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Healthcare Waste Treatment Centre Location and Route Optimization in Ilorin, Nigeria

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ABSTRACT
Healthcare Waste Management (HCWM) is a critical global issue due to environmental and health implications. This study aimed to determine suitable locations for healthcare waste (HCW) treatment centreand optimal routes for the collection of HCW from hospitals to achieve a sustainable HCWM in Ilorin, Kwara State, Nigeria. Key criteria influencing waste facility location were evaluated by experts, and analysed using the Analytic Hierarchy Process to determine priority weights. ArcMap, a Geographic Information System (GIS) tool utilized these weights to create location suitability maps for HCW treatment centre. Poor waste collection can increase fuel consumption, time, costs, and greenhouse gas emissions. Distance data obtained from Ilorin road network in GIS environment was applied in the Ant Colony Optimization (ACO) Algorithm and Google OR-Tools Suite to obtain optimal HCW collection routes. A suitable area of 33.06 ha in Ilorin East was obtained for siting HCW treatment centre. Google OR-Tools produced better optimized HCW collection routes than ACO, suggesting its use for HCW route optimization in similar regions. This study provides valuable insights for policymakers to develop sustainable HCWM strategies.
Keywords: *Healthcare Waste Treatment Centre, Route Optimization, Analytic Hierarchy Process, Geographic Information System, Ilorin.*

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I. INTRODUCTION

Healthcare facilities (HCFs), established for restoring and maintaining human health, can surprisingly produce substances endangering man's well-being. Healthcare waste (HCW) encompasses the entire waste generated in hospitals and other health facilities, mortuary and autopsy centres, testing laboratories and animal research centres, blood banks and collection services, and nursing homes for the elderly (WHO, 2017). Growing populations, easy access to healthcare, and improved technology have led to an increase in HCW generation (El-Hallaq&Mosabeh, 2019; Hassan &Shareefdeen, 2022). A safe and sustainable Healthcare Waste Management (HCWM) system is indispensable in maintaining human health and preserving the environment (Raji &Adeogun, 2024). Strategic siting of HCW centres and route optimization of HCW collection are vital issues of HCWM that cannot be overlooked (Wichapa&Khokhajaikiat, 2018).

Site selection aims to ensure that waste facilities are sited in areas with the least adverse impacts on the people and the environment (Asefa et al., 2022). Selection of suitable waste facilities such as waste treatment and disposal centres is a complex exercise as it depends on diverse criteria, regulations and guidelines, and a massive amount of spatial data (Barakat et al., 2017; Aarthi& Francina, 2018; Mohammed et al., 2019). Its complexity is also attributed to the many stakeholders of diverse fields that are involved (Tirkolaee&Torkayesh, 2022). Other challenges to waste facilities siting are poor knowledge, lack of insight, and inconsistency or uniqueness of the problem (Mishra & Rani, 2021; Salimian& Mousavi, 2021).

The collection of waste is critical to the success of any waste management system. Waste collection accounts for almost 80% of the total solid waste management expenditure in developing countries (Imam et al., 2008; Aremu, 2013). An effective waste management system is distinguished by its waste collection and transportation methods (Siddam et al., 2012). Route optimization or optimal routing aims to find optimal collection and transportation routes among facilities or locations. Poor waste collection and transportation lead to high expenditure and traffic congestion, piling of waste beyond due retention time, and higher fuel consumption, which leads to an increase in CO_2 emissions and ultimately, global warming. These risks and dangers increase in the case of HCWs due to their infectious and hazardous nature (Tirkolaee&Aydın, 2021).

Sustainable waste management is a global issue that requires adequate attention to avoid endangering human health and the environment and adversely affecting the socio-economic sector (Hannan et al., 2020).

Route optimization of HCW collection and strategic siting of waste facilities in HCWM systems are closely linked to some of the sustainable development goals (SDGs) as shown in Figure 1.

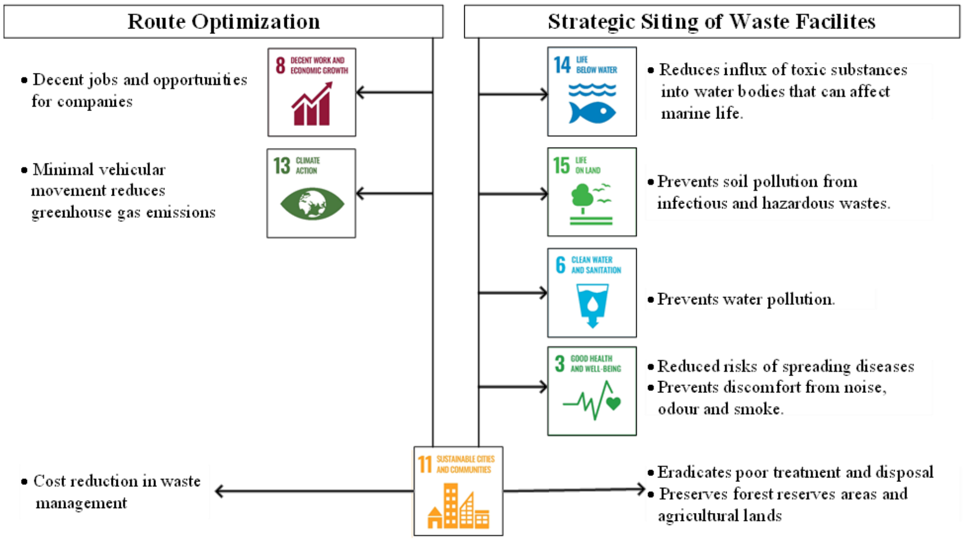

Figure 1: The Link Between Route Optimization and Siting of Waste Facilities to SDGs

1.1 Healthcare Waste Treatment Centre Location

With regards to HCWM, strategic siting of waste facilities refers to the systematic process of selecting suitable sites for HCW collection centres, sorting centres, treatment centres, and disposal sites. Treatment of HCWs helps to reduce the volume of the waste and reduce the potential health and environmental hazards of HCWs. Determination of the appropriate healthcare waste treatment centre (HCWTC) location is vital because the hazardous and toxic nature of HCW necessitates the need to treat it distinctly from municipal solid waste (MSW). For instance, as pointed out by Baran (2017), sharps that are resistant to breaking and explosion are even treated differently from other HCWs. HCW facilities must be able to serve nearby healthcare facilities and also reduce environmental and health risks (Wichapa&Khokhajaikiat, 2018). These risks can extend to surrounding areas (Nwosu &Pepple, 2016). Hence it is important to consider certain criteria which are related to the ecosystem when siting these facilities.

According to WHO (2021), HCW treatment systems are divided into three categories. On-site treatment enables each HCF to treat its waste. This system is viable for hospitals such as tertiary and large private hospitals. In a cluster treatment, an HCF treats its waste and waste from other HCFs in a small area, while a central treatment: implies a designated treatment facility treats waste from many HCFs in an urban centre or region.

MCDA is an approach that aids decision-making by establishing a framework for evaluating multiple criteria. Other synonyms of MCDA include multi-criteria evaluation, MCE (Barakat et al., 2017) and Multi-Criteria Decision-Making, MCDM (Taş, 2021; Torkayesh et al., 2021). An MCDA framework essentially has six components: the primary goal or the set of goals, the decisionmaker(s), the set of evaluation criteria, decision alternatives, the decision environment, and the set of outcomes (Asefa et al., 2022). Several MCDA methods are available and applicable to different areas. Some prominent MCDA methods are Analytic Hierarchy Process (AHP), Preference Ranking Organization Method for Enrichment (PROMETHEE), Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS).

The application of spatial models for site planning commenced over three decades before the advent of automated GIS (McHarg, 1969, as cited in Nwosu &Pepple, 2016). A geographic information system (GIS) is a computer-based system that helps in the manipulation of spatial data. GIS has a wide range of applications in areas such as waste management, disaster management and mitigation, agriculture, natural resource management, urban planning and economic development, and public health (Asefa et al., 2022). GIS enables the digital storage of spatial data, which aids in easy retrieval and editing (Ebistu&Minale, 2013). GIS has led to significant improvements in waste management (Kashid et al., 2015; Emmanuel et al., 2017). Key applications of GIS in waste management are the allocation of waste bins (Kashid et al., 2015; Khan &Samadder, 2016; Meribe et al., 2021), identification of suitable sites for landfills (Mohammed et al., 2019; Aslam et al., 2022; Gebremedhin et al., 2023), and route optimization of waste collection and transportation (Nguyen-Trong et al., 2016; Mete &Serin, 2019; Tirkolaee&Aydın, 2021). In site selection analysis, GIS can handle multiple and conflicting criteria, which saves time and enhances accuracy (Emmanuel et al., 2017).

Studies focusing on the use of GIS or MCDA methods for HCWTC location are limited. Shanmugasundaram et al. (2012) employed GIS to solve an HCWTC location problem in locating a centralized treatment plant for almost seven hundred (700) healthcare facilities in Lao People's Democratic Republic (Lao PDR) using geographical coordinates for the healthcare facilities and road network map amongst other data.

Hariz et al. (2017) combined GIS and MCDA to determine a suitable site to set up a new incineration plant to serve over 330 healthcare facilities in Kilifi County, Kenya. Eight criteria were used to evaluate eight potential sites determined through GIS techniques and three MCDA methods., namely the Analytic Hierarchy Process (AHP), the VIseKriterijumskaOptimizacija I KompromisnoResenje (VIKOR) and the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) were used to analyse and rank the potential sites. The three MCDA methods produced similar results. Employing the use of multiple MCDA methods increases the chance of producing better results (Leoneti, 2016).

Thakur (2022) introduced a hybrid approach of the grey analytical hierarchy process (G-AHP) and grey operational competitiveness rating analysis (grey-OCRA) to solve an HCWTC location problem in a district in India. Ten criteria were used to evaluate four potential candidates identified by GIS. The G-AHP was used to prioritize the evaluation criteria while the grey-OCRA was used to evaluate and rank the location alternatives concerning each criterion. The most significant criteria were distance from the existing HCW treatment facilities and distance from the hospitals.

Simic et al. (2023) combined MCDA and mathematical techniques to develop a novel decision support system by employing the random forest recursive feature elimination (RF-RFE) algorithm, the indifference threshold-based attribute ratio analysis (ITARA), and measurement of alternatives and ranking according to compromise solution (MARCOS), an MCDA method to tackle an HCWTC location problem in Istanbul, Turkey. They aimed to locate a disinfection facility for hazardous HCWs using thirty (30) criteria to evaluate five candidate locations.

1.2 Route Optimization of HCW

Waste collection often incorporates the collection itself and the transportation of waste. The waste collection system entails the quantity of waste generated, cost of waste handlers, drivers, waste collection vehicles, fuel and transportation. Route Optimization is a vital aspect of waste collection as it has positive impacts on the socio-economic and environmental aspects of the community (Aremu, 2013).

Some factors influencing HCW collection routing plans are waste generation rates, type and capacity of containers and vehicles used, traffic patterns, street configuration (and access), available time, and length of route(WHO, 2021). The storage time limit depends on the weather condition of the area (WHO, 2017). The steps for solving route optimization problems are depicted in Figure 2 and describedafterwards.

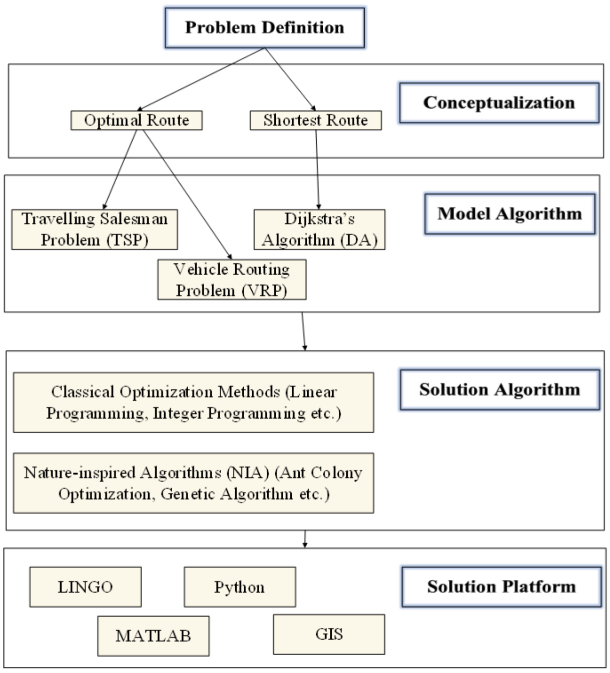

Figure 2: Steps in Route Optimization

Route Optimization can be conceptualized as a Shortest Path Problem, which involves finding the shortest route from a starting point to all destinations without returning to the starting point; hence minimizing distance. An optimal routing problem involves finding the shortest path from a start node to other nodes and returning to the start node while minimizing distance, cost, and or other variables.

Choosing the model algorithm for route optimization is vital. Dijkstra's Algorithm was created and published by Dr. Edsger W. Dijkstra, in 1959, and it aims to find the shortest paths from point node S (starting point) to all other nodes in a network with nonnegative arc lengths (Ahuja et al., 1993). The peculiarity of the Shortest Path Problem is that once the last destination is reached, the start point is not returned.

Travelling Salesman Problem (TSP) and Vehicle Routing Problem (VRP) are fundamental examples of optimal route problems. TSP can be explained as follows. Several cities are connected by roads or routes. The problem is for a travelling salesman to start from a city and visit every other city only once (without retracing) and return to the start city while minimizing the total distance and or cost. This path taken by the travelling salesman is called the Hamiltonian tour (Dorigo &Stützle, 2004; Vasuki, 2020).

TSP is a typical discrete combinatorial optimization problem that is intractable or NP-hard because of the different routes, constraints, and variables involved (Vasuki, 2020). Combinatorial optimization problem in that it involves finding the right combination of independent variables to maximise or minimise the function. It is a non-deterministic polynomial-time hard (NP-hard) problem implying there is no precise algorithm to solve it in polynomial time, hence it can take an infinitely long time to solve(Sembiring&Chailes, 2020). Other similar problems in this category are the graph partitioning (colouring) problem, job scheduling problem, and network routing problem.

VRP can be considered as the generalized form of TSP. While TSP considers a single vehicle, VRP involves a fleet of vehicles. There are several variants of VRP which depend on the peculiar characteristics and constraints of the route optimization problem. Capacitated VRP (CVRP) is a type of VRP in which the capacity of the vehicles is considered. In VRP with time windows (VRPTW), the destinations must be visited within a specific time frame. In Periodic VRP, customers need to be visited periodically rather than just once and at each time, the route needs to be planned. Capacitated Vehicle Routing Problem with Stochastic Demand (CVRPSD), the capacity of the vehicles and the varying customer demand are considered.

Route Optimization is generally solved by optimization techniques. Engineering optimization problems require finding the global optimum or the best solution among the feasible solutions based on the objective function and constraints (Vasuki, 2020). Optimization applies to diverse fields such as engineering design, network routing, job scheduling, communications, computer science, economics, business management, and a host of other complex applications.

Optimization algorithms can broadly be classified into classical optimization methods (COM) and nature-inspired optimization algorithms (Vasuki, 2020). COM are also referred to as exact algorithms and include linear programming, non-linear programming, integer programming etc.Nature-inspired optimization algorithms (NIA) are fundamentally based on Darwin's theory of survival of the fittest which relies on the collective intelligence and information-sharing capability of members of a population (Vasuki, 2020).

Ant colony optimization is an NIA inspired by the study of the swarm behaviour of ant colonies; and was first proposed by Marco Dorigo and Gianni Di Caro in 1999. Ants exhibit collective intelligence and accomplish tasks together as a swarm rather than individually. When an ant leaves home in search of food, it deposits a chemical known as pheromone along its path. When a food source is found, it takes the food, and on its way back home deposits more pheromones. When there are multiple paths between the ant nest and the food source, they tend to find the shortest path between the nest and food source and all the ants follow this. The basic features of ACO (Vasuki, 2020) are:

- The algorithm is population-based.
- It is a greedy algorithm which chooses the shortest path or the path with the least cost at every node in each iteration.
- ACO is an iterative algorithm where populations of ants build solutions in every iteration until the stopping criterion is attained
- ACO can provide solutions to discrete combinatorial optimization problems.

Some key parameters of the ACO algorithm are presented in Table 1.

Table 1: Key parameters of the ACO algorithm

Parameter	Influence	Adjustment Impact	
		Higher Value	Lower Value
Alpha (α)	determines how pheromone levels affect the behaviour of the ants on trails tracking	ants will follow trails with higher pheromone levels	ants will explore all trails
Beta (β)	determines how much the heuristic information (e.g., the distance) impacts the probability of choosing a path	makes ants more likely to choose shorter paths	makes the ants explore more paths
Evaporation coefficient (ρ)	regulates the rate of decline in the pheromone pathway	helps in exploring new paths	allows pheromones to persist longer
Common Cost	used to adjust the pheromone values after	removes the influence of less	retains pheromone

Elimination	each iteration.	successful paths more quickly.	levels longer

The TSP is instrumental in ACO research, such as Ant System, the first ACO algorithm, and many of its variants were first tested on the TSP (Dorigo & Stützle, 2004). Many studies have solved TSP using ACO (Shang et al., 2007; Hlaing &Khine, 2011; Hingrajiya et al., 2015; Rufai et al., 2021; Xuan-Shi et al., 2021).

As TSP belongs to the NP-hard complexity class, solving it through COM will take an infinitely long time, hence, the need to resort to NIA which can produce an optimum solution that closely approximates the actual solution in a finite short time (Hannan et al., 2020).

Due to the complexity of route optimization analysis, numerous computer applications have been developed while existing applications have become adaptable. They include LINGO, IBM CPLEX, Microsoft Excel, GIS, and Programming Platforms such as Python and MATLAB. GIS can analyse the collection and scheduling routes of vehicles through complex analysis (Haerani et al., 2019). GIS software such as ArcGIS and QGIS are specialized tools used to solve RO. The network analysis module in ArcGIS can perform route analysis (based on Dijkstra's algorithm) and VRP. QGIS can accommodate a plugin called ROAD GRAPH, which can calculate the shortest path between two points on any polyline layer and plot this path over the road network (Tlili et al., 2013).

Route optimization of HCWs has been studied by a number of researchers.Hachicha et al. (2014) employed a capacitated VRP (CVRP) to propose a model for the transportation of HCW from the 12 hospitals in the governorate of Sfax, Tunisia to a disposal site. Three (3) vehicles with individual routes were considered and the problem was modelled as a Linear Programming (LP) problem. Their result showed over 80% efficiency in the distance to be covered and the amount of waste collected. Mete and Serin (2019) employed QGIS, a GIS software to solve the HCW collection routing problem between 176 healthcare facilities and 5 disposal sites in the TRB1 region of Turkey. Based on the optimum routing distance, they were able to determine the best location for the disposal site.

Tirkolaee and Aydın (2021) developed a sustainable medical waste collection and transportation model for pandemics, with the problem considered as a CVRP and solved as a bi-objective Mixed Integer Linear Programming (MILP). To validate the proposed model, several illustrative examples were generated randomly and then solved.

Shih and Chang (2001) developed a Periodic VRP (PVRP) model for HCW collection from 348 hospitals in Tainan City, Taiwan. Determination of routes was conceptualized as a standard VRP and modelled as a Dynamic Programming (DP) problem. The assignment of routes to particular days of the week was modelled as Mixed Integer Programming (MIP). ArcView software was used to compute the distance between the hospitals and the depot. They were able to generate the hospitals, working time, waste collection capacity, and total distance to be covered for different collection days.

Daoud et al. (2020) solved a routing problem for infectious HCW in Sfax Governorate, Tunisia in which the problem was considered as a Capacitated Vehicle Routing Problem with Stochastic Demand (CVRPSD). An exact method, Monte Carlo (MC) simulation, and Clarke and Wright (C&W) saving approaches were employed. The routing system considered 16 hospitals and one disposal centre. The hospitals were clustered into three groups and a vehicle was allocated to each. Their solution provided a 74.55 % improvement compared to the existing route.

Alagoz and Kocasoy (2007) worked on the improvement of the routing system for HCW daily collection and transportation from the temporary storage rooms of the HCFs up to the disposal sites in Istanbul, Turkey. The input data taken into account were the geological coordinates of the hospitals, HCW generation data, the loading and unloading process times, and the capacity of the collecting vehicles. MapInfo software was used for mapping and geocoding analysis. Roadnet Transportation Suite was used to create optimized route and load plans. They were able to determine the optimum routes for the collection of HCWs.

To the best of our knowledge, there are no indications, records, or reports available showing that the optimization of HCW collection and the strategic siting of HCW treatment and disposal facilities has been studied either at the governmental level or at the academic level in Ilorin,Kwara State, Nigeria.

The Kwara State Government has been making continuous efforts to improve the municipal solid waste management in the state through initiatives like regular provision of waste bins, compactor trucks, and daily waste collection. However, HCWM has not received the same level of attention. With over 150 hospitals in Ilorin, there are is no central HCWTC. HCW central treatment centres are vital due to the high cost of establishing and maintaining these centres for individual healthcare facilities, easy monitoring and control of emissions, and the development of a good collection and transportation network. The geographical dispersion of healthcare facilities from one another makes the development of a routing system imperative.

The lack of well-defined and optimized routes for the collection of HCWs from hospitals is also a major challenge across Ilorin metropolis. This study aims to address this issue by identifying suitable locations for HCW facilities and developing an optimized HCW collection route plan for Ilorin, Nigeria. Ultimately, this research aims to provide recommendations that can support the development of a sustainable HCWM plan for Ilorin, which can be adapted in similar regions.

II. MATERIAL AND METHODS

2.1 Study area

The city of Ilorin lies on latitude 8°30′0″ N and longitude 4°33′00″ E with an altitude of 290 m and is located between the western and middle belt of Nigeria. it is the capital city of Kwara State. The city is situated in the North Central Zone of Nigeria, with a population estimate of 1,064,000 in 2024 (United Nations, 2024). The municipal zones in the city and their areas are Ilorin South (28,536.89 ha) and Ilorin West (14,832.25 ha), and Ilorin East (51,710.01 ha.) These municipals are represented in Figure 3. Ilorin is within the transitional climate zone of Nigeria, the average daily temperature ranges between 26.28°C and 31.95°C.

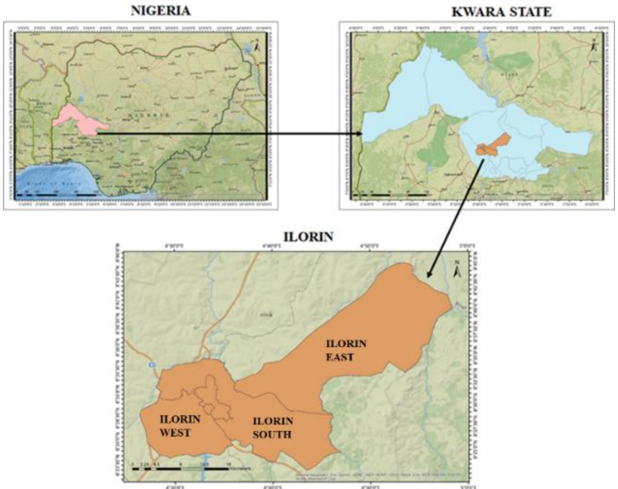

Figure 3: Map showing Ilorin

2.2 Siting of HCWTC

2.1.1 Selection of Criteria for MSW Disposal Site Selection

Analytic Hierarchy Process (AHP) was the MCDA technique adopted in this study. AHP was developed by Saaty in 1980 and is a method of relative measurement which determines the relativity between quantities rather than obtaining the exact measurement of the quantities(Brunelli, 2015). AHP is effective when combined with GIS for site selection or suitability analysis (Kalisha&Munthali, 2024) and is also easy to execute (Barakat et al., 2017).

The first step of AHP analysis is the selection of criteria for siting HCWTC. Presently, Nigeria has no guideline on waste management specifying the criteria for siting HCW Facilities, this study identified frequently used criteria for waste facilities location selection problem from literature (Ghoushchi et al., 2021; Mohammed et al., 2019; Salimian& Mousavi, 2021; Tirkolaee&Torkayesh, 2022).AHP relies heavily on human judgment. Miller (1956) pointed out that humans have a limited capacity for processing information and suggested that in judgments requiring human input, the number of categories should be limited to seven plus or minus two (7 ± 2). Based on this, Saaty and Ozdemir (2003) demonstrated that the criteria for AHP should be limited to this number. Hence, for this study, the number of criteria were limited to seven (7) and are land use/land cover, slope, elevation, population density, proximity to hospitals, proximity to roads, and proximity to rivers.

2.1.2 Expert Opinion Pairwise Comparison

The Saaty scale (Saaty& Vargas, 2012) is a frequently used to make pairwise comparisons between criteria. The Saaty scale in order of importance is illustrated as: 1 = Equal importance, 2 = Equal to average importance, 3 = Average importance, 4 = Average to strong importance, 5 = Strong importance, 6 = Strong to very strong importance, 7 = Very strong importance, 8 = Very strong or super strong importance, 9 = Super strong importance.

This scale was used to develop a questionnaire for experts to make step-wise comparisons of each criterion and assign values based on the intensity of importance. The experts were chosen from environmental engineering consulting firm, ministry of environment, research institute, and construction industry.

2.1.3 Spatial Information

To carry out an effective site selection, detailed spatial information is required. Table 2 outlines the spatial information for Ilorin obtained based on the criteria employed. ArcMap 10.8 was the GIS software utilised in this study.

Table 2: Spatial Information of Ilorin

S/N	Data	Source	Year	Resolution
1	Administrative Boundaries (Nigeria, Kwara, Ilorin)	GRID3 Nigeria	2024	-
2	Road Network	GRID3 Nigeria	2023	
3	River line	OCHA Nigeria	2019	1:1,000,000
4	Land Use/Land cover	ESRI	2023	Sentinel-2 10m
5	Digital elevation Model	NASADEM	2020	30 m
6	Slope	NASADEM	2020	30 m
7	Population Density	WorldPop	2018	1000 m
8	GPS coordinates of Healthcare facilities	Health Facility Registry and Field Survey	2024	

2.1.4 AHP Analysis

Pairwise comparison matrices were constructed from the experts' judgements. Afterwards, the weights of the criteria, consistency index, and consistency ratio were obtained from each expert opinion as outlined in Saaty& Vargas (2012). The final weights of the criteria were obtained by finding the mean of the weights from all experts as shown in equation (1).

$$w_f = \frac{1}{k}\sum_{i=1}^{k} w_i \quad (1)$$

Where w_f is the final weight
k is the number of experts
w_i is the weight from an expert,i

2.1.5 GIS Analysis

The GIS analysis involves the following steps:

1. **Extraction of Map Features:** Some of the maps obtained have a larger extent than the study area. Hence, it is important to trim the maps to the extent of the study area for better performance.
2. **Rasterization:** This refers to the conversion of all vector maps to raster form. A raster consists of pixels in grids of rows and columns. The process was done using the Euclidean distance analysis in ArcMap 10.8 which produces a set of classes based on measured distances computed from cell centre to cell centre.
3. **Reclassification:** This stage involved reclassifying the raster maps to create a single ranked map using a standard unit of measurement. Suitability levels from unsuitable to very highly suitable were assigned to the thematic maps and ranked from 1 to 5 i.e. 1 = Not suitable, 2 = Less suitable, 3 = Moderately suitable, 4 = Highly suitable, and 5 = Very Highly suitable. The criteria range and rankings used in the reclassification are presented in Table 3.
4. **Weighted Overlay Analysis:** this is a process of overlaying several raster maps using a common measurement scale. The weights of the criteria obtained from the AHP analysis were assigned to each reclassified raster in ArcMap to obtain a final suitability map.
5. **Final Site Selection:** The suitability raster was converted to a polygon feature and then to KML file format to examine the aerial view of the suitability areas on Google Earth. Google Earth can show satellite images of varied resolutions of the Earth's surface. The potential suitable sites were chosen afterwards.

Table 3: Summary of Rankings and Suitability Level Used for Reclassification for HCWTC Location

No.	Criteria	Range	Ranking
1	Slope	0° - 5° 5° - 10° 10° - 15° 15° - 20° >20°	5 4 3 2 1
2	Elevation	179 - 253 m 253 - 296 m 296 - 330 m 330 - 366 m 366 - 456 m	5 4 3 2 1

No.	Criteria	Range	Ranking
3	Land Use/Land Cover	Bare ground	5
		Built Area	2
		Rangeland	4
		Crops	2
		Flooded Vegetation	1
		Trees	3
		Water	1
4	Proximity to roads	<500 m	1
		500 - 1000 m	4
		1000 - 1500 m	5
		1500 - 2500 m	3
		>2500 m	2
5	Proximity to rivers	<500 m	1
		500 - 800 m	2
		800 - 1200 m	3
		1200 - 1500 m	4
		>1500 m	5
6	Population Density	12.24 - 606.76	5
		606.76 - 2033.79	4
		2033.79 - 4481.66	3
		4481.66 - 8340.99	2
		8340.99 - 15027.62	1
7	Proximity to Hospitals	<1500 m	1
		1500 - 2500 m	2
		2500 - 3500 m	3
		3500 - 4500 m	4
		>4500 m	5

2.3 HCW Collection Route Optimization

A survey of about 10 hospitals in Ilorin revealed a lack of space to establish on-site or cluster treatment facilities. The list of 229 hospitals originally obtained from the Health Facility Registry of the Federal Ministry of Health (2019)was trimmed down to 186 hospitals based on:

- Removal of duplicates.
- Temporary or permanent closure.
- Exclusion of University of Ilorin Teaching Hospital due to an operational incinerator for HCW treatment.

Figure 4 shows the hospitals taken into consideration in this study.

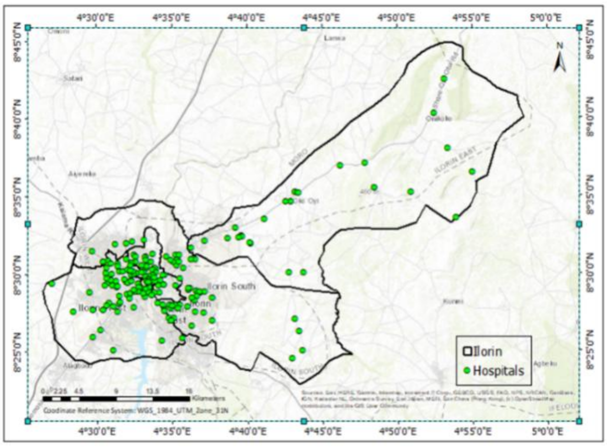

Figure 4: Map showing the hospitalsfor the study

2.3.1 Clustering Analysis

Clustering refers to identifying a homogeneous group of data based on their attributes. Spatial clustering refers to the clustering of spatial data. These are data that are related to space i.e. have a location attribute (Bindiya et al., 2013). Common algorithms for spatial clustering are Density-Based Spatial Clustering of Applications with Noise (DBSCAN), K-Means clustering, and Agglomerative Hierarchical Clustering.DBScan is useful for clustering data points of varying shapes and sizes and can also identify noise. DBScan was chosen for this study as it provides good results with spatial data(Boeing, 2018).

2.3.2 Origin-Destination (OD) Cost Matrix

The hospitals in each cluster were plotted on ArcMap. OD Cost Matrix solver in the ArcMap Network Analyst extension module obtains the distances between the respective nodes based on Dijkstra's Algorithm (i.e. based on the shortest path).

The main step before the OD Cost Matrix was to build a network dataset from the road network shapefile of Ilorin. This network dataset is important for identifying key features from the road shapefile such as junctions, barriers, one-way restrictions etc. Afterwards, The OD Cost Matrix solver was used to obtain the distance between the hospitals in each cluster and the proposed treatment centre.

2.3.3 Optimal Route Analysis

The optimal route problem in this study was conceptualized as a basic TSP which finds the optimal path from the treatment centre to all hospitals and returns to the treatment centre. This model was chosen based on the lack of an existing HCW collection system. Hence, data like HCW generation rate, number and type of vehicles are not available. In the context of this study, the assumptions which are peculiar to basic TSP (Baati et al., 2014) are:

1. One vehicle is assigned to each cluster.
2. A vehicle in a cluster cannot visit a hospital in another cluster.
3. Each vehicle starts the trip from the treatment centre to the hospitals and back to the treatment centre.
4. Waste Collection is daily.
5. A vehicle cannot visit the same hospital twice.
6. Vehicle capacity is not exceeded from visiting all hospitals.
7. Static model is adopted i.e. traffic pattern is not considered.

2.3.4 Implementation of TSP

TSP was implemented using ACO and Google OR-Tools. ACO implementation was carried out on MATLAB using code published by Sutrisno (2015) and available on the MATLAB Central File Exchange.Google OR-Tools (or OR-Tools) is a free and open-source software suite developed by Google for solving TSP, VRP, and other optimization problems. OR-Tools was created by Laurent Perron in 2011. The OR-Tools Implementation of TSP used in this study was carried out on Python 3.11.5.

III. RESULTS

3.1 HCWTC Location

3.1.1 AHP Analysis for HCWTC Location

The summary of the AHP analysis for HCWTC location is presented in Table 4.

Table 4: Summary of the AHP analysis for MSWDS Location

Criteria	Weight (W) of expert, E					Average Weight	Average Weight (%)
	E1	E2	E3	E4	E5		
Proximity to hospitals	0.449	0.274	0.217	0.157	0.269	0.273	27.32
Proximity to major roads	0.105	0.213	0.138	0.207	0.273	0.187	18.72
Proximity to rivers	0.177	0.283	0.196	0.164	0.096	0.183	18.32
Population density	0.092	0.115	0.143	0.157	0.113	0.124	12.4
Land use	0.08	0.058	0.13	0.207	0.103	0.116	11.56
Slope	0.05	0.036	0.084	0.037	0.07	0.055	5.54
Elevation	0.046	0.022	0.093	0.071	0.076	0.062	6.16
SUM	**1**	**1**	**1**	**1**	**1**	**1**	**100**
Consistency Ratio	**0.06**	**0.07**	**0.02**	**0.09**	**0.07**		

As the consistency ratios from each expert opinion is less than 0.1, the data was deemed consistent and reliable. The average weights for each criterion was used for the weighted overlay analysis in ArcMap 10.8.

3.1.2 GIS Analysis for HCWTC Location

Reclassification

Based on the suitability level and range defined, the reclassified maps with the areal extent of the suitability level are shown in Figure5.

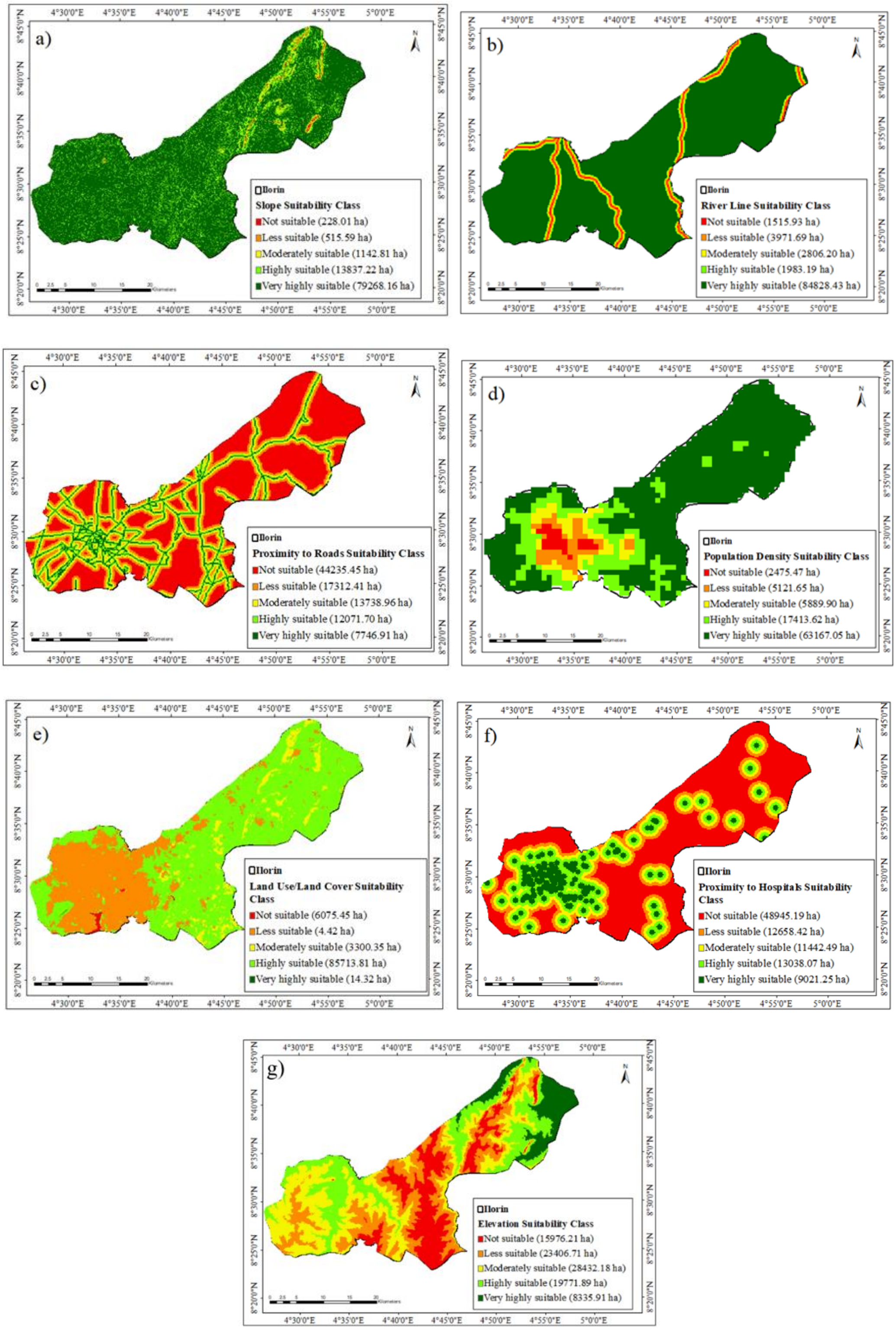

Figure 5: Reclassification Maps for criteria (a) Slope (b) Proximity to river (c) Proximity to road (d) Population Density (e) Land Use/Land Cover (f) Proximity to hospitals (g) Elevation

Weighted Overlay Analysis

The final suitability map for HCWTC location produced from the Weighted overlay Analysis is shown in Figure 6. The areal extent covered by each suitability class is also depicted.

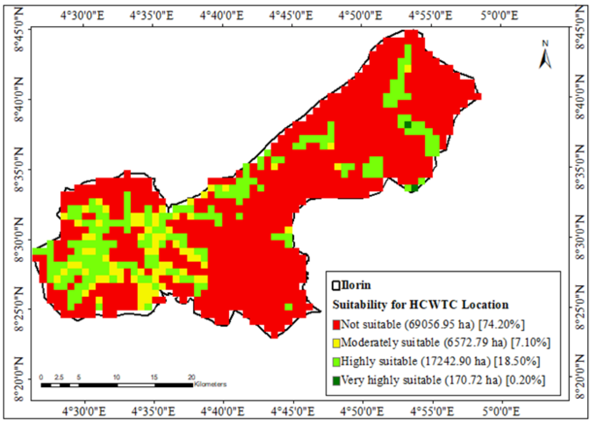

Figure 7: Final Suitability Map with Areal Distribution for HCWTC Location

Selection of a Suitable HCWTC

For this study, only the very highly suitable areas (170.72 ha) are considered as candidates for HCWTC. From the aerial view of the very highly suitable sites in Figure 7:

- Candidate site (1) has minimal vegetation compared to candidate site (2).
- The coloured portion of site (1) also has minimal vegetation compared to the other side of the road.

Hence, this coloured portion which lies on latitude 8°37'58" N and longitude 4°53'11" E, and located in Ilorin East with an approximate area of 33.06 ha was chosen as the proposed HCWTC.

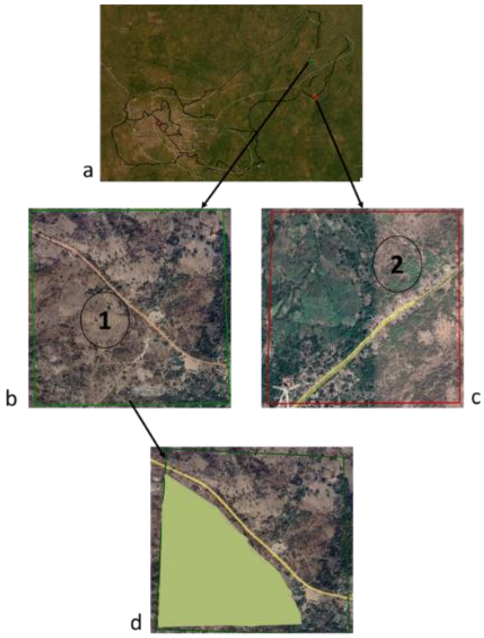

Figure 7: Aerial View of the very highly suitable sites for HCWTC a) location of the two very highly suitable areas, b) and c) enlarged images of the areas d) final proposed site for HCWTC

3.2 HCW Collection Route Optimization

3.2.1 Clustering Analysis

Based on visual examination, the 186 hospitals considered in this study were grouped into two (2) is shown in Figure 8. Group one (1) contains the majority of the hospitals in Ilorin East and a few in Ilorin South. Group two (2) contains all the hospitals in Ilorin West and some hospitals in Ilorin East and Ilorin South.DBScan was then used to divide the two groups into clusters in order to reduce the travel time and distance to be covered by the waste collection vehicles.

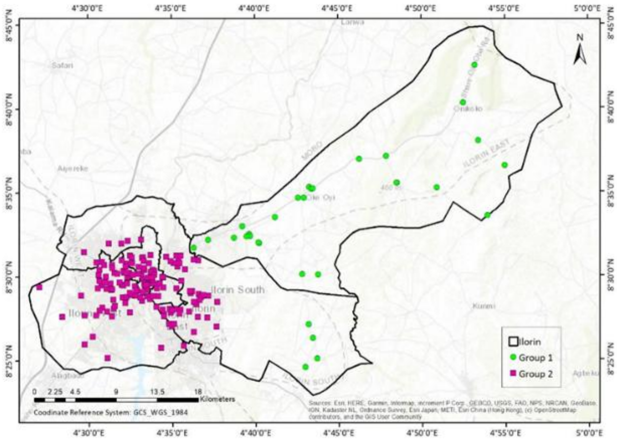

Figure 8: Grouping of the hospitals

DBScan parameters used for the clustering analysis is presented in Table 5. Figures 9 and 10 show the clustering results from DBScan analysis.The summary of the clustering result is shown in Table 6.

Table 5: DBScan parameters for Cluster Analysis

Parameter	Definition	Value
Epsilon	the radius around a data point used to determine the neighbours	0.6
MinPoints	minimum number of points required to form a dense region or cluster.	5
Distance metric	haversine	-

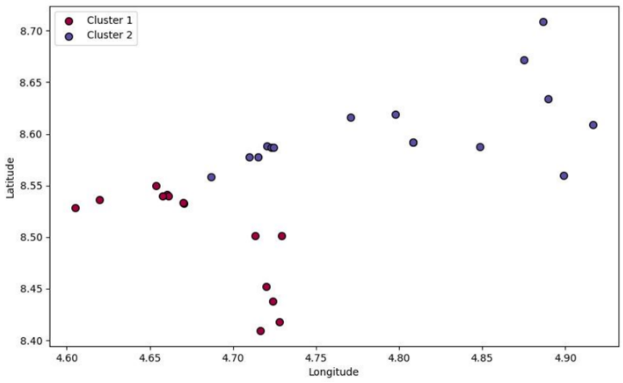

Figure 9: Group 1 Clustering Result

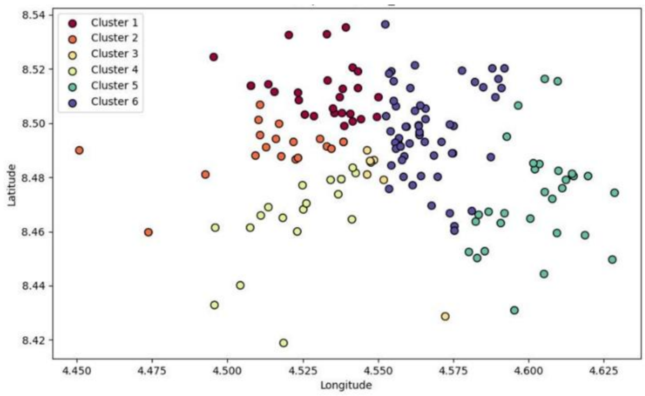

Figure 10: Group 2 Clustering Result

Table 6: Summary of Cluster Analysis

Cluster	Hospitals in the cluster	Number of hospitals
1	H28, H30, H33, H34, H35, H36, H37, H38, H41, H44, H58, H59, H60, H61	14
2	H01, H02, H03,H04, H27, H29, H31, H40, H42, H43, H45, H46, H47, H49, H51	15
3	H05, H102, H129, H130, H131, H132, H133, H134, H147, H148, H149, H150, H151, H152, H164, H165, H166, H182, H21, H22, H23, H24, H50, H90, H92, H97, H99	27

Cluster	Hospitals in the cluster	Number of hospitals
4	H119, H121, H122, H123, H125, H126, H128, H135, H137, H138, H139, H140, H144, H163, H167, H168, H169, H175, H179	19
5	H06, H103, H104, H105, H106, H107, H11, H110, H111, H112, H113, H114, H115, H116, H117, H118, H13, H136, H141, H142, H143, H160, H161, H185, H26, H70, H71, H76	28
6	H120, H124, H127, H145, H146, H153, H154, H155, H156, H157, H158, H159, H162, H170, H171, H172, H173, H176, H178	19
7	H174, H177, H187, H188, H189, H190, H191, H63, H64, H65, H66, H67, H68, H69, H72, H73, H74, H75, H77, H78, H79, H80, H81, H83, H84, H85, H86, H87, H88, H91, H94	31
8	H07, H08, H09, H10, H100, H101, H108, H109, H12, H14, H15, H16, H17, H180, H181, H183, H184, H186, H19, H25, H48, H52, H53, H54, H55, H56, H57, H82, H89, H93, H95, H96, H98	33
TOTAL		**186**

The large clusters are due to the high proximity of hospitals within such clusters which occurred predominantly around the clusters in Ilorin West as shown in Figure 8.

3.2.2 Origin-Destination (OD) Cost Matrix

The network dataset result depicted in Figure 11 is used to obtain the distances between the hospitals and the proposed treatment centre, which formed the basic input data for the optimal route analysis. Obtaining the distance using the road network rather than using the coordinates improves accuracy of the route optimization result since the road features such as length, curves and junctions are considered. The OD Cost Matrix map for cluster 1 is presented in Figure 12.

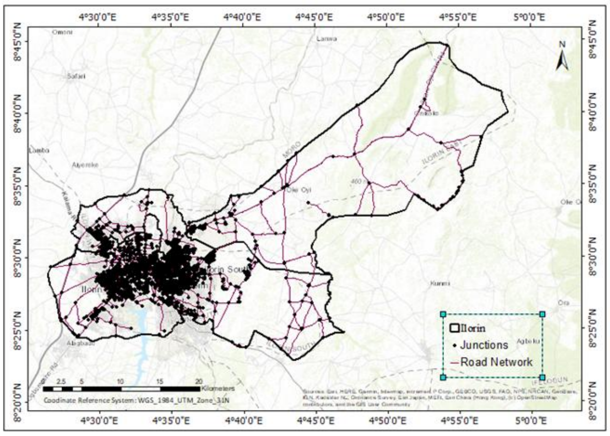

Figure 11: Network Dataset Map

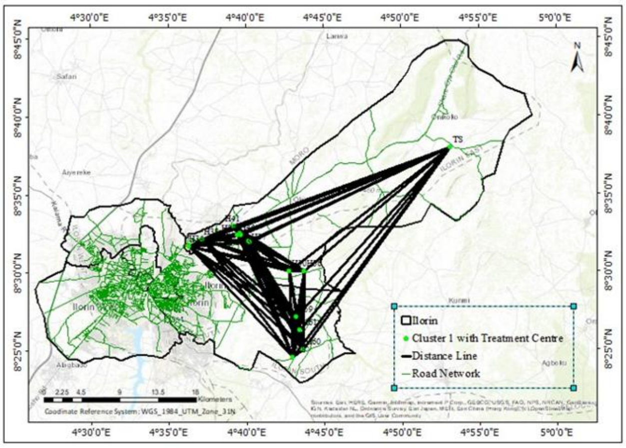

Figure 12: OD Cost Matrix map for Cluster 1

3.2.3 Optimal Route Analysis

ACO algorithm Implementation

The ACO algorithm was implemented in MATLAB for different combinations of parameter settings as shown in Table 7and executed four (4) times per combination resulting in 5,184 runs. Table 8 presents only the best ACO solution.

Table 7. Parameter Adjustment for ACO algorithm

Parameter	Symbol	Parameter setting
Effect of ants' sight	α	{1,2,3}
Trace's effect	β	{2,4,6}
Evaporation coefficient	ρ	{0.1,0.2,0.3}
Number of iterations	miter	{500, 3000, 10000}
Cost elimination	el	{0.96, 0.97}
Initial pheromone matrix	t	0.0001

Table 8. The ACO algorithm Implementation Optimal distance

Cluster	Best Parameter Combination					Best Solution i.e. Optimal distance (m)
	α	β	ρ	miter	el	
1	2	2	0.1	10000	0.97	110345
2*	-	-	-	-	-	97704
3	3	4	0.3	10000	0.97	117983
4	3	6	0.1	3000	0.96	131903
5	3	4	0.2	10000	0.97	107116
6	3	6	0.3	10000	0.97	124800
7	3	6	0.2	10000	0.97	121969
8	3	2	0.2	10000	0.97	106697

* all the combinations for this cluster produced the same solution

OR-Tools Implementation Results

Table 9 presents the results of the OR-Tools implementation in Python.

Table 9.OR-Toolsimplementation Optimal distance

Cluster	Optimal Route distance (m)
1	110344
2	97704
3	117552
4	131724
5	106994
6	124207
7	121298
8	103799

Comparative Analysis of ACO and Google OR-Tools Results

It is necessary to compare the results of both the ACO and Google OR-Tools results to determine the approach that best suits this dataset (problem). The graphical representation of the comparative analysis is shown in Figure 13.

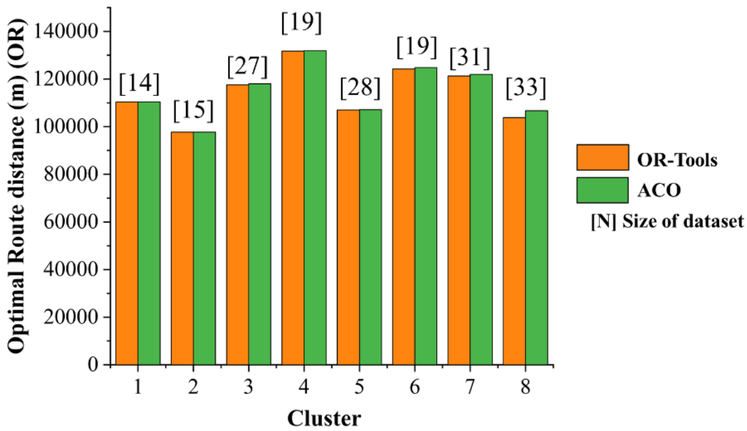

Figure 13: Comparison of ACO and OR-Tools Results

From Figure 13, ACO and OR-Tools produced a similar optimal distance for smaller datasets while for some larger datasets, OR-Tools produced slightly better i.e. lower optimal distances. This may be attributed to inefficiency in NIA like ACO when the dataset is large (Vasuki, 2020). Table 10 shows the final optimized route sequence and distance based on Google OR-Tools.

Table 10. Optimized Route Results for all clusters

Cluster	Final Optimized Route (Google OR-Tools)	Distance (m)
1	TC→H41→H34→H38→H44→H28→H35→ H37→H33 →H61→H60→ H58→H59 →H36 →H30→TC	110344
2	TC→H31→H29→H04→H27 →H51→ H49→H01→H02→H03→ H45→ H42→H46→H43→ H40→ H47→TC	97704
3	TC→H21→H22→H102→H133→H97→H92→H99→H166→H90→H165→H147→H164→H149→H130→ H131→H132→H129→H134 →H150→ H148→H05→H152→H24 →H151 →H23 →H182→H50→TC	117552
4	TC→H144→H135→H138→H137→H140→H122→H121→H179→H126→H123→ H119→H169→ H163→H167→H175→H168→H128 →H125 →H139→TC	131724
5	TC→H107→H104→ H105→H13→H103→H106→H115→H114 → H116 → H110→H111→ H112→ H141→H143→H136→H142→ H161→ H160→ H117→H113→ H185→H11→H06→ H70→H118 → H71→H76→ H26→TC	106994
6	TC→H162→H154→H157→H159→H156→H153→H170→H173→H172→ H176→H178→H124→ H120→ H127→H155→ H158→H146→H145 →H171→TC	124207
7	TC→H94→H91→H81→H86→H88→H87→H78→H68→H74→H67→H177→H65→H174→H66→H75→ H72→H63→H64→H69→H73 →H77→ H84→H187→ H83→H188→H80→H85 →H189→H190 →H191→ H79→ TC	121298
8	TC→H100→H98→H95→H101→H82→H25→H181→H17→H19→H180→H14→H53→H57→H52→ H16→H15→H56→H55→H183→ H184→H108 →H109→H54→H08→H12→H10→H48→H09→ H07→ H186→H93→ H96→H89→TC	103799

TC = Proposed HWCTC

IV. CONCLUSION

This study addressed the suitable location of HCWTC and the optimization of healthcare waste (HCW) collection routes to achieve a sustainable HCWM in Ilorin, Kwara State, Nigeria. The study considered several criteria such as slope, elevation, and proximity to roads and settlements which are very vital and identified sites with minimal or no risk to the ecosystem. A combination of AHP and GIS was used to identify suitable locations for HCWTC. An HCW treatment centre is proposed at latitude 8°37'58" N and longitude 4°53'11" E, in Ilorin East, with an available area of 33.06 ha.

Optimal routing of HCW collection will reduce fuel consumption, time, costs and greenhouse gas emissions. This study also determined optimal routes for HCW collection from hospitals by integrating GIS and optimization techniques. To improve accuracy, distance data based on Ilorin road network were applied in the Ant Colony Optimization (ACO) Algorithm and Google OR-Tools Suite to obtain the optimal HCW collection routes. Google OR-Tools gave better-optimized distances than ACO. Hence, we concluded that Google OR-Tools is better suited for the optimization of HCW collection routes in Ilorin.

Like any study, this research has its limitations, presenting opportunities for future investigation. In hospital clustering, future studies could consider additional criteria such as facility type, services offered, and patient volume, beyond just geographical distribution. Future research could also explore HCW generation patterns to more accurately determine the number and capacity of HCW collection vehicles needed for efficient waste collection. This study assumed a static traffic pattern for optimal route calculation, but in reality, traffic is dynamic due to delays, stops, and barriers. Incorporating real-time traffic patterns would be a valuable focus for further research.

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Appendix I
Details of the Hospitals Studied

No.	Code	Name	Longitude	Latitude
1	H01	Agbeyagi Primary Health Care Center	4.80849	8.59209
2	H02	Agbeyangi Health Centre	4.80834	8.59215
3	H03	Christanah Clinic &Materity (Oke-oyi Basic Health Center)	4.77092	8.61587
4	H04	Apado Primary Health Care Center	4.87522	8.67167
5	H05	Magaji Are Primary Health Center	4.54431	8.50167
6	H06	Civil Service Hospital	4.56964	8.48033
7	H07	Fogofolu Hospital	4.57468	8.48902
8	H08	Gss School Clinic	4.57492	8.49906
9	H09	Lifeline Hospital	4.57467	8.48902
10	H10	Olarenwaju Hospital	4.56837	8.48825
11	H11	Police Training School Clinic	4.56429	8.48063
12	H12	Sabo Oke Medical Centre	4.57101	8.49321
13	H13	Awodi Health Centre	4.55267	8.50285
14	H14	Abata Karuma Health Centre	4.555752	8.50636
15	H15	Jafmedge Clinic and Maternity	4.56582	8.50549
16	H16	Ojagboro Primary Health Care Centre	4.56396	8.50665
17	H17	Akanji Memorial Hospital	4.55444	8.51928
18	H19	Alimayaki Health Centre	4.55356	8.51836
19	H21	Dada Community Health Care Centre	4.54153	8.52065
20	H22	Fatimoh Memorial Clinic	4.5432	8.51915
21	H23	Okelele Primary Health Centre	4.54336	8.51301
22	H24	Oluwakemi Clinic and Maternity	4.53325	8.51586
23	H25	Omowumi Clinic & Maternity	4.56208	8.52145

No.	Code	Name	Longitude	Latitude
24	H26	Sobi-Medical Centre	4.5812	8.46762
25	H27	Iponrin Comprehensive Health Centre	4.88675	8.70875
26	H28	Ayinla Clinic & Maternity	4.66035	8.54148
27	H29	Eleshinmeta Primary Health Centre	4.91659	8.60909
28	H30	Lajiki Health Centre	4.71348	8.50153
29	H31	Marafa Health Centre	4.88994	8.63404
30	H33	Abanta Health Post	4.67061	8.53269
31	H34	Abiamo Clinic & Maternity	4.60519	8.52821
32	H35	Al-Iradat Hospital	4.66143	8.53996
33	H36	Budo-Are Health Centre	4.72931	8.50115
34	H37	Ile-Apa Health Centre	4.669979	8.533256
35	H38	Ore-Lope Hospital	4.61949	8.53592
36	H40	AIC Medical Limited	4.71523	8.57746
37	H41	AiyetoroOja Health Centre	4.653587	8.549508
38	H42	Ajibola-Alade Clinic&Materinty	4.72062	8.58825
39	H43	Ikoh-Allah Clinic &Maternity OkeOse	4.68664	8.55849
40	H44	OkeOse Model Primary Health Centre	4.657827	8.53962
41	H45	OkeOyi Basic Health Clinic	4.72289	8.58664
42	H46	OkeOyi Dispensary And Maternity	4.70962	8.57759
43	H47	OluwaFolaseyi Clinic & Maternity	4.72441	8.58699
44	H48	Amao-Megida Hospital	4.57465	8.48909
45	H49	Aregun Health Post	4.84847	8.58746
46	H50	Ibunku-Olu Clinic	4.5495	8.50234
47	H51	Panada Health Post	4.79775	8.61883
48	H52	Primary Healthcare Center Ojagboro	4.562201	8.504583
49	H53	Okesuna Health Centre	4.55934	8.49868
50	H54	Omolola Hospital	4.57368	8.49956
51	H55	Ore-Ofe Clinic	4.56352	8.49936
52	H56	Tosho Clinic and Maternaity	4.56581	8.50162
53	H57	Zango ward clinic and maternity	4.559232	8.498724
54	H58	Bada-Ifedapo Primary Health Care Center.	4.71634	8.40932
55	H59	Fufu Prototype Primary Healyh Care Center.	4.71999	8.45196
56	H60	Ilota-Apaola Primary Health Care Center.	4.72813	8.41777
57	H61	Mavelous Clinic and Maternity.	4.72418	8.43817
58	H63	Ayoade Hospital	4.59192	8.46681
59	H64	Danialu Primary HealtCare Centre.	4.60063	8.46502
60	H65	Delouse Medical Center.	4.58018	8.45271
61	H66	EroOmo Primary Health Care Center.	4.58536	8.45288
62	H67	Ife Olu Clinic and Maternity.	4.58232	8.46374
63	H68	Med Care Hospital	4.58652	8.46751
64	H69	Oke Ogun/Agbabiaka Primary Health Care Center.	4.60922	8.45958
65	H70	Ola-Olu Hospital	4.5678	8.46957
66	H71	Omosebi Hospital	4.57533	8.46213
67	H72	Onikanga Primary Health Care Center.l	4.59079	8.46328
68	H73	Opolo Primary Health Care Center.	4.61861	8.45889
69	H74	Royal Care Hospital.	4.58344	8.46642
70	H75	Tejumade Clinic and Maternity	4.60503	8.44455
71	H76	Yusjib Industrial Medical Hospital	4.57523	8.46051
72	H77	Ago Ayekale Primary Health Care Center.	4.62763	8.44981
73	H78	Anchormed Hospital.	4.60199	8.48318
74	H79	Crescent Gold Crown Hospital.	4.60996	8.48243
75	H80	Day Spring Hospital	4.61441	8.48082
76	H81	Ela Memorial Hospital	4.59644	8.50673
77	H82	Healing Wing Hospital	4.57782	8.51938
78	H83	IyanuOluwal Clinic and Maternity.	4.61486	8.48051
79	H84	Jalala Primary Health Care Center.	4.62844	8.47434
80	H85	OyinFolorunsho Hospital and Maternity	4.61234	8.47915
81	H86	Sarfam Hospital	4.59272	8.49527
82	H87	Tanke Primary Health Care Center.	4.60362	8.48519
83	H88	Tolulope Hospital	4.60147	8.4853
84	H89	Abidayo Clinic and Maternity	4.58995	8.51636
85	H90	Aminat Clinic and Maternity.	4.51341	8.51455
86	H91	Ara Olu Clinic and Maternity.	4.60964	8.51558
87	H92	Arewa Hospital.	4.49531	8.52455
88	H93	Godwill Clinic and Maternity	4.58896	8.50958
89	H94	Igbalaloju Clinic and Maternity	4.60521	8.51636
90	H95	Kulende Housing Estate Primary Health Care Cener.	4.58489	8.51341
91	H96	Kulende Primary Health Care Center.	4.59103	8.51319
92	H97	Madina Primary Health Care Center.	4.52031	8.53277
93	H98	Nakowa Medical Centre	4.58787	8.52046

No.	Code	Name	Longitude	Latitude
94	H99	Ogidi Cottage Hospital.	4.50779	8.51387
95	H100	Olutayo Hospital	4.59197	8.52044
96	H101	Police Cottage Hospital.	4.58201	8.51518
97	H102	Sobi Specialist Hospital	4.53932	8.53541
98	H103	Children Specialist Hospital Centre Igboro	4.55421	8.49725
99	H104	Fadimo Hospital	4.55654	8.49327
100	H105	Balogun Fulani Health Center.	4.55695	8.49458
101	H106	Kosemani Hospital	4.55566	8.49301
102	H107	Isale Asa Primary Health Care Center.	4.56037	8.49256
103	H108	Temitope Hospital	4.56358	8.49584
104	H109	U.I.T.H Maternity Wing.	4.56535	8.49307
105	H110	Doctors Clinic	4.55856	8.48782
106	H111	MagajiOkaka Primary Health Care Center.	4.55792	8.48643
107	H112	Bawa Clinic And Maternity	4.55428	8.48444
108	H113	Sadiku Hospital	4.55845	8.48022
109	H114	Awoli Primary Health Care Center.	4.55729	8.49154
110	H115	Oke Ogun Edun Primary Health Care Center.	4.556	8.49054
111	H116	Olufadi Primary Health Care Center.	4.557366	8.491556
112	H117	Femis Hospital	4.55352	8.47581
113	H118	Life Care Hospital	4.57381	8.46691
114	H119	Abaniselolu Hospital	4.51263	8.49117
115	H120	Adewole Cottage Hospital	4.51356	8.46906
116	H121	Adewole Health Centre	4.51782	8.48782
117	H122	Adeyi Hospital, Kuntu	4.52253	8.48666
118	H123	ApalaraMimitazHspital	4.50927	8.48804
119	H124	IderaOluwa Clinic & Maternity	4.51108	8.46611
120	H125	Idigba Health Centre	4.52184	8.49322
121	H126	Istijaba Clinic and Maternity, Gereu	4.49246	8.48104
122	H127	Kidiz Medical Centre	4.51819	8.46513
123	H128	Oke-Agodi Health Centre	4.51606	8.494215
124	H129	Agbaji Health Centre	4.53867	8.49913
125	H130	Aisat Memorial Hospital	4.525696	8.50335
126	H131	Ajikobi Cottage Hospital	4.52864	8.50282
127	H132	Arike Clinic & Maternity	4.54138	8.50067
128	H133	Harmony Clinic and Maternity	4.53283	8.53283
129	H134	Primary Health Centre Omoda	4.53546	8.50389
130	H135	Alanamu Basic Health Centre	4.53848	8.49333
131	H136	Baboko Clinic	4.54628	8.49004
132	H137	Orelope Clinic And Maternity	4.53293	8.49161
133	H138	Sifau Clinic and Maternity	4.53455	8.49079
134	H139	Tim Hospital	4.53074	8.49427
135	H140	Magajingeri Health Centre	4.52347	8.48742
136	H141	Badari Health Centre	4.54848	8.48636
137	H142	Delnic Hospital	4.5476	8.48555
138	H143	Eyitayo Clinic and Maternity, OjaIya	4.54731	8.48616
139	H144	Emir's Palace Health Clinic	4.53848	8.49322
140	H145	General Hospital Ilorin	4.53407	8.47913
141	H146	MaxiHealth Hospital Ilorin	4.52482	8.47711
142	H147	Ogidi/ Banni Basic Health Centre (Ilorin West)	4.52347	8.51151
143	H148	Oju-Ekun Health Centre	4.54069	8.50354
144	H149	Olaotan Clinic and Maternity	4.53496	8.50544
145	H150	Olorunlambe Clinic And Maternity	4.53785	8.50383
146	H151	Opeyemi Clinic & Maternity	4.53816	8.51289
147	H152	Zarumi Health Centre	4.53717	8.509743
148	H153	Asadam Clinic And Maternity	4.52318	8.46013
149	H154	Ayeitoro Health Centre	4.53779	8.47947
150	H155	Ayodele Medical Centre	4.52516	8.46815
151	H156	Duromedics Hospital	4.54133	8.46459
152	H157	Ekundayo Clinic And Maternity	4.53779	8.47947
153	H158	Odookun Health Centre	4.52621	8.47064
154	H159	Oko Erin Health Centre	4.53665	8.47377
155	H160	Olalomi Hospital	4.55178	8.47917
156	H161	Oyebanji Hospital	4.54626	8.48104
157	H162	Tobi Hospital	4.54263	8.48176
158	H163	303 M A G Medical Centre	4.51072	8.50691
159	H164	Ilorin Clinic and Maternity, Oloje	4.52361	8.5087
160	H165	Oloje Basic Health Centre	4.51552	8.51157
161	H166	Temidayo Hospital	4.50782	8.51387
162	H167	Zakary Memorial Hospital	4.51016	8.50139
163	H168	Olupelu Clinic and Maternity	4.51075	8.49582

No.	Code	Name	Longitude	Latitude
164	H169	Pakata Health Centre	4.51715	8.49997
165	H170	Idera Clinic & Maternity	4.50419	8.44038
166	H171	Surulere Medical Centre	4.54138	8.48376
167	H172	Akorede Clinic & Maternity	4.49571	8.43289
168	H173	Egbejila Health Centre	4.51867	8.41899
169	H174	Offa-garage Health Centre	4.58291	8.45037
170	H175	Ogundele Health Centre	4.45078	8.49002
171	H176	Omolewa Hospital & Maternity	4.50745	8.46146
172	H177	Osin / Aremu Health Centre	4.57225	8.42871
173	H178	Staff Clinic	4.49597	8.46155
174	H179	Wara Health Centre	4.47369	8.45995
175	H180	Mubbas	4.55519	8.50827
176	H181	Al-Shifau Clinic & Maternity	4.55246	8.5366
177	H182	Ajike Clinic & Maternity	4.55012	8.50966
178	H183	Oore-Ofe Hospital	4.56333	8.49918
179	H184	Olotu Clinic	4.56368	8.49687
180	H185	Ireti Clinic & Maternity	4.56148	8.47719
181	H186	Leah Medical Centre	4.58748	8.48772
182	H187	Ajifat Medical Centre	4.6196	8.48069
183	H188	Dayspring	4.61448	8.4813
184	H189	Al-Mubeen Clinic & Maternity	4.61102	8.47624
185	H190	Abicare Hospital	4.60787	8.47212
186	H191	Ibn Adua Hospital	4.60535	8.47472

Appendix II
Origin-Destination (OD) Cost Matrix for Cluster 1 (distance in metres)

	TC	H28	H30	H33	H34	H35	H36	H37	H38	H41	H44	H58	H59	H60	H61
TC	0	31092	31046	32589	35960	31293	33959	32497	34207	30008	31208	41804	36747	41449	38357
H28	31092	0	9567	1498	7113	201	10841	1405	5359	1293	631	18607	13549	18252	15160
H30	31046	9567	0	8069	16679	9366	2913	8161	14926	10860	10198	10758	5701	10403	7311
H33	32589	1498	8069	0	8610	1297	9343	92	6856	2791	2128	17109	12052	16754	13662
H34	35960	7113	16679	8610	0	7314	17954	8518	2018	6162	7229	25719	20662	25364	22273
H35	31293	201	9366	1297	7314	0	10640	1204	5560	1495	832	18406	13348	18050	14959
H36	33959	10841	2913	9343	17954	10640	0	9436	16200	12135	11472	11735	6678	11380	8289
H37	32497	1405	8161	92	8518	1204	9436	0	6764	2699	2036	17201	12144	16846	13755
H38	34207	5359	14926	6856	2018	5560	16200	6764	0	4408	5475	23966	18908	23610	20519
H41	30008	1293	10860	2791	6162	1495	12135	2699	4408	0	1410	19900	14843	19545	16453
H44	31208	631	10198	2128	7229	832	11472	2036	5475	1410	0	19238	14180	18882	15791
H58	41804	18607	10758	17109	25719	18406	11735	17201	23966	19900	19238	0	5057	2105	3447
H59	36747	13549	5701	12052	20662	13348	6678	12144	18908	14843	14180	5057	0	4702	1611
H60	41449	18252	10403	16754	25364	18050	11380	16846	23610	19545	18882	2105	4702	0	3092
H61	38357	15160	7311	13662	22273	14959	8289	13755	20519	16453	15791	3447	1611	3092	0

*TC =Proposed HCWTC