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Solid Waste Generation, Composition and Optimized Route System for Effective Management in University of Ibadan, Nigeria.

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Abstract

Municipal solid waste (MSW) management remains a significant global environmental issue, with far-reaching effects on sustainability, public health, and economic growth. Reliable data on MSW generation and composition are crucial for creating effective waste management systems. This study utilized field observations, surveys, and analytical methods to evaluate MSW generation, composition, and transportation within the University of Ibadan (UI). Findings indicate an average daily waste generation rate of 0.34 kg per person. The composition analysis shows that organic waste (37.9%) and polythene bags (30.7%) constitute the largest portions, followed by plastics (23.2%) and other materials (8.2%). The study offers important insights into the current MSW situation at UI and supports the development of improved strategies such as waste minimization, recycling, and composting. Route optimization analysis demonstrated a potential reduction of 24.5% in travel distance and 35.7% in travel time, thereby lowering operational costs, enhancing efficiency, and reducing environmental impact. Ultimately, this promotes a more sustainable waste management system within the university.

Keywords: Municipal solid waste (MSW), Waste generation, Waste composition, Route optimization, GIS, Waste management.

Introduction

Solid waste refers to the remnants of human activities, whether domestic, commercial, or industrial, that are discarded due to a perceived lack of value (Lilliana *et al.*, 2013; Enumah *et al.*, 2020). Historically, waste disposal posed minimal challenges due to abundant unused land. However, as urban populations and per capita waste production have risen, the availability of land for waste disposal has diminished proportionally.

In recent decades, waste generation and improper disposal practices have escalated sharply. Advances in science and technology have introduced new products and processes, resulting in increasingly complex and hazardous waste streams (Sangodoyin and Ipadeola, 2000). To minimize the environmental and health risks associated with solid waste, and to leverage opportunities for recycling and value recovery, it is essential to quantify waste generation rates (Lohri *et al.*, 2014).

Universities, in addition to households, are significant contributors to solid waste. These institutions accommodate large populations who frequently utilize facilities such as cafeterias, print and copy centers, health services, sports complexes, and janitorial support. Such diverse activities result in substantial waste production, with notable environmental repercussions (Alshuwaikhat and Abubakar, 2008; Adeniran *et al.*, 2017).

Enhancing the efficiency of waste collection can be achieved through the optimization of collection truck routes. This process involves determining the most effective paths between various collection points (Reinhardt *et al.*, 2011). Inadequate planning of these routes, often relying on intuition rather than systematic methodologies, has led to inefficient and costly practices in developing countries (Tavares *et al.*, 2009; Kanchanabhan *et al.*, 2011). These inefficiencies not only raise operational costs but also have adverse effects on public health and the environment (Apaydin *et al.*, 2004; Sanjeevi *et al.*, 2015).

Poorly designed routes can contribute to traffic congestion, increase greenhouse gas emissions, and hinder timely waste collection (Arribas *et al.,* 2010). Effective routing seeks to reduce time, costs, and distance while accommodating operational constraints (El-Hamouz, 2008; Arribas *et al.,* 2010). The objective of this research is to evaluate solid waste generation and composition within the University of Ibadan, and to develop an optimized collection system. Specific aims include: (i.) assessing current waste disposal practices and identifying inefficiencies; (ii.) analyzing the composition and volume of waste generated on the main campus; and (iii.) proposing optimized collection routes that minimize environmental impact and improve resource utilization.

Materials and Methods

Waste Disposal Practices and Management

To evaluate the waste disposal and management practices at the University of Ibadan, a structured questionnaire was developed using Google Forms. The survey targeted selected faculties and gathered information on respondents' demographics and knowledge regarding waste disposal practices. The collected data were analyzed using descriptive statistics, including frequency distributions and graphical summaries.

Assessment of Solid Waste Generation and Composition

The study concentrated on students residing in the University's halls of residence. A systematic sampling method was employed to select 50 students, 10 from each of five different halls. Each participant was provided with a waste collection bag and instructed to store all daily waste for a period of seven days. The collected waste was sorted, weighed, and analyzed daily to determine the generation rate. The method used to calculate the solid waste generation rate followed the model proposed by Tchobanoglous *et al.* (1993):

i. Total Weight (TW): Sum of all collected waste weights from individual participants.
ii. Average Weight (AW): Total weight divided by the number of participants.
iii. Net Total Weight (NTW): Product of the average weight and the total number of students in the University.

Route Optimization Process

Geographic Positioning System (GPS) tools were utilized to gather spatial data on all waste collection points within the University. Information about the existing waste collection routes was obtained from the Health, Safety, and Environmental unit of UI Ventures Limited, the body responsible for waste management on campus.

The GPS coordinates were imported into ESRI ArcGIS software to perform route optimization, focusing on reducing both travel distance and time. The optimized routes were compared with the current system to highlight potential improvements. Microsoft Excel (2010 version) was used to input geospatial data, while ArcGIS Pro, integrated with Google API and Searchlight, plotted optimized collection paths in real-time. The model accounted for relevant constraints such as pedestrian crossings, one-way routes and traffic lights.

Results and Discussion

Existing Waste Collection System at the University

Waste management at the University of Ibadan is overseen by the Health, Safety, and Environmental Unit of UI Ventures Limited. Collection activities cover various campus zones, including administrative blocks, residential halls, academic buildings, health facilities, religious centers and the Student Union Building.

However, no formal documentation exists on the amount or trends of waste generation across the University. Waste is collected manually using fixed concrete pits and strategically positioned containers. The transportation fleet includes three compactor trucks, one tipper and one capster, each operated by a team of one driver and three loaders. Despite this system, improper storage

remains prevalent (as shown in Plate 1), often complicating waste collection and posing environmental hazards.

Plate 1: Improper Storage of Waste in the University.

Waste Disposal Practices and Management

Out of all collected surveys, 140 responses were deemed valid for analysis, providing a reliable dataset for interpreting waste management patterns.

Respondent Demographics

The survey sample showed a slight male majority (57.9%), while 42.1% of respondents were female. Most participants (62.9%) were between the ages of 20 and 29, with another 33.5% under the age of 20. The Faculty of Technology contributed the most responses (30.7%), followed by Education (23.6%) and Arts (20.0%). By academic level, 500-level students formed the largest group (25.7%), followed by 100-level (24.3%) and 200-level (20.0%) students. This demographic reflects typical university population trends, particularly regarding age and program engagement.

Awareness and Perception of Waste Disposal

Respondents' awareness and perceptions around waste disposal revealed that 72.9% were familiar with the concept of sorting waste. A significant portion (84.3%) used waste bins for disposal. However, only 36.4% believed that recycling was the primary disposal method in the University, and 34.3% admitted to not knowing the methods in place. Importantly, 81.4% acknowledged the severe health and environmental consequences of solid waste. Commonly identified issues included polluted surroundings, toxic emissions, and clogged drainage systems.

The data suggest a strong baseline awareness among respondents regarding the use of waste bins and basic sorting, yet notable knowledge gaps remain regarding waste handling and disposal processes within the institution. These findings point to a pressing need for targeted education and communication strategies to improve student awareness and participation in sustainable waste practices.

Solid Waste Management Perception

Survey results, illustrated in Figure 1, show that 46.4% rated the frequency of waste collection as good, and 28.6% rated it fair. For recycling initiatives, 38.6% considered them satisfactory, while 32.1% marked them as average. However, 36% rated awareness campaigns poorly, indicating a weak information outreach system. In terms of waste types (Figure 2), plastic emerged as the most commonly generated (43.6%), followed by paper (28.6%) and food waste (26.4%). Suggestions for improvement (Figure 3) focused on multiple strategies: 42.9% supported a mix of increased pickups, better recycling infrastructure, stronger public awareness, and tighter regulations. Individually, 17.1% prioritized more frequent collections, while 16.4% preferred improved recycling.

Overall, these findings reveal mixed opinions on the University's current waste management system. While collection frequency and recycling show moderate approval, awareness efforts

appear to fall short. The results emphasize the need for a more holistic approach to waste handling, one that includes infrastructure improvements, increased engagement and policy enforcement.

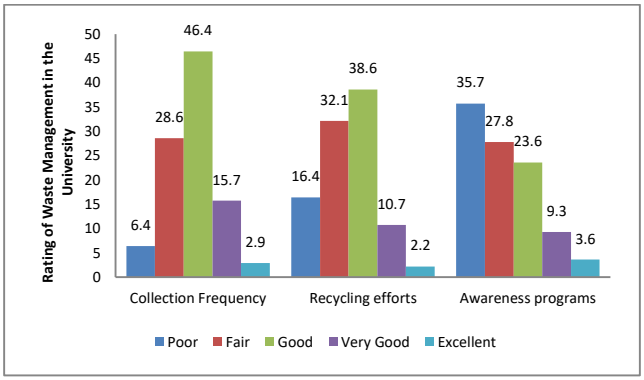


Figure 1: Respondent Rating of Waste Management in the University

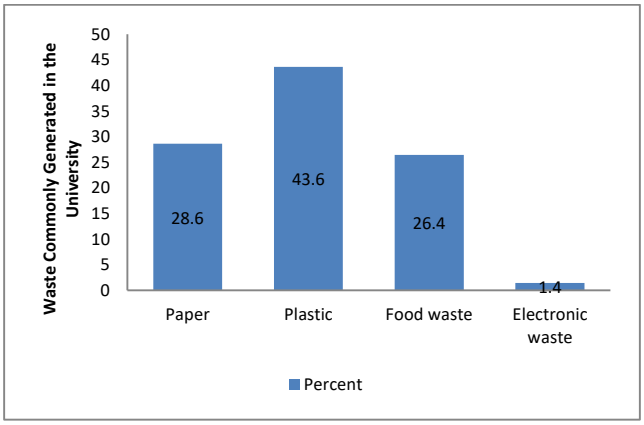


Figure 2: Composition of Waste Commonly Generated in the University

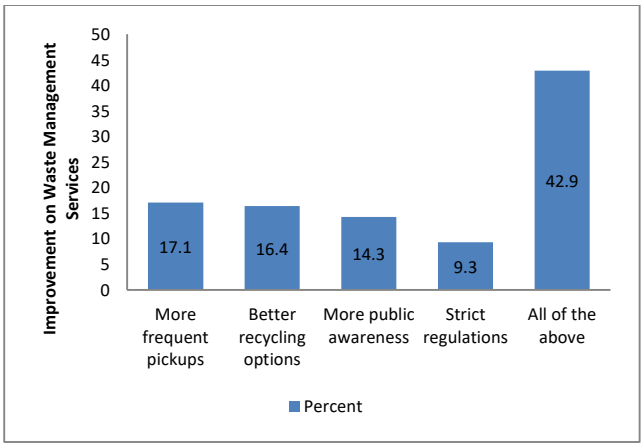


Figure 3: Respondent Opinion on Improvement on Waste Management Services within UI

Proposed Solutions

A vast majority of respondents (84%) supported a comprehensive strategy involving government policies, NGO-driven awareness campaigns, and individual responsibility. Moreover, 43% believed individual actions alone could make a significant impact.

These responses reinforce the importance of collective responsibility, suggesting that combining institutional frameworks with personal commitment is the most effective way to address waste management challenges.

Assessment of Solid Waste Generation and Nature of Waste

This component of the study focused on waste generated by students living in campus residence halls. A representative group of 50 students, comprising both male and female residents, was selected using a systematic sampling method to ensure objectivity and reflect the broader student population. Waste collected over seven consecutive days was sorted and weighed daily. Plate 2 captures the sorting and weighing process conducted during the study.

Plate 2: Sorting and Weighing of Generated Waste

Waste Generation Rate

Table 1 displays the weekly volume of waste produced by each volunteer across the five residence halls. The average daily waste generation at the University of Ibadan was found to be approximately 0.34 kg per person. This figure is comparable to the University of Lagos (Adeniran *et al.,* 2017) but significantly higher than that of Covenant University and the University of Nigeria, Nsukka (UNN), both of which record about 0.06 kg/person/day. International comparisons reveal varied results. For instance, Bahir Dar Institute of Technology in Ethiopia reports 0.17 kg/person/day (Tadele *et al.,* 2015), while the University of Tabriz in Iran produces around 0.13 kg/person/day (Sepideh *et al.,* 2012). These disparities are likely influenced by income levels, lifestyle choices, purchasing behavior, and institutional waste management protocols.

Waste Characterization

Table 2 outlines the physical breakdown of waste materials collected from the selected halls. Organic waste made up the highest percentage, averaging 37.9% across all halls. Polythene bags were the next most common, constituting 30.7%, followed by plastic waste at 23.2%. The predominance of organic waste suggests significant food waste generation, potentially due to limited composting or organic waste recycling infrastructure. The high quantities of polythene and plastic are particularly concerning, given their long decomposition periods and environmental impact. These findings highlight the urgent need for improved waste reduction and recycling initiatives. Effective strategies could include educational outreach on waste segregation, expanded recycling facilities, and incentivized participation in waste reduction programs. Such interventions would not only reduce environmental harm but also instill sustainable habits among campus residents.

Table 1: Results Of Weekly Solid Waste Generated per Volunteer from Both Male and Female Hall of Residence.

Volunteer	Queen Elizabeth Hall (kg)	Kuti Hall (kg)	Independence Hall (kg)	Queen Idia Hall (kg)	Abdulsalam Hall (kg)
1st	0.85	0.18	0.07	0.38	0.82
2nd	0.43	0.20	0.15	0.81	1.06
3rd	0.68	0.28	0.19	0.22	0.34
4th	0.46	0.20	0.06	1.21	0.34
5th	0.15	0.24	0.11	0.31	0.24
6th	0.30	0.34	0.20	0.26	1.74
7th	0.06	0.11	0.23	0.25	0.14
8th	0.12	0.16	0.14	0.28	0.86
9th	0.15	0.14	0.06	0.25	0.28
10th	0.32	0.12	0.09	0.29	0.27
TW	3.52	1.97	1.30	4.26	6.09
AW	0.352	0.197	0.130	0.426	0.609
NTW	285.472	109.138	122.2	543.15	416.556

TW = Total Weight, AW = Average Weight, NTW = Net Total Weight

Table 2: Physical Composition of Waste from the Selected Halls of Residence (%)

Components	Abdulsalam	Queen Idia	Queen Elizabeth	Kuti	Independence	Average
Paper	4.4	3.0	4.7	3.2	9.6	4.98
Plastic	10	5	11.6	58.2	31.4	23.24
Glass	1.6	0	0	0	0	0.32
Metal	0	1.6	0.3	0	0	0.38
Polythene bags	21.4	20.6	22.0	32.8	56.8	30.72
e-waste	1.1	0	0	0	0	0.2
Sanitary waste	0.5	1.3	0	0	0.1	0.38
Disposable waste	0.1	0.9	1.4	0.9	0.6	0.78
Organic waste	59.5	65.1	59.5	3.8	1.5	37.88
Sweepings	1.1	2.4	0.4	1.1	0	1.0
Hair	0.4	0.1	0.1	0	0	0.12
Total	100	100	100	100	100	100

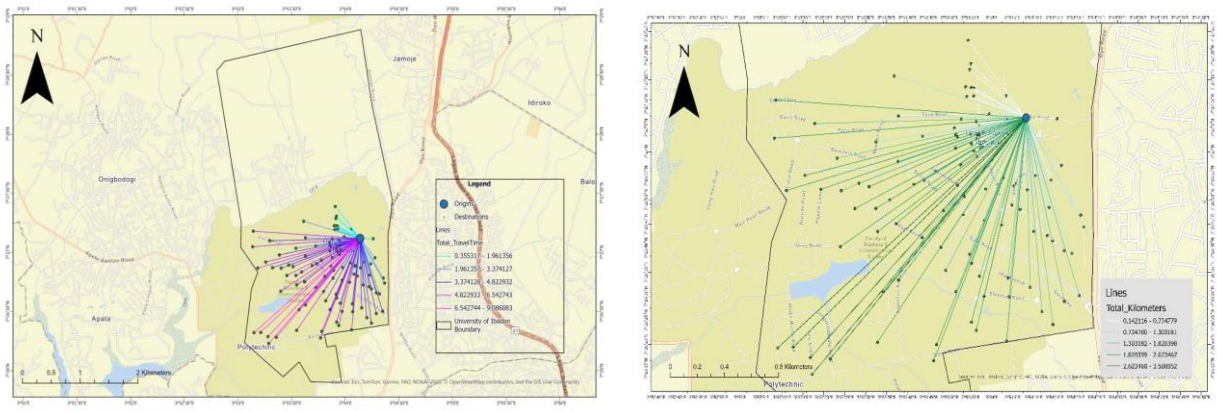
Route Optimization

Optimizing waste collection routes is a critical strategy for improving operational efficiency. By applying mathematical models and Geographic Information Systems (GIS), it is possible to determine the most efficient paths for waste collection vehicles, thus reducing operational costs. Notably, the collection phase accounts for approximately 60–80% of total solid waste management expenses (Sulemana *et al.*, 2018). This section evaluates strategies for route optimization at the University of Ibadan.

Variations in Travel Distance and Time

Figure 4a reveals that distances between waste collection origin points and various destinations across campus range from 0.1 km to 3.6 km. This variation indicates a mix of short-distance trips, likely within academic or residential clusters, and longer journeys potentially extending to more remote disposal locations. Such diversity necessitates a flexible and well-organized collection system that can efficiently manage both short and long hauls. Similarly, travel time (Figure 4b) fluctuates from under one minute to as long as nine minutes. Shorter durations likely reflect close-range pickups, whereas longer times may correspond with trips to more distant waste drop-off points. These differences underscore the importance of route planning tools that can accommodate spatial variability while minimizing delays. Integrating GPS-based monitoring and route planning software helps improve fleet efficiency and reduces fuel usage.

Additionally, these variations suggest a need for tailored vehicle deployment. Smaller vehicles could be reserved for navigating tighter, short-range routes, while larger trucks may be better suited for longer trips requiring higher waste capacity. Strategically addressing these logistical differences can lead to more reliable, sustainable, and cost-effective waste management across the campus.



(a) (b)

Figure 4: Travel Distance and Time Variation: (a) Travel distance in km (b) Travel time in minutes.

Optimized Collection Route Design

Figure 5 illustrates the proposed optimal waste collection route within the University. The route begins and ends at UI Ventures (designated as point 108). Using ESRI ArcGIS Pro (version 3.4), the optimized path covers a total distance of 24.63 km and requires 72 minutes for completion. Table 3 presents a comparative analysis showing that the optimized route reduces travel distance by 24.5% and cuts travel time by 35.7% relative to the current system. These findings are consistent with similar studies such as Apaydin and Gonullu (2007), who used Route View Pro™ and achieved distance savings of up to 59% and time savings of up to 65%. Likewise, Sulemana *et al.* (2020) employed ArcGIS in Kumasi, Ghana, achieving reductions in travel time and distance ranging from 9.1–33.5% and 16.8–19.6%, respectively.

The development of this optimized route leveraged two primary datasets: a digital road network derived from Open Street Map (OSM) and geospatial coordinates for origin and destination points. By employing ArcGIS Network Analyst, the study applied Dijkstra's algorithm to calculate the shortest and most time-efficient paths between points. This methodology not only streamlines route planning but also has broader implications for traffic management, safety and operational reliability within the University. The resulting route minimizes unnecessary detours, reduces fuel consumption, and ensures quicker, more consistent waste collection services.

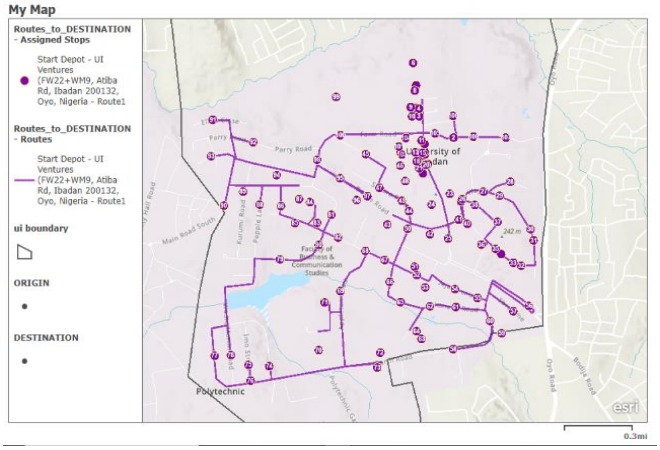


Figure 5: Optimal Routing of Collection Points

Table 3: Comparison of Existing and Optimized Travel Distance and Time

	Existing route	Optimized route	Savings	Reduction (%)
Travel distance (km)	32.6	24.6	8.0	24.5
Travel time (min)	112	72	40	35.7

Conclusion

This study has provided valuable insight into the current state of solid waste management at the University of Ibadan. The results indicate an average daily waste generation of 0.34 kg per person. Organic waste constitutes the largest portion (37.9%), followed by polythene bags (30.7%) and plastic waste (23.2%). Currently, the University does not have a system in place for source separation of organic (compostable) and non-biodegradable waste. Additionally, there is a general lack of awareness and improper disposal habits among waste generators on campus.

The study identifies significant opportunities to enhance waste collection efficiency through route optimization. By utilizing GIS-based tools like Esri ArcGIS Network Analyst, waste collection routes can be redesigned to reduce travel distances and idle times. This strategy offers multiple benefits, including decreased fuel consumption, lower carbon emissions, and cost savings. Optimized routes also ensure timely waste pickup, minimizing waste overflow and promoting a cleaner campus environment.

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