Oluwaseyi *et al*. / KJSET: Vol. 3, No. 2, (Dec 2024) 123-132. https://doi.org/10.59568/KJSET-2024-3-2-11

KAMPALA INTERNATIONAL UNIVERSITY

KIU
Journal of Science, Engineering and Technology

KJSET

Research Article

Logistics dynamics and optimization of solid waste disposal landfills in Lagos Metropolis Nigeria

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Paper history:
Received 05 October 2024
Accepted in revised form 17 December 2024

Keywords
Waste disposal, Optimization, Landfill, GIS, Logistics, Lagos metropolis

Abstract

The complexity of growth in population and rapid urbanization has complicated the problem of prompt evacuation of solid waste in Lagos metropolis. Besides the collection process, the disposal of the collected waste is highly important for gaining satisfactory results on waste management. The main objective of the study was to optimize the location of waste transfer loading stations and landfill sites using Geographic Information System (GIS) in order to improve solid waste management system in Lagos metropolis. Data on the GIS Network Analyst was carried out with the p-median method of location-allocation models. The p-median allocates the transfer stations to the nearest landfill, thus giving an efficient pattern of movements from transfer stations to landfill sites while maximizing total solid waste collection and disposal for environmental sustainability. The optimisation of waste management system using ArcGIS analysis showed a reduction in mean distance travel of 1.43km from existing transfer loading stations and landfills (11.92 km) to proposed transfer loading stations and landfills (10.49 km). This implies a reduction of 12 percent in the mean distance from transfer loading stations to proposed landfills. Based on the findings, the study therefore recommends possible interventions such as regular collection of solid waste, proper management of the transfer loading stations and landfills, adequate resources for the waste management authority, and there should be more efforts at ensuring that waste containers are provided where solid wastes from households can be collected and transported to the final disposal landfill.

1.0 Introduction

Logistics management is the process that typically includes the coordination of product usage with other activities like material handling, packaging, facility location, transportation, warehousing, inventory management and control (Coyle, Bardi & Langley, 2013). It involves all activities relating to storage and transportation of materials as well as auxiliary services needed to get the materials to a given location in a given condition.

An important question in modern day wastes management is – what exactly is a waste? A substance regarded as a waste to one individual, may be a resource to another. Therefore, a material can only be regarded as a waste when the owner considers it as such (Dijkema, Reuter & Verhoef, 2010).

The challenge of solid waste management is a global phenomenon in which the developed and the developing countries have to deal with humongous waste as a result of accelerated urbanization. The management of solid waste collection is the most complex and difficult in an urban centre because the generation of residential and industrial/commercial solid wastes takes place in every home and every industrial and commercial facility, as well as in the streets, vacant areas and in parks. As the total quantity of solid waste increases, the collection logistics become more complex (Agbesola, 2013).

Logistics of solid waste management is primarily used as a tool for the management of all kinds of waste in an appropriate manner. The solid waste management processes etched into the scope of logistics, together with increasing amounts of waste, consumer goods and by-products that are already useless after a period of use (Aziale & Asafo-Adjer, 2018). The main components of logistically integrated solid waste management system include waste collection, separation, handling, transportation, treatment; as well as processes of disposal of waste according to hierarchical values in the waste recovery. Waste management authority are unable to provide efficient and effective waste management system and the provision of collection, transportation and disposal services for refuse is not perceived as deserving higher priority. One of the simplest ways to bring innovations into solid waste management system is to study and document the existing system and provide appropriate measures at various levels through the introduction of cost effective and innovative solutions (Bakare, 2016).

There have been developments of new technologies for improving the solid waste management framework. Industrialized countries are finding solutions to the overproduction of waste with the development of new technology. The technologies adopted in solid waste management in most developing countries are said to be inadequate and inappropriate. Zurbrugg (2013) has observed that adoption of the conventional solid waste collection vehicles used in developed countries constrain solid waste management operations in many developing countries. Apart from the high maintenance and acquisition costs involved, developing countries actually lack the expertise to support the maintenance and operation of such sophisticated equipment. Yet, this is the equipment usually deployed by waste management authorities and private sector waste contractors in many developing countries (Achankeng, 2019). The high cost of new equipment compels many developing countries to import second hand equipment from developed countries (Achankeng, 2019). In the absence of required expertise and the needed spare parts to maintain the trucks, only a small part of the vehicles usually remains in operation after a short period of their use.

Also, Due to lack of technology in solid waste management in Nigeria, scavengers or waste pickers became the only machinery for recovering, reuse and recyclable materials from solid waste in Nigeria (Janus & Dima, 2014). Thus, a perfect strategy for solid waste management would be the use of scientific methods to develop appropriate technology that will pave way for integrated solid waste management such as source reduction, reuse, recycling, incineration, composting and landfilling.

It is therefore necessary to study how important proper solid waste management and its processes are in Lagos metropolis. Such effective tool as logistics of solid waste management will give a big support for the authority managing the solid wastes. It is expected that the outcome of this paper will contribute significantly to policies that will improve solid waste management system in Lagos metropolis.

2.0 Literature Review

In major cities of today, waste is either disposed or recycle or reuse. Therefore, the inabilities of stakeholders to manage it effectively contribute significantly to the increasing environmental impacts. Solid waste management should provide a sustainable environment that is environmentally effective, economically affordable and socially acceptable (Malcom, 2020).

Aziale & Asafo-Adjer (2018) reported that, in 2005, about half of a million tons of generated waste in Central London were being transported for a distance of about 64 kilometres to be dumped because all the waste disposal sites in Central London were full.

There are variations in waste disposal methods in the European countries. Italy and UK dispose about 80% and 84% respectively at disposal landfill sites. Other countries having higher landfilling include France (49%), Norway (58%), Spain (74%), while the Netherlands, Switzerland and Denmark account for only 12%, 13% and 11% respectively of the waste generated. Australia, Germany and Sweden also followed them (Malcom, 2020). Scarcity of land or space for waste disposal services around or in the cities leads to long-haul location of disposal facilities. This phenomenon increases the costs of transportation. According to Themelis (2020), in New York; 7 of 14 transfer loading stations, and its landfills, are sited outside the city. The 20-ton vehicles travel 21600km daily while 10-ton vehicles travel 64000km transporting solid waste. This approach contradicts UK's proximity policy, which emphasizes that solid waste services must be closer to the generation areas (Achankeng, 2019; Malcom, 2020).

Nevertheless, there are some countries namely the Netherlands, Denmark, and Australia that have introduced important processes to effectively manage the collection and disposal challenges by encouraging their people to segregate their waste into plastic, paper, glass categories by ensuring easy waste collection and subsequent reuse and recycling. Italy and Spain recycle only 3% of its household waste, UK only 11%, Austria 50% and Denmark 29%.

Recently, there has been an increase in the study that incorporated GIS application as a technique for data collection, analysis or presentation.

Ghose *et al* (2019) observed that GIS can be used to find the minimum distance/cost effective paths for waste collection and transportation.

Apaydin and Gonullu (2020) design a framework for appropriate routes which is based on a "bin to bin" waste collection in the city of Trabzon, Turkey. In their study, they suggested GIS technology and optimized routes.

According to Coffey (2022), most developing countries lack the required technologies to solve solid waste problems. Problems arise most times when consultants from developed nation are engaged to manage waste in developing countries. Often times, these consultants tend to impose technologies and solutions from their climes on their host nations or cities with no or little consideration for different socio-economic factors and particularly the different waste composition.

Kinobe (2018) mapped the solid waste disposal methods in Kampala, Uganda using ArcGIS Software, to examine the present collection methods to the disposal sites. The study also optimized travel distances, collection time and number of vehicles. He opined that waste management in Kampala is characterized by insufficient collection and also improper waste disposal.

Afon (2017) opines that efficient waste disposal in the country is different as a result of the peculiar nature of the terrain and some other constraint. Waste disposal is still carried out haphazardly in most parts of the country using open trucks, wheel barrows, tippers, lorries and compactor trucks. It is very obvious to see most streets or roads littered with solid waste from vehicle in transit when open trucks and lorries are used for transporting waste.

Oluwayemi *et al* (2021) in their study in Ido LGA of Oyo State using a satellite imagery of moderate resolution from Google Satellite in conjunction with Global Positioning System (GPS) field data to map the present dumpsite and encroachment. The results showed that while the dumpsite expanded over the years, buildings also increased towards the dumpsite. This uncontrolled development has increased to the present level where they have encroached on the initial boundary of the dumpsite.

Siji (2020) examine waste collection logistics in Lokoja metropolis using GIS to estimate the interrelationship between the dynamic factors and optimize solutions where the appropriate routes were determined for waste collection.

The complexity of growth in population and rapid urbanization has complicated the prompt evacuation of waste in the city. However, integrated logistics is the point of contact between the waste management system and the waste generators. Meanwhile, how this point of contact can be effectively and efficiently managed in Lagos metropolis are lopsided in the literature.

3.0 Materials and Methods

3.1 The Study Area

According to the UN (1989), Lagos had an estimated total population of 8,157,000 million people, with less than 5% of the people living in rural areas. This is further buttressed by the fact that out of the twenty local governments of the state, sixteen are found within Lagos metropolis having a population of 7.94 million by 2006 and currently stands at about 20.8 million and still growing at an average of 5% per annum (LASG, 2018).

The state has 3 major landfills and 2 temporary dumpsites which serve as final disposal destinations for all solid waste collected. The Olushosun landfill Sited in Ojota (Ikeja LGA), with a total land area of about 42.7 hectares is the largest landfill in Lagos state and it receives approximately 40 per cent of the total waste disposed in Lagos. It is reported to have been in use since 1992. The second landfill is at Abule-Egba in Alimosho LGA of the state. It covers about 10.2 hectares of land and receives waste from the densely populated area. The third landfill is sited in Lasu-Iba Road in Alimosho LGA and they are split into two with Solous II covering about 7.8 hectares and Solous III about 5 hectares. Each site receives an average of about 2,250 m^3 of waste per day. The dumpsites have been in operation since 2006 and 2009 respectively. Other temporary sites comprise of Ewu-Elepe landfill (Ikorodu) and Temu landfill (Epe). These sites serve as back–ups for the other three main landfill sites, and also have an advantage of proximity. They are temporary sites, and receive an average waste of about 1,864 cubic metres per day (Olubori, 2011; Agbesola, 2013).

The expansion of urban centres widens the waste collection zones. It is possible to improve the efficiency of collection and transport operations in cities with widening collection zones by setting up waste transfer stations where solid wastes can be transferred from small-or-medium-sized garbage trucks to larger trucks. Improving the efficiency of collection and transport leads to cost reduction while maintaining or improving services to residents. Generally speaking, when the transport distances exceeds 18km, a transfer station should be considered.

Table 1: Waste Management Facilities in Lagos State

S/N	Local Government Area	Estimated Daily Waste Generated (Kg)	Waste Facilities
1	Badagry	166.82	Sanitary Landfill (Planned)
2	Ojo	381.86	Depots, Office, Proposed Transfer Loading Station
3	Alimosho	680.03	Dumpsite-Solous II&III, Abule Egba
4	Ifako-Ijaiye	825.69	
5	Agege	578.59	Built Transfer Loading Station
6	Ikeja	285.97	Dumpsite-Olushosun
7	Oshodi/Isolo	627.28	Built Transfer Loading Station
8	Surulere	641.41	Depot Office, Recycling Bank
9	Eti-Osa	214.48	Satellite Dumpsite
10	Ajeromi Ifelodun	836.14	Office
11	Mushin	746.70	
12	Lagos Island	290.86	Built Transfer Loading Station, Depot, Office, Recycling Bank
13	Lagos Mainland	317.54	Office, Recycling Bank
14	Kosofe	972.94	Depot, Recycling Bank, Closed Dumpsite
15	Ikorodu	101.44	Satellite Dumpsite
16	Epe	142.99	Satellite Dumpsite, Proposed Sanitary Landfill
17	Ibeji-Lekki	36.69	
18	Apapa	234.48	Office
19	Amuwo-Odofin	309.8	
20	Shomolu	566.43	Recycling Bank

Source: (Hoelzel, 2018)

3.2 Data Collection and Analysis

The study involved the use of ArcMap Network Analyst. Data of the study area on the existing map was digitized and geo-referenced to define all the geographic dataset in the study area. The ArcGIS was used to manage large amounts of spatial data including maps showing spatial information, spatial data about location of waste transfer loading stations and landfills as well as attribute information about spatial data. Global Positioning System (GPS) was also used to get the coordinates of the transfer loading stations and landfill sites. Using GIS analysis tools can assure that all constraint was met to fulfill the landfill site selection. Data were collected through spatial data and attribute data and Table 2 shows the attribute data that contained the detail of transfer loading stations and landfill sites, while the spatial data contain map of Lagos State showing all the Local Government Areas.

Table 2: Attribute Table for the Landfill and Transfer Loading Station

OBJECT ID	SHAPE	NAME	FUNCTION	EASTINGS	NORTHINGS
1	Point	Abule Egba Landfill	Existing Landfill	533563.571	733771.809
2	Point	Olusosun Landfill	Existing Landfill	542039.074	728799.838
3	Point	Lasu Igando Road Landfill	Existing Landfill	527932.204	726248.397
4	Point	Ijede Ikorodu Landfill	Existing Landfill	564206.122	729319.687
5	Point	Epe Landfill	Existing Landfill	603975.913	725192.051
6	Point	Oshodi Transfer Loading Station	Existing Transfer Loading Station	537747.265	723924.959

7	Point	Simpson Transfer Loading Station	Existing Transfer Loading Station	544587.022	713696.875
8	Point	Agege Transfer Loading Station	Existing Transfer Loading Station	536748.858	732603.63
9	Point	Alimosho Outskirt Ogun State Landfill (Proposed)	Proposed Landfill	527719.237	737705.199
10	Point	Lagos Badagry Exp Way Landfill (Proposed)	Proposed Landfill	493003.276	711835.228
11	Point	Ikorodu Epe Exp Way Landfill (Proposed)	Proposed Landfill	558608.754	732991.562
12	Point	Lagos State University Transfer Loading Station (Proposed)	Proposed Transfer Loading Station	524493.211	713896.348
13	Point	Olusosun Transfer Loading Station (Proposed)	Proposed Transfer Loading Station	542039.074	728799.838

Source: Authors' computation, 2023

Acquired data was used in Network Analyst tools to get the shortest distance from transfer loading stations to the landfill sites. Therefore, the comparison distance between current and optimised distance are obtained. Mention has also been made about the road network, location of transfer loading stations and landfill sites within the local government area in Lagos state, where the waste transfer loading stations and landfill are proposed (See Figure 1).

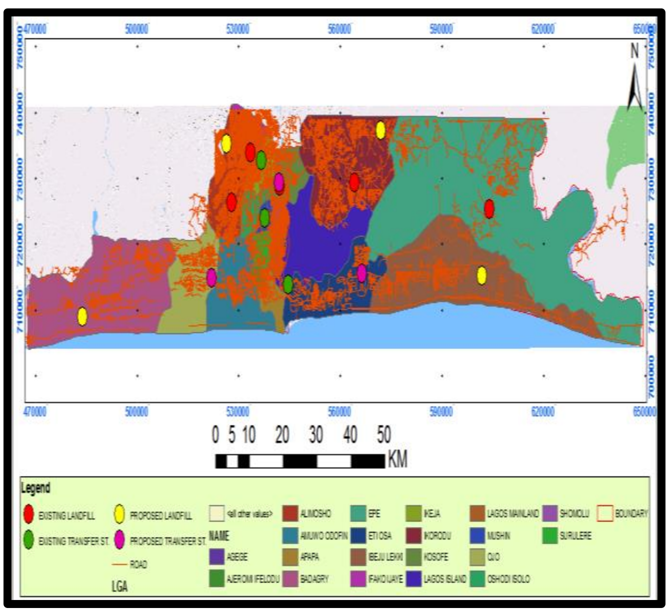

Figure 1: Map of Lagos State showing Local Government Areas with Transfer Loading Stations and Landfill (Existing and Proposed)

4.0 Results and Discussions

4.1. Waste Collection Routes Optimization

Households are represented spatially in GIS using a coordinate system. The location information and other spatial information such as streets are brought together. This allows GIS to represent the exact time and distances and on a street network between any two given points, taking into account various constraints, including accurate distances, speed limits and directional attributes of the street. GIS consists of tabular data (in reports and forms) and a map displaying waste collection points, transfer loading stations, landfills, and other facilities against a background of streets and other geographical boundaries.

The optimal truck routes were developed using ArcGIS software to find the shortest distance from the transfer loading stations to the landfill. The speed of the trucks was assumed to be the same because common type of truck is used for waste collection in the study area. The software calculated the travel distance and time of the truck per trip. Using the GIS software, Arc map tools were used to build a network database of the routes and the data was stored in shapes, polylines, nodes and arcs. Within the GIS software, an extension tool of Network Analysis tool was applied in vehicle routing to determine the shortest route from the transfer loading stations to the landfill i.e. travel distance (km) and travel time (minutes) for the calculation of optimal path. The ArcGIS generated optimized routes in the study were compared with the present routes for the three (3) existing transfer loading stations to the landfills as given in Table 3.

Table 3a: Travel Distance Comparison for Present and Optimize Routes for Existing Transfer Stations and Existing Landfill

From Existing Transfer Stations	To Existing Landfill	Present Travel Distance (Km)	Optimised Travel Distance (Km)	Benefit, %
Agege Station	Abule-Egba	6.34km	4km	2.34km

Oshodi Station	Olusosun	2.45km	1.395km	1.06km
Simpson Station	Olusosun	20.278km	18.847km	1.431km
Oshodi Station	Lasu / Igando Road	17.572km	15.122km	2.45km
Agege Station	Lasu / Igando Road	15.235km	13.00km	2.235km
Agege Station	Olusosun	14.101km	12.911km	1.19km

Source: Author's computation, 2022

Table 3b: Travel Time Comparison for Present and Optimize Routes for Existing Transfer Stations and Existing Landfill

From Existing Transfer Station	To Existing Landfill	Present Travel Time (mins)	Optimised Travel (mins)	Benefit
Agege Station	Abule-Egba	7.608mins	4.8mins	2.808mins
Oshodi Station	Olusosun	2.94mins	1.674mins	1.266mins
Simpson Station	Olusosun	24.3336mins	22.6164mins	1.717mins
Oshodi Station	Lasu / Igando Road	21.0864mins	18.1464mins	2.94mins
Agege Station	Lasu / Igando Road	18.282mins	15.6mins	2.682mins
Agege Station	Olusosun	16.9212mins	15.4932mins	1.428mins

Source: Author's computation, 2022

Tables 3 showed the analysis of driving time and distances for present route and optimize route. It should be noted that the differences between the current routes and optimised routes of each scenarios are not significant and as such making the optimised routes good choices in the event of impedance. On average, the results also show that in the event of obstruction along the optimize route, the alternative route is preferred.

4.2 Movement of wastes from transfer loading stations to landfills

This is a one demand point -to-one supply point. Here, all transfer loading stations (demand points) are allocated to the nearest landfill (supply point) concurrently. Thus, this section evaluates distances covered in moving wastes from transfer loading stations to landfill. The discussion is divided into two. The first sub-section evaluates the movements from existing transfer loading stations to existing landfills. The second sub-section evaluates the movements from both existing and proposed transfer loading stations to existing and proposed landfills. The analysis was carried out with the p-median method of location-allocation models. The p-median allocates the transfer loading stations to the nearest landfill, thus giving an efficient pattern of movements from transfer loading stations to landfills.

a. Pattern of movements from Existing Transfer Loading Stations to Existing Landfills

Transfer loading stations are to be allocated to the nearest landfills for efficiency. Table 4 showed the allocation of the three existing transfer loading stations to the closest landfills. P-median location-allocation method was used for the analysis and the result is shown on the map in Figure 2.

Table 4: Allocation of Existing Transfer Loading Stations to Existing Landfills

S/n	Allocation Pattern	Distance in Km
1	Agege transfer loading station to Abule Egba Landfill	5.66
2	Oshodi transfer loading station to Olusosun Landfill	10.34
3	Simpson transfer loading station to Olusosun Landfill	19.79

Source: Generated with Location Allocation Module of ArcGIS V 10.**3**

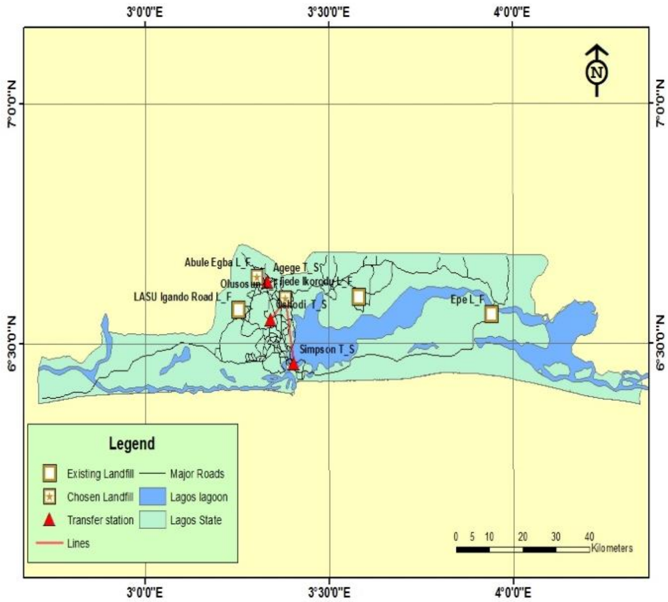

Figure 2: Allocation of Existing Transfer Loading Stations to Existing Landfills

Table 4 and Figure 2 showed that the closest landfill to Agege transfer loading station is Abule-Egba and it is 5.66 km away. Also Olusosun landfill is the closest to Oshodi transfer loading station and the distance separating them is 10.34 km. This is illustrated in the bar chart in Figure 3.

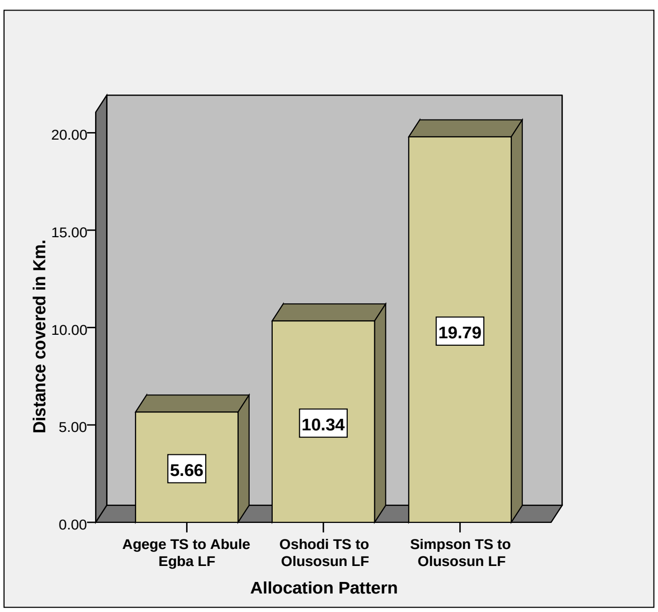

Figure 3: Distance covered between existing transfer loading stations and existing landfills

Table 5: Summary statistics of movement between existing transfer loading stations and existing landfills

S/n	Parameter	Value
1	Minimum distance between transfer loading station and landfill	5.66 km
2	Maximum distance between transfer loading station and landfill	19.79 km
3	Total distance covered from all transfer loading stations to landfills	35.8 km
4	Mean distance from all transfer loading stations to landfills	11.92 km
5	Standard deviation of distances covered	5.88 km

Source: Generated with Location Allocation Module of ArcGIS V 10.3

Table 5 shows the characteristics of distance between transfer loading stations and landfills. The shortest distance is between Agege transfer loading station and Abule-Egba landfill. The farthest distance is between Simpson transfer loading station and Olusosun landfill. The minimum and maximum distances are illustrated by the bar chart in figure 3. The total distance between the three transfer loading stations and the closest landfills is 35.8 km, while the mean distance is 11.92 km. The variability in distances between transfer loading stations and landfills as measured by the standard deviation is 5.88 km.

b. Pattern of movements from Existing and Proposed Transfer Loading Stations to Existing and Proposed Landfills

This focused on movement of solid wastes from existing transfer loading stations to existing landfills. However, to improve efficiency in movement of solid wastes in Lagos state some transfer loading stations and landfills are proposed. Thus examined movement of solid wastes from both existing and proposed transfer loading stations to existing and proposed landfills. Table 6 showed the minimum distance of zero kilometer is between a proposed transfer loading station at Olusosun and the existing landfill at the same location. The maximum distance (19.79 km.) is recorded between existing transfer loading station at Simpson and existing landfill at Olusosun. Figure 4 shows the pattern of allocating existing and proposed transfer loading stations to their nearest landfills.

Table 6: Summary statistics of movement between transfer loading stations and landfills

S/N	Parameter	Value
1	Minimum distance between transfer loading station and landfill	0 km
2	Maximum distance between transfer loading station and landfill	19.79 km
3	Total distance covered from all transfer loading stations to landfills	52.46 km
4	Mean distance from all transfer loading stations to landfills	10.49 km
5	Standard deviation of distances covered	7.18 km

Source: Generated with Location Allocation Module of ArcGIS V 10.3

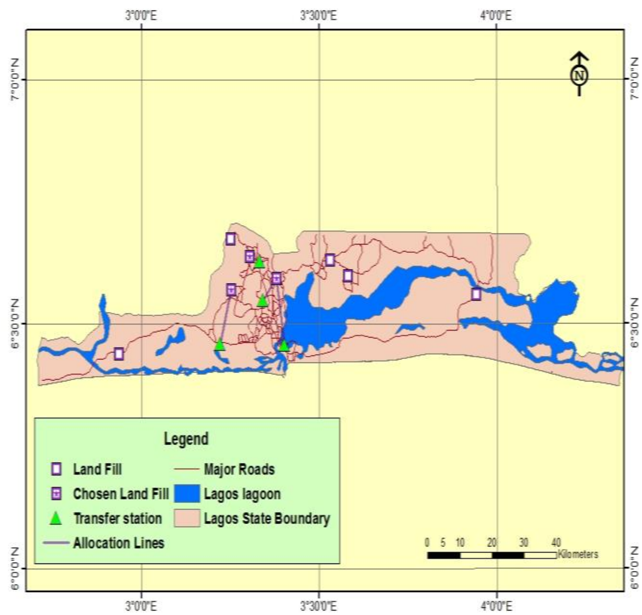

Figure 4: Allocation of Existing and Proposed Transfer Loading Stations to Existing and Proposed Landfills

Table 7 shows the characteristics of distance between existing and proposed transfer loading stations and their nearest existing and proposed landfills. The shortest distance is zero which is a location for a transfer loading station and a landfill. The farthest distance is 19.79 km. and is between existing transfer loading station at Simpson and existing landfill at Olusosun. The minimum and maximum distances are illustrated by the bar chart in figure 5. The total distance between the existing and proposed transfer loading stations and the closest landfills is 52.46 km, while the mean distance is 10.49 km. The variability in distances between existing and proposed transfer loading stations, existing and proposed landfills as measured by the standard deviation is 7.18 km.

The addition of proposed transfer loading stations and proposed landfills to the waste management system will cause a reduction from 11.92 km to 10.49 km (12 percent) in the mean distance travel from transfer loading stations to landfills.

Table 7: Allocation of Transfer Loading Stations to Landfills

S/N	Allocation Pattern	Distance in Km
1	Agege transfer loading station to Abule Egba Landfill	5.66
2	Oshodi transfer loading station to Olusosun Landfill	10.34
3	Simpson transfer loading station to Olusosun Landfill	19.79
4	Olusosun transfer loading station to Olusosun Landfill	0.0
5	LASU transfer loading station to LASU- Igando Road Landfill	16.66

Source: Generated with Location Allocation Module of ArcGIS V 10.3

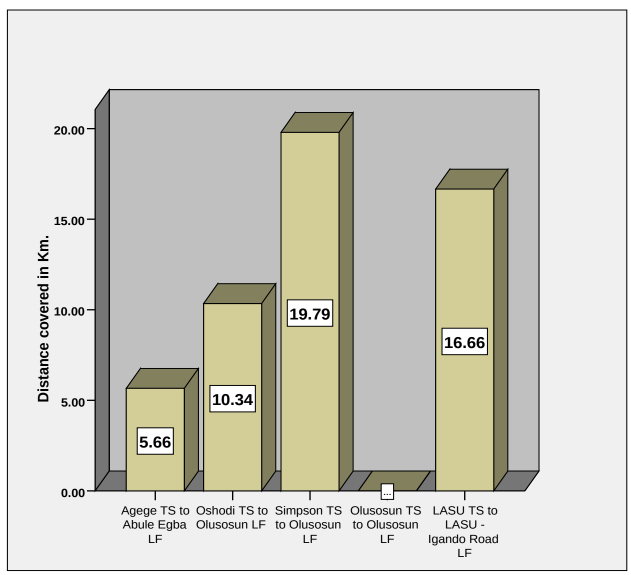

Figure 5: Distance covered between transfer loading stations and landfills

The GIS database of the Lagos state was created in ArcGIS software. The results from the GIS analysis are products of the appropriate maps that concerns dynamic and static parameters of the solid waste management in Lagos state, such as waste generated in various areas, locations of the waste collection point, transport routes, and the number of landfill sites and their attributes. The database contains various feature classes (point and line) like roads. While applying GIS model in the study area, all waste transfer stations and landfill were considered in the analysis for this study.

The adoption of location-allocation analysis helped to efficiently allocate waste transfer loading stations to their nearest landfills. The system cost is reduced by simultaneously allocating transfer loading stations to landfills. The cost was further reduced (12 percent reduction) by adding proposed transfer loading stations and landfills to existing ones.

5.0 Conclusions

Like in most other urban centres, solid waste logistics in Lagos metropolis remains a challenge, especially with its attendant population growth. The current disposal method in Lagos metropolis has failed to solve the challenges inherent in city's waste management. The study examined the logistics of solid waste management in Lagos metropolis. The study has achieved several milestones and revealed several critical issues that relates to the waste management in Lagos metropolis. Furthermore, the study concludes that waste management in Lagos metropolis is characterised by insufficient coverage of collection system, inefficient collection approach and improper disposal. In this study, the GIS software was used to identify the optimum routes for the transfer loading stations and landfills in Lagos state. The GIS techniques used all the geographical data such as various zone boundaries, road network, location of transfer loading stations and landfills. Route Optimisation is one of the aspects of solid waste logistics that has been left out in the state. Its main objective is to reduce travel distances and time. It has been demonstrated that GIS is an important technique for finding the suitable locations for disposal sites and determining the least-cost routes for solid waste disposal. Therefore, the proposed waste disposal landfill sites should be considered as appropriate. The study therefore recommended that municipalities must use Geographic Information System techniques and specially location-allocation modeling to develop effective system for the solid waste collections.

Acknowledgements

The authors would like to express their gratitude to the Olabisi Onabanjo University, Ago Iwoye for the support provided while carrying out this research.

Declaration of conflict of interest

The authors have collectively contributed to the conceptualization and writing of this journal. They have worked on revising the article to include very significant intellectual content. This manuscript has not been previously reviewed or submitted to any other journal outlet. Additionally, the authors do not have any affiliation with any organization that has a direct or indirect financial stake in the subject matter discussed in this manuscript.

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