RESEARCH ARTICLE

A GIS and Multi-Criteria Decision Analysis for Landfill Site Selection and Management in Ibadan, Nigeria

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ABSTRACT

Many counties are striving against the incessant wave of urbanization and increasing population to establish a sustainable integrated waste management system. No doubt, the establishment and maintenance of an efficient sanitary landfill is a challenge, especially in developing countries, where many of the required standards and the legal, environmental and socioeconomic factors are frequently unavailable. Ibadan, a city in the south-west of Nigeria, for instance, there is a major problem of insufficient landfill sites, with those available mostly not being quite fit for purpose. Thus, this study investigates the viability and sustainability of the existing dumpsites in the city, using Geographic Information System (GIS) and Multi-criteria Decision Analysis (MCDA)-based Analytical Hierarchy process (AHP) techniques. Waste managers from private firms and the Oyo State Waste Management Agency (OYWMA), as well as citizens across the study area (of Ibadan- North) were interviewed. AHP was used to obtain the weights of factor parameters. Also done was a thematic mapping of the ten selected criteria, viz: closeness to airport, distance from industries, distance from gas pipeline, proximity to road, built-up area distance, slope, land cover and use, distance from highways, distance from rivers, and distance from wetlands. Suitability mapping was prepared by overlay analyses and assigned as 'very low', 'low', 'moderate', 'high' and 'highest' suitability. The results of the weighted overlay analyses showed that 4.2% of the total space had very low suitability, 5.7% had low suitability, 27.4% was moderately suitable, 45.3% was highly suitable and 17.4% had highest suitability. Given these findings, it is recommended that the existing landfills should be relocated, alongside the creation of five new landfill sites. It is also recommended for government to conduct periodic holistic evaluations of the functionality of landfill sites.

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1.0 Introduction

Waste is the inevitable by-product of human activities in solid, liquid or gaseous form. When improperly disposed of, waste can have harmful effects on both human health and the environment (Nguyen et al., 2024). The management of solid waste has become a global issue that impacts the health, environmental and socioeconomic life of the people in all parts of the world, developed or developing (Ali et al., 2014; Christensen &

Stegmann, 2020). However, waste-management problems are more intense in the developing countries, given the alarming increase in population, urbanization, socioeconomic issues and the poor waste-handling culture there, compared to the developed world (Jayaweera et al., 2019; Obasi & Maduekwe, 2021). Besides the matter of finding suitable waste-management and disposal methods, there is also the more general problem of land management. Nowadays dumpsites are becoming fewer in the face of increasing waste-disposal costs and rising levels of environmental and health hazards (Chukwuemeka et al., 2021; Manjula et al., 2019).

Various methods and tools have been used in the past to analyze land-use problems with a view to proffering solutions to them. Site suitability analyses is one of the more popular methods being adopted, especially with GIS. In recent years, GIS has been proficient as a spatial decision support system (SDSS) tool that can handle large volumes of data from different sources, particularly because of its ability to enter, store or create, display or utilize, analyze and model attributes of spatial data. GIS is a highly useful and high-performance tool in land use, site selection and management studies that saves time and cost while providing a digital database for long-time landfill site selection and management (Adewumi et al., 2019).

Multi-criteria analysis is proficient for dumpsite site selection and management techniques owing to its inherent structure that allows complex decision-making problems to be divided into smaller segments that can be addressed separately. A meaningful, pertinent and ideal answer will be obtained by logically integrating the segments at the conclusion of the analysis (Ali et al., 2020; Barzehkar et al., 2019; Manjula et al., 2019; Mohamed & Asfaha, 2023). Many studies in solid waste management have utilized various techniques of MCDM, especially AHP, which is also deployed in this work because of its wide acceptability and usability. AHP is mostly used to analyze and support decisions in which multiple and competing objectives are involved with multiple possible alternatives. Integrating GIS with MCDM-based AHP makes a perfect combination in site selection problems because GIS simultaneously analyzes the spatial and descriptive criteria, while AHP addresses ranking and prioritizing aspects in the face of socioeconomic and ecological variables.

Several studies have been undertaken on landfill site selection using GIS-MCDM-based approaches (Adewumi et al., 2019; Ahmed et al., 2014; Mussa & Suryabhagavan, 2021; Olatunji, 2022; Paul & Ghosh, 2022; Burlakovs et. al., 2013). Over the decades, these techniques have proved effective and efficient in solving the problems of waste-site selection. Waste and dumpsite management falls within the purview of the Environmental Protection Agency (EPA), which was established in 1999. Later renamed the Federal Environmental Protection Agency (FEPA), it has the responsibility of ensuring proper waste disposal and management, including managing the risks and hazards posed by existing and potential landfill sites, among other functions (FEPA, 1999; Odili, 2021). Regrettably, however, city neighbourhood and road medians are increasingly being converted to dumpsites, even as waste collectors complain about inadequate landfills. Given rising conflict between informal waste collectors and formal waste-disposal firms, it is necessary to conduct an empirical study on the state of things. Thus, this study, done in the ArcGIS 10.4 environment, aims to evaluate the present dumpsites in Ibadan and its suburbs, focusing on suitability based on ecological and socioeconomic data.

2.0 The Study Area

The study area is Ibadan, the capital city of Oyo State. Ibadan is located on seven hills, with an average elevation of about 210 metres above sea level in the south-eastern part of the state. Ibadan is about 100 miles (160km) from the Atlantic coast and about 120km east of the Republic of Benin in the forest zone, close to the boundary between the forest and the savannah. Its geographical coordinates are 7^0 18’ 41.32” North (Latitude) and 3^0 50` 29.34” East (Longitude). Ibadan is the largest city in the south-west and the third largest city in Nigeria, spanning a total area of 3080km^2. Ibadan has 11 local government areas, with five in the metropolis and six in the suburbs. There are four landfill sites in the city and these were originally located in the suburbs but are now in the city centre owing to rapid urbanization and development.

The population of Ibadan, according to the 2006 Census, is 2,550,593 (NPC, 2006), which was estimated to be 5,618,598 in 2023 at a growth rate of 2.35%. There are two distinct climates in Ibadan: the rainy season and the dry season. With the peak rainfall of 170mm (6.69 in) in September, the rainy season lasts from March to October while the dry season lasts from November to February. Ibadan experiences temperatures from 21^0 and 35^0 degrees Celsius (69.80 and 95 degrees Fahrenheit). The extracted map of the study area is presented in the Figure 1.

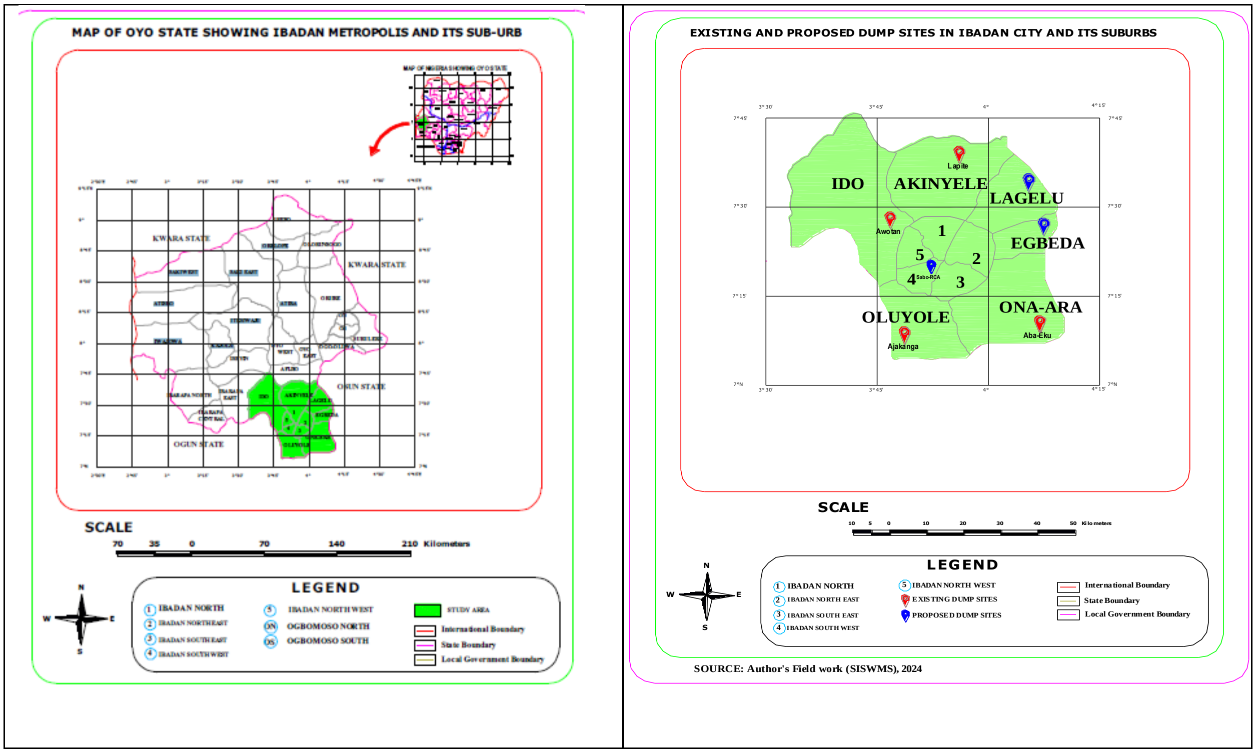

Figure 1: Location map of the study area. Source: Author's Fieldwork, 2024

3.0 Materials and Methods

Data Sets

Manuals and records on dumpsites were obtained from the Urban and Regional Planning Unit of the Ministry of Land and Housing, the Oyo State Waste Management Agency (OYWMA) and the Environmental Protection Agency (EPA). Thematic layers were obtained from the Topographic Map (1:500000), LANDSAT-8 satellite imagery (30m), the Digital Elevation Map (DEM-30m) obtained from Shuttle Radar Topographic Mission, Open Street Map (OSM accessed, August 12, 2024) and Google Earth (GE) Map (accessed August 8, 2024).

The Global Positioning System (GPS) was used to collect the coordinates of the locations. A total of twenty (20) waste managers with more than ten years' experience from five prominent private firms were selected. Fifteen (15) members of staff of OYWMA and five dumpsite managers were interviewed. Sixty (60) residents in all (15 around each dumpsite) were selected and interviewed.

The information obtained from dumpsite visits, the final drafts of previous and existing situation analysis, guidelines and checklists through record viewing, and structured interviews of stakeholders, e.g., dumpsite managers and town planners, was used to select ten (10) criteria for the work.

A spatial geodatabase comprising input datasets, derived datasets, weighted analysis map, and the final result was designed. The study area map was derived from pre-processed sentinel-2A, which was set to the World Geodetic Survey (WGS) 1984, Universal Transversal Mercator (UTM) Zone 31N coordinate system, and reclassified using the AHP weights to generate new maps.

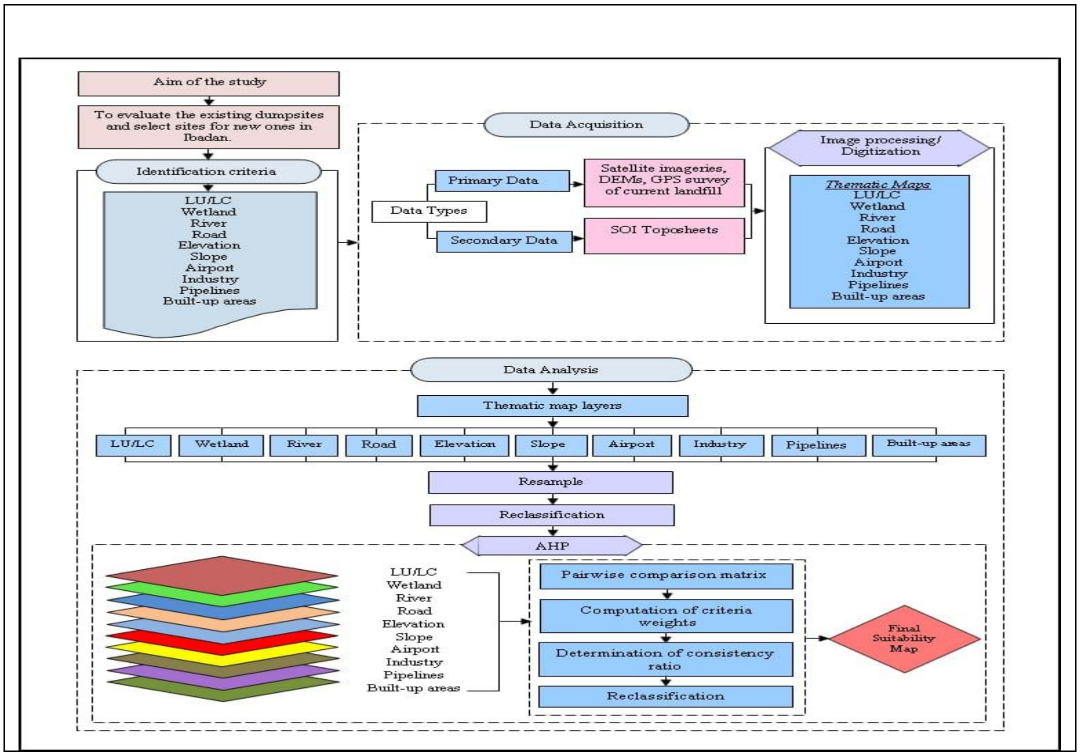

Figure 2: Methodology of the study Source: Author's Fieldwork, 2024

4.0 The Methods of Study

Having identified the physical, environmental and socioeconomic factors influencing suitability, based on the literatures and information derived from expert interviews, the study selected ten key factors, viz: proximity to airport, industrial distance, gas pipeline distance, built-up area distance, land cover and use, slope, elevation, proximity to road, river, and proximity to wetland. Each factor was represented as a thematic map layer. A thematic map of each factor was produced, standardized and analyzed using spatial analysis techniques. Some factors are more important than the others, hence, the need to assign weight based on expert opinion or using MCDA-based AHP, as deployed in this study. Weighted overlay analysis was done using the spatial analyst toolbox in GIS. The factors were reclassified into different suitability classes by assigning a common scale of 1 to 5, where 1 is 'unsuitable', 2 is 'less suitable', 3 is 'moderately suitable', 4 is 'suitable' and 5 is 'highly suitable'. Weights were assigned to the thematic layers representing the factors using AHP. The final suitability map was prepared using the GIS toolbox. The output of the final suitability map shows different areas classified from the least suitable to the most suitable.

Multi-Criteria Decision-Making AHP

The AHP integrates the empirical data with the subjective judgement of the decision-makers to arrive at an optimal decision. AHP has an in-built mechanism that minimizes bias in decision-making and ascertains the consistency of the evaluation criteria (Saaty, 2004). It takes pair-wise comparisons as inputs and uses a scale with values from 1 to 9 to generate outputs that are relative weights of the criterion. Eigenvectors formed from pair-wise comparison matrix of the criteria, based on expert judgement, were obtained with a consistency ratio (CR) for each criterion. The weighting scale and the consistency ratio is presented in Tables 3 and 4 below.

Table 1: The weighting scale for pair-wise comparison

Level of Importance	**Suitability class**	**Description**
1	Low suitability	Equally important
2	Very low suitability	Equal to moderate important
3	Low suitability	Moderately important
4	Moderately low suitability	Moderately to strong importance
5	Moderately suitable	Strong importance
6	Moderately high suitability	Strong to very strong importance
7	High suitability	Very strong importance
8	Very high suitability	Very to extremely strong importance
9	High suitability	Extremely strong importance

Source: Author 2024 adapted from Saaty (2004).

Table 2: Random index (RI)

Order matrix	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Author (2024), adapted from Saaty (2004)

To create the weighted sum vector, the weight of each criterion is multiplied by the column in the original pair-wise comparison matrix, from the first criterion, times the first column to the final criterion times the last column. The values are then added together across the rows. Using the random index (RI), which is the number of elements being compared, and the consistency index (CI), which is a measure of consistency in the decision-making process, the consistency ratio (CR) is used to analyse the rational degree of consistency in the pair-wise comparison. The consistency vector is obtained by dividing the weighted sum vector by the criterion weights determined previously. CI is calculated using the average value of the consistency vector (lamda-λ) and the number of criteria (n) using the equation below:

$$CI = \frac{(\lambda - n)}{(n-1)} \qquad 1$$

The CR is obtained using the equation:

$$CR = \frac{(CI)}{RI} \qquad 2$$

CR <0.1 indicates a rational level of consistency in the decision-making process, while a CR >0.1 indicates inconsistent judgements. However, the lamda in this work is 10.5364, n = 10 and RI = 1.49; therefore, the CR = 0.04.

The multi-criteria model-AHP was used to compute the weights of each factor, with the local weight being multiplied by the weight of the criteria to obtain the global weights, which are used for the final suitability map. The eigenvectors of the pair-wise comparison factor is presented in the table below:

Table 3: The pair-wise comparison's matrix

Factors	LU	WL	RP	RDP	EL	SL	AP	IP	PP	BA	Weight
Land use (LU)	1	2	1/2	1/2	1/3	1/3	1/5	1/4	1/7	1/6	0.0279
Wetlands (WL)	½	1	1/2	1/2	1/3	1/3	¼	1/4	1/5	¼	0.0274
River proximity (RP)	2	2	1	1/2	1/3	1/3	¼	1/4	1/5	¼	0.0358
Road proximity (RDP)	2	2	2	1	1	½	1/3	¼	1/5	1/5	0.0483
Elevation (EL)	3	3	3	1	1	1	1/2	½	1/3	1/3	0.0711
Slope (SL)	3	3	3	2	1	1	1/3	½	1/3	½	0.0768
Airport proximity (AP)	5	4	4	3	2	3	1	½	1/3	½	0.1245
Industry proximity (IP)	4	4	4	4	2	2	2	1	1/3	1/2	0.1375

Pipelines proximity (PP)	7	5	5	5	3	4	3	3	1	2	0.2556
Built-up Areas (BA)	6	4	4	5	3	4	2	2	1/2	1	0.1952

Consistency Ratio: 0.04 **Source**: Author's fieldwork, 2024

Suitability Calculation Using Thematic Map Layers

The suitability analysis was performed using the Google Earth (GE) and ArcMap 10.4 software, specifically the spatial analysis toolbox in GIS. Each of the influencing factors is represented as a thematic layer. The raster data, e.g., the Digital Elevation Model-DEM and satellite imagery for land use, was collected. Vector data, e.g., on roads, was collected and converted to raster using the "feature to rater" tool in the spatial analyst toolbox. All layers were converted to the same coordinate system and cell size before being re-classified using the "reclassify" tool.

A common suitability scale of 1 to 5 was assigned to the parameters with which the factors were measured. A scale assigned as 1 means unsuitable, 2 means less suitable, 3 means moderately suitable, 4 means suitable and 5 means highly suitable. Since some factors are more important than others, there is the need for weighting the thematic layers using the expert opinion and/or AHP. These weights are ensured to be 100%. The weighted overlay analysis was performed with the "weighted overlay" tool in the spatial toolbox and visualization was enhanced using the "symbology" tool in the ArcGIS. The results were validated via expert review and ground truth data. The output maps shows the areas classified from least suitable (low values) to the most suitable (high values).

$$Suitability\ map = \sum[Criteria\ map \times Weight] \qquad 3$$

$$Suitability\ index\ (SI) = \sum_{i=1}^{n} W_i C_i \qquad 4$$

Where W_i is the weight of each factor i and C_i is the factor scores.

SI= [(LULC*0.0279) + (WL*0.0274) + (RP*0.358) + (RDP* 0.0483) + (EL*0.0711) + (SL*0.0768) + (AP*0.1245) + (IP*0.1375) + (PP*0.2556) + (BA*0.1952)

The result shows that 4.2% of the total area of the space was found to have very low suitability and 5.7% low suitability, while 27.4% was moderately suitable, 45.3% highly suitable and 17.4% had the highest suitability. The standard parameters used are presented in Table 4:

Table 4: Criteria and standards for suitability classes

S/N	Criteria	Standard parameter
1	Land use/Land cover	Vacant space
2	Wetlands	More than 1000m away
3	Rivers proximity	More than 1000m away
4	Road proximity	200-800m
5	Elevation	35-70m
6	Slope	Less than 10 degrees
7	Airport proximity	More than 25 km
8	Industry proximity	≥1000m
93	Pipelines proximity	≥1000m
10	Built-up Areas	≥1000m

Source: FEPA 1999

5.0 Results

The dumpsites having exceeded the useful life span of 25-30 years, are old and need to be closed and relocated. Findings revealed that out of the four existing dumpsites in Ibadan and its suburbs, one is moribund, one is in deplorable conditions, one is under rehabilitation, and one is just manageable. There was no dumpsite with a functioning weighbridge as at the time of this study. In fact, only at Awotan was waste covered with soil. Table 5 presents the standing of the dumpsites and the issues with them.

Table 5: The Dumpsites: Location, size and details

Dumpsites	Aba Eku (East)	Ajakanga (West)	Lapite (North)	Awotan (South)
In service date	1985	1996	1996	1987
Approximate Size(ha)	9.419	10.034	9.1	20.259
Location	N07°32 E03°98	N07°46’3 E03°85	N07°57 E03°91	N07°31 E03°84

Multi-criteria decision-making techniques integrated with GIS offer the opportunity to combine stakeholder decisions with socioeconomic and geographical data in the evaluation, selection and management of dumpsites. The ten criteria used in this study were ranked and analysed using the standards presented in Table 4. The following table lists the selection criteria for dumpsite sites along with their suitability, rank and weights.

Table 6: Dumpsite site selection criteria together with their weight, rank and class

Criteria	Parameter	Suitability Class	Rank	Weight	Area (Sq. Km	Area (%)
LULC	Built-Up Area	Unsuitable	1	0.2202	1427.89	46.34
	Agriculture	Less suitable	2	0.1354	728.73	23.66
	Vegetation	Moderately Suitable	3	0.1323	532.22	17.28
	Vacant Space	Highly Suitable	5	0.5121	391.78	12.72
Wetlands proximity	<1000m	Unsuitable	1	0.1201	320.94	10.42
	1001m-2000m	Moderately Suitable	3	0.1236	583.04	18.93
	2001m-3000m	Suitable	4	0.2431	855.93	27.79
	>3000m	Highly Suitable	5	0.5132	1320.08	42.86
Rivers proximity	<1000m	Unsuitable	1	0.0383	388.38	12.61
	1001m-2000m	Moderately Suitable	3	0.1045	534.07	17.34
	2001m-3000m	Suitable	4	0.2252	640.02	20.78
	>3000m	Highly suitable	5	0.6320	1517.52	49.27
Elevation	>100m	Unsuitable	1	0.0682	260.88	8.47
	71m-100m	Moderately Suitable	3	0.1553	744.74	24.18
	35m-70m	Suitable	4	0.2950	1577.88	51.23
	<35m	Highly Suitable	5	0.4797	496.49	16.12
Slope	$>25^0$	Unsuitable	1	0.0713	39.17	1.27
	16^0-25^0	Moderately Suitable	3	0.1372	99.18	3.22
	10^0-15^0	Suitable	4	0.2203	257.79	8.37
	$<10^0$	Highly Suitable	5	0.5715	2221.91	72.14
Airport proximity	<15Km	Unsuitable	1	0.0246	530.36	17.22
	15Km-30Km	Moderately Suitable	3	0.2663	713.94	23.18
	31Km-45Km	Suitable	4	0.1478	866.40	28.13
	>45Km	Highly suitable	5	0.5613	969.28	31.47
Industry proximity	<1000m	Unsuitable	1	0.0682	190.65	6.19
	1001m-2000m	Moderately Suitable	3	0.1664	403.79	13.11
	2001m-3000m	Suitable	4	0.2726	752.44	24.43
	>3000m	Highly suitable	5	0.5128	1733.12	56.27
Pipeline proximity	<1000m	Unsuitable	1	0.0344	158.31	5.14
	1001m-2000m	Moderately Suitable	3	0.1612	342.80	11.13

	2001m-3000m	Suitable	4	0.2436	689.30	22.38
	>3000m	Highly Suitable	5	0.5610	1923.46	62.45
Built Area	<1000m	Unsuitable	1	0.0323	190.04	6.17
	1001m-2000m	Moderately Suitable	3	0.1634	716.72	23.27
	2001m-3000m	Suitable	4	0.3522	311.70	10.12
	>3000m	Highly Suitable	5	0.4521	1861.55	60.44

Land Use and Land Cover (LULC)

Apart from an area's natural vegetation cover, socioeconomic activities also determine land cover and land use over time. Four land-use classes were identified in this study, viz: agricultural or cultivated land (ranked less suitable -2), vegetation-covered land (ranked moderately suitable -3), populated or built-up area (ranked unsuitable -1) and vacant space (ranked suitable -4). The information on land use and land cover (Figure 3) indicates that 46.34%, 23.66%, 17.28% and 12.72% of the study areas in Ibadan and its suburbs are unsuitable, less appropriate, moderately acceptable, and suitable for sanitary landfills respectively.

Wetlands

To avoid risks from leachates and other types of contamination, landfill locations should be situated far from water sources and places that are prone to flooding. The total areas were classified into four: places less than 1000m to a water source are unsuitable (ranked 1), places between 1000-2000m to waterlogged area are moderately suitable (ranked 3), areas between 2000-3000m are suitable (ranked 4) and areas more than 3000m away from a water source are highly suitable (ranked 5). The figure on proximity to wetlands above shows that 10.42%, 18.93%, 27.79% and 42.86% of the entire area are unsuitable, somewhat suitable, appropriate, and extremely appropriate in that order for Ibadan landfill sites.

Rivers Proximity

To prevent water contamination or pollution, landfill sites should not be close to any water surface.. As a result, buffer zones farther from rivers have better appropriateness ratings, with four classes identified. An area less than 1000m to the river is unsuitable (ranked 1), any area between 1000-2000m to a river source is moderately suitable (ranked 3), an area between 2000-3000m to the river source is suitable (ranked 4) and any area more than 3000m is highly suitable (ranked 5). Given these figures, 12.61%, 17.34%, 20.78% and 49.27% of the entire area are respectively unsuitable, moderately appropriate, suitable and extremely suitable for the location of a dumpsite.

Road Proximity

The placement of landfills near major roads and highways lowers construction costs and minimizes the disruption of primary traffic caused by waste-carrying vehicles. A location less than 200m to the main road is desirable, while a distance of about 1km is to be avoided in the present design. A proximity zone less than 100m is assigned highest suitability (ranked 5), places between 100m and 200m to the main road are suitable (ranked 4), places between 200m and 800m are moderately suitable (ranked 3), places between 800m and 1000m are less suitable (ranked 2), while places greater than 1km are unsuitable (ranked 1). The figure on road proximity shows that none of the existing and proposed sites is unsuitable when it comes to road proximity, with 9.38%, 20.53%, 24.56% and 45.53% being less appropriate, somewhat appropriate, appropriate and extremely appropriate respectively, given the location of the dumpsite in Ibadan.

Elevation

The city of Ibadan is located on seven hills. Such a hilly landscapes marks is an additional problem for waste-carrying vehicles, apart from increasing construction costs. High elevations are assigned the least suitability, while low elevation is desirable. Places with elevations less than 35m are assigned the highest suitability (ranked 5), places with elevation from 35-70m are assigned high suitability (ranked 4), places with elevations from 70-100m are rated to be moderately suitable (ranked 3), while places with elevations greater than 100m are judged to be unsuitable (ranked 1). The figure on elevation above shows that 8.47%, 24.18%, 51.23% and 16.12% of the total study areas are respectively unsuitable, moderately appropriate, suitable, and highly suitable.

Slope

An area with a slope that is more than 25 degrees is not suitable (ranked 1), an area with between 15 and 25 degrees sloping is moderately suitable (ranked 3), one with between 10 and 15 degrees is suitable (ranked 4), while an area with less than 10 degrees is highly suitable (ranked 5). Figure 3 shows that, as far as slopes are concerned, 1.27%, 3.22%, 8.37% and 72.14% of the entire area are unsuitable, moderately acceptable, suitable, and highly suitable respectively as new landfill sites.

Airport Proximity

Landfills draw dust and birds, which impede air travel; therefore, landfills should not be located within 20km of an airport. In this work, places less than 15km to the landfill are considered unsuitable (ranked 1), places from 15-30km are moderately suitable (ranked 3), places from 30-45km are suitable (ranked 4) and places beyond 45km are highly suitable (ranked 5). The figure on the proximity to airport shows that 17.22%, 23.18%, 28.13% and 31.47% of the total area are unsuitable, moderately suitable, suitable and highly suitable respectively for landfill sites based on proximity to an airport.

Industry Proximity

Industrial activities close to landfills increases the risks of soil erosion and sedimentation. Also, percolation of leachate to the surface and groundwater resources will cause pollution. A landfill at a distance less than1000m is not suitable (ranked 1), places from 1000-2000m are moderately suitable (ranked 3), places from 2000-3000m are suitable (ranked 4) and, places more than 3000m are highly suitable (ranked 5). Thus, 6.19%, 13.11%, 24.43% and 56.27% of the entire study area are unsuitable, moderately acceptable, suitable and extremely suitable for landfill location, according to the figure on closeness to industry.

Pipeline Proximity

Excavation and construction of pipelines sometimes lead to soil erosion and surface water pollution. As such, landfill sites should not be located within 1000m to any pipelines network, as it is adjudged unsuitable (ranked 1), while places from 1000-2000m are moderately suitable (ranked 3), places from 2000-3000m are suitable (ranked 4) and places more than 3000m away are highly suitable (ranked 5). Thus, 5.14%, 11.13%, 22.38% and 62.45% of the total area are respectively unsuitable, moderately appropriate, suitable and extremely favourable for landfill placement, based on data on proximity to pipelines.

Built-up Areas

Locating a landfill in the midst of a residential area brings adverse environmental effects such as odour, traffic, dust and noise from vehicles and mechanical equipment. Therefore, a landfill is not to be allowed to be within 1000m to a residential area. In this work, landfills falling within 1000m to a neighbourhood are unsuitable (ranked 1), those between 1000-2000m are moderately suitable (ranked 3), those between 2000-3000m are suitable (ranked 4), and those located more than 3000m are highly suitable. The data on built-up areas shows that 61.44%, 23.27%, 10.12% and 6.17% of the total area are unsuitable, moderately suitable, suitable and highly suitable respectively as landfill locations.

6.0 Discussion

The data analysis shows that waste-disposal practices in Ibadan are not in line with international best practices in terms of public health and environmental protection. The study has used geospatial technology and multi-criteria decision-making techniques to assess and evaluate the state of waste management and disposal with a view to proffering lasting solutions to existing issues while identifying viable dumpsites in the city of Ibadan, Nigeria. Remote data sensing and online screening were used to analyse the present state of waste-disposal facilities and map out potential waste dumpsites in the areas. The result of the buffer operation on the study areas shows that they have less suitable areas for landfills owing to increasing urbanization and development in Ibadan and its suburbs. Buffering analysis was used to determine the proposed landfill locations at a slope less than 10 degrees, an elevation less than 35m, road proximity of between 200m and 800m, and more than 25km from the airport on a vacant land or light vegetation areas. These locations are at a proximity of more than 1km to built-up areas, pipeline networks, industries, rivers, and wetlands. These trends are observed globally, especially in the developing countries (Aderoju et al., 2018; Ali et al., 2020; Ugoji et al., 2020; Alam et al., 2022).

These results are in consonance with similar studies (though not in the same part of the country) that have found some dumpsites to be unsuitable because of their locations, which were originally the outskirts of town but have now become city centres owing to rapid urbanization and development (Aderoju et al., 2018; Meidiana & Gamse, 2016; Vambol et al., 2019; Zulu & Jerie, 2017). The overall suitability map is presented in Figure 3 while the thematic layers of the criteria, overall area-wise suitability classes, location and size of proposed (including the existing) dumpsites are presented in Figure 4, tables 7 and 8 respectively in the appendix section.

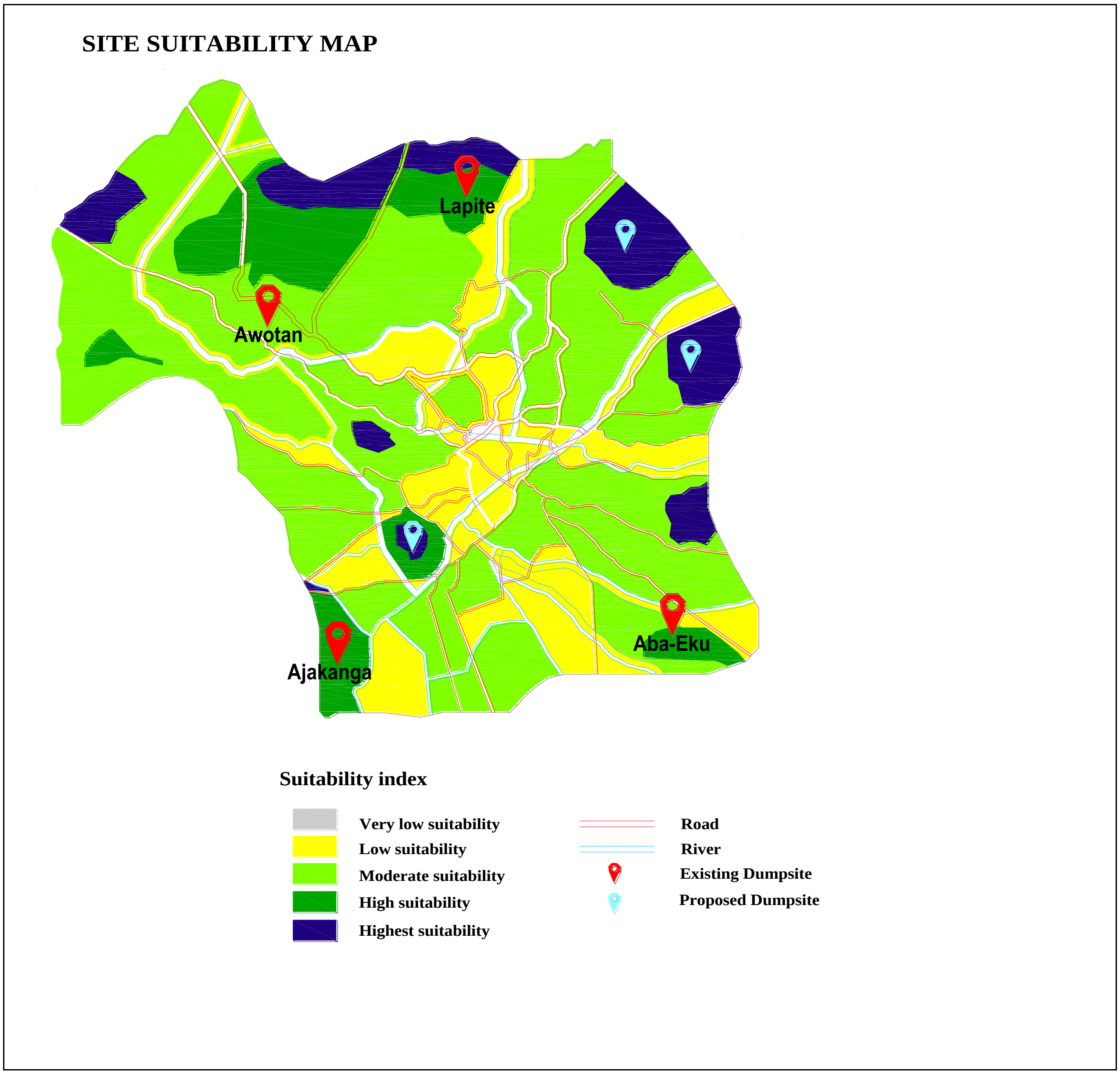

Figure 3: Final suitability map

Source: Author’s fieldwork, 2024

7.0 Conclusion

Wastes are the inevitable products of daily human activities posing a heavy challenge to humanity owing to rising population and urbanization, coupled with improper disposal and poor management in developing cities such as Ibadan. In this work, the researcher conducted suitability assessments of existing landfill sites in the city. It was found that many of the existing dumpsites that were formerly in suitable locations have now ended up as unsuitable because of rapid urban development. Since this empirical study was limited to solid-waste disposal in Ibadan and its environs, it is necessary to include more criteria with a view to increasing the accuracy of the assessment. Accordingly, other MCDM methods, e.g., fuzzy-based techniques, should be explored and compared with these findings. Moreover, sustainable integrated solid-waste management, alongside many waste-treatment alternatives (e.g., recycling and re-use, composting, and anaerobic digestion), should be explored before re-usable materials and raw materials are sent to the existing landfills.

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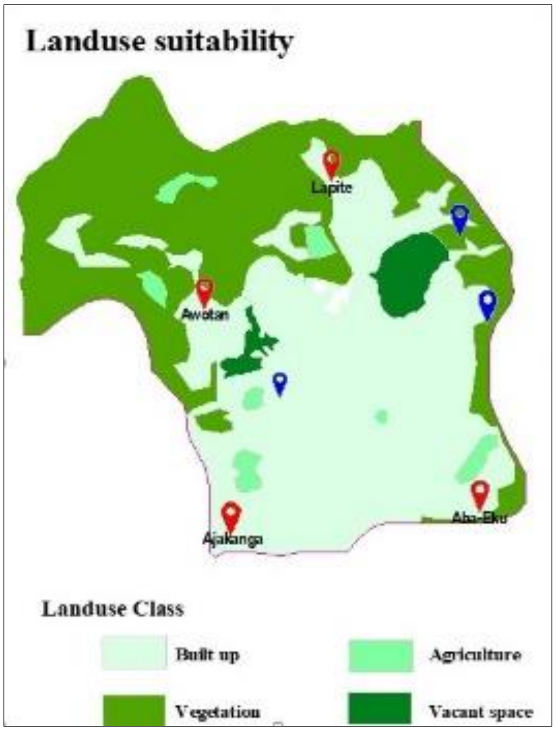
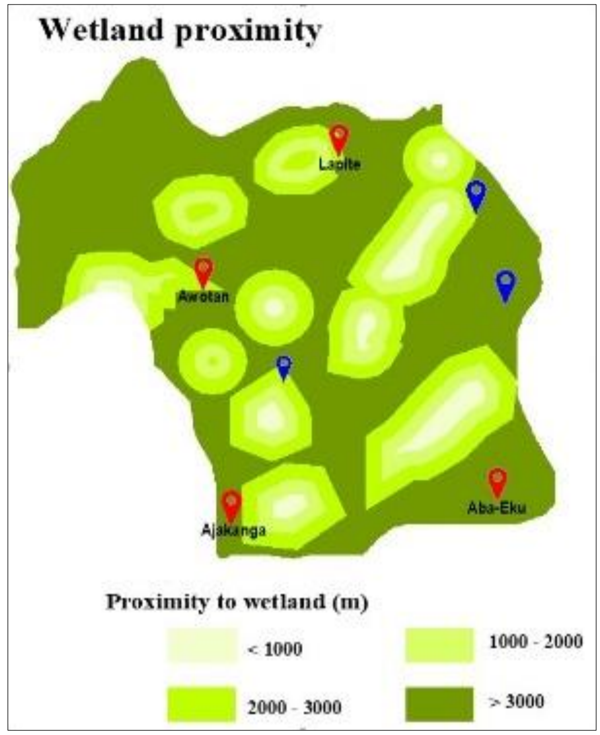
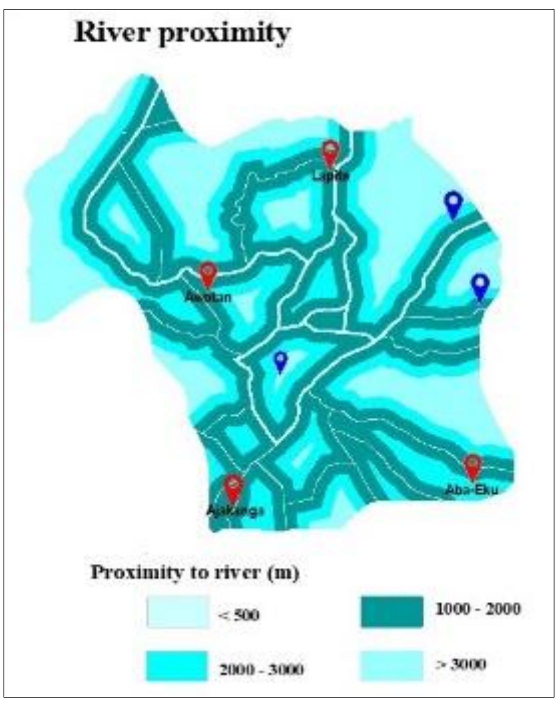
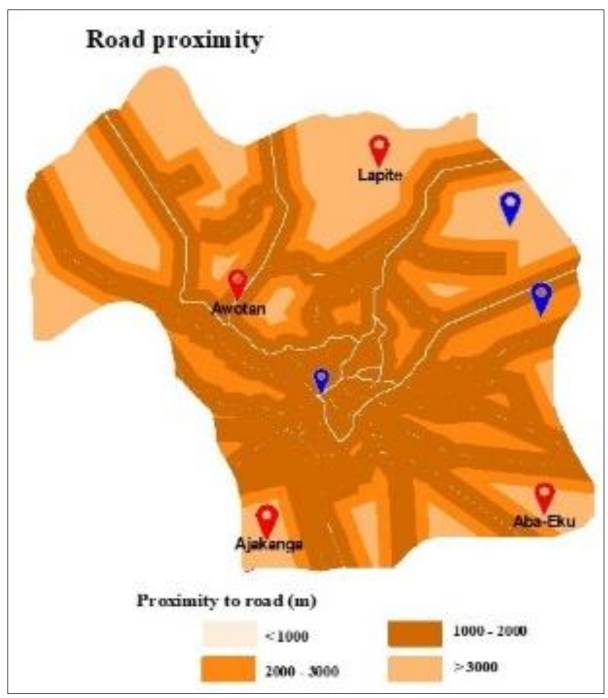
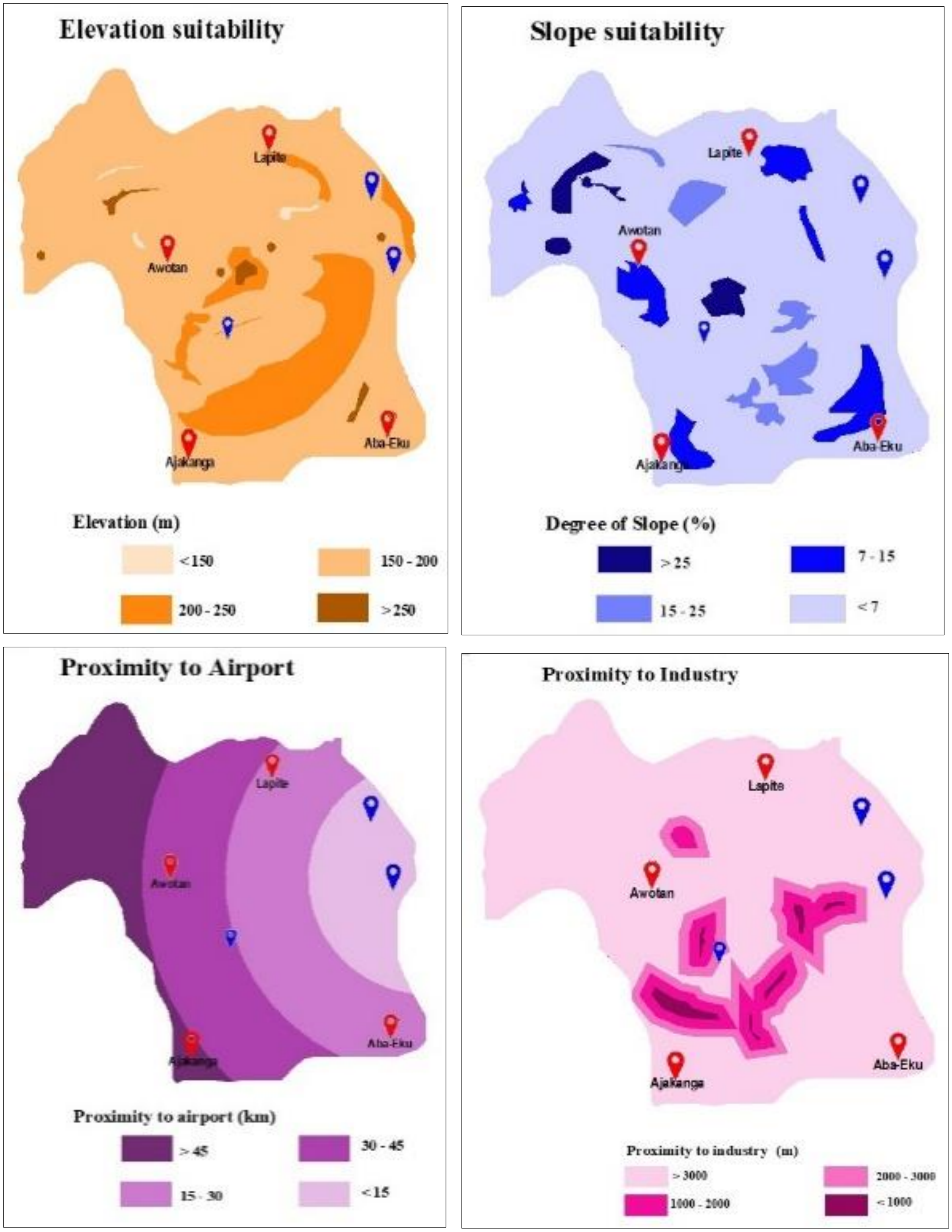
Appendices


Landuse suitability
Lapite
Awotan
Ajakanga
Aba-Eku
Landuse Class
Built up
Agriculture
Vegetation
Vacant space


Wetland proximity
Lapite
Awotan
Ajakanga
Aba-Eku
Proximity to wetland (m)
< 1000
1000 - 2000
2000 - 3000
> 3000


River proximity
Awotan
Aba-Eku
Proximity to river (m)
< 500
1000 - 2000
2000 - 3000
> 3000


Road proximity
Lapite
Awotan
Ajakanga
Aba-Eku
Proximity to road (m)
<1000
1000 - 2000
2000 - 3000
>3000


Elevation suitability
Lapite
Awotan
Ajakanga
Aba-Eku
Elevation (m)
<150
150 - 200
200 - 250
>250
Slope suitability
Lapite
Awotan
Ajakanga
Aba-Eku
Degree of Slope (%)
> 25
7 - 15
15 - 25
< 7
Proximity to Airport
Lapite
Awotan
Aba-Eku
Proximity to airport (km)
> 45
30 - 45
15 - 30
<15
Proximity to Industry
Lapite
Awotan
Ajakanga
Aba-Eku
Proximity to industry (m)
> 3000
2000 - 3000
1000 - 2000
< 1000

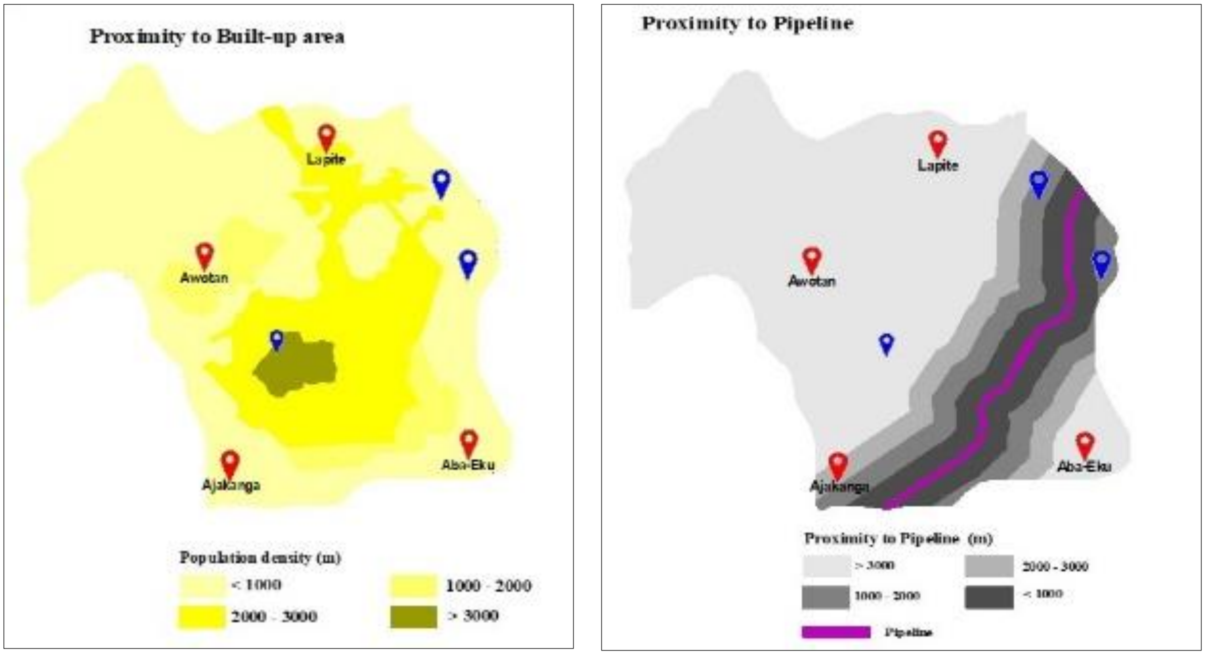


Figure 4: The thematic layers
Source: Author's fieldwork, 2024

Table 7: Area-wise suitability classes

Suitability Class	Area (Sq Km)	Area %
Very low suitability	129.36	4.2%
Low suitability	175.56	5.7%
Moderate suitability	843.92	27.4%
High suitability	1395.24	45.3%
Highest suitability	535.92	17.4%
Total	3080	100%

Table 8: The location and size of proposed and existing dumpsites

Site No.	Name of Site	Status	Approximate size
1	Awotan	Existing	20.26 (ha)
2	Ajakanga	Existing	10.03(ha)
3	Lapite	Existing	9.1(ha)
4	Aba-Eku	Moribund	9.42(ha)
5	RCA	Proposed	4.12(Sq. Km)
6	Ona-Ara LG (Akanran)	Proposed	8.5 (Sq. Km)
7	Egbeda LG (Akiti)	Proposed	10.3(Sq. Km)
8	Lagelu LG (Apatere)	Proposed	10.5(Sq. Km)
9	IDO LG (Ido)	Proposed	9.2 (Sq. Km)