Research Article

A GIS–AHP-based approach in siting MSW landfills in Lokoja, Nigeria

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Abstract
The acute shortage and scarcity of lands for suitable waste disposal is rapidly becoming a critical growing potential problem in most urban cities in developing countries of the world, and several fast-growing cities in Nigeria are not exempted from this menace. In this study, geographic information system (GIS) and analytic hierarchy process (AHP) are combined to select the most suitable landfill location in Lokoja, Nigeria. The landfill site selection criteria considered include proximity to major road, powerline, water body, landfill areas and built-up area. GIS was used to digitize spatial features related to unsuitable landfill site. A total of 19 candidate landfill sites were identified from GIS analysis. AHP model was developed from the GIS result as multi-criteria decision tool in evaluating each candidate site so as to choose the best appropriate landfill site. AHP model rated candidate site 11 located along Jimgbe road has the most preferable site to locate a landfill in Lokoja with an approximate area of 3.4204 km^2; the distance from the minor road, nearest water body, powerline and built-up areas to the location is 210.50 m, 1408.20 m, 1810.80 m and 205.61 m, respectively. Also, the model rated candidate site 16 located along 500 housing units as the least preferable site to locate a landfill in Lokoja. The characteristic features of the site location as obtained from GIS analysis include an approximate area of 2.5680 km^2 at an approximate distance of 2430.75 m, 594.04 m, 1980 m and 200.68 m from the major road, water body, powerline and built-up areas, respectively. This result will greatly serve as guide in landfill site selection in major urban states of other developing countries.

Keywords GIS · AHP · Site selection · Multi-criteria decision (MCD) · Landfill

1 Introduction

A pertinent issue which is related to environmental management via proper supervision and control of solid waste, pollution and health risks which arise in open dumping sites that are often commonly used for waste disposal is termed solid waste management (SWM) [1–4]. The menace of environmental pollution ensuing from indiscriminate waste disposal through open and poor waste disposal techniques has been a threat to the inhabitants of most developing countries [5–7], and its harmful effects on the (soil and water) environment and human health are considered to be frightening [8–11]. Throughout history, the commonest technique of organized waste disposal has been landfills and it has remained so in several places worldwide. Some landfills have been utilized in waste management application such as temporary storage and the combining, transferring and processing of waste material [12]. Landfills have also proved to be productive relative to the cost of waste disposal, particularly in locations having large spaces that are opened. As incineration, resource recovery and materials recovery require large

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investments in infrastructure, and extensive manpower to maintain, landfills have low capital and operational costs which make them compete favourably. In addition to the aforementioned benefits of landfill, gas generated from it can be improved to natural gas for domestic utilization which is a potential revenue stream [13].

Most cities and communities all over the world are often faced with task of making a suitable decision when finding the most appropriate sites for new landfills [14, 15] as process of making choice is a complex procedure since social, environmental and technical factors must be considered together [16, 17]. Siting evaluations are ruled by employing the pre-existent land-use changes in the developed area as well as the nature of plausible interactions of the landfill with the previous environmental, geologic, hydrological and socioeconomic parameters of the area [18]. Siddiqui et al. [19] had been amongst the first to combine GIS and AHP for landfill siting. This integration performs an extensive function in locating landfills for waste management. Some techniques have been singularly used in landfill site selection study such as geographic information systems (GISs) [20, 21], analytical hierarchy process (AHP), analytical network process (ANP), simple additive method (SAM), weighted linear combination (WLC), multi-criteria decision analysis (MCDA) and fuzzy logic [22–24], whereas in some studies, two or more techniques were combined. In recent studies, Chabuk et al. [25] combined GIS and MCDA methods for selecting landfill of an area in Iraq called Al-Hashimiyah Qadhaa in Babylon. Two landfill locations which were suitable candidates were identified in Al-Hashimiyah Qadhaa which were able to retain solid waste from years 2020 to 2030. Moeinaddini et al. [26] and Salman and Gholamalifard [27] experimented on landfill siting through weighted overlay using the weighted linear combination (WLC) method. Bottero et al. [28] combined AHP and ANP methods in selecting in a landfill site. Pandey et al. [29] employed in Bhagalpur, India, an expert-based ranking method for selecting suitable municipal solid waste (MSW) landfill site. Isalou et al. [30] systematically distributed fuzzy logic by integration into ANP in another part of Iran. All the aforementioned researcher's findings revealed that combining two or more methods can help define and select a site that is more appropriate than applying them differently.

In the consideration involving all factors in landfill siting techniques, the combination of GIS and AHP will form an efficient tool to solve the problem of landfill site selection and also to research criteria within the modelling process. It is generally used to consider location problems [31]. GISs provide competent manipulation and presentation of data and can manage great bulk of spatially distributed data from a variety of sources as it effectively stores, recover, examine and show information in accordance with the user-defined specifications [26, 32], while AHP helps to rank suitable sites and choose the best one as it supplies consistent ranking of the potential landfill areas based on a variety of criteria available [33]. This study is aimed at combining GIS with AHP techniques coupled with field analysis for analysing the best location for landfill siting in Lokoja, Nigeria.

2 Materials and methods

2.1 Study area

Lokoja is the capital of Kogi State with a total population of about 196,643 in 2006 [34] with approximate area of 3180 km^2 with location between latitude 7° 46′ N–7° 52′ N and longitude 6° 38′ E–6° 46′ E. The city is the seat of government activities in the state, a factor majorly responsible for its urbanization. The major occupations of the indigenes are farming, fishing and weaving. It is also a trade centre with respect to its agricultural products because of its proximity to the new Federal Capital of Nigeria in Abuja. Lokoja is also, the headquarter of Lokoja Local Government, and the major confluence town in Nigeria. The study area enjoys both wet season from March to November and dry seasons from December to February with a total annual rainfall ranging between 804.5 and 1767.1 mm. The mean annual temperature is about 27.7 °C having 30% and 70% relative humidity in both dry and wet seasons. Mean daily wind speed and vapour pressure are 89.9 km/h and 26 Hpa, respectively. One paramount hydro-geological feature in the study area is the River Niger and the confluence of Rivers Niger and Benue [35]. The geology of the study area consists of mainly of Precambrian basement complex rock and elevation on the western side which varies from 273 to 333 m above sea level while on the eastern side it varies from 273 to 364 m. Figure 1 represents administrative map of Kogi State showing some settlements and the study area (Lokoja).

2.2 Data acquired and source

This study combines spatial data analysis in GIS environment with multi-criteria decision-making process. Map of the area was firstly georeferenced and subsequently digitized to show criteria features considered for selecting landfill site of municipal solid waste in the GIS environment. Buffer analysis was performed on the digitized features to exclude areas where municipal solid waste landfill cannot be located. Maps showing criteria features and buffer analysis were subsequently prepared. The buffered maps were analysed to show potential landfill sites in the

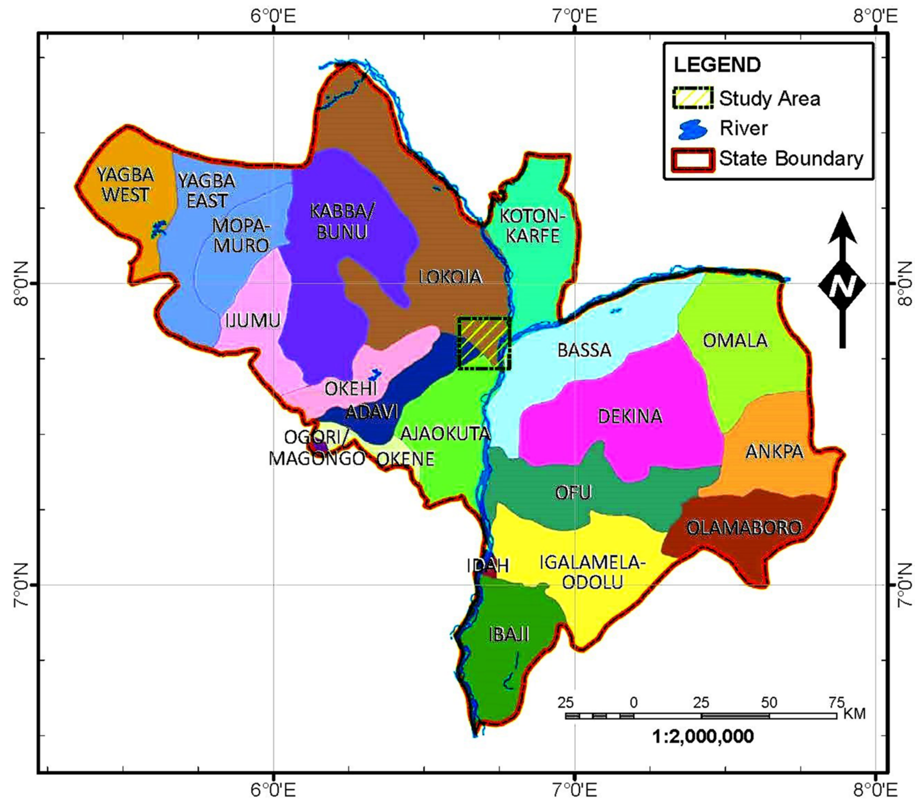

Fig. 1 Map showing study area in Kogi State, Nigeria

study area. Based on geographical location and characteristic features, the potential landfill sites were reduced and the AHP model was adopted as a MCDA making process to identify the best landfill site in the study area.

2.3 Data gathering

The data needed for this research include available analogue maps, digital elevation modem (DEM) and digitalized maps showing required features. The digital maps contain information on built-up areas, housing estates, property boundaries, undeveloped areas, water bodies, air-strip, pipeline, road network and railway line within the study area. Then, the available analogue maps containing the features required for the study area are scanned and saved.

2.4 Digitization

For the process of digitization, new layers are created in the ArcCatalog by creating a personal geodatabase. From the personal geodatabase (this personal geodatabase is renamed to reveal different features from the scanned maps), new features for road, water bodies and land use were then created for various features on the scanned map.

2.5 Buffering

The buffering operation was performed from the ArcMap window by choosing "Buffer" from the analyst tools in the ArcTool Box. The linear distances for creating buffer zones around the various features were adapted from Sumathi et al. [20] having linear distances of 200 m each for road and river buffer, respectively. A linear distance of 500 m was adopted for land-use/land-cover buffer [18] and 1500 m linear distance for power station buffer [15].

2.6 Extraction of potential landfill sites

The potential landfill sites were extracted from the combined buffer maps by removing the combined buffer areas obtained via map overlay.

2.7 Application of AHP in siting solid waste landfill

For valuation of the criteria features obtained from the GIS analysis, various methods such as logistic regression, AHP, weight of evidence, ratio estimation and the Delphi process could be chosen. AHP model was adopted in this research in order to give value to the criteria and select the best appropriate site. The incorporation of AHP and GIS facilitates decision-making process significantly [36, 37]. Satty [38] was the first to propound AHP and it is asserted

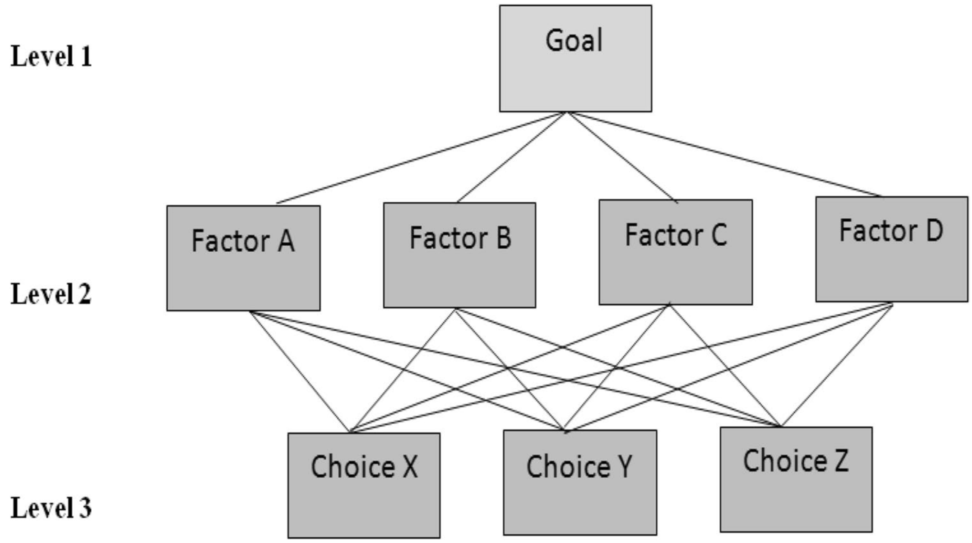

Fig. 2 Hierarchy in AHP for selection of landfill site

Table 1 Comparison scale in AHP. *Source*: Saaty (1980)

Level of relevance	
9	Absolute relevance
7	Demonstrated relevance
5	Essential or strong relevance
3	Weak relevance of one over another
1	Equal relevance
2, 4, 6, 8	Intermediate values between the two adjacent judgments
Reciprocal of the above nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

to be one of the best decision-making methods. It is one of the most all encompassing systems designed for making multi-criteria decisions since it relates the prospect for developing problems in a hierarchical manner [39]. It is a flexible and powerful tool for both qualitative and quantitative investigation of multi-criteria problems [40]. AHP is characterized based on paired comparisons as it is helpful in breaking down complicated problems with multiple criteria into number of matched comparisons [41].

2.8 AHP process in selecting the best landfill site

The development of AHP model using criteria features obtained from the GIS analysis help to rank alternatives (candidate landfill sites) in order of priorities. Figure 2 depicts the AHP process that was used for the selection of the best landfill site. The topmost level (level 1) of the hierarchical structure represents the main goal which is the location of the best suitable site. Level 2 represents the criteria considered in the selection process which involves the characteristics features of candidate sites obtained from the GIS analysis. The last level (level 3) represents various alternatives (candidate landfill sites) represented in GIS analysis. However, the alternatives are trimmed down to reasonable numbers owing to the geographical location of the site or land area considered.

The AHP method mainly allows assigning a priority to a number of decision alternatives and/or to relate criteria characterized by qualitative and quantitative assessments (often not directly comparable), combining multidimensional measures into a single scale of priorities [38]. AHP is used to derive ratio scales from paired comparisons [19, 21, 42–44]. Using a nine-point scale which includes 9, 8, 7,…, 1/7, 1/8, 1/9, the comparison was made, where 9 represents extreme preference, 7 represents very strong preference, 5 represents strong preference, and so on until it gets down to 1, which signify no preference (Table 1). This pair-wise comparison permits for an independent rating of each factor's contribution, which therefore simplify the decision-making process. The pair-wise comparisons of different criteria were usually arranged into a square matrix with the diagonal elements of the matrix being 1. Bhusan and Rai [45] observed that the corresponding normalized right eigenvector and the principal eigenvalue of the comparison matrix gave the relative importance of the criteria being compared. The elements of the normalized eigenvector were weighted with respect to the criteria or sub-criteria and rated with respect to the alternatives.

The consistency check offered by AHP makes it a unique tool in the cause of decision-making [46]. The consistency check allows for improvement in making decision. The consistency of judgment can be determined by the eigenvalue method which evaluates maximum eigenvalue (λ_{max}) of the pair-wise comparison matrix [47]. The comparison matrix for a given n rows and n columns is given by the matrix relation.

$$A = a_{ij} = a_{21}\begin{pmatrix} a_{11} & a_{12} \dots a_{1n} \\ a_{22} \dots a_{2n} & \\ a_{n1} & a_{n2} \dots a_{nn} \end{pmatrix}$$

where a_{ij} is the value obtained from the fundamental scale of comparison.

The maximum eigenvalue (λ_{max}) is evaluated from the average column vector determined from the following relation.

$$\begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & & \\ a_{n1} & a_{n2} & \dots & a_{nm} \end{pmatrix} \tag{1}$$

where λ_n is the eigenvalue.

PV_n is the priority vector.

The priority vector for the comparison matrix formed is evaluated from Eq. 2, while the maximum eigenvalue is computed using Eq. 3.

$$PV = \frac{\frac{an_1}{\sum ai_1} + \frac{an_2}{\sum ai_2} + \cdots \frac{an_n}{\sum ai_n}}{n} \tag{2}$$

$$\lambda max = \frac{\lambda_1 + \lambda_2 + \cdots + \lambda_n}{n} \tag{3}$$

The consistency ratio (C.R) which evaluates the consistency in judgment is given by the relation.

$$\text{Consistency Ratio (C.R)} = \frac{\text{C.I}}{\text{R.I}} \tag{4}$$

The judgment is considered to be consistent if the consistency ratio (C.R) is less than 0.1; else the judgment has to be re-evaluated to ensure proper decision-making. It must, however, be noted that the priorities vector must always add up to unity with C.I representing consistency index and R.I representing random consistency index. The random consistency index (R.I) is the average of C.I shown in Eq. 5.

$$\text{C.I} = \frac{\lambda max - n}{n - 1} \tag{5}$$

where λ_{max} represents the maximum eigenvalue and n represents the number of rows or columns in the comparison matrix. Therefore, C.I can further be calculated as:

$$\text{C.I} = 1.98\left[\frac{n-1}{\frac{n}{2}(n-1)}\right]$$

1.98 is the average value of the ratio of each value computed for $n = 3–15$

3 Results and discussion

3.1 Generated maps from spatial features

The map of the road network, water body, powerline and land use/land cover of the research area is illustrated in Figs. 3, 4, 5 and 6, respectively. The road map features both major roads and minor roads with the major roads consisting of dual- and single-carriage roads with large volume of traffic along Natako-Abuja express way, Lokoja ultra-modern market road and Ganaja–Otokiti Estate road while the minor roads shows small volume of traffic compared to the major roads. Water body map consists of major rivers and streams. The major rivers are River Niger and River Benue, while the minor ones include Meme River and River Zango. The powerline station map shows grid lines direction from the state capital to other neighbouring town and communities. The landuse/landcover map shows the built-up areas (residential areas, commercial areas and developed housing estates), undeveloped areas and other extensions where appropriate landfill can be correctly sited.

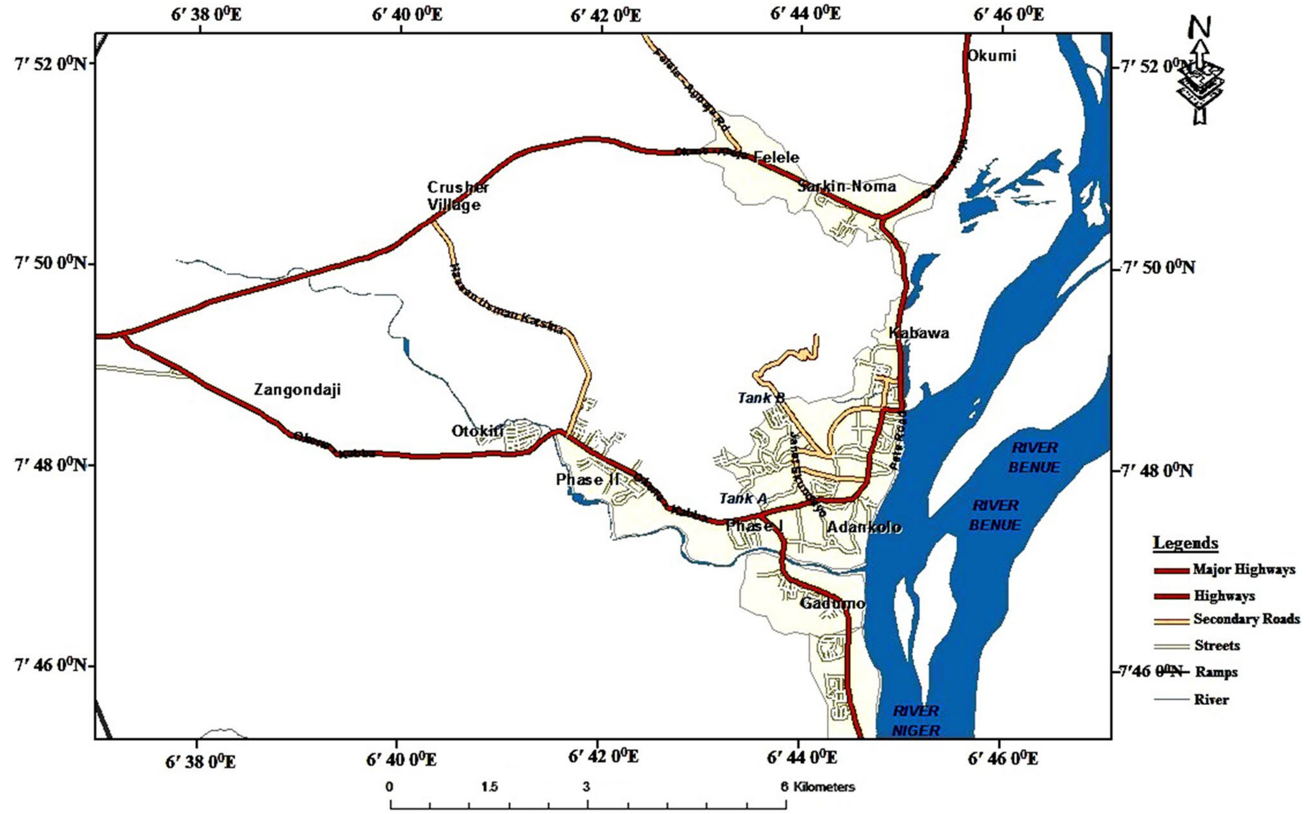

Fig. 3 Road network map in the study area

3.2 Buffer analysis of digitized features

Maps prepared from the buffer analysis show suitable areas and unsuitable areas required for sanitary landfill in the area.

3.2.1 Distance to Road

The road buffer map in Fig. 7 shows areas where municipal solid waste landfill site cannot be sited while the unlabelled areas are areas suitable for municipal solid waste landfill location based on the EPA standards for municipal waste landfills location. Areas less than 100 m from the road (especially major roads) are unsuitable for landfill, distances from road greater than 2000 m are less suitable, while a distance between 100 and 1000 m is mostly considered suitable. This result is in agreement with the studies of Allen et al. [48] and Khan and Samadder [49] who affirmed that a distance greater than 1 km from main roads and highways should be strongly avoided while supporting their assertions that, landfill sites placed too far away from existing road networks most often incur expensive cost of constructing new roads and also increase the transportation and collection costs of solid wastes. A distance between 200 and 500 m from the main road is considered most suitable which is in tandem with the assertions made by Al-Anbari et al. [50] and Karimi et al. [51]. The potential landfill located in this suitable location ensures solid wastes are transported to site at reasonable cost.

3.2.2 Distance to water bodies

The water bodies buffer map in Fig. 8 reveals the uncoloured zones suitable for landfill location while the "blue" zone is not proper for siting landfill. The uncoloured zones are areas > 100 m from water bodies which

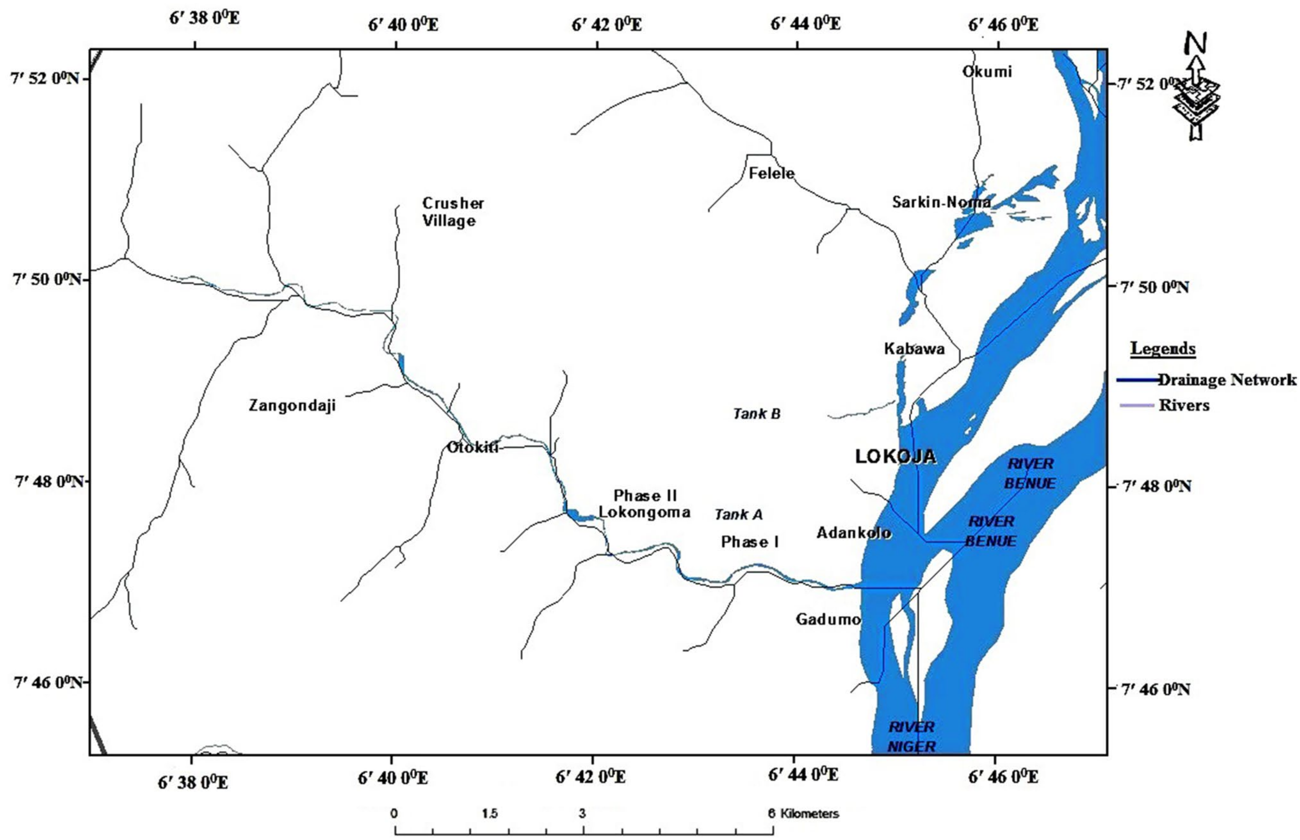

Fig. 4 Water body map in the study area

are considered suitable for siting landfill while the blue zone are areas < 100 m from water bodies considered as unsuitable. Distance from water bodies (especially for surface water bodies) was buffered at varying distance not < 500 m. For groundwater bodies, areas having the maximum depth of water table from ground surface were buffered. Only distance from the water bodies more than 500 m was considered safe for constructing landfill in the study area. This is to ensure water bodies in the study area are not polluted. Dorhofer and Siebert [52] agree to the fact that as landfills release pernicious gases and leachate, they should not be in proximity to water wells and surface water bodies. For groundwater bodies, landfill site should be located in area where they are sufficiently deep in order not to affect leachate movement. Similarly, this result is in agreement with the findings and assertions of Manual on Municipal Solid Waste Management [53], Khan and Samadder [49] and Yousefi et al. [54] on siting MSW landfill.

3.2.3 Distance to powerline

The powerline buffer map displayed in Fig. 9 portrays the uncoloured zones appropriate for landfill location, whereas the "blue, red, yellow and light red" zones are not inappropriate for siting landfill. These uncoloured zones are areas with distance more than 30 m away from the high-voltage powerlines. This result is in line with Al-Ansari et al. [55] who asserted that landfill site locations should not disturb infrastructures including high-voltage powerlines. It is also in tandem with the findings of Al-Anbari

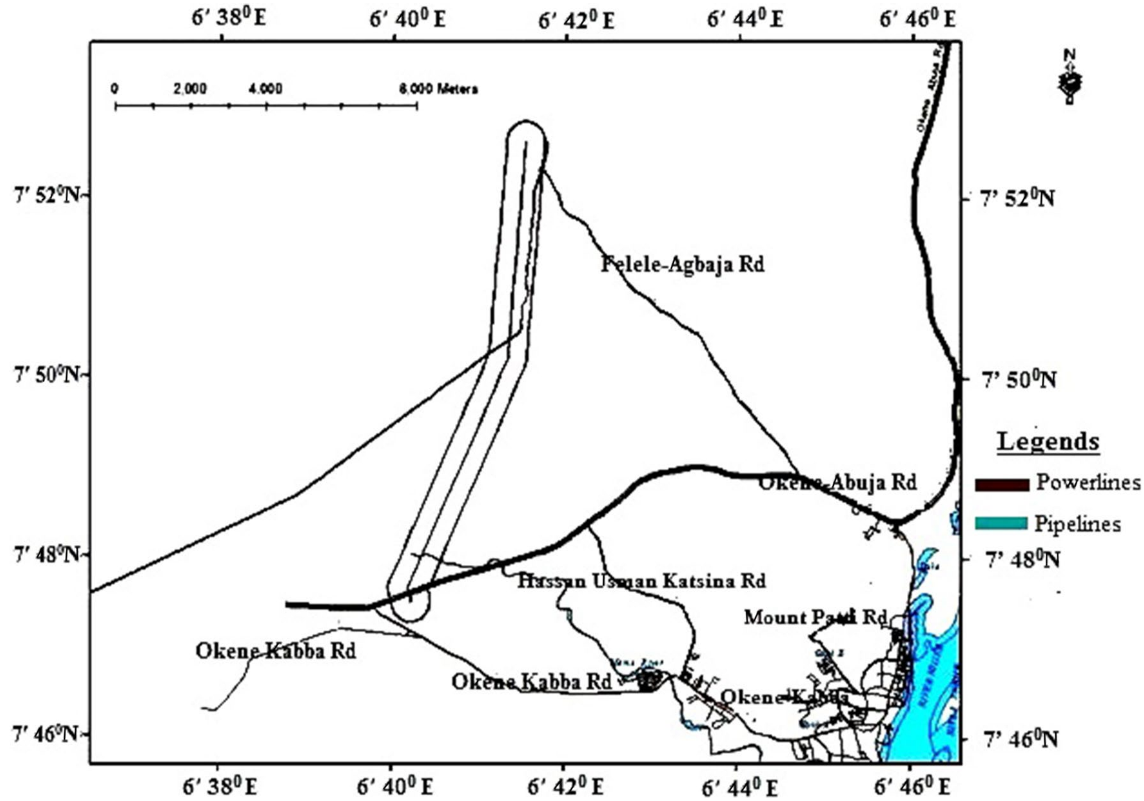

Fig. 5 Map showing powerline in the study area

et al. [56] who classified layer of powerlines by assigning values in Al-Hashimiyah Qadhaa as suitable (for powerlines having distance > 30 m) and unsuitable (for powerlines having distance from 0 to 30 m).

3.2.4 Land use/land cover

Land use is vital to resolving public scuffle of the endorsement of unnecessary area of landfill amenities [57, 58]. The land-use buffer map was prepared so as to avoid odour resulting from landfill sited within the study area. The "red" zones are areas where municipal solid waste landfill cannot be situated, while the blue zones are locations where municipal solid waste landfill can be stationed. The red zones include residential and other settlement areas, recreational areas, vegetation and airport areas. These areas were assigned relatively high grade in order to discard them for landfilling while the blue zones include areas which are exclusively barren lands without and with some scrubs. They were considered as suitable for siting landfills and hence were thus assigned low grades. These land-use/land-cover factors considered are similar to the findings of Khan and Samadder [49] and Kapilan and Elangovan [59]. Settlements were also given due consideration, as landfill site should not be in the vicinity of residential or urban area to avoid adverse impact on land value and future development. This will protect the people from possible environmental hazards resulting from landfill sites. According to Demesouka et al. [60], landfill must be located within 10 km but should not be within 500 m of an urban area. A distance of more than or equal to 250–500 m from settlement was taken as suitable for landfill siting in this study. The airport and pipeline buffer maps are provided in supplementary file (Figs. S1 and S2).

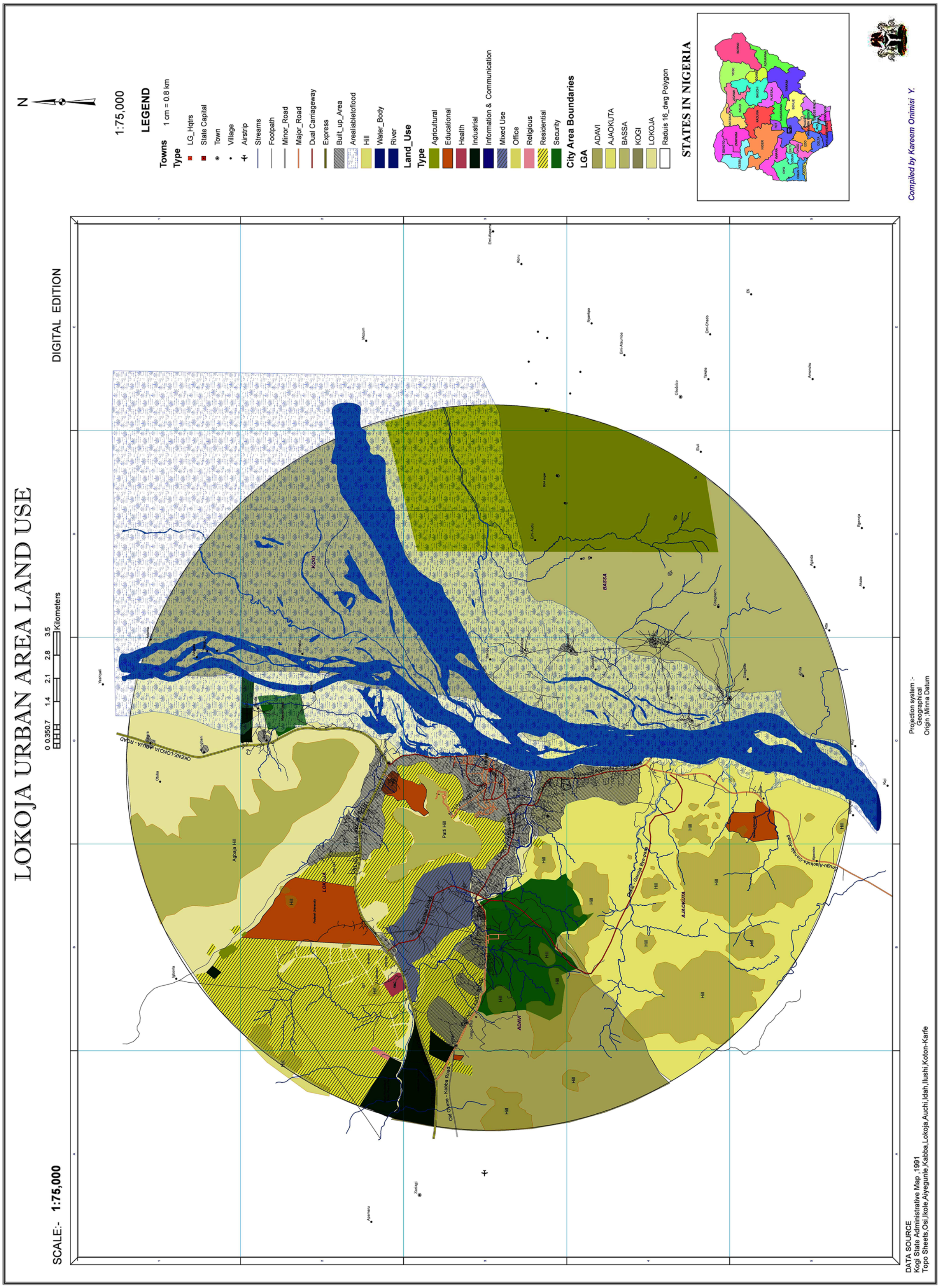

Fig. 6 Land-use/land-cover map in the study area

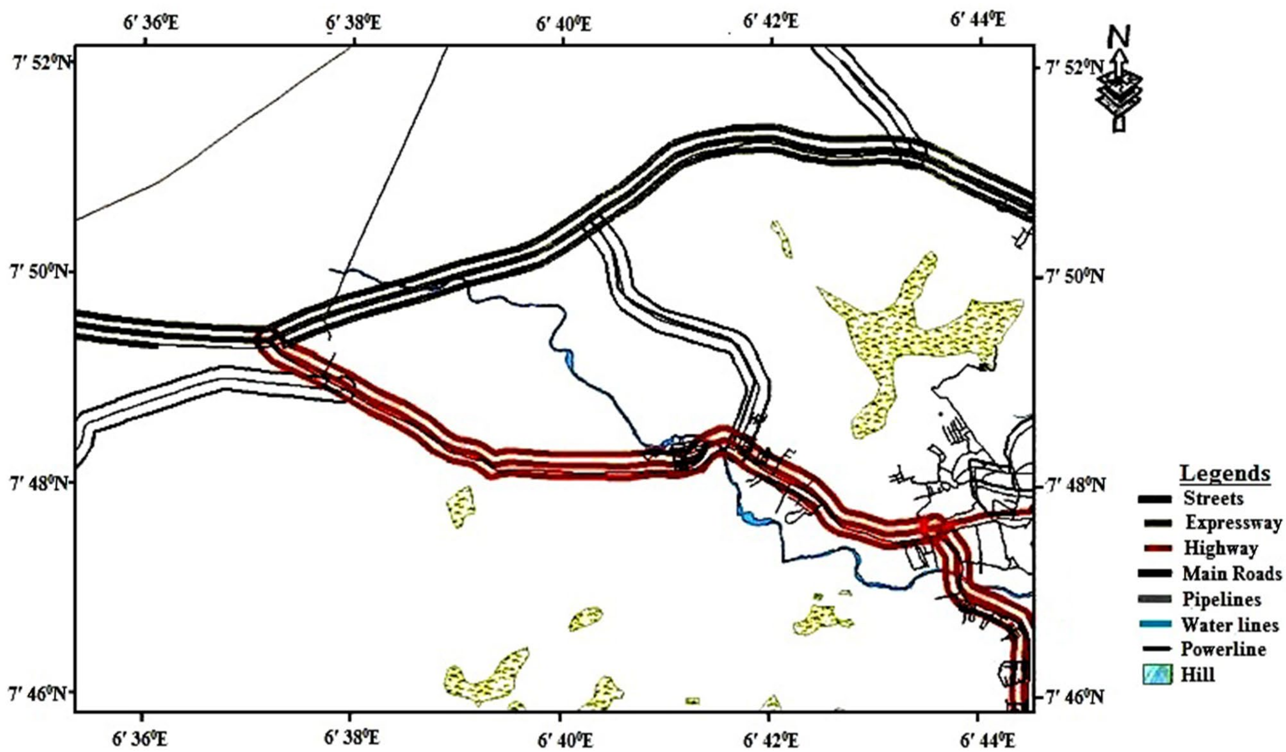

Fig. 7 Map of the major roads buffer

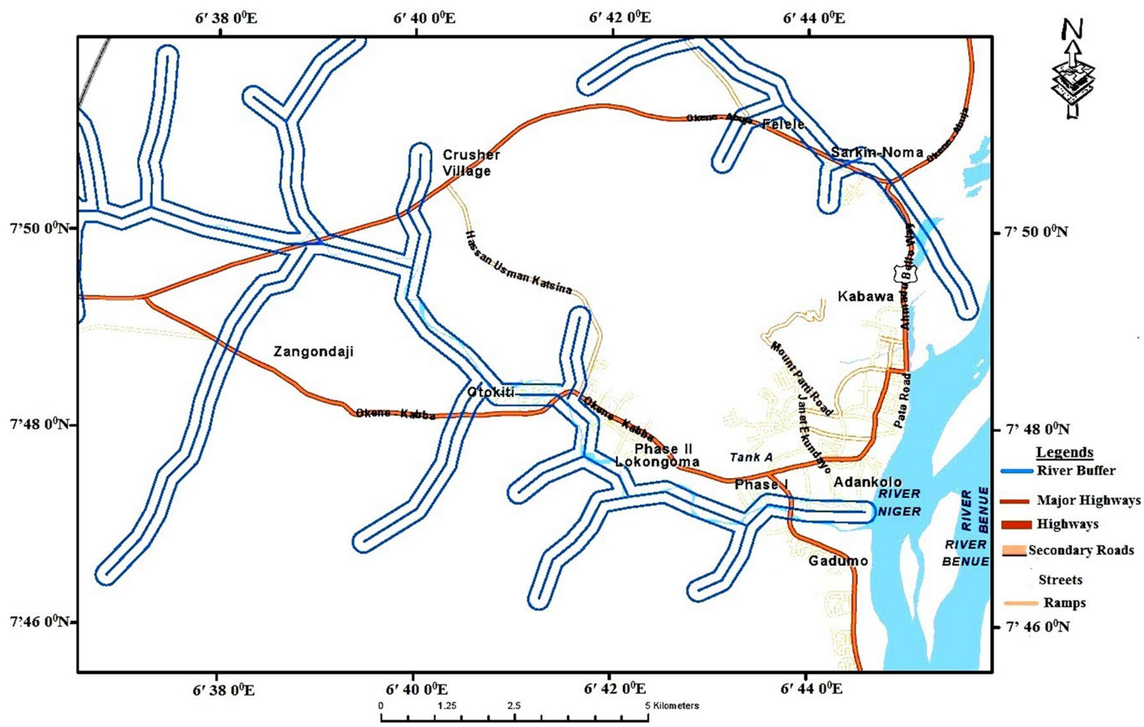

Fig. 8 Map of the water body buffer

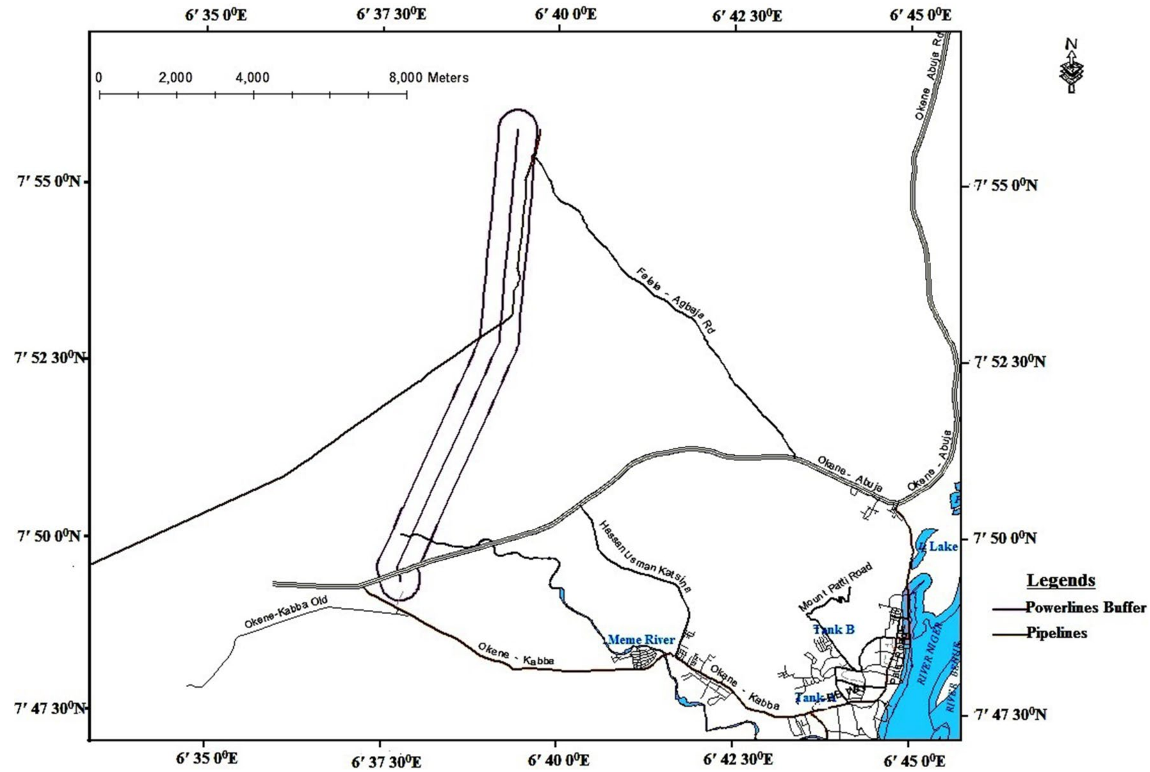

Fig. 9 Powerline buffer map

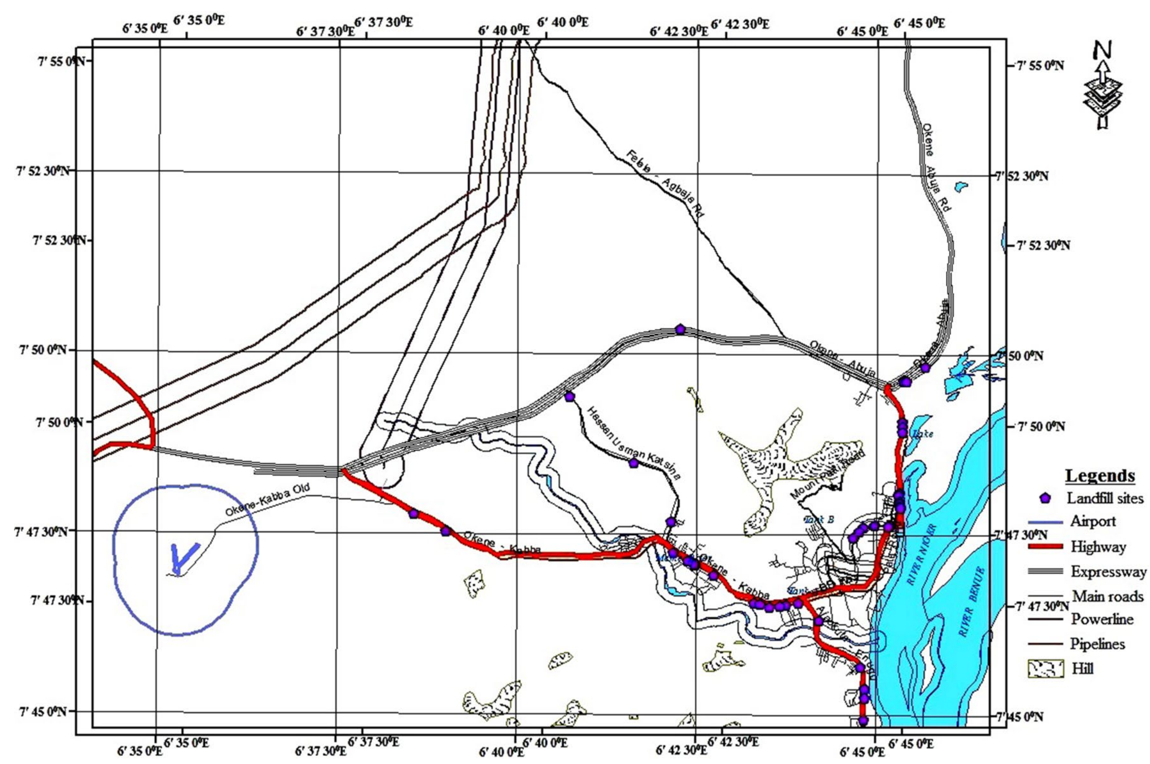

Fig. 10 Map overlay of all the buffered zones

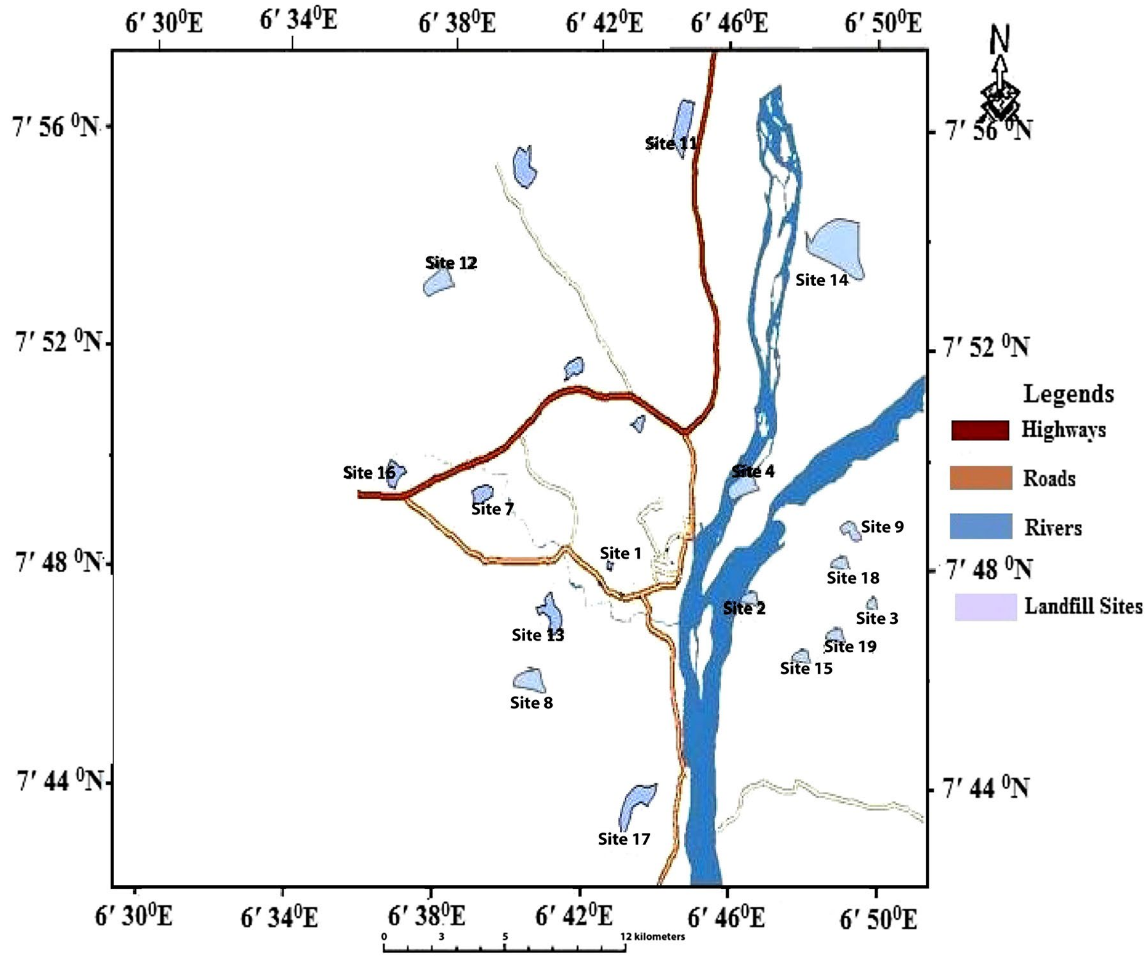

Fig. 11 Map of landfill site identified in the study area

3.3 Map overlay and collection points for potential landfill sites

Potential landfill sites were extracted from the combination of the buffered maps of road, water body and powerline (Fig. 10). These locations are where municipal solid waste landfill can be located appropriately based on the various factors considered which include proximity to site, distance to water body, distance to powerline, distance to built-up areas and land use.

The potential landfill sites were further reduced based on geographical locations. Therefore, the boundary sites were not considered for the purpose of selecting the best landfill among various alternatives. Nineteen candidate sites (Fig. 11) were subsequently identified from these potential landfill sites. The characteristic features of these candidate sites and their locations obtained from the GIS analysis are presented in Table 2. The suitable zones are zones considered for landfill site and they are areas with asterisk, while the unsuitable zones are zones not considered for landfill site. The 19 landfill sites

Table 2 Characteristic features of candidate landfill site and their location

Candidate landfill site	Landfill area (km^2)	Proximity to major road (m)	Proximity to water body (m)	Proximity to powerline (m)	Proximity to built-up area (m)	Location
1	0.0187	201.61	260.20	1134.02	230.14	Patti
2	0.8421	556.42	2968.49	4008.55	308.96	Assembly quarter
3	0.5079	1011.90	608.23	7010.49	215.22	200 Housing units
*4	5.6230	460.31	632.32	2035.94	208.20	Kogi Poly
*5	3.2086	249.24	768.56	3001.53	260.81	Elete
6	0.9019	1346.01	1864.34	1970.30	270.80	Felele
*7	8.1348	1238.10	508.68	2010.39	216.10	Barrack area
*8	2.3121	518.80	523.78	4236.86	219.20	Kabba road
9	0.2890	284.86	1980.68	6812.34	189.01	Otokiti estate
*10	1.3620	290.80	2024.42	6012.02	250.48	Zango
*11	3.4204	210.50	1408.20	1810.80	205.61	Jimgbe
*12	2.2334	2880.51	3030.41	1101.20	230.20	GidaBassa
13	0.6804	530.40	584.72	3030.40	220.20	Commissioner's Quarter
*14	1.1616	244.30	580.30	3602.48	281.62	Locongoma
*15	2.8026	218.80	540.12	3514.40	218.72	500 Housing units
*16	2.5687	2430.75	594.04	1980.80	200.68	Ganaja village
*17	1.2838	1742.40	504.34	3480.86	216.76	Phase 1
18	0.0314	204.36	640.06	3208.60	250.64	Adankolo
19	0.6432	260.90	486.20	8986.20	202.38	Phase 2

*The suitable zones considered for landfill site

Table 3 Paired comparison matrix for landfill criteria

Landfill criteria	Road	Water body	Powerline	Landfill areas	Built-up areas
Road	1	3	5	7	9
Water body	0.3333	1	0.2000	4	5
Powerline	0.2000	5	1	0.1111	7
Landfill areas	0.1428	0.2000	0.1666	1	6
Built-up areas	0.1111	0.3333	0.2500	0.1666	1

were subsequently reduced to eleven landfill sites based on geographical location and landfill area of candidate sites. Areas less than 1 km^2 (which include sites 1, 2, 3, 6, 9, 13, 18 and 19) were not considered further for AHP analysis as they will not last up to 20 years. The preliminary factors which are proximity/nearness to the road, distance to water body, distance to powerline, distance to built-up areas and land use were used to consider the adequacy of a site.

Table 4 Normalized matrix for landfill criteria

Landfill criteria	Road	Water body	Powerline	Landfill areas	Built-up areas
Road	0.5595	0.3147	0.7557	0.5701	0.3214
Water body	0.1864	0.1049	0.0302	0.3258	0.1786
Powerline	0.1119	0.5245	0.1511	0.0009	0.2500
Landfill areas	0.0798	0.0209	0.0252	0.0814	0.2143
Built-up areas	0.0622	0.0349	0.0378	0.0136	0.0357

Table 5 Paired comparison matrix for landfill criteria (re-evaluated)

Landfill criteria	Road	Water body	Powerline	Landfill areas	Built-up areas
Road	1.0000	3.0526	2.4280	5.9822	13.7038
Water body	0.3275	1.0000	0.7953	1.9596	4.4891
Powerline	0.4118	1.2572	1.0000	2.4638	5.6440
Landfill areas	0.1671	0.5103	0.4058	1.0000	2.2907
Built-up areas	0.0729	0.2227	0.1771	0.4365	1.0000

Table 6 Normalized matrix for landfill criteria (re-evaluated)

Landfill criteria	Road	Water body	Powerline	Landfill areas	Built-up areas	Priority vector
Road	0.5051	0.5051	0.5051	0.5051	0.5051	0.5051
Water body	0.1654	0.1654	0.1654	0.1654	0.1654	0.1654
Powerline	0.2080	0.2080	0.2080	0.2080	0.2080	0.2080
Landfill areas	0.0844	0.0844	0.0844	0.0844	0.0844	0.0844
Built-up areas	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368

Table 7 Grading of characteristic features of landfill site

Characteristic feature	Scale	Characteristic feature	Scale
Landfill area (km^2)		Proximity of water body (m)	
1.0–2.0	3	500–510	3
2.1–3.0	5	511–530	5
3.1–4.0	7	531–600	7
> 4.0	9	> 600	9
Proximity to major road (m)		Proximity to built-up area (m)	
200–215	9	200–210	3
216–250	7	211–217	5
251–510	5	218–220	7
511–1000	3	> 221	9
> 1000	2		
Proximity to pipeline (m)			
800–2000	3	> 5000	9
2001–3500	5		
3501–5000	7		

3.4 Analytical hierarchy process (AHP) model

Comparison matrix developed using Saaty scale in Table 3 was used to get the normalized matrix for landfill criteria in Table 4 in order to produce the local and the global priority which will determine the best suitable site. Consistency check of judgment made in the development of the comparison matrix was done, and the maximum eigenvalue (λ_{max}), C.I, R.I and C.R were determined using Eqs. 1–5 to get 5.9159, 0.2289, 1.1880 and 0.1926, respectively. Following the rule of consistency check, the judgment is re-evaluated, since the consistency ratio (C.R = 0.1926) is greater than 0.1 to ensure better decision-making and ranking of alternatives. The new paired comparison matrix was developed by pairing the vector priorities of the criteria obtained in Table 4 to

Table 8 Grading of candidate landfill site with characteristic features

Candidate landfill site	Landfill area (km^2)	Major road (m)	Water body (m)	Power-line (m)	Built-up area (m)
Proximity to					
4	9	5	7	5	3
5	7	7	7	5	9
7	9	2	7	5	5
8	5	3	7	5	7
10	3	5	9	9	9
11	7	9	5	3	3
12	5	9	3	3	9
14	3	7	5	7	9
15	5	7	3	7	7
16	5	2	3	3	3
17	3	2	5	5	5

give Table 5. The new normalized matrix is presented in Table 6.

The priority vectors: 0.5051, 0.1654, 0.2080, 0.0844 and 0.0368 are the multiplication coefficient that will be multiplied by the local priority which will give that global priority that determines the suitability of a landfill site. The maximum eigenvalue (λ_{max}), C.I, R.I and C.R now becomes 5.001796, 0.000449, 1.62 and 0.000277, respectively, and since the consistency ratio (C.R = 0.000277) is less than 0.1, the judgment is acceptable.

3.5 Development of scale for candidate landfill Sites

The characteristic features of candidate landfill site were used to determine appropriate scale using Saaty scale developed in 1980 (Table 7) for judgment such that candidate landfill site closer to the road is of extreme importance and vice versa. The combined scale of candidate landfill sites and the corresponding landfill criteria are presented in Table 8. It portrays the candidate landfill site that is above 1 km^2 and can serve as landfill site. The grading of candidate landfill site with the feature characteristics in Table 8 is obtained from Tables 2 and 7. Table 8 shows the value to be paired and equally to be normalized with respect to landfill area, road, water body, powerline and built-up area. The paired comparison matrix was developed using the scale. Each candidate landfill site was compared with another using the

Table 9 Normalized and re-evaluated matrix of characteristics features

Landfill criteria	Road		Powerline		Water body		Landfill areas		Built-up areas	
	NM	RM	NM	RM	NM	RM	NM	RM	NM	RM
Maximum eigenvalue (λ_{max})	11.2742	11.0935	13.0400	11.0911	11.0340	11.0030	13.4523	11.9918	12.7529	11.4439
Consistency index (C.I)	0.2742	0.0094	0.2050	0.0091	0.0034	0.0030	0.2452	0.0992	0.1753	0.0444
Random consistency index (R.I)	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62
Consistency ratio (C.R)	0.1692	0.0058	0.1250	0.0056	0.0020	0.0018	0.1513	0.0612	0.1082	0.0274

NM and RM represent normalized matrix and re-evaluated matrix, respectively

Table 10 Overall rank of candidate sites under various factors considered

Candidate site	Landfill area (0.0844)	Water body (0.1654)	Road (0.5051)	Built-up area (0.0368)	Powerline (0.2080)	Overall rank
Proximity to						
4	0.0109	0.0190	0.0484	0.0013	0.0160	0.0956
5	0.0085	0.0190	0.0678	0.0039	0.0160	0.1152
7	0.0085	0.0190	0.0193	0.0022	0.0160	0.0650
8	0.0060	0.0190	0.0290	0.0031	0.0160	0.0731
10	0.0036	0.0244	0.0534	0.0064	0.0287	0.1165
11	0.0145	0.0136	0.0872	0.0019	0.0287	0.1459
12	0.0060	0.0081	0.0200	0.0039	0.0096	0.0476
14	0.0100	0.0136	0.0699	0.0039	0.0224	0.1198
15	0.0060	0.0081	0.0699	0.0031	0.0224	0.1095
16	0.0060	0.0081	0.0200	0.0019	0.0096	0.0456
17	0.0036	0.0136	0.0200	0.0048	0.0224	0.0644

road, powerline, water body, landfill areas and built-up areas criterion selection. The paired comparison matrix and the vector priority (global) of each candidate site were then evaluated and judged. The judgments made were tested for consistencies. The maximum eigenvalue (λ_{max}), C.I, R.I and C.R were finally determined in order to make a suitable and final decision. Table 9 shows the result for the normalized and re-evaluated matrix of road, powerline, water body, landfill areas and built-up areas. This analysis was performed according to Kapilan and Elangovan [59].

3.6 Ranking and selection of best candidate site

The overall rank of the candidate landfill site is evaluated by adding up the priority vector (global) of the landfill under various criteria considered in landfill selection process. The overall rank is presented in Table 10. From Table 10, candidate site 11 has the highest priority vector of 0.1459 and as such considered the best site location among alternatives sites to establish municipal solid waste landfill, while candidate site 16 has the lowest vector priority of 0.0456 and is therefore considered the least suitable site location among alternative sites considered.

4 Conclusion

GIS and AHP have been combined to select the well-suited landfill location in Lokoja, Nigeria. The landfill site selection criteria taken into consideration include proximity to major road, built-up areas, land use, powerline and water bodies. GIS was employed to digitize all the spatial features related to suitably siting landfill areas. A total of 19 candidate landfill sites were identified via the GIS analysis out of which 11 candidate sites were given high priority because their land areas were above 1 km^2 and eight candidate sites were eliminated because their land areas were less than 1 km^2. AHP model was developed from the GIS result as MCD tool to evaluate these candidate sites so as to choose the most apposite landfill site. The AHP model rated candidate site 11 along Jimgbe road as the highly preferable site to locate a landfill in Lokoja which has an approximate area of 3.4204 km^2; the distance from the minor road, the nearest water body, powerline and built-up areas to the location is the site which is 210.50 m, 1408.20 m, 1810.80 m and 205.61 m, respectively.

The application of GIS–AHP has helped solved time-consuming challenges which are often associated with selection of landfill site. Environmental planners can easily apply them to spatially buffer unsuitable locations for landfills, identify criteria priorities, and select the most suitable site under each criterion. It can be a measure for siting municipal solid waste landfill in developing areas which minimizes social, economic and environmental impacts which results from municipal solid waste management.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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