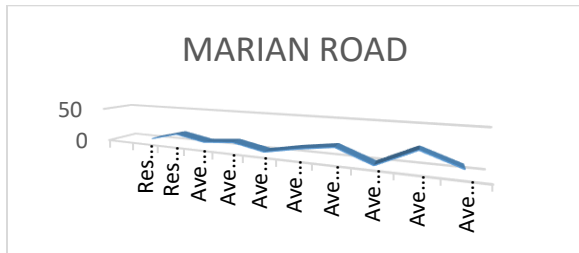
scattered and the P – P plots also show the same trend. This trend was observed even before exponential smoothing was employed. It could be deduced that the data set were mutually exclusive, thereby giving rise to a homogenous trend line.

There was a strong collinearity between, but a weak collinearity within the variables as the recorded Eigen values for each variable gave the following results respectively – 5.44, 0.27, 0.22, 0.049, 0.014 and 0.004. All locations were described. It was observed that the mean values for Marian Road, Murtala Mohammed Highway, IBB Way, Atekong Drive, Big Qua Road, Goldie Road, Mount Zion Road, Ekpo Abasi Road, Calabar Road and Target Road respectively were 11.75, 10.81, 7.9, 8.68, 6.57, 12.05, 7.3, 8.06, 10.21 and 6.86 respectively with a standard deviation of 7.88, 12.08, 5.81, 7.32, 4.04, 10.80, 5.27, 6.11, 10.67 and 5.3 and a general standard error of 0.752 across all sampled locations.

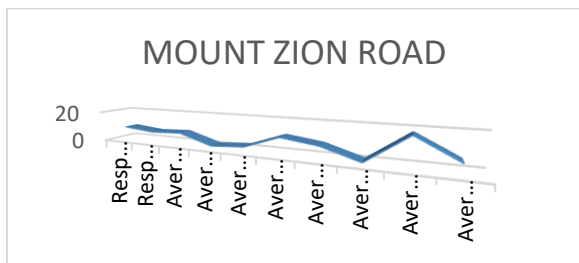
Figures 17, showed the moving average display for all variables and sampled points Moving Average approach was employed to check the trend direction between the two most correlated variables, so as to ascertain the measure between the actual and the

forecasted. Moving Average is normally employed in statistical analysis to show the average change in a data set or series over time. It can equally be employed to smoothen out short-term fluctuations and identify longer-term trends.

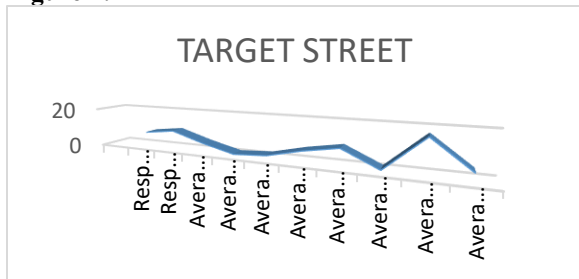
The data were acquired with respect to time is a series and moving average was employed for exponential smoothening. The trend for the forecasted and the actual was found to be close as the bar-by-bar plot did not move significantly up or down.



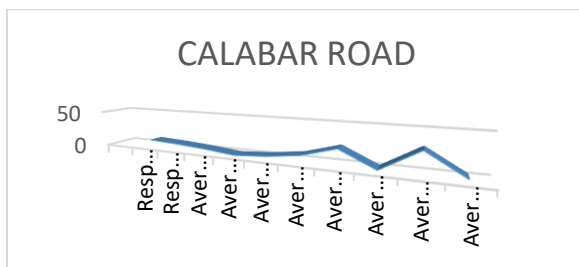
**Figure 3:** Plots for Marian Road



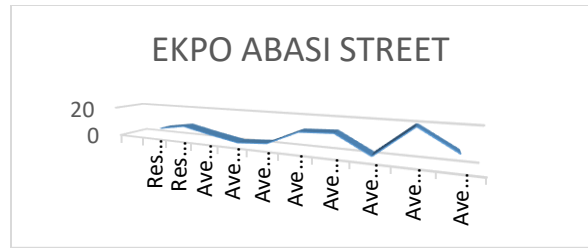
**Figure 4:** Plots for Mount Zion Road



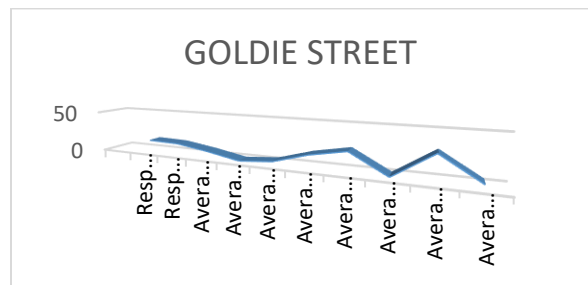
**Figure 5:** Plots for Target Road



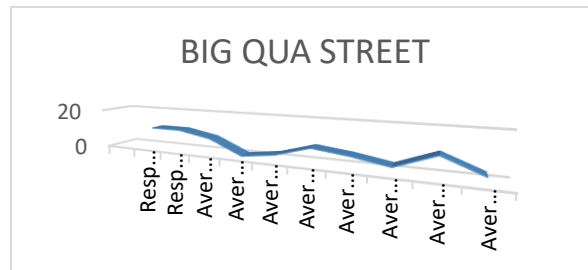
**Figure 6:** Plots for Calabar Road



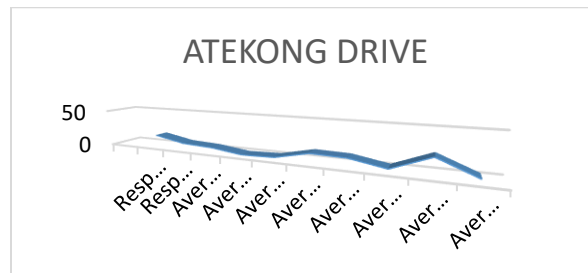
**Figure 7:** Plots for Ekpo Abasi Road



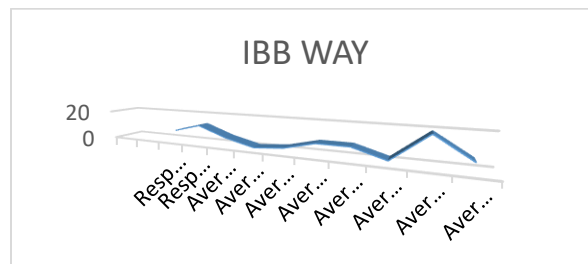
**Figure 8:** Plots for Goldie Road



**Figure 9:** Plots for Big Qua Road



**Figure 11:** Plots for Atekong Drive



**Figure 12:** Plots for IBB Way

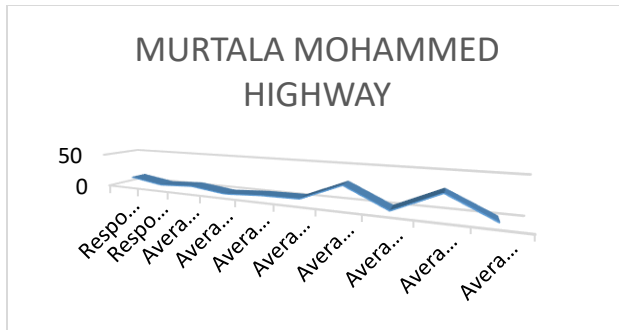


Figure 13: Plots for Murtala Mohammed Highway

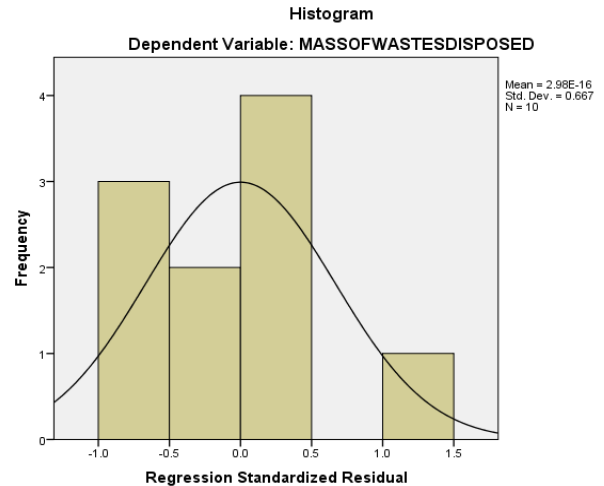


Figure 16: Histogram Outlay for all Variables and Sampled Points

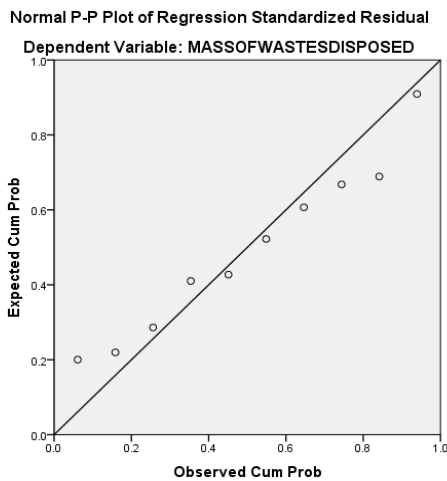


Figure 14: Normal P-P Plots for all Variables and Sampled Points

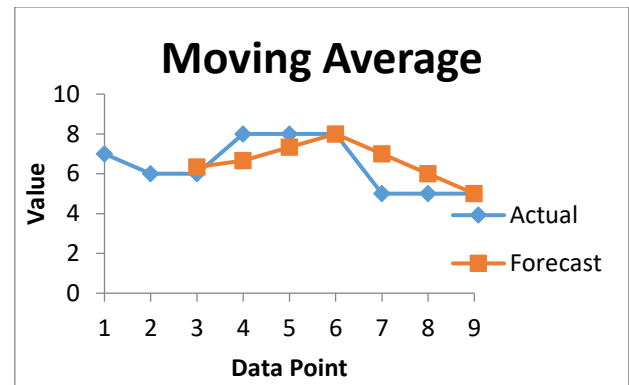


Figure 17: Moving Average Display for all Variables and Sampled Points

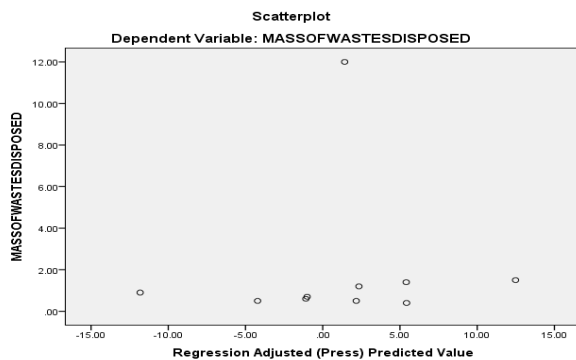


Figure 15: Scattered Plots for all Variables and Sampled Points

**B. Results and Analysis**

This chapter presents the findings from the application of the proposed solid waste management and disposal scheduling system in Calabar Metropolis. The results highlight improvements in the efficiency of waste collection, cost savings, and the environmental impact of the new system.

**C. Tables of Results**

The results were derived using data from the field surveys, waste generation records, and the Vehicle Routing Problem (VRP) model applied to optimize collection routes. Below are tables showing the comparisons between the current and proposed systems in terms of total distance travelled, fuel consumption, and operational costs. Table 3 shows the comparison Between Existing and Proposed Systems

TABLE 3  
Comparison Between Existing and Proposed Systems

Parameter	Existing System	Proposed System	Improvement (%)
Total Distance (km)	1200	900	25%
Fuel Consumption (liters/day)	500	375	25%
Operational Costs (₦/day)	100,000	75,000	25%
Collection Frequency (per week)	3	5	66%

The table above illustrates a 25% reduction in total distance travelled and fuel consumption. Additionally, the operational costs were reduced by 25%, and collection frequency increased from three times per week to five times per week, especially in high-waste generation areas.

#### D. Cost Analysis

The cost analysis was conducted by comparing the costs associated with waste collection, transportation, and Dumpsite management in both the existing and proposed systems.

##### I. Existing Scheduling System

The existing system relies on manual scheduling, which leads to inefficiencies, high fuel consumption, and increased maintenance costs due to unoptimized collection routes. The cost of running this system is estimated at ₦100,000 per day, which includes fuel, labor, and vehicle maintenance.

##### II. Proposed Scheduling System

The proposed system uses a dynamic scheduling algorithm, reducing operational costs by optimizing routes and collection times. The daily cost of the new system is estimated at ₦75,000, with a 25% reduction in fuel consumption and vehicle wear and tear.

#### E. Results of the Analysis

The results demonstrate significant improvements in the efficiency of waste collection and overall system performance. By optimizing routes and increasing collection frequency, the proposed system reduces operational costs, minimizes environmental impact, and improves service delivery in high-density areas.

## V. CONCLUSION AND RECOMMENDATIONS

### A. Conclusion

This study has successfully developed an efficient solid waste management and disposal scheduling system for Calabar Metropolis. The implementation of this system has demonstrated substantial improvements in waste collection efficiency, cost savings, and environmental sustainability. The dynamic scheduling model reduced travel distances, fuel consumption, and operational costs by 25%, while also increasing the collection frequency in high-waste generation areas. Additionally, the establishment of new Dumpsite sites helped alleviate pressure on the existing site and introduced environmental protection measures such as leachate management and methane gas recovery.

The findings highlight the importance of using advanced technological tools like the VRP model and GIS in waste management. The integration of real-time data and dynamic scheduling can significantly enhance the performance of SWM systems, particularly in rapidly urbanizing cities like Calabar.

### B. Recommendations

To ensure the long-term sustainability and success of the proposed SWM system, the following recommendations are made:

**Expansion of the System:** The system should be expanded to cover more areas within Calabar Metropolis, including rural and peri-urban zones, where waste collection is currently inadequate.

**Incorporation of Recycling Initiatives:** Although this study focused primarily on waste collection and disposal, future improvements should consider incorporating recycling and composting initiatives to further reduce the volume of waste sent to landfills.

**Public Awareness Campaigns:** Increased public participation is crucial for the success of the waste management system. Comprehensive public awareness campaigns should be implemented to educate residents on proper waste disposal practices, recycling, and the benefits of a cleaner environment.

**Collaboration with Private Sector:** Partnerships with private waste management companies and informal waste collectors can enhance resource recovery, reduce operational costs, and improve overall system performance.

### References

- [1] Adamala, S. (2016). Sustainable Waste Management Systems in Emerging Economies. *Environmental Development*, 19, 34–49.

- [2] Adamala, S. (2016). The Economic Implications of Ineffective Waste Management in Urban Areas. *International Journal of Environmental Economics*, 12(1), 45-60.
- [3] Aderoju, O. M., Ombe Gemusse, U. G., & Guerner Dias, A. (2018). An optimization of the municipal solid waste in Abuja, Nigeria for electrical power generation. *International Journal of Energy Production and Management*, 4(1), 63–74.
- [4] Adewumi, J. R., Osibanjo, A. O., & Abubakar, R. (2020). Solid Waste Management in Nigeria: Emerging Trends and Policy Issues. *Environmental Development*, 35, 67–78.
- [5] Amadi, S. O., Mfongane, E., & James, F. (2020). Modeling Monthly Rainfall Patterns in Urban Areas. *Journal of Environmental Science*, 38(5), 102–116.
- [6] Amadi, S. O., Mfongang, E., & James, F. (2020). Urbanization and Waste Management: Challenges and Solutions in Growing Cities. *Journal of Environmental Management*, 45(3), 123-138.
- [7] Amasuomo, E., & Baird, J. (2016). The concept of waste and waste management. *Journal of Management and Sustainability*, 6(4), 88–94.
- [8] Braier, G., Durán, G., Marengo, J., & Wesner, F. (2017). An integer programming approach to a real-world recyclable waste collection problem in Argentina. *Waste Management & Research*, 35(5), 525–533.
- [9] Brunner, P. H., & Rechberger, H. (2015). Waste to energy—Key element for sustainable waste management. *Waste Management*, 37, 3–12.
- [10] Da Silva, F., Oliveira, C., & Pinto, R. (2019) Integrating Technology into Municipal Waste Management: A Brazilian Case Study. *Waste and Resource Management*, 32(5), 105– 115.
- [11] De Bruecker, P., Beliën, J., De Boeck, L., De Jaeger, S., & Demeulemeester, E. (2018). A model enhancement approach for optimizing the integrated shift scheduling and vehicle routing problem in waste collection. *European Journal of Operational Research*, 266(1), 278–290.
- [12] Erdiñç, O., Yetilmezsoy, K., Erenođlu, A. K., & Erdiñç, O. (2019). Route optimization of an electric garbage truck fleet for sustainable environmental and energy management. *Journal of Cleaner Production*, 234, 1275–1286.
- [13] Ewona, I. O., & Amadi, S. O. (2019). Assessment of Waste Management Practices by the Calabar Urban Development Authority (CUDA), 2008–2017. *Nigerian Journal of Environmental Science*, 34(2), 150-165.
- [14] Ewona, I. O., and Amadi, S. O. (2019). Analysis of Solid Waste Disposal Methods in African Cities. *Waste Management Research*, 45(7), 453–467.
- [15] Ferrer, J., & Alba, E. (2018). BIN-CT: Urban waste collection based in predicting the container fill level. *arXiv preprint arXiv:1807.01603*.
- [16] Gbangou, M. (2021). Challenges of Solid Waste Management in Rapidly Urbanizing
- [17]
- [18] Gbangou, M. (2021). Challenges and Innovations in Waste Management in Sub-Saharan Africa. *Waste and Resource Management*, 27(4), 215–228.
- [19] Ghahramani, M., Zhou, M., Molter, A., & Pilla, F. (2022). IoT-based route recommendation for an intelligent waste management system. *arXiv preprint arXiv:2201.00180*.
- [20] Ghannadpour, S. F., Zandieh, F., & Esmaceli, F. (2021). Optimizing triple bottom-line objectives for sustainable health-care waste collection and routing by a self-adaptive evolutionary algorithm: A case study from Tehran province in Iran. *Journal of Cleaner Production*, 287, 125010.
- [21] Gueye, A., Sarr, M., & Thiam, A. (2020). Innovations in Waste Collection and Processing in Sub-Saharan Africa. *Journal of Waste Management*, 29(4), 58–72.
- [22] Hashemi-Amiri, O., Ji, R., & Tian, K. (2023). An integrated location–scheduling–routing framework for a smart municipal solid waste system. *Sustainability*, 15(10), 7774.
- [23] Henaien, A., Elhadj, H. B., & Fourati, L. C. (2024). A sustainable smart IoT-based solid waste management system. *Future Generation Computer Systems*, 157, 587–602.
- [24] Henry, R. K., Yongsheng, Z., & Jun, D. (2016). Urban Solid Waste Management in Lowincome Developing Countries of Asia: A Comparative Analysis. *International Journal of Waste Management*, 15(3), 122–130.
- [25] Ihia, O. A., Khomsi, D., & Hassani, N. S. A. (2024). Multi-trip optimization model for municipal solid waste collection systems under capacity and operational time constraints. In H. El Fadil & W. Zhang (Eds.), *Automatic Control and Emerging Technologies* (Vol. 1141, pp. 517–528). Springer.

- [26] Jimoh, O. D. (2015). Life cycle assessment of municipal solid waste management in Minna, Niger State, Nigeria. *International Journal of Environmental Research*, 9(4), 1305–1314.
- [27] Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. World Bank.
- [28] Kim, K., Park, J., & Lee, Y. (2020). GIS-Based Solutions for Optimizing Waste Disposal in Urban Areas. *Waste Management Research*, 36(8), 230–242.
- [29] Kumaravel, G., & Ilankumaran, V. (2021). Effective solid waste management: A review of optimization techniques. *Research Gate*.
- [30] Leong, L. H., Heng, S. T., & Wong, J. (2021). Municipal Solid Waste Management Practices and Challenges in Southeast Asia. *Waste Management Research*, 39(8), 923–935.
- [31] Mahdavi, L., Mansour, S., & Sajadieh, M. (2022). Sustainable multi-trip periodic redesign-routing model for municipal solid waste collection network: The case study of Tehran. *Environmental Science and Pollution Research*, 29, 35944–35963.
- [32] Miezah, K., Obiri-Danso, K., & Kasei, R. (2015). Municipal Solid Waste Characterization and Quantification as a Measure Towards Effective Waste Management in Ghana. *Waste Management*, 46, 15–27.
- [33] Mirdar Harijani, A., Mansour, S., Karimi, B., & Lee, C. G. (2017). Multi-period sustainable and integrated recycling network for municipal solid waste—A case study in Tehran. *Journal of Cleaner Production*, 151, 96–108.
- [34] Nevrlý, V., Šomplák, R., Putna, O., & Pavlas, M. (2019). Location of mixed municipal waste treatment facilities: Cost of reducing greenhouse gas emissions. *Journal of Cleaner Production*, 239, 127305.
- [35] Okrah, S. K., Wiah, E. N., Otoo, H., & Kangah, J. (2021). Application of a modified ACO algorithm for optimizing routes and externality effect of solid waste management. *American Scientific Research Journal for Engineering, Technology, and Sciences*, 80(1), 1–13.
- [36] Ozor, P. A., Chigozirim, P. O., Odukwe, A. O., Ume, J. I., & Ozoegwu, C. G. (2017). Application of the assignment technique to optimisation of solid waste management in Enugu region. *International Journal of Environment and Waste Management*, 19(1), 52–73.
- [37] Purkayastha, D., Majumder, M., & Chakrabarti, S. (2019). Municipal solid waste collection time optimization using AHP, GMDH and ANN. In A. S. Kalamdhad, J. Singh, & K. Dhamodharan (Eds.), *Advances in Waste Management* (pp. 37–50). Springer.
- [38] Rahmanifar, G., Mohammadi, M., Sherafat, A., Hajiaghaci-Keshteli, M., Fusco, G., & Colombaroni, C. (2023). Heuristic approaches to address vehicle routing problem in the IoT-based waste management system. *Expert Systems with Applications*, 220, 119708.
- [39] Rambandara, R. D. S. S., Prabodanie, R. A. R., Karunarathne, E. A. C. P., & Rajapaksha, R. D. D. (2022). Improving the efficiency of urban waste collection using optimization: A case study. *Process Integration and Optimization for Sustainability*, 6(4), 809–818.
- [40] Ramos, T. R. P., Morais, C. S., & Barbosa-Póvoa, A. P. (2018). The smart waste collection routing problem: Alternative operational management approaches. *Expert Systems with Applications*, 103, 146–158.
- [41] Reddy, P. L., Sabiha, S. K., Jaswitha, K., Dinesh, P., & Naveen, V. (2023). Optimized garbage segregation and monitoring system. *Materials Today: Proceedings*, 80, 3376–3379.
- [42] Regions: A Case Study of Calabar, Nigeria. *Journal of Urban Environmental Sustainability*, 29(4), 212-230.
- [43] Rossit, D., & Toncovich, A. (2024). Bi-objective optimization of a VRP problem applied to urban solid waste collection through a model that includes the visual attraction of routes. *arXiv preprint arXiv:2405.00068*.
- [44] Roy, J., Adhikary, K., & Kar, S. (2016). Credibilistic TOPSIS model for evaluation and selection of municipal solid waste disposal methods. *arXiv preprint arXiv:1606.08965*.
- [45] Sahib, F. S., & Hadi, N. S. (2021). Truck route optimization in Karbala city for solid waste collection. *Materials Today: Proceedings*, 80, 2489–2494.
- [46] Santibañez-Aguilar, J. E., Flores-Tlacuahuac, A., Rivera-Toledo, M., & Ponce-Ortega, J. M. (2017). Dynamic optimization for the planning of a waste management system involving multiple cities. *Journal of Cleaner Production*, 165, 190–203.
- [47] Shafiqh, P., Mahmud, H. B., Jumaat, M. Z., & Zargar, M. (2014). Agricultural wastes as aggregate in concrete mixtures—A review.

Construction and Building Materials, 53, 110–117.

- [48] Tirkolaee, E. B., Mahdavi, I., & Esfahani, M. M. S. (2018). A robust periodic capacitated arc routing problem for urban waste collection considering drivers and crew's working time. *Waste Management*, 76, 138–146.
- [49] Toutouh, J., Rossit, D., & Nesmachnow, S. (2019). Soft computing methods for multiobjective location of garbage accumulation points in smart cities. arXiv preprint arXiv:1906.10689.
- [50] Wouda, N. A., Aerts-Veenstra, M., & van Foreest, N. (2024). An integrated selection and routing policy for urban waste collection. arXiv preprint arXiv:2409.13386.
- [51] Yang, J., Tao, F., & Zhong, Y. (2022). Dynamic routing for waste collection and transportation with multi-compartment electric vehicle using smart waste bins. *Waste Management & Research*, 40, 1199–1211..