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SITE SUITABILITY ANALYSIS FOR LANDFILL IN AN INDUSTRIAL AREA IN NIGERIA

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Abstract

This study was set against the background of identifying management strategies to combat the menace associated with poor solid waste management in urban areas of Nigeria. Therefore, it becomes highly necessary to determine suitable sites for landfill. Using remote sensing and geographic information tools and technologies the study identified the scenes of present dump sites; evaluated the conditions for selecting landfill sites; and determined suitable landfills in Ajaokuta, Nigeria. Data for the study were sourced from Sentinel-2A, 2021. Integrated GIS-based analysis using multi-criteria evaluation method was employed to scrutinise the appropriateness of the existing dumpsites for siting landfills. However, with reference to Federal Environmental Protection Agency (FEPA) guidelines, results of buffering and proximity analyses indicated that none of the existing dumpsites could be converted to landfill sites. Moreover, a fuzzy overlay of all the criteria considered was employed to identify and propose the most suitable areas for solid waste disposal sites in the study area. Based on the official stipulated distance, new sites were proposed for landfills. The study emphasised the increasing mounds and improper disposal of municipal solid wastes in Nigerian urban centres which have become too agonising and repulsive to sights. Nevertheless, if the recommendations of this study are taken with utmost seriousness, any unexpected outbreak of epidemic and environmental pollution will be greatly avoided in the study area.

Keywords: solid waste management, dumpsite, landfill, urban area, site suitability, multi-criteria decision analysis

INTRODUCTION

Land use and landcover are often used interchangeably, however, each term has its own unique meaning. Landcover refers to the surface cover on the ground like vegetation, water, bare soil, wetlands and impervious surfaces (Comber et al., 2005). Land use, on the other hand, is used to describe the human use of land; it refers to the purpose the land serves (Comber et al., 2005; Fisher et al., 2005). When used together, land use/landcover (LULC) implies the categorisation or classification of human activities and natural elements on the landscape within a specific time frame. Landcover changes with alteration in the environment such as improper solid waste management.

Indiscriminate dumping of wastes, whether liquid or solid and whether domestic or industrial, is not limited to just a part or region of the world. Though in the developed countries with many industrial establishments and advanced technologies, there is evidence of organised waste management (Chung & Lo, 2008; Shamim & Muzafar, 2014; Srivastava, 2016; Usman, 2017; Suleiman et al., 2019). Yet, studies have shown that inadequate collection and unrestrained dumping of wastes persist in many of these countries (Aderoju, 2014; Chen et al., 2017; Nascimento et al., 2017; Andrew et al., 2018). The situation of poor waste management is reportedly worse in the less developed countries where there are high rates of threat of the adverse effects of improper management of solid wastes (Chokor, 1993; Ajibade, 2007; Ayaim, 2019; Mekuria et al., 2019).

Landfills have been acknowledged as an appropriate method of organised solid waste disposal in urban areas (Ebistu & Minale, 2013; Zadawa et al., 2015; Osei et al., 2016; Jibril et al., 2017; Ezeudu, 2020). However, many countries are yet to adopt the strategy because of the technical expertise required in the design, operation and monitoring that will ensure compliance with environmental regulations. In this regard, the roles of Geographic Information System (GIS) in selecting appropriate locations for landfills have been emphasised. There are several GIS techniques that have been applied to the problem of locating landfill sites more efficiently. For instance, multi criteria decision analysis (MCDA) has been employed with great successes in some countries (Akbari, 2011; Jayprakash et al., 2015; Motlagh & Sayadi, 2015; El Maguiri et al., 2016; Al-Anbari et al., Terseer & Bibi, 2017; 2018; Ajibade et al., 2019; Karimi et al., 2019; Rezaeisabzevar et al., 2020), analytical hierarchical process (AHP) method (Siddiqui et al., 1996; Saaty, 2008; Djokanovic et al., 2016; Randazzo et al. 2018; Yakubu & Zhou, 2018; Kamdar et al., 2019; Sener & Sener, 2020; Sulemana et al., 2020; Younes, 2020), and Integration of a median ranked sample set and an analytic network process (MRSS-ANP) methods (Husby et al., 2005; Younes et al., 2015). Furthermore, while Idowu et al. (2012) adopted macromedia and Graphical User Interface (GUI) approaches, Demesouka et al. (2016) considered measuring attractiveness by a categorical based evaluation technique (MACBETH) technique appropriate for analysing GIS-Based landfill site suitability. Also, Saeedi et al. (2019) employed multiple attribute decision-making (MADM) methods which is a combination of fuzzy-analytical hierarchy process and ordered weighted average (FAHP and OWA) to assess the choice of landfill site for solid drilling waste of an oilfield in Southwest Iran.

In Nigeria, the Federal Environmental Protection Agency (FEPA) was established in 1999 and was reorganised as Environmental Protection Agency (EPA) in 2006. The agency is responsible for, among other functions, ensuring that wastes are disposed in an environmentally responsible manner. This includes ensuring that existing and potential landfill occupiers are aware of the risks landfill poses to the quality of air, water and land resources (FEPA 1999; EPA 2006; Usman 2017). Therefore, the landfill occupiers are responsible for the management of the risks in the most effective way possible (Zadawa et al., 2015; Sridhar, 2017; Suleiman, 2019). The guideline stressed that selection of a landfill cannot be confirmed prior to completion of feasibility study and Environmental Impact Assessment (EIA) of the site. Also, it is pointed out that there should be consideration for land use and landcover types, particularly natural vegetation and cultivated land. However, the guidelines allow a reasonable comparison and retention of alternate sites if the preferred site proved unworkable (Ladan, 2007; Suleiman, 2019). To improve the level of waste management and to ensure a beautiful and clean Nigeria, EPA (2006) highlighted some guidelines for a more organised waste management system in the country. The guidelines specify that potential landfill sites can be selected based on the suitability of the area. The minimum criteria specify that a landfill should be:

i. 200 metres away from all surface water;
ii. 100 metres away from all transport routes;
iii. 2,500 metres buffer zone around all buildings; and
iv. Slope of the area should be between 8° and 10°.

Ajaokuta is the home of the largest steel company in Nigeria called Ajaokuta Steel Company (ASC). As a result of increase in economic activities brought about by the large iron and steel company, there has been a very rapid growth of municipal solid wastes in Ajaokuta. Most of the waste generated from households and companies is dumped along river courses and roads. Thus, the need arises to site solid waste landfills in Ajaokuta. To do this effectively and following the EPA (2006) standard, this study used integrated GIS-based analysis to assess the criteria for selecting suitable sites for solid waste landfills in Ajaokuta, Nigeria. To achieve this, the study identified the location of existing dump sites in Ajaokuta; evaluated the parameter for landfill locations; and suggested landfill sites in the study area. This study will educate the general public, stakeholders in environmental management and policy makers on the problems of solid waste management.

STUDY AREA

Ajaokuta is the headquarters of Ajaokuta Local Government Area, Kogi State, Nigeria. It is located on the left bank of River Niger between latitudes 7° 31'N and 7° 38'N, and; longitudes 6° 35'E and 6° 43'E (Fig. 1). The population of Ajaokuta in according to the 2006 census was 122,321 over a land area of about 1,362 km^2 square

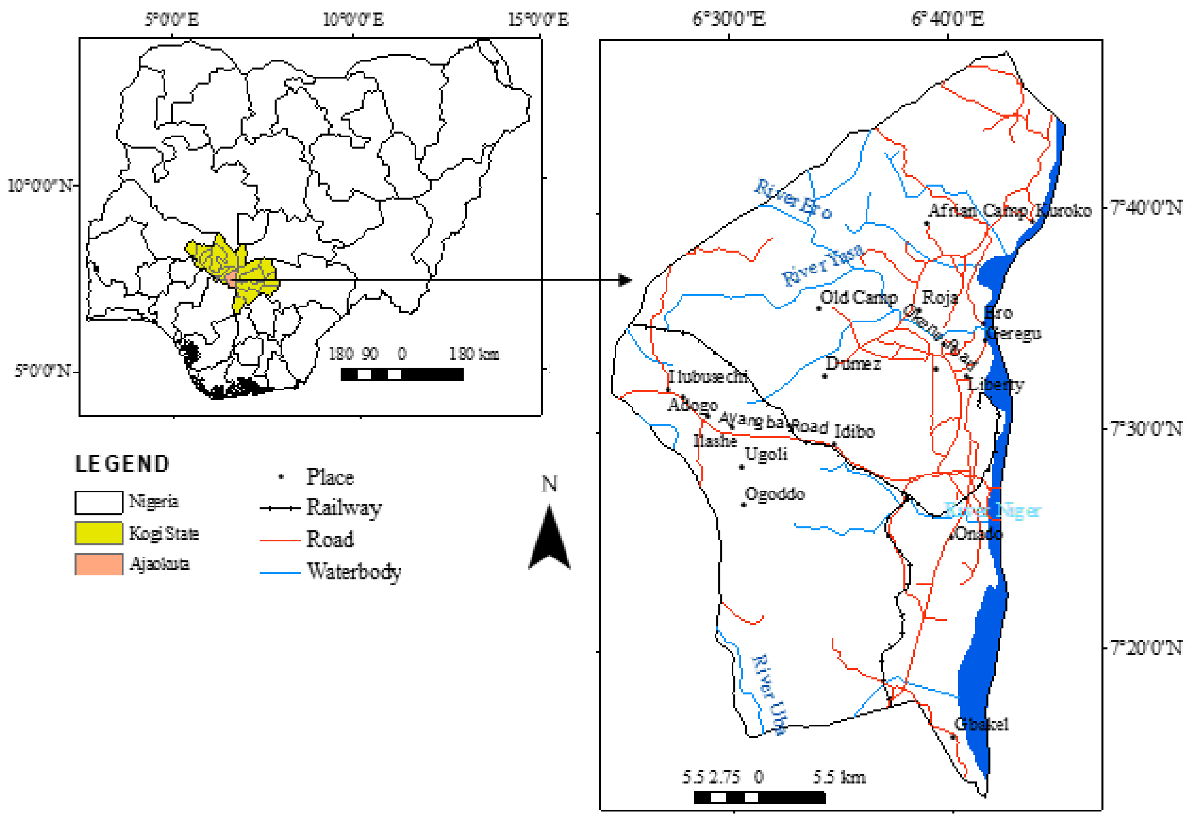

Fig. 1 The study area.
Sources: Sentinel- 2A (February, 2021), Field Research, 2021, Openstreetmap (accessed on August 25, 2021)

(National Population Commission of Nigeria, NPC, 2006). Most of the residents in Ajaokuta are engaged in the civil service and farming, at subsistence levels. Ajaokuta is in the tropical zone characterised by two climatic conditions; rainy and dry seasons. While the annual rainfall is between 1100 mm and 1300 mm, the annual average temperature of 36.7 °C (Agbor & Shehu, 2013; Tokula & Eneche, 2018). The vegetation is guinea savannah containing tall grasses and few trees (Adegbe et al., 2014; Tokula & Eneche, 2018).

MATERIALS AND METHODS

This study used secondary data derived from Sentinel-2A, imagery (2021), Open Street Map (OSM) of Ajaokuta (accessed, 25 August, 2021), Google Earth (GE) map (accessed, 12 September, 2021) and digital elevation model (DEM) acquired from Shuttle Radar Topography Mission (SRTM). Based on EPA regulations, four factors influencing siting of landfills were selected for this study. Proximities of landfills to the built-up area, transport network and waterbodies were extracted from OSM of Ajaokuta. Slope was derived from DEM data to evaluate landfill siting suitability. This was complemented with field survey using handheld GPS receiver used to obtain the coordinates of the existing dump sites and digital camera which was used to record and show their exact locations.

Sentinel imagery was processed using digital image processing techniques with a view to increase the pictorial quality of the image and to clearly identify various landcover in the study area (Braun, 2020; Muhammed, 2020; Wu et al., 2020; Lu 2021 et al.). The study area map was clipped out from the pre-processed Sentinel-2A, which has been set to World Geodetic Survey (WGS) 1984, Universal Transverse Mercator (UTM) Zone 31N. Thereafter, false colour composite was adopted to enable visual interpretation of the wavelengths (Mishra et al., 2016; Lyons et al., 2018). Following a modified version of Maximum Likelihood Classification methods, the area was classified into five different landcover classes: water body, dense vegetation, light vegetation, built-up and bare land. The false colour composite was used to distinguish between vegetation and farmland; while vegetation is usually in deep (dark) red, farmlands are light (bright) red. Using ArcMap 10.6 software, on-screen digitizing was done to create shape files for all features of interest extracted from OSM. In addition, existing dumpsites coordinates taken during the field survey were also plotted and then converted to shape files.

Accuracy assessment was conducted to ensure accurate interpretation of the data obtained from remotely sensed sources, Sentinel-2A and SRTM data. These data were validated using GE map, ground truthing and visual interpretation. GE map of the study area was downloaded and digitised to extract 65 reference points for imagery validation exercise (Table 1). These points were exported into ArcGIS as *.kml* files and used to validate and confirm the accuracies of data obtained from remotely sensed sources. Also, remotely sensed data were evaluated through ground truthing and visual interpretation. By this, GPS was used to take and record geographic coordinates of 90 control points in the study area (Table 1). In ArcGIS environment (ArcMap 10.6 software), these points were converted from vector to raster data and integrated with stable images to produce a confusion matrix (Lyons et al., 2018; Chen et al., 2019; Congalton & Green, 2019; Braun, 2020).

Table 1 Distribution of Validation Points (by LULC)

S/N	LULC Class	No. of Points	
		GoogleEarth Map	Ground Points
1	Water body	12	20
2	Dense vegetation	15	20
3	Light vegetation	13	15
4	Built-up	15	25
5	Bare Land	10	10
	Total	65	90

Sources: GoogleEarth map (accessed on 12 September, 2021), ground truthing (2021)

The landcover classification method was initiated through the clipping of the satellite imageries using a vector map of the administrative boundary of the study area. Supervised maximum likelihood classification was performed using ArcMap image processing tool in ArcGIS environment. Five LULC types were identified from the images, these are water body, dense vegetation, light vegetation, built-up and bare surface (Table 2). Results of the classification were used to analyse landcover statistics, the distance between the existing dumpsites and the evaluation criteria using attribute table and field calculator tools in ArcGIS.

Generally, the slope of Ajaokuta ranges between 0º and 89.9º (Shuttle Radar Topography Mission, SRTM). The slope of the area was grouped into three convenient classes based on EPA recommendation that the slope of a landfill should be between 8º and 10º:

i. Less than 8º
ii. 8º - 10º; and
iii. Higher than 10º.

Table 2 Landcover Classification Schema

S/N	LULC Class	Land use/cover
1	Water body	river, stream, pond, lake and any other kind of surface water
2	Dense vegetation	orchards, mixed forest and plantation
3	Light vegetation	grass, nurseries, farmland/crop land
4	Built-up	Residential, commercial, industrial and transportation
5	Bare Land	Sandy area, paved surface, and open land

Source: Sentinel-2A, (February, 2021)

To facilitate easy comparisons, values of all the constraints for analysis were standardised to a common scale using Byte Scale in a range of 0–255; where 0 = least suitable and 255 = most suitable (Eastman, 2003; Makropoulos & Butler, 2006; Mahini & Gholamalifard, 2006; Ferretti & Pomarico, 2013). Then, the criteria scores were standardised using Fuzzy Membership Functions in ArcGIS environment (Tuzkaya & Gulsu, 2008; Sener & Sener, 2020). The decision on which function should be used for each criterion was based on EPA guidelines.

Furthermore, the weight of each criterion was determined using analytical hierarchy method of ranking/rating procedure (Malczewski & Rinner, 2005; Sulemana et al., 2020). The rankings were standardised to numerical weights on a scale 0 to 1 with overall summation of 1. By this, the four criteria of surface water, transport routes, buildings (built-up area) and slope were ranked based on their importance to landfill site selection as stipulated by EPA (2006). Vegetation, though not a criterion for analysis in this study, was included as a fifth criterion in the ranking because it is a major component in the area consisting of both the natural and artificial features. All the criteria were aggregated in Weighted Linear Combination (Equation 1), which is the most used decision rule (Mahini & Gholamalifard, 2006; Malczewski & Rinner, 2015).

$$S = \Sigma wixi \times \pi cj \qquad (1)$$

Where:
S = composite suitability score, x_i = factor scores (cells), w_i = weights assigned to each factor, c_j = constraints (or Boolean factors), $\sum$ = sum of weighted factors, π = product of constraints (1-suitable, 0-unsuitable). This was applied in GIS raster calculator

S = [(C1 * 0.50) + (C2 * 0.30) + (C3 * 0.10) + (C4 * 0.07) + (C5 * 0.30)] * cons_boolean

C1 to C5 and cons_boolean are thematic layers representing the factors and constraints. The reliability of the results was validated through ground truth verification. After weightings have been applied, the aggregation of all the criteria considered for analysis were fuzzified using a Fuzzy Overlay. By this, good sites for landfills in the study area are those areas that fall within the 8º - 10º class and satisfy other conditions as specified by Environmental Protection Agency (2006).

In effect of the foregoing, the basic spatial analysis employed in this study was buffering operation in which criteria were analysed in the ArcGIS environment. Buffers of specific distance were created around the dumpsites to determine their proximity level to the transport routes, rivers and the built-up areas. Slope analysis of between 8º and 10º was considered to determine areas with the best slope suitable for landfill.

RESULTS

Results of Accuracy Assessment

Table 3 indicates that water body had the highest accuracy (both UA and PA recorded 100%). With overall accuracy of 94.88% and kappa value of 0.860, therefore there are high significant agreements between the reference points and the extracted classes (Mishra et al., 2016; Congalton & Green, 2019; Braun, 2020).

General Pattern of Landcover in the Study Area

Figure 2 shows the general pattern of landcover in the study area. Based on the objectives of this study, the whole area was classified into vegetation, waterbody, bare land and built-up area. Vegetation class includes all parts containing both usual and reproduced vegetal cover. Therefore, vegetated area was divided into sparse and dense classes for the purpose of differentiating between vegetation and cultivated or secondary regrowth. For instance, whereas vegetation includes all wilderness areas, cultivated or secondary regrowth comprises grazing or pasture land, farmlands, fields and open green spaces. Waterbody in the area are largely rivers and streams of which River Niger is the major drainage system. Bare land includes outcrop areas, paved surfaces, open top soils impervious surfaces and all other areas, asides built-up and waterbody, that are not vegetated. The built-up area includes residential, industrial, commercial and all other areas containing buildings (regardless of the quantity and quality of the buildings).

Table 4 shows the proportion of each landcover in the study area. Most of the area consisted of light vegetation which could have been used for farming activities or any other open green field. Of the 1364.41km², only 216.67 km² (representing 15.88% of the total land area) was built up with the greatest concentration of development in the eastern part of the area. However, there were dispersed development of the built-up land use in the northern section, some parts of the west and the central segment of the southern area. The southwest and north-western parts of the study area are devoid of any human habitation (Fig. 2).

Table 3 Confusion Matrix for Landcover Classification (2021)
Source: Sentinel-2A, (February, 2021)

LULC classes	Classification Accuracy (%)	
	User's Accuracy	**Producer's Accuracy**
Water body	100	100
Dense vegetation	87.5	90.1
Light vegetation	84.2	100
Built-up	100	89.7
Bare Land	93	85
Overall Accuracy	94.88	
Kappa Index (KI)	0.860	

Source: Sentinel-2A, (February, 2021)

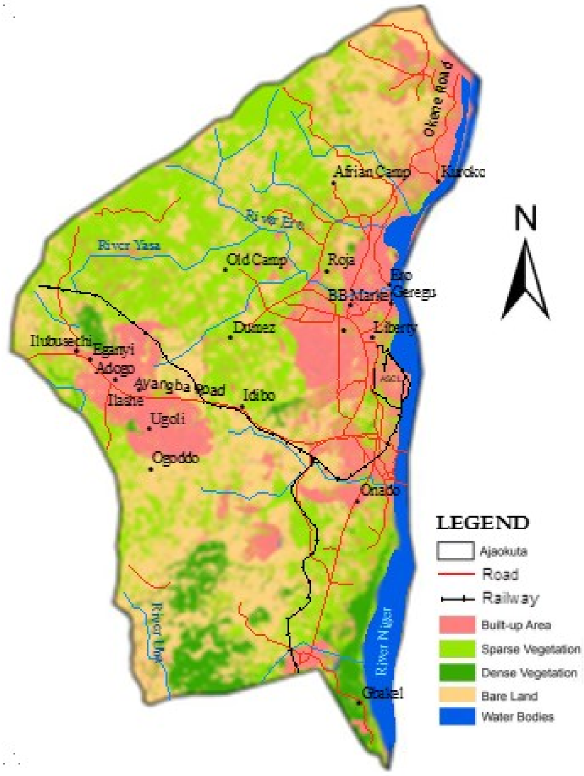

Fig. 2 Landcover in Ajaokuta
Source: Sentinel-2A (February, 2021)

Location of Existing Dumpsites in Ajaokuta

The major system of waste disposal in the study area was open dumpsites; there was no land fill in Ajaokuta. Table 5 contains the locations and nearness of the present major dumpsites in Ajaokuta to the nearest selected criteria for assessment. The distances were calculated in ArcGIS and verified with a handheld GPS with accuracy of not more than 4%. At individual level of assessment, some of the existing dumpsites might just be suitable for landfills. For instance, considering slope criterion, dumpsites D1, D2, D13 and D14 are located within the slope range of 8° - 10° and can accommodate landfills. Also, on account of waterbody factor, only D15 and D20 were too close at 250 m minimum setback to surface water; all other areas are suitable for landfills. Moreover, using transport route as primary criterion, only site D11 was found at a distance below the minimum setback of 100 m. All the twenty dumpsites in the study area were found either within settled area or at a very short distance from the built-up area, therefore, none of the sites is suitable for landfill based on buffer zone of 2,500 m from built-up area.

Figure 3 indicates that the dumpsites were located close to transport routes, buildings and water bodies. Dumpsite D11 at BB Market was located almost on the road at a short distance of 14.2 m. However, based on the criteria selected for analysis, these are unsuitable areas for siting a landfill (Table 5). In effect of these observations, none of the existing dumpsites fits the criteria for siting a land fill, therefore, it is imperative to find suitable sites.

Table 4 Landcover classes of Ajaokuta

LULC classes	Area (km²)	%
Water body	47.48	3.48
Dense vegetation	82.96	6.08
Light vegetation	844.7	61.91
Built-up	216.67	15.88
Bare Land	172.6	12.65
Total	1364.41	100.00

Source: Generated from Figure 2 based on Sentinel-2A (February, 2021)

Selection of suitable landfill sites in Ajaokuta

The variables considered in the final suitability map are: distance to surface water, proximity to building, distance to transport route and slope. The built-up area was buffered at 2500 m (Fig. 4A). The purpose is to create adequate set back between dwelling areas and the landfill sites to avoid any form of pollution. The areas outside the buffered zone are potential areas for siting of landfills because they are out of the restricted areas. Furthermore, roads were buffered at 100 m in order to consider aesthetics and safety (Fig. 4B). Moreover, in order to mitigate conflicts relating to the

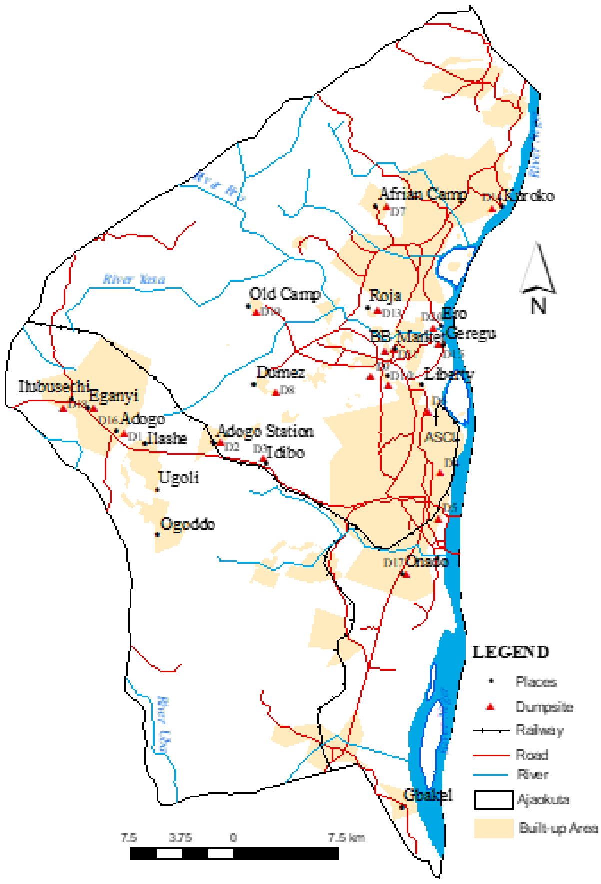

Fig. 3 Spatial pattern of existing dumpsites in Ajaokuta
Sources: Sentinel-2A (February, 2021), Openstreetmap (accessed on August 25, 2021)

Table 5 Proximity of existing dumpsites to the nearest selected criteria for evaluation

Dumpsite Tag	**Location of Dumpsite**	**Slope** (in degrees)	**Distance** (in Metres)			**Remark**
			Built-up Area	**Water Bodies**	**Transport Route**	
D1	Adogo	9.8	118.3	2951.7	715.9	Not suitable
D2	Adogo Station	9.4	within	3227.9	565.0	Not suitable
D3	Idibo	6.9	within	2166.9	422.7	Not suitable
D4	ASCL	3.3	within	877.9	628.2	Not suitable
D5	ASCL	3.1	within	654.7	499.5	Not suitable
D6	ASCL	5.7	within	1288.2	103.5	Not suitable
D7	African Camp	7.1	within	2,893.6	860.2	Not suitable
D8	Dumez	3.7	within	3,098.2	1,793.8	Not suitable
D9	Mechanic Village	16.4	within	5,383.6	953.8	Not suitable
D10	Mechanic Village	7.3	within	3,640.8	762.9	Not suitable
D11	BB Market	5.9	within	396.9	14.2	Not suitable
D12	BB Market	5.6	within	825.5	383.3	Not suitable
D13	Roja	8.4	71.8	1,467.1	689.0	Not suitable
D14	Kuroko	9.2	within	418.7	627.1	Not suitable
D15	Geregu	1.3	within	243.6	115.3	Not suitable
D16	Eganyi	14.8	within	2706.4	516.7	Not suitable
D17	Onado	5.4	within	1766.5	360.3	Not suitable
D18	Ilubusechi	2.7	within	2225.2	573.5	Not suitable
D19	Old Camp	7.6	13.7	1,792.1	731.0	Not suitable
D20	Ero	0.6	within	51.2	579.6	Not suitable

Sources: Shuttle Radar Topography Mission (SRTM), Sentinel-2A (February, 2021), Openstreetmap (accessed on August 25, 2021), Field Research, 2021

contamination of sources of water supply, surface water bodies were buffered at 200 meters (Fig. 4C).

The slope height is an essential parameter that must be considered in case of flood which can lead to water pollution, too low or steep slopes must be avoided in the selection of landfill sites (Fig. 4D). Areas with slope of 0° to 7.9° are considered as too low for siting landfills because they may be undulating terrain or, even a basin, that would not encourage such an earth drilling landscape. Also, areas with slope above 10° are too steep and may accelerate erosion and consequently, may result in flooding. In Fig. 4D, these are the yellow and white portions, respectively. Furthermore, Fig. 4D indicates relatively level land areas with slope between 8º and 10º as green where landfill can be sited.

However, it might be dangerous to compare data at different measurement levels. Therefore, using analytical hierarchy method of ranking/rating procedure, a standardised data of the five ranked criteria for landfill site selection was produced (Table 6). Buildings/built-up area (C1) was the most important criterion while C5 (vegetation) was the least important (Table 6). Vegetation had the least weight since it was not even a factor for consideration. Nevertheless, vegetation must be retained in the analysis to maintain a balance of 100% score and 1.0 weight aggregate.

Figure 5 is a fuzzy overlay of all the four criteria (road, water body, built-up area and slope) considered for analysis in this study. Based on EPA (2006) requirements for siting landfills in Nigeria, all the grey areas are not suitable for landfill sites on account of too low (below 8°) or too steep (above 10°) slope and proximity to human habitation, surface drainage system and closeness to transport routes. To avoid all kinds of environmental and health problems, it is very important to abide by all the laid-down rules and regulations, available guidelines and stipulated criteria for siting landfills (Dijkstra et al., 2018). Considering the criteria for evaluation, areas marked green in Figure 5 are the appropriate sites for locating landfills in the study area (EPA, 2006).

Table 6 Standardised data for landfill site selection

Criterion No	Criteria/Constraints	Score (%)	Weight	Suitability Values	Buffer (m)
C1	Buildings (built-up area)	50	0.5	decreases with distance to buildings	2,500m
C2	Surface Water	30	0.3	decreases with distance to surface water	250m
C3	Transport Routes	10	0.1	decreases with distance to transport routes	100m
C4	Slope	7	0.07	decreases with increase in elevation	8º - 10º
C5	Vegetation	3	0.03	source of nectar and pollen	
	Total	100	1.0		

Source: Field Research, 2021

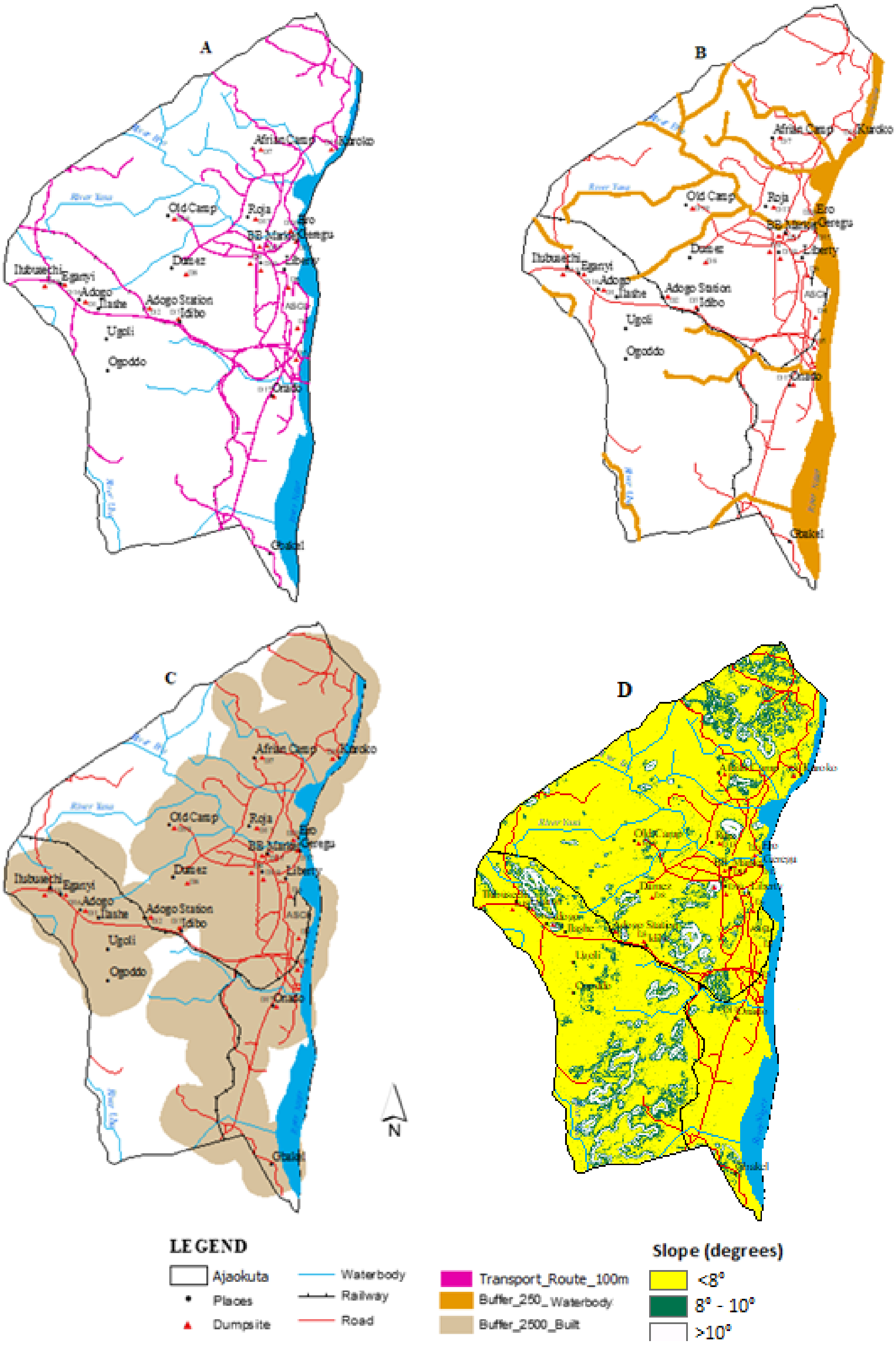

Fig. 4 Buffering around the considered Landfill Siting Criteria. A) 100 metres buffer around all transport routes. B) 200 metres buffer around all surface water. C) 2,500 metres buffer zones around all built-up areas. D) Slope of the area
Sources: Sentinel-2A (February, 2021); Shuttle Radar Topography Mission (SRTM), Openstreetmap (accessed on 25 August, 2021)

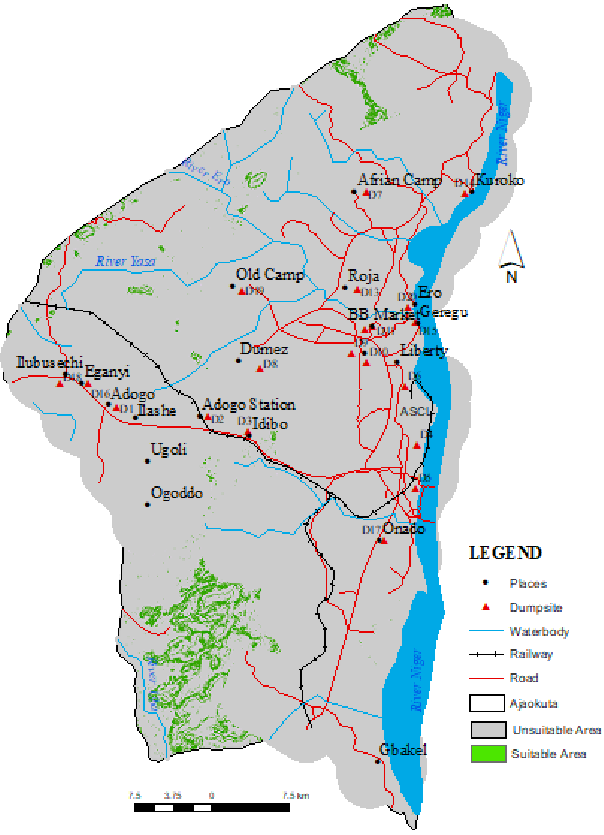

Fig. 5 Fuzzy Overlay of the Considered Landfill Siting Criteria
Sources: Sentinel-2A (February, 2021), Openstreetmap (accessed on August 25, 2021)

DISCUSSION

Solid wastes are not properly disposed in Ajaokuta, Nigeria; the open dump solid waste disposal practice is not in accordance with the best principles of public health and environmental protection. Thus, this study employed the use of geospatial technology to acquire information on dumpsites in Ajaokuta with the hope that it will enable proper monitoring and management of the existing dumpsites. This was with the view of preventing environmental hazards which might cause disease outbreak. Also, geospatial technology was used to determine the location of the most suitable place for landfills so that a healthy environment can be maintained in Ajaokuta.

This study used OSM and remotely sensed data to analyse and map out the possible sites for landfills in Ajaokuta, Nigeria. Proposed landfill sites were determined using buffering analysis of the dumpsites at 100 m, 200 m, and 2,500 m around roads, rivers/watercourses and built-up areas, respectively. However, all of these were ascertained on slopes that are between 8° and 10°. The results indicated that many parts of Ajaokuta, Nigeria are not suitable for the siting of landfills. The study area presents low suitability for siting landfills because of large network of transport routes, wide expanse of the built-up area and availability of many surface waterbodies. Furthermore, the slope of the area did not permit landfill to be sited in most parts of the industrial town. This implies that very little land is available and suitable for landfill in the study area. This is not different from some previous observations (Mahini & Gholamalifard, 2006; Jibril et al., 2017) which established that only sizeable areas are suitable for landfill development within their respective study areas.

Results of buffer operation indicated that all the existing dumpsites are unsuitable locations to accommodate landfills in Ajaokuta. Through the spatial multi-criteria analytical methods adopted for this study, it was revealed that there are quite a few sites within the iron and steel industrial town of Ajaokuta, Nigeria where landfills can be located. Subsequently, two major areas were identified in the northern and southwestern parts as the most suitable sites for siting of landfills. However, outside these two major areas, there are a few other possible landfill sites, especially, in the western and central parts of the study area. This result corresponds with the findings of other studies that have found the existing dumpsites as unsuitable possible suitable sites for establishing a dumpsite in their respective study areas (Ebistu & Minale, 2013; Zulu & Jerie, 2017; Krčmar et al., 2018).

CONCLUSION

This study observed that the proposed landfill sites in the industrial town of Ajaokuta, Nigeria are easily accessible, far away from human dwellings and at safe distances from any surface water. The proposed landfill sites are in relatively dry areas, bare land with light vegetation (mostly, agricultural land) where the slope is between 8 and 10 degrees. Nevertheless, it is important to note that areas to be used for landfill may gradually become less accessible with progressing time and might result in great increase in the costs of disposing wastes and high level of environmental risks. Therefore, to improve the quality of urban environment as well as that of life of the inhabitants, there should be proper land use planning which, in turn, should lead to efficient land use. Also, there is the need to update, improve and increase the level of waste management services in Ajaokuta.

Overall, the use of geospatial technology should be encouraged by the environmental ministry for proper monitoring and management of the environment. There should be strict regulations and policies guiding solid waste disposal and management such that defaulters are made to pay fine based on the extent of pollution.

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