OSUN GEOGRAPHICAL REVIEW

Journal of the Department of Geography,
Osun State University, State of Osun, Nigeria

Volume 4, 2021

ISSN: 2695 - 1959

Editor-in-Chief
Prof. Olusegun Ekanade

Published by the
Department of Geography, Osun State University,
State of Osun, Nigeria

EDITORIAL BOARD

CONTENTS

OSUN GEOGRAPHICAL REVIEW
Published by the Department of Geography, Osun State University, State of Osun, Nigeria
ISSN: 2695 - 1959 Volume 4, 2021; 1 - 8

NETWORK ANALYSIS AS A POTENT TOOL FOR WASTE EVACUATION: A CASE STUDY OF NORTHWESTERN AREA OF LOKOJA, NIGERIA

S.A. Joseph
Department of Environment and Physical Infrastructure Policy Department,
Nigerian Institute of Social and Economic Research (NISER), Ibadan.
josephsiji12@gmail.com

Abstract

Municipal solid waste accretion is persistent due to human population growth, urbanization and the inability to integrate technologies into managing the resulting wastes. The condition is worrisome in developing countries as most city authorities lack an organized or schematized waste management approach. Developing an organized system for waste evacuation is particularly important for managing Municipal Solid Waste Management through solid waste evacuation planning.

This occasioned the need for the application of an environmental decision modelling tool, Geographic Information System(GIS) for the analysis of important criteria for evaluating the prospective location of dumpsters to ensure easy location for prompt solid wastes evacuation and route planning.

This study adopted a survey approach that involved the collection of field data with the aid of a Geographical Positioning System(GPS) to obtain geographical coordinates of suitable locations of dumpsters after defining environmentally safe areas and sensitive zones. ArcGIS Network Analyst was then applied for analyzing routing systems in the study area for creating the best and alternative routes.

While the best route determines the quickest and shortest route to the approved refuse dumpsite measuring a total distance of 18.1 km, the alternative route distance measured a relative distance of 18.5 km and is suitable for use in a situation of impedance to the best route. In this regard, this technique has the potential to aid the formation of improved waste collection service coverage in the study area.

Keywords: Network analysis, Potent tool, Waste Evacuation, Lokoja

Introduction

Wastes are products or materials that have reached the end of their lives and they include scrap materials or excess items deemed for disposal (Aguda et al, 2020). While it is established that the issue of municipal solid waste is ubiquitous (Murali, Lakshmana and Nooka, 2014, p. 1) owing to rising global population vis-a-vis urbanization that compound environmental issues through waste generation. According to Hoornweg, Bhada-Tata and Kennedy (2013, p. 2) solid waste generation is rising at an exponential rate that is expected to exceed 11 million tonnes per day by 2100. This portends waste management upheaval for urban areas across the world and particularly developing countries' cities, including Nigeria, that witness steady urban expansion and population growth (Oyinloye, 2013, p. 106; Amal, Son, Chabchoub and Lahiani, 2019, p. 1). African nations have performed poorly in managing solid waste following endemic; budgetary problems, weak institutional frameworks, poor planning as well as insufficient information concerning the quantity of solid waste generated by the ever-growing populace (El-Hallaq and Mosabeh, 2019, p. 33). The foregoing therefore leads to indiscriminate waste dumping which remains a common feature of most African countries where deterioration of environmental components such as air, land, water quality and by extension environmental problems like flooding are prevalent (Iro et al, 2012, p. 61).

Nigerian cities, in particular, reflect poor waste

management performance following conspicuous waste litres in most Nigerian cities' drainages, along the roads, open plots and other visible places. Lokoja, the administrative capital of Kogi State, is not exempted from the issues of environmental problems associated with poor solid waste management. This is because a heap of solid waste is visible in most sections of the city just as rapid population growth and physical expansion become notable in the city following its state capital status attainment in 1991(Alabi, 2009, p. 158-159). In the same manner, the city's unique geographical location engenders a massive influx of both residents and transit migrants (Joseph, 2015; Alabi, 2009). The northwestern part of the city is particularly hit with the menace of poor waste management owing to land availability that encourages physical expansion and population growth as well as growing waste management problems.

The situation, therefore, requires a need to desperately address issues of resulting waste generation concerning aerial coverage, as well as designing plans that could ameliorate problems in setting up the systems for evacuation, transportation and safe disposal of wastes (Murali, Lakshmana and Nooka, 2014, p. 1).

In the meantime, achieving this objective will require a well-designed system for prompt evacuation of waste to the designated landfill in Lokoja with the aid of environmental decisions and analytical tools. It is in this light that ArcGIS Network Analyst will be employed to plan, locate and display waste collection routes in the Northwestern Part of Lokoja, Nigeria.

Theoretical Framework

Graph Theory

Network analysis in GIS can be explained through theoretical applications of the mathematical sub-disciplines of graph theory and topology consisting of a set of vertices and the edges that connect them. Graph theory is a mathematical branch concerned with network encoding as well as measuring its properties (Rodrigue and Ducruet, 2013). Importantly, the interest of this research lies in its quest to investigate spatial networks in the northwestern part of Lokoja while employing ArcGIS Network Analyst backed by graph theory. The idea of graph theory was brought to the fore by Leonhard Euler a Swiss mathematician who devised in 1735 a problem "Seven Bridges of Konigsberg"(Flovik, 2020). The notion arose from an older method that had someone traversing all of the bridges in a continuous series, a challenge Euler proved to be unsolvable. His representation of this approach with a set of nodes and links led to the foundation of graph theory and its subsequent improvements gave rise to Dijkstra Algorithm by Dutch Scientists in 1959.

Mathematical notions relating to topology and graph theory have been adjudged useful in disclosing information and analyzing the spatial network of spatial arrangement as well as in different applications of a wide range of network analysis (Almeida, Morley and Dowman, 2007, p. 428). Within the context of geography, graph-theory estimates are potent tools capable of illustrating transport networks structure, describing and analyzing network structure and accessibility, and evaluating and comparing the evolution of networks through time.

Dijkstra algorithm is applicable for traversal of shortest path problem for weighted graphs and solves that problem that does not have the edge with a negative weight by creating the shortest path tree from the start point to all vertices (Ayazi, Mashhorroudi and Ghorbani 2014, p. 69).

A graph symbolizes a network relative to reality for a simplified set of linked nodes. Going forward the bulk of networks, such as road transit and rail networks, have distinct geographic characteristics that may be seen more through their links than through their nodes. The theory's elements are fundamental at understanding graph theory and a graph '**G**' is a set of vertex (nodes) **v** connected by edges (links) **e**.

Thus G = (v, e)…… I

Vertex (Node): A node v is an abstraction of a location such as a city, an administrative division, a road intersection, or a transit terminal, and denotes a graph's terminal point or intersection point. **Edge (Link):** A link between two nodes is called an edge e, and the link (**i j**) has an initial terminal I and a terminal extremity j. A link is a piece of transport infrastructure that allows for travel between nodes in a specific direction, which is commonly indicated by an arrow.

Shortest Path Algorithms:

A) Djikstras' Algorithm is a finite sequence of well-stated computer instructions for the problem-solving operation that replaced the Breadth-First Search (BFS) queue with a Priority Queue and finds the

single-source shortest path in a weighted graph; a feature particularly relevant to the waste routine planning. This is because it incorporates vertices to the Priority Queue based on distance away from the source like the waste loading points.

The runtime of Djikstras' depends on how the Priority Queue is implemented for example how the stops and loads points are planned. The application of graph theory to network analysis and the comprehension of complicated urban settings is becoming increasingly relevant. Starting with initially unstructured geospatial data sets of urban areas entities, this study demonstrates how a graph-theoretic technique may be used to analyze urban scene spatial topology (networks) for the goal of determining the shortest path inside a particular network system.

Literature Review

Debate on effective management of Municipal Solid Waste (MSW) in the world is an ongoing exercise within the research community as the diverse perception of solid waste management approaches are converging. Solid waste management concerns in Nigeria are not new; they have been a topic of discussion and debate in the country for decades. Through intensive analysis of the effects and implications of MSW on our environment, the existence and maybe the danger of; indiscriminate waste disposal, irregular waste evacuation caused by inadequate planning have been brought into the discussion. Importantly, several experts have brought to the fore viable strategies of regulating this inescapable occurrence known as "waste" by quick evacuation with the use of environmental analytical tools. In this regard, a special study on the application of environmental analytical tools for solid waste management has been carried out in different parts of the globe. Wide application of these tools has been carried out by Kallel, Serbaji, and Zairi (2016); Chalkias and Lasaridi (2009); Nagrale et al (2018); Malakahmad et al, (2014); Desai, Shah and Zaveri (2018) among other scholars. The studies offer a blueprint for approaching the global Municipal Solid Waste management challenge that persists across the globe especially irregular waste evacuation that has attracted the interest of societies, ministries, government functionaries and stakeholders generally.

This is in recognition of the fact that the process of solid waste management is very compounded and involves many scientific applications and disciplines concerning controlling generation, handling, storage, collection, transfer, transportation, processing, and disposal of solid waste (Kallel, Serbaji, and Zairi 2016, p. 1).

A vital entry point into waste management practice is the collection process which requires proper planning to achieve practicable results. These contemporary waste issues concerning uncollected solid wastes within some world's cities have prompted some metropolitan areas to embrace the adoption of relevant environmental decision tools like Network Analyst for municipal solid waste evacuation and transportation. The process was better illustrated in some studies that revealed the relevance of network analysis in explaining and predicting urban phenomena as well as usefulness in explaining intersection relevance in transportation network systems (Sevtsuk and Mekonnen, 2012, p. 288).

Network Analyst has therefore been widely used and proven to be cost-efficient when applied for Municipal Solid Waste evacuation routing (Kallel, Serbaji, and Zairi 2016, p. 1). Chalkias and Lasaridi (2009) synthesized waste evacuation scenarios in the municipality of Nikea, Greece by adopting three key steps; establishment of a spatial database of the study area, reallocation of waste collection bins and optimization of waste collection route (p. 644). The aforementioned processes enabled them to achieve a reduction of 17% of working hours and 12.5% of the distance travelled (p. 647). Nagrale et al (2018, p. 8) optimized routes for transporting solid wastes from (generating nodes) using ArcGIS to select distance criterion while reordering the evacuation points to provide the shortest route for the optimization process which reduced distance travelled by 9.93%. Kallel, Serbaji and Zairi (2016) equally employed GIS for optimizing waste collection system in the district Cite El Itabilis, city of Sfax, by designing geodatabase (p. 4) and suggested three scenarios (p. 5-6) for waste collection performance that resulted in 31 km reduction in distance travelled and 21 litres fuel consumption. In another instance, Malakahmad et al, (2014) created Network Database and selected five routes for a pilot study in various areas of Ipoh city (p. 24) while using street plain in digital format, Orthophotos of a community of Ipoh and GPS (p. 22) to analyze information for optimizing the current routes, to shorten the routes and completion time for garbage collection. The routes were shortened by up to 22% in length, and the collection time was cut from 6934s to 4602s, according to their findings. (p. 25). In embracing its importance equally, Desai, Shah and

Zaveri (2018, p. 138), employed the GIS Network Analyst technique in their work to integrate some required data such as; the study boundary, road names and width, traffic volume details, number of storage bins and their location, capacities of the bin, the time taken for collection of waste per bin etc were employed to generate a relevant database for optimizing the solid waste route. This process makes the evacuation process efficient saving 14% cost per month while reducing the time taken for waste collection (p. 139). In a like manner, Amal et al (2019) determined the most appropriate waste evacuation route in Sfax by identifying relevant scenarios using Multi-criteria decision aid methods. They proposed and analyzed three waste collection scenarios using ArcGIS for route map creation and determining optimal routes with travelling distances along with three scenarios (p. 196). The scenarios were ranked using the ELECTRE III method to give efficient and environment-friendly waste evacuation scenarios (p. 206).

From the forging, reviewed literature revealed the importance and appreciation of environmental decision tools concerning municipal solid waste management. However, much has not been done with regards to applying these tools in Nigerian cities even in the face of a seeming overwhelming waste management situation. With ArcGIS capable of planning and executing waste collection and disposal, the study will therefore employ the tool for developing a solid waste collection route in the northwestern part of Lokoja.

The Study Area

The study area is Northwestern part of Lokoja, the administrative headquarters (Capital) of Kogi State, Nigeria and lies within 7° 41' N and 7° 50' N latitudes, and 6°42'E and 6°43'E longitudes in the lower Niger trough (Figure 1). The area has an estimated landmass of 17.52 sq km and is located close to the confluence of the River Niger and Benue which shape the region in seeming squeezed or restricted to a linear form between River Niger and Mount Patti (Alabi, 2009, p. 160). The study area has a population of 71,464 and lies in the Guinea Savannah belt characterized by a tropical climate with wet and dry seasons. The annual rainfall of the area is about 1150mm with a mean annual temperature of about 27.70°C. On the one hand, undulating plains appear in an ordered structure while elevated hill masses among which Mount Patti stands dominant characterize the relief of the town on the other hand (Ukoje, Makanjuola, And Oluleye, 2017, p. 1760).

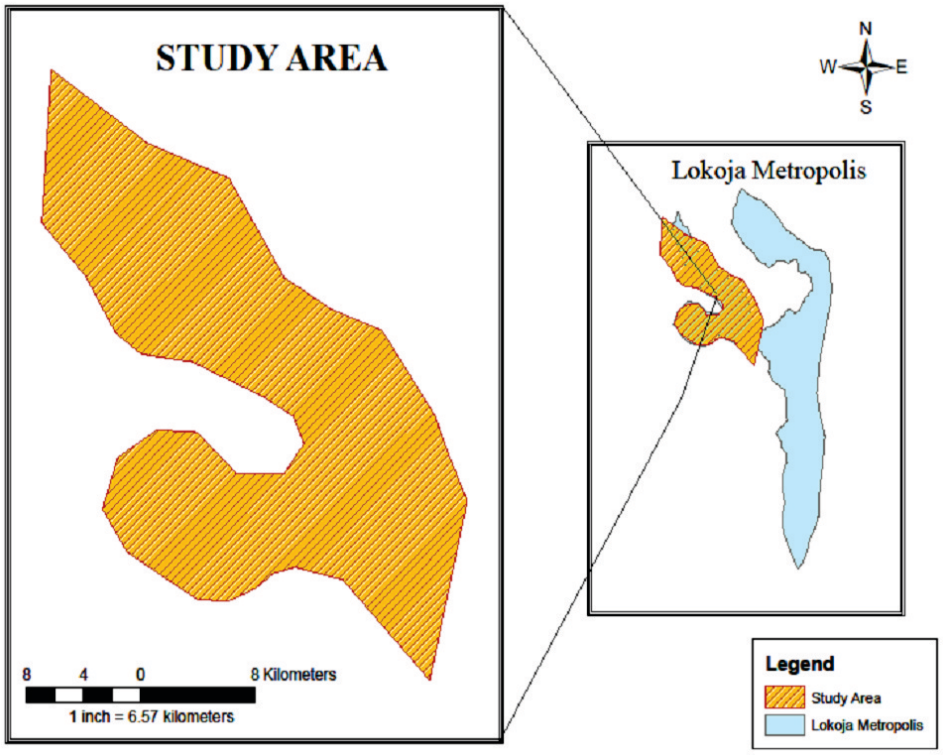

Figure 1: Map showing study area

Material and Method

This study relied on the use of the Global Positioning System to obtain the coordinates of the appropriate location of dumpsters while adopting the Aremu, Adeleke and Sule, (2011, p. 67) method. Available data of the study area like roads, rivers etc were geo-referenced on the digitized study area base map to define all the geographic datasets in the study area.

Query was done to define environmentally safe areas, accessible areas and environmentally sensitive zones that may be adversely impacted by wastes. This guided the synthesis of suitable sites for locating dumpsters 10 meters away from the roads where regular waste evacuation based on the convenient distance to households and maximum service coverage will be enhanced.

The suitable location of dumpsters followed Aremu, Adeleke and Sule, (2011; p, 67) standard buffer of; Maximum service coverage, minimum walking distance, and consideration of the physical and socio-cultural context of a given service area.

The details of constraints integrated into the GIS interface that aided the location of dumpsters at the shoulders of roads are:

- 30-meter distance away from environmentally fragile zones like rivers.
- 30- meter distance away from edifices like junctions, bus stops
- 10-meter distance from fenced facilities.
- 20-meter shoulder space for truck manoeuvring at service points.

Further, the process aided the generation of the best and alternative route for the area under study.

The spatial analytical process comprises three phases:

Phase I consists of the construction of a road network "DATASET" using ArcGIS Network Analyst;

phase II analyses and calculates the length of arcs along with the road network that participated in the network;

Phase III focuses on MSW collection optimization for best routes and alternative routes using the ArcGIS Network Analyst tool.

The computation of the route was done using a local network dataset in ArcGIS of the study area map. Since the dataset contains vital elements like; location, interconnectivity, road/street names etc it is suitable for the computation. The process, therefore, involves dragging **Streets_ND (Network Dataset)** Icon onto the map and added to the content pane. Since wastes will be evacuated from different spots, point tools were used to create stops on the map for the study area. Thereafter, **Run** is clicked to align all the created stops on the generated route. The same process is repeated for the alternative route but with a modification informed by dataset characteristics such as the forbidden turn, road closure and other issues of impedance etc. The barrier on the alternative route is simulated by drawing a polygon barrier around an area with the aforementioned changes to alter the route.

Results and Discussion

GIS was employed to model an optimum routing network for transferring MSW from a network of collecting points that reduces distance and costs to the approved dumpsite at Crusher, Felele in Lokoja. The network was created to provide information and optimize plans for the collection of wastes in the study area. The planned service coverage comprises Barracks, House of Assembly Quarters, Phase I and Phase II housing Area of Lokoja, Nigeria.

The application considers all of the criteria that are necessary for waste collection to enable a realistic network model condition and structure. The simulation in this example comprises of visiting evacuating points in the study area aided by the application of Network Analyst for solid waste evacuation and disposal within the study area. They are enumerated and explained through the created scenario:

Created Scenario: In the event of waste evacuation from Barracks, house of Assembly quarters and environs, like Phase I and II housing area to the approved refuse dumpsite at crusher, Felele. The simulated best route is shown in Figure 2. And the route determines the quickest, shortest or most scenic route to the approved refuse dumpsite which measures a total distance of 18.1 km. Conversely, there could be situations in the form of barriers on the route like traffic conditions, obstruction such as fallen trees, accidents, as well as road maintenance that could lead to road closure. This would therefore call for the need for an alternative route as shown in Figure 3. The simulated alternative route on the other hand measures a relative distance of 18.5 km and is appropriate in a situation of the need for an alternative route.

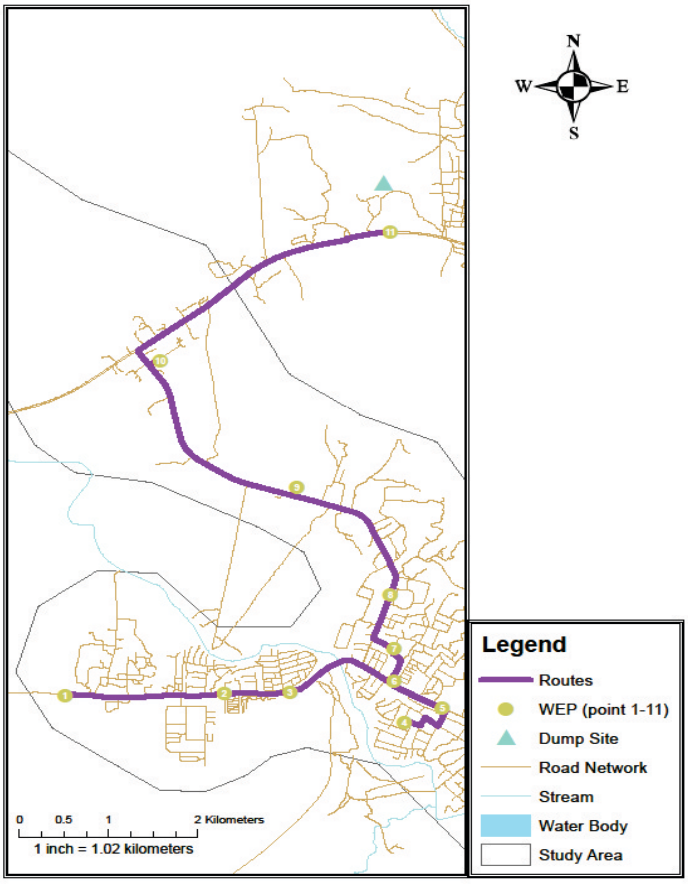

Figure 2: Map showing optimized route (Best Route)

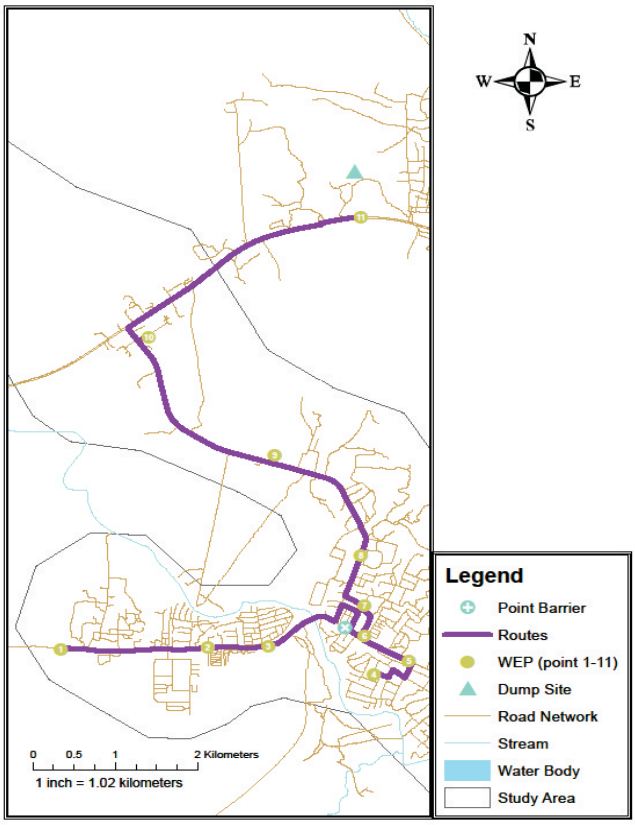

Figure 3: Map showing alternative route for the study area.

Conclusion

This study optimized the waste evacuation system in the northwestern part of Lokoja, Nigeria to enhance efficiency in waste management. After consideration of criteria for locating dumpsters in the study area as adopted by Aremu, Adeleke and Sule, (2011; p, 67), potential positions of the dumpsters were identified using ArcGIS. ArcGIS NA equally aided the creation of driving directions and the building of optimal routes for the simulated municipal solid waste collection system. From the output, the total distance to be covered in the course of waste evacuation in the study area along the best route is 18.1km while the alternative route covers 18.5km. It should be noted that the differences between the best route and alternative route in the study area are not significant as to incur additional significant costs in the event of imminent alternatives. The alternative route, therefore, offers a good choice in the event of impedance and any other issue that may inform the choice of another route.

From the foregoing, further research on the findings of this study could aid officials of Waste Management Authority in underdeveloped countries to determine parameters like an appropriate buffer for dumpsters location while recommending to the city planning authority on the future development plan of the city that will keep abreast Network Analyst application in the course of city expansion.

References

Adeofun, C O, Achi, A H, Ufoegbune, G C, Gbadebo, A M, and Oyedepo, J A (2011), 'Application of

Remote Sensing and Geographic Information System for selecting Dumpsites and Transport Routes in Abeokuta, Nigeria', *Proceedings of the Environmental Management Conference,* Federal University of Agriculture, Abeokuta, Nigeria, 2011

Aguda, D U, Johnson, N G, Yaya, A L, Abraham, S S and Ejikeme, J O(2020) Evaluating the solid waste dumpsite within Lokoja metropolis using Geospatial Techniques. *Journal of Geography Meteorology and Environment.* Vol 3 No 1, pp 84-95. ISSN2449-2051

Alabi, M O and Enete, I C (2012), 'Using multi-criteria decision model and GIS to determine land suitability for development purposes in Lokoja, Kogi State, Nigeria', *Journal of Environmental Management and Safety*: www.cepajournal.com

Alabi, M.O. (2009): "Urban sprawl, pattern and measurement in Lokoja, Nigeria". Theoretical

and Empirical Researches in Urban Management. Vol. 13. No 4 pp 158-154

Almeida, J P, Morley J G and Dowman I J (2007), 'Graph theory in higher-order topological analysis of urban scenes' *Computers, Environment and Urban Systems* ,Vol. 31 pp426–440

Amal, L Son, L H, Chabchoub, H and Lahiani, H (2019), 'Analysis of municipal solid waste collection using GIS and multi-criteria decision aid', *Applied Geomatics*. Vol 12:pp193–208. https://doi.org/10.1007/s12518-019-00291-6

Aremu, A S, Adeleke, O O and Sule, B F (2011), 'A GIS-Based optimization technique for spatial location of municipal waste bins in developing city', *Ethiopian Journal of Environmental Studies and Management.* Vol. 4, No. 3. Pp 65-72.

Ayazi, Mashhorroudi and Ghorbani (2014). Modified Algorithm Implementation in the Routing Optimized for Use in Geospatial Information Systems. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* Volume XL-2/W3, pp 69-71

Bhambulkar, A V (2011), 'Municipal solid waste collection routes optimized with Arc GIS network analysis', *International Journal of Advanced Engineering Sciences and Technologies*. Vol. 11, No.1. pp 202-207

Chalkias, C and Lasaridi, K (2009), 'A GIS-based model for the optimisation of municipal solid waste collection: the case study of Nikea, Athens, Greece', *Wseas Transactions on Environment And Development*

Desai, S N, Shah, M, and Zaveri, P (2018), 'Route Optimisation for Solid Waste Management Using ArcGIS Network Analyst: A Review', *International Journal of Engineering Technology Science and Research.* Volume 5, Issue 1. ISSN 2394 – 3386

El-Hallaq, M and Mosabeh, R (2019), 'Optimization of Municipal Solid Waste Management of Bins Using GIS. A Case Study: Nuseirat City', *Journal of Geographic Information System*, 11, 32-43. doi: 10.4236/jgis.2019.111003.

Flovik, V (2020), 'What is graph theory and why should you care? From graph theory to path optimization', Medium. Towards Data Science.

Hoornweg, D Bhada-Tata, P and Kennedy C (2013), 'Waste Production Must Peak This Century*', issue of Nature.*

Iro, S I, Okorondu, U V, and Mbano, E (2012),

'Implications of Geographic Information System in Mapping Solid Waste Collection Points in New Owerri, Imo State', *An International Journal of Science and Technology Bahir Dar, Ethiopia* Vol.1, No.1 pp 60-69.

Kallel, A, Serbaji, M M and Zairi, M (2016), 'Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia' *Journal of Engineering.* Hindawi Publishing Corporation

Karsauliya, S (2013), 'Application of Remote Sensing and GIS in Solid Waste Management: A Case Study of Surroundings of River Yamuna, India' *International Journal of Environmental Engineering and Management.* Vol. 4, No. 6, pp. 593-604

Malakahmada, A Bakria, P M Mokhtara, M R M and Khalila, N (2013), 'Solid waste collection routes

optimization via GIS techniques in Ipoh city, Malaysia. *Fourth International Symposium on Infrastructure Engineering in Developing Countries, IEDC 2013*

Murali, K. G, Lakshmana, D. B, Nooka R, K (2014), 'An Appraisal of Sustainability Scenario of Solid Waste Management: A GIS Study on Municipal Wards of Hyderabad, India' *Journal of Geology and Geosciences*. Vol.3: No. 2. 143. doi:10.4172/2329- 6755.1000143

Nagrale, S D Khedkar, S Rangdal, A Patil, S and Patil A (2018), 'Route Optimization of Solid Waste by using ArcGIS Application in Pune, India' *International Journal of Science Technology & Engineering.* Vol. 4 Iss 12 ISSN (online): 2349-784X

Oyinloye, M A, (2013), 'Using GIS and Remote Sensing in Urban Waste Disposal and Management: A Focus on Owo L.G.A, Ondo State, Nigeria' *European International Journal of Science and Technology* ISSN: 2304-9693 www.eijst.org.uk

Ramdhani, M N, Baihaqi, I and Siswanto, N (2017), 'Optimization of municipal waste collection scheduling and routing using vehicle assignment problem (Case study of Surabaya city waste collection). *International Conference on Industrial and System Engineering.* Doi:10.1088/1757-899X/337/1/012013.

Rodrigue, J P and Ducruet, C (2013), 'Graph theory: Definitions and Properties' *The geography of transport system*

Sevtsuk. A and Mekonnen, M(2012), 'Urban network analysis: A new toolbox for ArcGIS' *Revue Internationale De Géomatique.* Vol. 22. No 2, pp 287-305. Doi:10.3166/RIG.22

Tavares, G Zsigraiov, A Z Semiao V and Carvalho, M G (2008), 'Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling' *Journal of Waste Management*. Pp. 1176–1185

Ukoje, J E, Makanjuola, M I And Oluleye, M K(2017) Exploration Of Municipal Expansion and Land-Use Terrestrial Cover Change: A Study of Lokoja, Nigeria. *International Journal of Scientific & Engineering Research.* Volume 8, Issue 7, ISSN 2229-5518.