JOURNAL OF GEOSPATIAL SCIENCE AND TECHNOLOGY

ISSN: 2408-6517 (Print) | 2756-4088 (Online) | www.afrigistjournals.com/jgst

AFRIGIST

Geospatial Analysis of Lagos State Landfill Site Suitability and Multi-Criteria Spatial Decision Support System

Nathaniel Olugbade ADEOYE and Collins Chidiebele OKELEKE

To cite this article: Nathaniel Olugbade ADEOYE and Collins Chidiebele OKELEKE, Geospatial Analysis of Lagos State Landfill Site Suitability and Multi-Criteria Spatial Decision Support System, (2022), *Journal of Geospatial Science and Technology*, 3(1), 36-56, https://afrigistjournals.com/index.php/jgst/article/view/3a4

Link to this article: https://afrigistjournals.com/index.php/jgst/article/view/3a4

Date published online: 02 June 2022.

chiefeditor@afrigistjournals.com

Journal of Geospatial Science and Technology 3 (1): 36-56, 2022
ISSN: 2756- 4088 (Online), 2408-6517(Print) doi: https://doi.org/10.54222/afrigist/jgst/3a4
Accepted: May 30, 2022

Geospatial Analysis of Lagos State Landfill Site Suitability and Multi-Criteria Spatial Decision Support System

Nathaniel Olugbade ADEOYE and Collins Chidiebele OKELEKE
Department of Geography, Obafemi Awolowo University, Ile-Ife
Correspondence: nadeoye@yahoo.com

Abstract
Landfill siting is an extremely complex task, mainly because of the process and strict regulations engrossed. This study determined suitability of Lagos State landfill sites by combining geographic information system (GIS) and multi-criteria decision-making method (MCDM) known as analytic hierarchy process (AHP). Global Positioning System (GPS) receiver was used to acquire x, y coordinates of the existing landfills. These were interpolated on the administrative map of the study area to show their spatial pattern. Environmental Protection Agency (EPA) landfill site selection criteria were afterward used to identify set standards and requirements for optimum landfill site. Landsat 7 ETM$^+$2012 was utilized to analyze various land uses around the existing landfills in the study area while ASTER DEM was used to assess the elevation of the study site. The imageries were enhanced and geo-referenced for correct locational identity. Landsat imagery was however, classified into different land uses using supervised classification algorithm. The extracted spatial data were prepared in ArcMap 10.5, processed with AHP weighting/ranking operation and finally produced a suitability map, which was labeled as highly suitable, moderately suitable, less suitable and unsuitable. The results revealed that landfills in Lagos State were no longer suitable in their existing locations. Besides, only 0.001% of the total land area of the study area was identified as highly suitable, 0.119% as moderately suitable and 99.4% unsuitable for landfill site. In conclusion, the study generated a synthesis of knowledge valuable for the planners and stakeholders in the management of urban waste.

Keywords: Analytic hierarchy process (AHP); Geographical information systems (GIS); landfill site selection; Lagos; Nigeria.

ANALYSE GÉOSPATIALE DE L'ADÉQUATION DU SITE D'ENFOUISSEMENT DE L'ÉTAT DE LAGOS ET SYSTÈME D'AIDE À LA DÉCISION SPATIALE MULTICRITÈRE

Résumé
L'emplacement des décharges est une tâche extrêmement complexe, principalement en raison du processus et des réglementations strictes absorbées. Cette étude a déterminé la pertinence des sites d'enfouissement de l'État de Lagos en combinant un système d'information géographique (SIG) et une méthode de prise de décision multicritère (MCDM) connue sous le nom de processus de hiérarchie analytique (AHP). Le récepteur du système de positionnement global (GPS) a été utilisé pour acquérir les coordonnées x, y des sites d'enfouissement existants. Ceux-ci ont été interpolés sur la carte administrative de la zone d'étude pour montrer leur modèle spatial. Les critères de sélection des sites d'enfouissement de l'Agence de protection de l'environnement (EPA) ont ensuite été utilisés pour déterminer les normes et les exigences relatives à un site d'enfouissement optimal. Landsat 7 ETM$^+$2012 a été utilisé pour analyser diverses utilisations des terres autour des sites d'enfouissement existants dans la zone d'étude, tandis qu'ASTER DEM a été utilisé pour évaluer l'élévation du site d'étude. Les images ont été améliorées et géoréférencées pour une identité de localisation correcte. L'imagerie Landsat a toutefois été classée en différentes utilisations des terres à l'aide d'un algorithme de classification supervisé. Les données spatiales extraites ont été préparées dans ArcMap 10.5, traitées avec une opération de pondération/classement AHP et ont finalement produit une carte d'adéquation, qui a été étiquetée comme très appropriée, modérément appropriée, moins appropriée et inappropriée. Les résultats ont révélé que les décharges de l'État de Lagos ne convenaient plus à leurs emplacements existants. En outre, seulement 0,001 % de la superficie totale de la zone d'étude a été identifiée comme hautement appropriée, 0,119 % comme modérément appropriée et 99,4 % impropre au site d'enfouissement. En conclusion, l'étude a généré une synthèse des connaissances précieuses pour les planificateurs et les parties prenantes de la gestion des déchets urbains.

Mots-clés : Processus de hiérarchie analytique (AHP); Systèmes d'information géographique (SIG); le choix des sites d'enfouissement; Lagos; Nigéria.

1. Introduction

Landfill has been recognized as the cheapest form of final disposal of municipal solid waste. It is the oldest form and most common method of waste treatment and disposal in so many places around the world. Three types of landfills are normally used for solid waste disposal; these include open dumps, secured or sanitary landfills and controlled landfills (Egun, Iniaghe, and Evbayiro, (2016). Open dumps are where there are no standards for refuse dumping (Gouveia and Prado, 2010). They are locations where illegally dumped, abandoned piles of garbage and debris are left in large quantities.

Secured or Sanitary landfills are carefully engineered depression in the ground (or built on top of the ground, resembling a football stadium) consisting of a bottom liner, a leachate collection system, a cover, and the natural hydrogeologic setting. The aim is to avoid any hydraulic (water-related) connection between the wastes and the surrounding environment, particularly groundwater (Environmental Research Foundation, 2011). Controlled landfills on the other hand are non-engineered disposal sites at which wastes are deposited in accordance with minimum prescribed standards of site operation. Typically, controlled landfills have minimal site infrastructure, with improved operational and management procedures. The site is generally identified on the basis of land availability and convenience and is already being used as an open dump; and not on the basis of technical, environmental or financial criteria. Also, there is typically little provision for the management of pollutants released during decomposition of municipal solid waste (Egun, *et al.,* 2016).

Siting landfill is an extremely complex task mainly because of the identification and selection process, which involves many factors and strict regulations. In general, economic, environmental and social criteria are required in the first phase of evaluation. Economic criteria (distance to roads, slope, etc.) must be considered in siting of landfills, which include the costs in relation with the development and operation of the site (Erkut and Moran, 1991). Environmental criteria (distance to surface waters, dam, lake, etc) are also very important due to the fact that the landfill may affect the ecology of the vicinity (Kontos, Komilis, and Halvadakis, 2003). Furthermore, social/physical criteria (distance to residential, commercial, industrial areas, etc.), should be considered important factors since "Not in my backyard" (NIMBY) or "Not in anyone's backyard" (NIABY) syndromes are creating tremendous pressure on the decision makers dealing with landfill site selection (LSS) (Chang *et al.,* 2008).

For proper identification and selection of appropriate sites for landfills, careful and systematic procedures need to be adopted and followed. This is because wrong siting of landfill may result in environmental degradation and oftentimes, public opposition. Literature is replete on the adverse environmental impacts, public health problems, socio-economic challenges and increased public opposition of uncontrolled municipal solid waste landfills (Bagchi, 1994; WHO, 2000; Aatamila, *et al.,* 2010; Ayub and Khan, 2011; Alanbari, *et al*., 2014; Egun, Evbayiro and Ukeko 2015, Guler and

Yomralioglu, 2017). As expressed by Iwugo (1986), landfilling activities usually impact negatively on not only groundwater quality, but also induce negative health implications on the repository communities like the incidence of malaria, typhoid and diarrhoea, and respiratory diseases such as, cough and catarrh. In the study of Aatamila *et al.,* (2010); Gouveia and Prado, (2010); Nwanta *et al.,* (2010); Ogunrinola and Adepegba (2012), it was reported that there were correlations between environmental pollution arising from waste dumps/landfills and public health, and the social consequences of the present urban waste management issues in developed and developing countries.

The location of Lagos State landfill sites has become an issue of concern to the stakeholders, scholars and private individuals, which culminated into scholarly studies. Majaro and Abu (2004) studied the three principal landfills in Lagos State and discovered that residential, commercial and industrial landuses were found within 60 metres to the landfills, making them unsuitable location. Kola (2012) assessed the impact of municipal solid waste on underground water sources in Lagos and reported that the analysis of water samples from Olusosun landfill and surrounding areas confirmed the presence of fecal coliforms during microbiological analyses, suggesting that the water sample collected from Olusosun was not suitable for consumption. The results further showed that the pH value of the well samples (5.85) was acidic and less than the recommended WHO limits of 7–8.5. This suggests that there could be harmful effects as a result of consumption of the well sample, especially, where the sampled wells were depended upon by the communities residing around the landfill site. The increased pH conclusively can be linked to the leachate arising from the landfill site.

Most existing studies of landfills in Lagos States have focused mainly on the environmental challenges and health implications posed by the landfills. The main thrust in this study is from the guidelines of landfill site selection (LSS) standard laid by the Environmental Protection Agency (EPA) on landfill of 2006, which specified that no sensitive landuse should be found within 500 metres of any landfill; and such sensitive landuses should include water bodies, highways, commercial centres, residential areas, and the geology of the site should be impermeable, etc. This study therefore, analyzed different land uses around three principal landfills in Lagos State, viz; Olusosun, Solous I & II and Abule-Egba landfills; assessed their levels of conformity to EPA landfill site criteria, and finally determined appropriate sites for landfill in Lagos State by combining GIS and a multi-criteria decision making method (MCDM) known as Analytic Hierarchy Process (AHP) for the determination of the relative importance weights of factors (criteria).

Geographical Information Systems (GIS) have emerged as useful computer-based tools for spatial operations. It is a computer-based technology for collecting, processing, managing, analyzing, modeling and presenting spatial data for a wide range of applications. Due to its ability to manage large volume of spatial data from various resources, GIS is ideal for site selection studies (Kao and Lin, 1996). It has been widely applied in the past for site selection studies (Woodhouse, *et al.,* 2000, Thomas, 2002; Nikolakaki, 2004; Haaren and Fthenakis, 2011; Chabuk *et al*., 2017, Shah, *et al.,* 2019). GIS is therefore, an important tool because it not only reduces time and cost of the site selection, it also provides a digital data storage for long term management and planning.

2. Study area

Three principal landfills in Lagos State were selected for the study, viz; Olusosun, Solous I & II and Abule-Egba landfills. They were formerly located at the outskirt of the city. But as a result of urbanization process, they become unfit for the environment because of the threat they pose to the immediate environment. Lagos is in southwestern Nigeria, lies between longitudes $2^{0}42'$ and $4^{0}21'$East of Greenwich and latitudes $6^{0}22'$ and $6^{0}41'$ North of Equator. The southern boundary, a length of 180 km along Atlantic coastline, is bounded in the north and east by Ogun State (Figure 1) (Lagos Bureau of Statistics, 2011).

Lagos State is characterized by a tropical climate, with two climatic seasons, namely; the dry (November-March) and wet (April-October). The state, however, experiences predominantly southwesterly wind and sea breezes all year round. The average maximum temperature in Lagos between 2001 and 2010 was 31°C (Anthony and Kehinde, 2014). Four soil groups are identifiable in the state, viz; juvenile soils on recent windborne sands, juvenile soils on fluvio-marine alluvium (mangrove swamp), mineral and/or organic hydromorphic soils and red ferrallitic soils on loose sandy sediments. Geologically, the study area lies within the Nigerian part of the extensive Dahomey Basin. The drainage system of the state is characterized by a maze of lagoons and waterways, which constitute about 22%, or 787 sq. km of the state total landmass. The vegetation types are swamp forest of the coastal belt and dry lowland rain forest.

According to 2006 census figure, Lagos State population was 17.5 million people, with a growth rate of 3.2%. Lagos State has an estimated population of over 21 million people. The State is essentially a Yoruba speaking State (Lagos Bureau of Statistics, 2011).

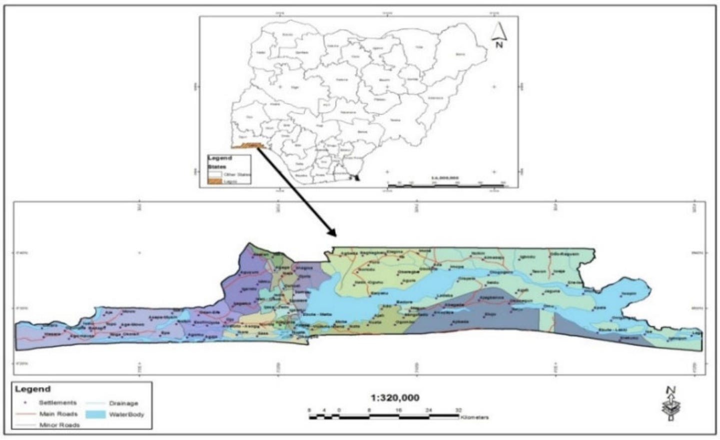

Figure 1: Lagos State map showing LGAs

3. Materials and Method

The study relied on both primary and secondary source data. The primary data emanated from a handheld Global Positioning System (GPS) receiver used to acquire X, Y coordinates of the existing landfills in the study area. The coordinates were subsequently interpolated on the administrative map of the study area to show the spatial pattern of the existing landfills in the study area. The boundary of the landfills was digitized and mapped out. The secondary data used include Environmental Protection Agency (EPA) landfill site selection criteria (Table 1), Landsat 7 ETM^{+} of 2012, ASTER

DEM and administrative map of the study area.

While the EPA data were used to identify the set standards and requirements that must be satisfied in determining the optimum site for a landfill, Landsat imagery was used to generate and analyze various land uses around the existing landfills. ASTER DEM data were used to assess the elevation of the study site. The spot height of the terrain was extracted and the slope calculated in ArcMap 10.5. The slope of terrain is an important factor that is useful in evaluating Landfill Site Selection (LSS). The information derived from the slope analysis helped in identifying the locations within the study area that have the required slope gradient that satisfies the EPA LSS standards.

The imageries were enhanced and geo-referenced to give them correct locational identity. Landsat imagery was classified into different land uses using supervised classification algorithm. The different land uses identified include built-up area, waterbody, bare soils and shrubs. These extracted spatial data served as individual layer in the ArcMap environment as determined by the Environmental Protection Agency (EPA)landfill site selection criteria. The data layers created from the criteria were subjected to the Analytic Hierarchy Process (AHP)weighting/ranking operation and the GIS spatial analysis operation was used to produce a suitability map. The AHP developed by Saaty (1980a) is a technique for analyzing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles, viz; decomposition, comparative judgment and synthesis of priorities.

Table 1: Factor Criteria Formulated from EPA Landfill Manual 2006

Criteria	Least suitable	Moderately suitable	Highly suitable
Distance to water body	160-480m	480-960m	>960m
Slope	0^0-5^0	5^0-10^0	10^0-15^0
Distance to road	100-1000m	1000-2000m	>2000m
Distance to residential area	300-500m	500-800m	>800m
Soil	Alluvial	Alisols	Nitisols
Geology	Sandstone, unconsolidated sandstone/ gravel, Quartzite	Migmatite-Gneiss complex	Charnock/Granite

4. Results and Discussion

The negative impacts of landfills such as obnoxious odours, polluted underground water, endemic disease etc., on sensitive landuses are felt within 250 meters radius of any landfill site. Such impacts are capable of posing health risks to the residents of the area, obstructing social and economic activities and inviting epidemics to the area. To avoid these impacts around the land uses, authority must ensure that the landfills satisfy the criteria for siting it. The three landfills selected for the study include Olusosun, Solous I & II and Abule-Egba landfills. They were tested against EPA criteria to ascertain their conformity to the regulation for siting landfill.

4.1 Analysis of EPA Landfill Conformity of Olusosun Landfill

Olusosun landfill is situated in-between Ojota-Ikorodu Road, and adjacent Lagos-Ibadan express way at the outskirt of Lagos State. The level of conformity of the landfill to the EPA landfill site selection criteria is shown in Table 2. As regards the road conformity, Ikorodu Road seems closest to it with a distance of 103.74m while Lagos-Ibadan express way measured184.58m from the site. Kudirat Abiola Road though farther away from the site (281m), did not also satisfy the locational criterion of landfill site. It therefore, implies that Olusosun landfill did not satisfy road distance criteria.

The field measurement from Olusosun landfill site to nearby water body shows that the landfill partially satisfied the distance criteria to water body. For instance, the nearby canal southeast of the site measured 840.12m, which could be said to have moderately satisfied the criterion. The canal located southwest of the landfill seemed farther away but the measurement reveals that it was only 941.65m away, which did not make it to be highly suitable site (Table 2). The EPA suitability gauge put the landfill suitability location of water body at 960m above, which implies that Olusosun landfill did not also satisfy water body criteria.

The study further discovered that urbanization has caught up with Olusosun landfill and the site is no longer suitable because of large number of offices, commercial centres, religious, educational centres and residential areas surrounded it. Observation made during the field survey revealed continuous rising of smokes of burnt refuse and obnoxious odours to the sky and surrounding areas. The EPA requirement specified that for any landfill to be suitable such must not be found around the residential area but this was not the case of Olusosun landfill. There were three communities found around Olusosun landfill, these include Ketu, Ojota and Alapere. The study discovered that while Ketu was 690.85m away from the site, Alapere was 940.90m away when Ojota was less than 600m away. The critical examination of EPA criteria revealed that the location of Olusosun landfill is no longer fit for the environment.

As regards the slope criteria, the site has a lowest slope gradient of 0.2^0 and highest slope gradient of 1.4^0, which did not satisfy the criterion of 10^0-15^0slope recommended for suitable landfill site. The underlying soil type of Olusosun was Nitisols, which fulfilled the suitability criterion. This was discovered when Olusosun landfill map was overlaid on the soil map of Lagos state, making it the only feature that fulfilled site suitability criterion for landfill. The geological formation underlying Olusosun landfill is coastal plain sand as against Charnock /Granite, which was recommended for highly suitable landfill site. This was realized after overlaying the landfill on the geological map of Lagos State and became obvious that it was not a suitable landfill site (Table 2).

Table 2: Olusosun Landfill Conformity Check

Layer	EPA criteria	Field measurements	Conformity/suitability status
Distance from Road	100m - 1000m (Least Suitable) 1000m - 2000m (Moderately Suitable) > 2000m (Highly Suitable)	184.58m from Lagos-Ibadan Express Way, 103.74m from Ikorodu Road; and 281m from Kudirat Abiola road.	Not Suitable
Distance from Water body	160m - 480m (Least Suitable) 480m - 960m (Moderately Suitable) > 960m (Highly Suitable)	840.12m from the water body on its southeastern side; and 941.65m from the water body on the southwestern location.	Moderately Suitable
Distance to Residential Area	300m - 500m (Least Suitable) 500m - 800m (Moderately Suitable) > 800m (Highly Suitable)	Urbanization has caught up with the location of Olusosun landfill. It is only 690.85m from ketu, 940.90m from Alapere and it is within Ojota.	Not Suitable
Slope	0^0 - 5^0 (Least Suitable) 5^0 - 10^0 (Moderately Suitable) 10^0 - 15^0 (Highly Suitable)	The highest slope gradient of Olusosun landfill is 1.4^0 and the lowest 0.2^0 which does not satisfy the EPA requirement	Not Suitable
Soil	Alluvial (Least suitable) Alisols (Moderately suitable) Nitisols (Highly suitable)	On overlaying Olusosun landfill on the Soil map of Lagos state, it was discovered that its soil type is Nitisols which happens to be highly suitable for a landfill site	Suitable
Geology	Quartzite (Least suitable) Migmatite-Gneiss complex (Moderately suitable) Charnock/Granite (Highly suitable)	The geology formation of Olusosun landfill is coastal plain sand. This was realized after overlaying the landfill on the geological map of Lagos State and this is not suitable for a landfill site.	Not Suitable

4.2 Land use/cover around Olusosun landfill

It becomes obvious from Figure 2 that Olusosun landfill is no longer suitable in its present location because of the sensitive land uses/covers that surrounded it. When the landfill was created some decades ago, it was at the outskirt of the city but the city has grown to the extent that a fully developed built up area and network of road now surrounded it. Although the surface water is at a distance place, the seepage from it could make the underground water unsafe for consumption. A 200m interval buffering analysis was performed and was repeated for seven times to extend to 1.4km radius distance around it. This was aimed at determining the land use/cover mostly susceptible to endemic diseases associated with the landfill and also to assess the best location it could be sited. It shows in Figure 2 that the built-up area, which comprises of residential areas, offices, institutions, manufacturing industries and commercial centres (as observed from the field survey), was prone to suffer from diseases associated with the landfill area. Also, that there was no land use/cover that can accommodate the relocation of landfill in that catchment area even if an incinerator system is going to be adopted. However, the forested area located northeast of the area could be a best location even though there is evidence of urban sprawl towards the area, which could also restrict its suitability.

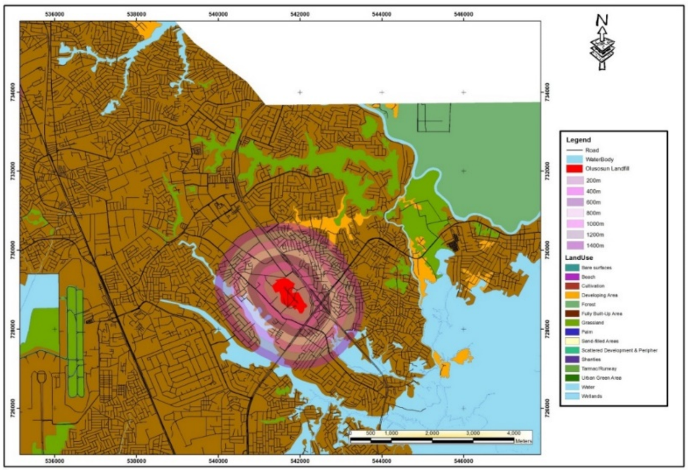

Figure 2: Land use/cover around Olusosun landfill

4.3 Slope analysis of Olusosun landfill

The study utilized ASTER imagery to determine the gradient around Olusosun landfill. According to EPA recommendation, a landfill will be better situated on slope, which is from 10^0-15^0. As shown in Figure 3, the location of Olusosun landfill did not meet the recommendation of EPA and there is no location within the catchment area that is suitable for the siting of a landfill.

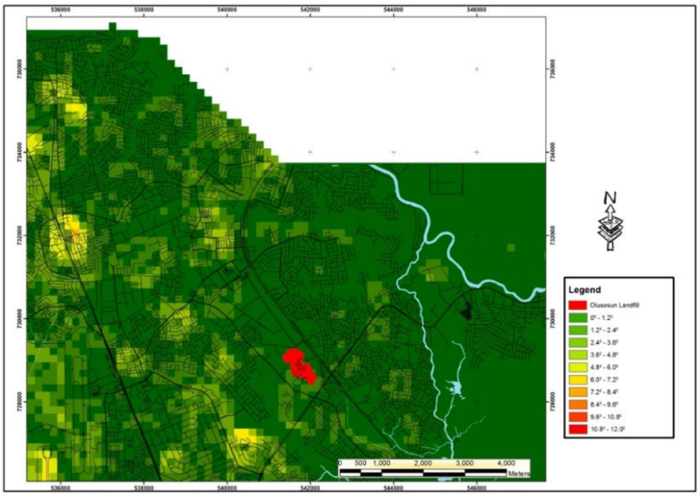

Figure 3: Slope map of Olusosun landfill

4.4 Geological analysis of Olusosun landfill

The geological map of Lagos State was superimposed on Olusosun landfill map to determine the underlying rock on which the landfill was sited. Based on the criterion of EPA, a landfill will be suitable on a Charnock/Granite rock, which Olusosun landfill did not satisfy. As shown in Figure 4, the landfill was sited on coastal sand and there is no area where granite rock could be found. This implies that the location of Olusosun landfill was on a wrong geological surface.

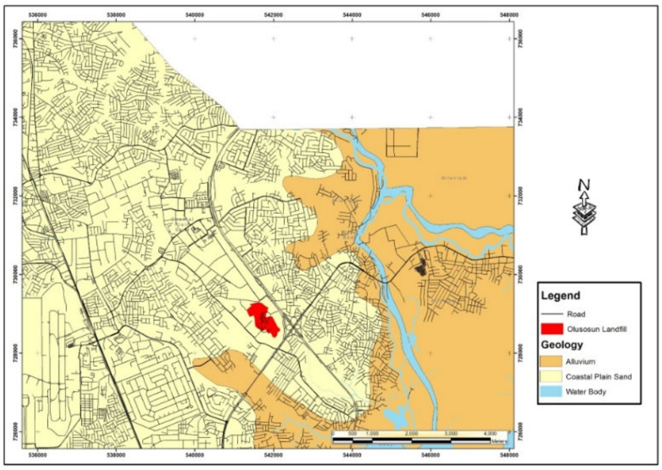

Figure 4: Geology map of Olusosun landfill

4.5 Soil types around Olusosun landfill

The soil type on which Olusosun landfill was sited is Nitisols, which is the recommended soil type suitable for landfill. Among the EPA criteria set for the suitable location for landfill, it was the only criterion fulfilled by Olusosun landfill. As shown in Figure 5, it became obvious that the soil type around the landfill is Nitisols though there were some other soil types.

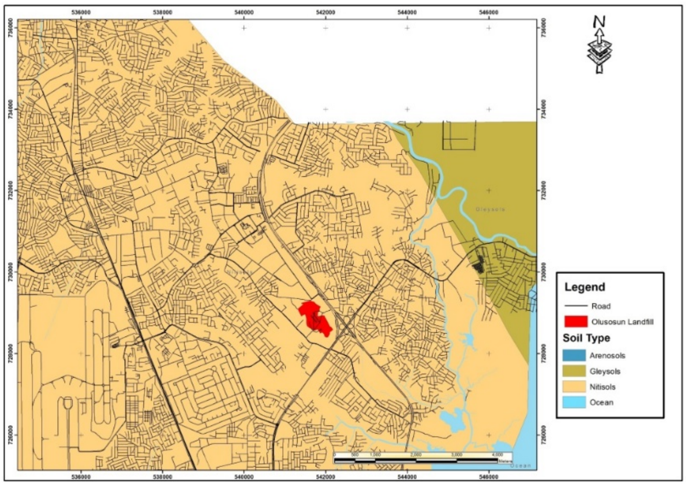

Figure 5: Soil types around Olusosun landfill

4.6 Analysis of EPA Landfill Conformity of Solous I & II Landfill

The second landfill considered in the study is Solous I and II, located in the heart of Igando community, along Isheri-Olofin road at the outskirt of Lagos State. Various measurements were carried out to determine the level of its suitability in relation to EPA landfill conformity criteria. In Table 3, the distance of the site to Igando main road measured 24.16mand from Isheri-Olofin road, it was 20.29m to the site. This shows that Solous I & II were no longer suitable for that location.

The closest water body to Solous landfills was 530.41m away, which made it to be moderately suitable location. But according to EPA standard, a highly suitable landfill location must be above 960m away from any water body. The implication thus, is that Solous I and II landfills were not suitable for the environment.

The location of Solous landfills was at the outskirt of Lagos city as at the time it was created. But urbanization caught up with it and the landfills now share boundary with both residential and commercial areas. Observation made during the field survey revealed that the residents of the area have adapted with the obnoxious environment as they carried out their normal businesses without any complaints.

The highest gradient of Solous landfills was 0.4^0 and the lowest 0.08^0, which made it unsuitable location based on EPA requirement. The soil map of Lagos State was superimposed on Solous landfill to determine the soil type on which it was sited. Suitable soils (Nitisols) recommended by EPA criteria was the soil on which it was sited, which was the only feature met the requirement of EPA. The underlying rock of Solous landfill was determined by overlaid geological map of Lagos State on the landfill. Coastal plain sand was realized, which is not suitable for a landfill site.

Table 3: Solous I and II Landfill Conformity Check

Layer	EPA criteria	Field measurements	Conformity/suitability status
Distance from Road	100m - 1000m (Least Suitable) 1000m - 2000m (Moderately Suitable) > 2000m (Highly Suitable)	Solous landfill is 24.16m from Igando road and 20.29m from IsheriOlofin road.	Not Suitable
Distance from Water body	160m - 480m (Least Suitable) 480m - 960m (Moderately Suitable) > 960m (Highly Suitable)	Solous landfill is 530.41m from the closest water body.	Moderately Suitable
Distance to Residential Area	300m - 500m (Least Suitable) 500m - 800m (Moderately Suitable) > 800m (Highly Suitable)	Urbanization has caught up with the location of Solous landfill, it is in the heart of Igando, sharing boundary with residential and commercial buildings on both sides.	Not Suitable
Slope	0^0 - 5^0 (Least Suitable) 5^0 - 10^0 (Moderately Suitable) 10^0 - 15^0 (Highly Suitable)	The highest slope gradient of Solous landfill is 0.4^0 and the lowest 0.08^0 which does not satisfy the EPA requirement.	Not Suitable
Soil	Alluvial (Least suitable) Alisols (Moderately suitable) Nitisols (Highly suitable)	Soil type on which Solous landfill situated is Nitisols which happens to be highly suitable for a landfill site.	Suitable
Geology	Quartzite (Least suitable) Migmatite-Gneiss complex (Moderately suitable) Charnock/Granite (Highly suitable)	The geological formation of Solous landfill is coastal plain sand, this was realized after overlaying the landfill on the geological map of Lagos State and this is not suitable for a landfill site.	Not Suitable

4.7: Land use surrounding Solous I and II landfill

The evidence that Solous I and II landfills were no longer suitable in the present location was determined by buffering operation of GIS. As shown in Figure 6, the closest land use/cover to the landfills was built up area, which comprises of residential areas, markets, commercial and worship centres respectively. The buffering operation shows that the built-up areas were found within 200m radius distance to the landfills, which makes it an unsuitable site. The main road in front of the landfill was less than 30m while the inlet behind it was found between 400 and 600m buffer. With all indications, Solous I and II landfills were no longer fit for that environment because of proximity to sensitive land uses/covers.

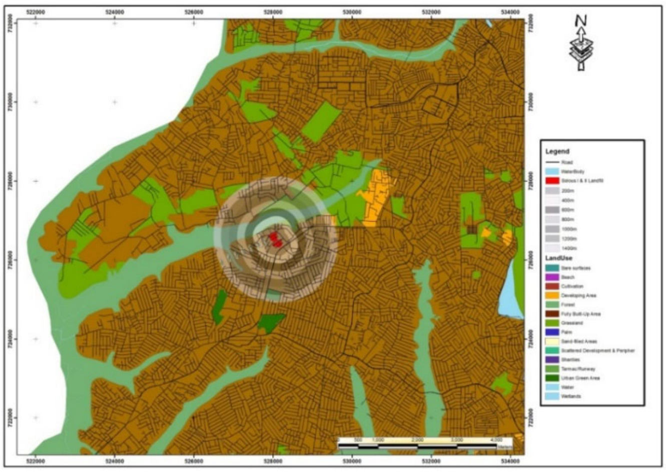

Figure 6: Land use surrounding Solous I and II landfill

4.8 Slope map of Solous I and II landfill

It becomes obvious that Solous landfills did not meet the recommended slope criteria. As shown in Figure 7, the landfills situate on 0^0 - 1.2^0 gradient, which is far below the recommended criteria for a landfill. Even if a new site is being sought for landfill within the catchment area, there is no area that meets the slope requirement as the location with the highest slope reveals 4.8^0-6.0^0. As recommended by EPA, an area is considered highly suitable for landfill when the gradient is between 10^0 and 15^0 (Table 1).

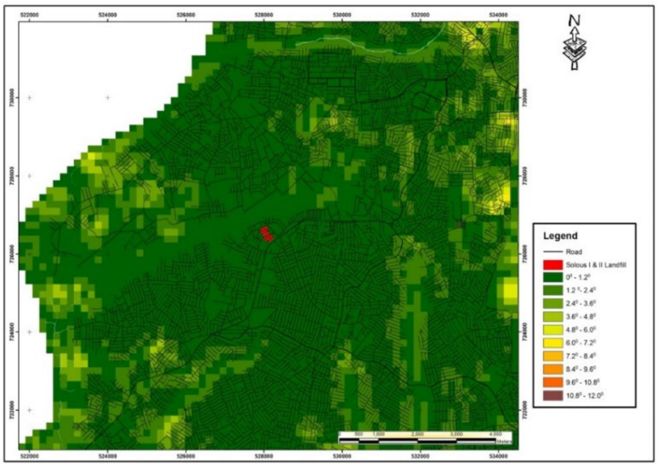

Figure 7: Slope map of Solous I and II landfill

4.9: Geological map of Solous I and II landfill

Similar operation on Olusosun landfill was performed on Solous landfills to determine the underlying rock in which it was positioned. It becomes evident in Figure 8that the rock structure was coastal sand, which spread across the area and there is no area where Charnock /Granite rock recommended for a suitable landfill site could be found. It therefore, means that aside from the fact that the landfill was located on a wrong rock structure, no suitable location could be found in the area as an alternative location

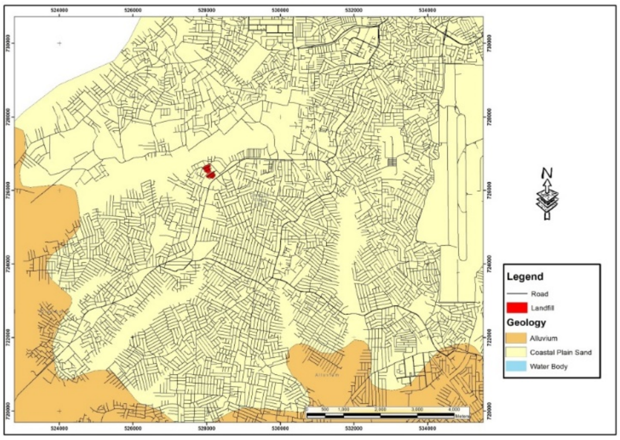

Figure 8: Geological map of Solous I and II landfill

4.10: Soil map of Solous I and II landfill

The prominent soil where Solous landfill was sited is Nitisols (Figure 9), which is the recommended soil on which landfill could be sited. This is the only required feature fulfilled by Solous landfill.

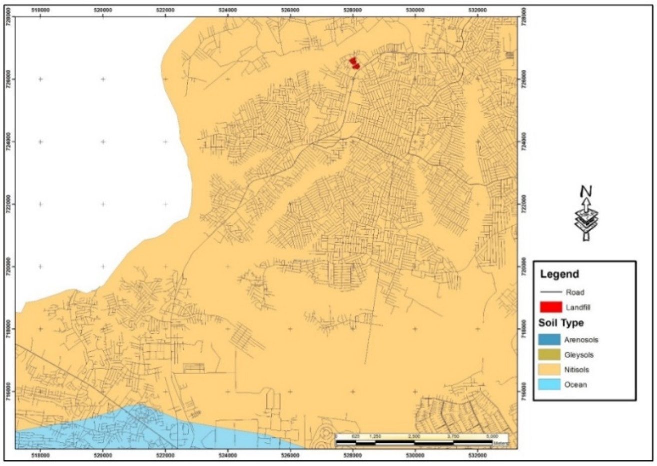

Figure 9: Soil map of Solous I and II landfill

4.11 Analysis of EPA Landfill Conformity of Abule-Egba Landfill

The third landfill considered in the study is located in Alimosho Local Government Area of Lagos State. It was sited at the outskirt of the city to serve as sanitary landfill for the people living around the axis. It was named Abule-Egba landfill after the community that it situates. The site suitability of the landfill was considered in relation to EPA standard. The study measured the distance from the landfill to the main road of Oshodi-Abeokuta express road and the distance was 8.6m(Table 4). As specified by EPA standard, the site of any landfill is considered suitable when its location is 2000m away from the main road, which Abule-Egaba landfill failed to fulfil. Based on this discovery, the landfill is no longer suitable for the environment.

In terms of proximity to the water body, the nearby canal to the site was 1,291.86m, away, which makes it a suitable site going by EPA requirement (Table 4). It also implies that the infiltration of effluence to the surface water may be doubtful. However, the underground water is not safe to the residents of the area that are living within 500m radius to the site. This is because EPA regulation specified that residential area must be at least 800m away from the landfill site before it can be considered a suitable site. But the landfill under consideration (Abule-Egba landfill) violated the condition as markets, shopping malls, business centres and residential area share boundary with it. The horrible odours and emission from the site to the residents and people on business transaction around the landfill call for urgent attention by the authority of Lagos State. A scene at the site during field survey where effluence was oozing out to the main road was an object of concern to the residents and private individuals. Although the waste management authority of Lagos State ensured there was no epidemic outbreak from the site, it becomes obvious that Abule-Egba landfill was no longer suitable in that environment.

The study further examined the gradient of the site to determine whether it conformed to EPA criteria. It was found out that the highest slope gradient of the landfill was 0.8^0 while the lowest was 0.14^0, which did not satisfy the EPA requirement (Table 4). Again, when the landfill was overlaid on the Soil map of Lagos state, it was discovered that its soil type was Nitisols, which was highly suitable for the landfill site. Moreover, the study examined the geological structure on which Abule-Egba landfill was built to determine whether it conforms to the standard of EPA. This was realized through overlay operation of GIS. It was discovered that the underlying rock structure was coastal plain sand, which did not meet the requirement of suitable landfill site.

Table 4: Abule-Egba Landfill Conformity Check

Layer	EPA criteria	Field measurements	Conformity/suitability status
Distance from Road	100m - 1000m (Least Suitable) 1000m - 2000m (Moderately Suitable) > 2000m (Highly Suitable)	Abule-Egba landfill is 8.6m from Abeokuta Express way	Not Suitable
Distance from Water body	160m - 480m (Least Suitable) 480m - 960m (Moderately Suitable) > 960m (Highly Suitable)	Its distance from the closest water body is 1,291.86m	Suitable
Distance to Residential Area	300m - 500m (Least Suitable) 500m - 800m (Moderately Suitable) > 800m (Highly Suitable)	Urbanization has caught up with the location of the landfill, it is within the residential area so much that it shares boundary with residential properties.	Not Suitable
Slope	0^0 - 5^0 (Least Suitable) 5^0 - 10^0 (Moderately Suitable) 10^0 - 15^0 (Highly Suitable)	The highest slope gradient of Abule-Egba landfill is 0.8^0 and the lowest 0.14^0 which does not satisfy the EPA requirement	Not Suitable
Soil	Alluvial (Least suitable) Alisols (Moderately suitable) Nitisols (Highly suitable)	On overlaying Abule-Egba landfill on the Soil map of Lagos state, it was discovered that its soil type is Nitisols which happens to be highly suitable for a landfill site	Suitable
Geology	Quartzite (Least suitable) Migmatite-Gneiss complex (Moderately suitable) Charnock/Granite (Highly suitable)	The geological formation of Abule-Egba landfill is coastal plain sand, this was realized after overlaying the landfill on the geological map of Lagos State and this is not suitable for a landfill site.	Not Suitable

4.12: Land use surrounding Abule-Egba landfill

At Abule-Egba landfill, the study examined the land uses/covers that were closer to the site to be able to assess the most vulnerable land use/cover to the negative effect of the landfill. Buffering analysis was performed to that effect. As revealed in Figure 10, the landfill is established in the heart of a well-developed area sharing boundary with commercial and residential area. This implication is that all the hazards associated with the landfill are borne by the residents of the area. It was also noticed in the Figure that the main road (i.e. Oshodi-Abeokuta express road)that passes along was just few metres away to the landfill. Again, the nearby canal was found within 1,400m buffer zone, which confirms the measurement earlier reported. But the stream that flows across was found within 600m buffer zone to the landfill. This implies that the surface water was not free from the infiltration of the effluence from the landfill. It was further observed that it will be difficult for a new landfill site to be found in the area because virtually all the lands are occupied with a land use or the other.

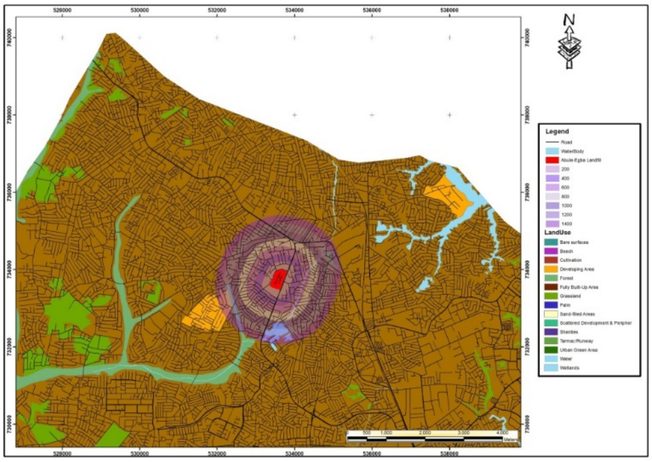

Figure 10: Land use surrounding Abule-Egba landfill

4.13 Slope map of Abule-Egba landfill

Abule-Egba landfill violated slope site suitability requirement for landfill as shown in Figure 11. According to EPA requirement, a landscape is highly suitable for a landfill when the gradient is between $10^0$and 15^0.But the landfill under consideration was on a landscape whose gradient was between 0^0 and 1.2^0, which made it inappropriate for that location.

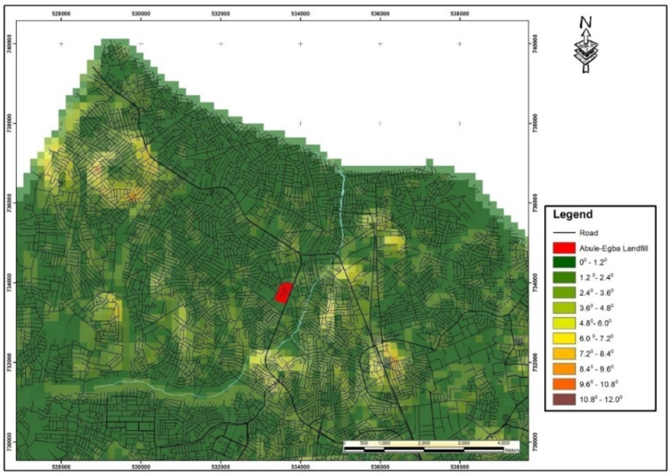

Figure 11: Slope map of Abule-Egba landfill

4.14 Geological map of Abule-Egba landfill

The geological structure under Abule-Egba landfill was similar to that of other landfills considered in the study. This is because of the location of the study sites, which is in coastal area. Generally, Lagos State is in the coastal region and the rock structure has uniform coastal landform. Although the recommended rock structure for any landfill is Charnock/Granite, Abule-Egba landfill, like any other in the study did not meet the standard rock structure requirement for the landfill (Figure 12).

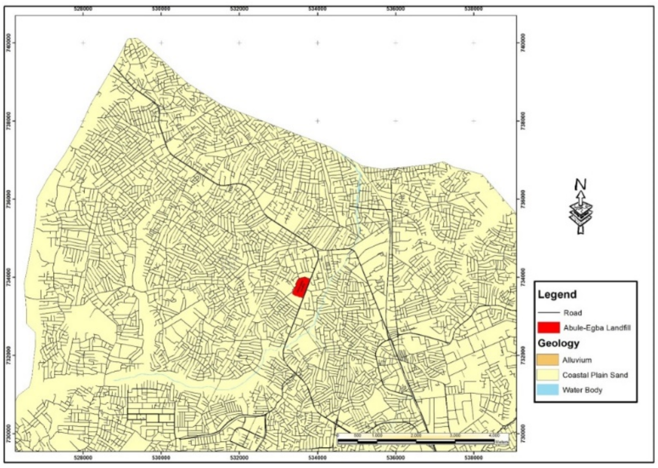

Figure 12: Geological map of Abule-Egba landfill

4.15: Soil map of Abule-Egba Landfill

Nitisols is the soil type highly suitable for a landfill according to EPA requirement. As Shown in Figure 13, the general soil type under Abule-Egba landfill is Nitisols.

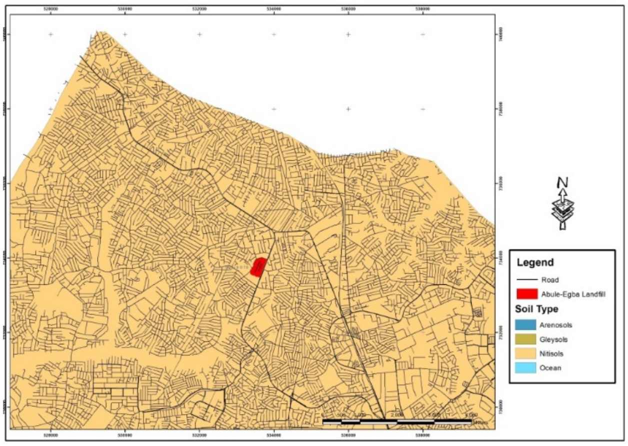

Figure 13: Soil map of Abule-Egba landfill

4.16 Criteria Weights

Criteria weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration. The procedure by which the weights were produced follows the logic developed by Saaty (1980a; 1980b) under the Analytical Hierarchy Process (AHP). Weight rates were given based on pairwise comparison of factors as shown in (Table 5). These pairwise comparisons were then analyzed to produce weights that sum to 1 (Table 6).

Table 5: AHP pairwise comparison scale

Intensity of importance	**Definition**
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Source: Saaty, 1980a

Table 6: Comparison matrix of physical and socio-economic criteria

Landfill Site Selection	**Physical Criterion**	**Socio Economic Criterion**	**Relative Importance weight or weight value**
Physical Criterion	1	1	0.5
Socio Economic Criterion	1	1	0.5

Source: Saaty, 1980a

4.17 Criteria Analysis

The decision tree developed for the landfill site selection problem in Lagos State is such that criteria were prepared as input digital map layers including land use, geology, soil, roads, residential area, water body, and slope types. The comparison matrix indicating the relative importance of the criterion in the columns compared to the criterion in the rows is shown in Table 7and Table 8. Foreach comparison it was decided which of the two criteria was most important, and then assigned score was given to show how much more important it was.

Table 7: Comparison matrix of physical sub criteria

Physical Criterion	Slope	Soil	Water body	Geology	Relative Importance Weight
Slope	1	1/2	1/2	1/2	0.195
Soil	2	1	1/2	1	0.138
Waterbody	2	2	1	2	0.555
Geology	1/2	1/2	1/2	1	0.112

Table 8: Comparison matrix of socio-economic sub criteria

Socio Economic Criterion	Road network	Residential Area	Land use	Relative Importance Weight
Road network	1	1/3	1/2	0.163
Residential Area	3	1	2	0.540
Land use	2	1/2	1	0.297

The resulting weights in is shown in Table 9. According to the external weights generated by the AHP method, the maximum weight (0.2775) was placed on waterbody area factor map as the runoff or pollutants could pollute the waterbodies. Residential area had the second highest weight (0.27) since the pollution could endanger human life. Landuse was third highest (0.1485). The fourth significant highest (0.0975) was attributed to slope, since there is a risk of leachate contamination in the case of a slope failure. The descending order of the weights was assigned to roads, soil and geology factor criteria. The factors and their resulting weights were used as input for the Multi Criteria Evaluation (MCE) module for weighted linear combination of overlay analysis.

Table 9: Final Weights assigned to physical and socio-economic sub criteria

Criterion	Physical Criteria				Socio-Economic Criteria		
Criterion weight	0.5				0.5		
Sub criterion	Slope	Soil	Waterbody	Geology	Road network	Residential area	Land use
Weight	0.195	0.138	0.555	0.112	0.163	0.54	0.297
Final weight	0.0975	0.069	0.2775	0.056	0.0815	0.27	0.1485

4.18 Overlay analysis and identification of suitable sites

In order to combine all the layers to process overlay analysis, standardization of each dataset to a common scale of 1, 2, 3, 4 (value 1 = unsuitable (restricted), value 2 = less suitable, value 3 = moderately suitable, value 4 = highly suitable) was performed. Finally, all the parameters were weighted with their respective percent of influence and overlay to produce the suitability map. The factors, their values and weights were summarized in Table 10. As shown in Table 10, only 0.001% of the total land area in Lagos State is suitable for landfill site whereas, 99.4% are not suitable for landfill site. This has serious environmental implications considering the volume of solid waste generated daily in Lags State.

Output values was prepared using weight overlay analyses of ArcGIS Spatial Analyst, landfill suitability of the study area to produce suitable landfill site map for Lagos State (Figure 14). It therefore, becomes obvious from Figure 14 that no area can be designated as a suitable landfill site in Lagos. The brown colour shown all over the area indicate unsuitable site for landfill in Lagos State.

Table 10: Suitability area analysis

Suitability	Scale	**Area in Ha**	**Area %**
Highly suitable	4	4.532	0.001
Moderately suitable	3	431.247	0.119
Less suitable	2	1,597.997	0.44
Unsuitable	1	361,219.23	99.44
Total		363,253.003	100

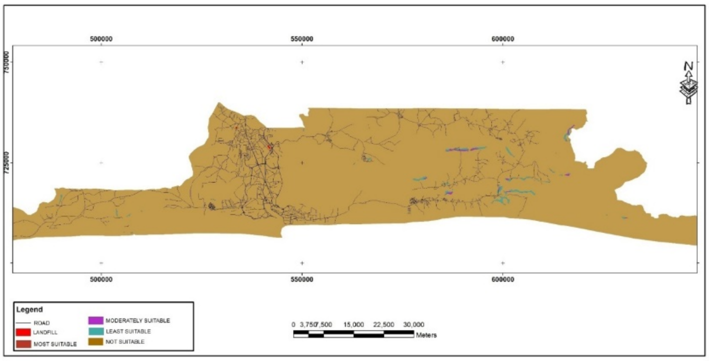

Figure 14: Suitability map of the study area

4.19 Discussion

It is important for the government or any stakeholders to be embarking on site suitability or feasibility study before placing any project in any location. This is because of the discoveries of this study. Although the landfills considered in the study were located at the outskirt of the city when they were created by the authority of Lagos State, the study revealed that certain conditions might not have been put into consideration. In the first place, all the landfills in the study were found in the heart of the metropolis and this indicated that Lagos State waste management authority never thought that rapid urbanization could easily catch up with the location of the landfills. Today, sighting sanitary landfills in the heart of the city becomes eye-sore. The obnoxious odour, swarms of flies and incessant smokes of burnt refuse in the environment were menace to the residents living around the landfills thereby, making the locations of Lagos state landfill unsuitable. As observed by Egun, *et al.,* (2016), dumpsites/landfills in Delta State were breeding sites for disease vectors. The study thus, recommended improved waste and environmental management in the State. Similarly, the Lagos State government in collaboration with Lagos State waste management agency was making frantic efforts to ensuring safety of the residence living around landfill area. As observed during the field survey, refuse was burnt, buried and sand filled regularly to prevent outbreak of epidemic and safety of the residence around the site. Notwithstanding, the sites were being condemned because of their negative impact on the immediate environment.

Again, the study discovered that none of the landfills satisfied environmental protection agency criteria recommended for landfill site. Except soil type requirement that was fulfilled by all the landfill sites, the remaining criteria, slope, geology, proximity to main road and water body were not met by any of the landfill considered in the study. The underlying rock structure in Lagos State was coastal sand, which can easily allow seepage of effluence into the nearby streams or rivers and pollute both surface and underground water. The implication is that residents around the landfills could not guarantee safe water for their consumption. This was the discovery of Kola (2012) who reported that the analysis of water samples from Olusosun landfill in Lagos and surrounding areas confirmed the presence of fecal coliforms during microbiological analyses, suggesting that the water sample collected from Olusosun was not suitable for consumption.

In the study, only 0.001% of the total land area in Lagos State, which represented 4.53

hectares, was suitable for landfill site selection whereas, 99.4%, constituting 361,219 hectares were not suitable for landfill site. The remaining land surface of Lagos State was either moderately suitable (0.119%) or less suitable (0.44%). The Analytic Hierarchy Process (AHP) for the determination of the relative importance weights of factors revealed the true picture of suitable landfill location of Lagos State considering the physical development all over the State. For instance, scarcely can an extensive land area be found without a physical development and/or a proposed site for a project in Lagos State. Besides, an extensive area of Lagoon, canal, water body and swamp areas put limitation to the locations that could have been suitable for landfill site selection. In any urban centre, inappropriate landfill sites can become a problem to the municipal area. As expressed by Iwugo, (1986); Jerie and Zulu, (2017); Senkiio, *et al.,* (2022), landfilling activities in a wrong location usually impact negatively on not only groundwater quality, but also induce negative health implications on the repository communities like the incidence of malaria, typhoid and diarrhoea, and respiratory diseases such as, cough and catarrh. Therefore, proper planning for land use and deciding on the appropriate areas for waste disposal/landfill facilities demand spatial analysis and sound judgment.

In addition to the AHP relative importance weights values, which revealed the percentage land area of Lagos State suitable for landfill site selection, the study further analyzed the weight output values in ArcGIS Spatial Analyst using weight overlay analyses to produce suitable landfill site map of Lagos State. The visual/graphical representation further proved that there is no area in Lagos state suitable for landfill site selection due to urban growth across the State. According to Ogunrinola and Adepegba, (2012); Olusina and Shyllon, (2014); Olanibi and Adebayo, (2022), the increasing growth of cities has implications for municipal waste management among other social services required in the urban communities. Since urbanization has brought its attendant problems especially waste management problem, implementation of environmental policies and adoption of waste reduction and reuse in our urban centres will go a long to guarantee safe environment.

5. Conclusion

This study utilized EPA landfill site suitability criteria to explore the status of three principal landfill sites in Lagos State. It also determined appropriate sites for Lagos State landfill by combining geographic information system (GIS) and a multi-criteria decision-making method (MCDM) known as analytic hierarchy process (AHP) for the determination of the relative importance weights of factors (criteria). It therefore, becomes evident in the study that the locations of the existing landfills in the study area had outlived their relevance, that is, no longer suitable in their areas. This is because places considered as outskirt of the city when they were created has become centre of human activities. This implies that none of the landfills satisfied environmental protection agency criteria recommended for landfill site. Again, the AHP for the determination of the relative importance weights of factors (criteria) revealed only 0.001% of the total land area in Lagos State as appropriate site for landfill whereas, 99.4% were considered not suitable for landfill site. With these discoveries, it becomes necessary for the residence of Lagos State to adopt waste reduction policy to prevent the outbreak of epidemic in the state since the population of the state has remained unchecked. In addition, the authority of Lagos State should implement waste recycle or reuse system to generate money for the economy. It is instructive to note that solid waste management is an obligatory function of the urban local bodies. Thus, appropriate landfill site in a growing city cannot be compromised to prevent unhealthy environment and environmental degradation, which characterize poor landfill sites.

References

Aatamila, M., Verkasalo, P., Korhonen, M.J., Viluksela, M.K., Pasanen, K., Tittanen, P., & Vevalainen, A. (2010). Odour annoyance near waste treatment centres: A population- based study in Finland, *Journal of Air and Waste Management Association*, 60: 412-418.

Adedibu, A.A. (1983). Solid waste characteristics and management in Ilorin,*Journal of Nigeria Institute Town Planning, 3*(1), 33-42.

Alanbari, M.A., Al-Ansari, N., Jasim, H.K., & Knutsson, S. (2014). Modeling landfill suitability based on GIS and multi-criteria decision analysis: Case study in Al-Mahaweelqadaa, *Natural Science*, 6, 828-851. http://dx.doi.org/10.4236/ns.2014.61 1081.

Anthony, N. & Kehinde, O. (2014). Mitigation strategies for the effects of climate change on road infrastructure in Lagos State, *European Scientific Journal, 10(11),* 1857-7881.

Ayub, S. & Khan, A.H. (2011). Landfill practice in India: A review, *Journal of Chemical and Pharmaceutical Research,* 3(4), 270-279. ISSN No: 0975-7384, CODEN(USA): JCPRC5, Available on line www.jocpr.com.

Bagchi, A. (1994). Design, construction and monitoring of landfills, 2nd Edition, John Wiley & Sons, Inc., New York.

Banai-Kashani, R. (1989). A new method for site suitability analysis: The analytic hierarchy process, *Environment Management, 6*, 685-693.

Chabuk, A.J., Al-Ansari, N., Hussain, H.M., Knutsson, S., & Pusch, R. (2017). GIS-based assessment of combined AHP and SAW methods for selecting suitable sites for landfill in Al-Musayiab Qadhaa, Babylon, Iraq, *Environ Earth Sci.,* 76(209), https://doi.org/10.1007/s12665-017-6524-x.

Chang, N., Parvathinathanb, G., & Breden, J.B. (2008). Combining GIS with fuzzy multicriteria decision making for landfill siting in a fast-growing urban region, *Journal of Environmental Management*, 87, 139-153.

Eastman, J.R. (1993). *IDRISI: A grid based Geographic Analysis System, version 4.1.* Graduate School of Geography: Clark University, Worcester.

Egun, N.K., Evbayiro, O.J. & Ukeko, A.O. (2015). Landfill site selection in Delta State Nigeria, *Journal of Global Ecology and Environment*, 3(1), 63-67.

Egun, N.K., Iniaghe, O.P. & Evbayiro, O.J. (2016). Assessment of landfill sites for solid waste management in Delta state, Nigeria, *Journal of Environment and Waste Management,* 3(1), 116-122.

Erkut, E. & Moran, S.R. (1991). Locating obnoxious facilities in the public sector: An application of the hierarchy process to municipal landfill siting decisions, *Socio Economic Planning Sciences, 25*, 89-102.

Environmental Research Foundation, (2011). The basics of landfills: How they are constructed and why they fail, http://www.zerowasteamerica.org/BasicsofLandfills.htm, Accessed August 31, 2011.

Faniran, A. (1982). Solid waste management: A preliminary survey of environmental pollution,, in Filani, M.O. (ed.), *Ibadan Region*, Geography Department, University of Ibadan: University of Ibadan Press.

FME, (Federal Ministry of Housing and Environment). (1982). The State of the environment in Nigeria: Solid waste management in fifteen cities and urban areas of Nigeria. *FMHE, Lagos, Nigeria, No.2* (Monograph Series), 38.

Guler, D. & Yomralioglu, T. (2017). Alternative suitable landfill site selection using analytic hierarchy process and geographic information systems: a case study in Istanbul, *Environ. Earth Sci*., 76(20), https://doi.org/10.1007/s12665-017 7039-1.

Gouveia, N. & Prado, R. (2010). Health risks in areas close to urban solid waste landfill sites, RevSaude Publication, 44(5), 1-8.

Haaren, R. & Fthenakis, V., (2011). GIS-based wind farm site selection using spatial multi-Criteriaanalysis (SMCA): Evaluating the case for New York State,*Renewable and Sustainable Energy Reviews,* 15(7), 3332-3340.

Iwugo, K. O. (1986). Groundwater quality treatment and pollution in Nigeria: The Lagos Metropolis Case Study, *Paper presented at theFirst Annual Symposium on Groundwater Resources, Nigeria Water and Sanitation Association*, Lagos.

Janskowski, P. (1995). Integrating Geographical Information Systems and Multiple Criteria Decision Making Methods,*International Journal of Geographical Information Systems,* 9(3), 279-299.

Jerie, S. & Zulu, S. (2017). Site Suitability Analysis for Solid Waste Landfill Site Location Using Geographic Information Systems and Remote Sensing: A Case Study of Banket Town Board, Zimbabwe, *Review of social Sciences*, 2(4), 19-31, DOI: http://dx.doi.org/10.18533/rss.v2i4.9 9.

Kao, J.J., & Lin, H. (1996). Multifactor spatial analysis for landfill siting, *Journal of Environmental Engineering,* 122(10), 902-908.

Kirkwood, C.W. (1997). *Strategic Decision Making: Multi-objective Decision Analysis with spreadsheets*. Belmont: Duxbury Press.

Kola, O. (2012). Impact of municipal solid wastes on underground water sources in Nigeria *European Scientific Journal,* 8(11), 1-18.

Kontos, T.D., Komilis, D.P. & Halvadakis, C.P. (2003). Siting MSW landfills on Lesvos Island with a GISbased methodology,*Waste Management & Research,* 21, 262-277.

Lagos Bureau of Statistics (2011). Lagos State Government Digest of Statistics.

Majaro, O. & Abu, A. (2004). *Suitability of landfill sites in Lagos: A GIS approach.* University of Lagos, University of Lagos Press.

Malczewski, J. (1997). Propagation of errors in multi-criteria location analysis: A case study, in Fandel,G. & Gal, T. (eds.), *Multiple criteria decision making*, 154-155.

Malczewski, J. (2006). Ordered weighted averaging with fuzzy quantifiers: GIS-based multi-criteria evaluation for land-use suitability analysis. *International Journal of Applied Earth Observation and Geoinformation,* 8, 270-277.

Olanibi, O.A. & Adebayo A. E. (2022). Site Suitability Analysis of Solid Waste Disposal in Ilesa, Nigeria, *European Journal of Development Studies*, 2(2), https://www.ej-develop.org/index.php/ejdevelop/article/view/60/32 1/1.

Olorunfemi, F.B. (2011). Economic attitudes and responses to waste facilities location in residential areas: The case of landfills in Lagos metropolis, Nigeria, *Global Journal of Human Soc Sci,* 11(1), 72-81.

Ogunrinola, I.O. &Adepegba, E.O. (2012). Health and economic implications of waste dumpsites in cities: The case of Lagos, Nigeria, *International Journal of Economics and Finance*, 4(4), 239-251.

Nikolakaki, P. (2004). A GIS site-selection process for habitat creation: Estimating connectivity of habitat patches, *Landscape and Urban Planning,* vol. 68,(1), 77-94.

Nwanta, J.E., Onunkwo, J. & Ezenduka, E. (2010). Analysis of Nsukka metropolitan abattoir solid waste in South-Eastern Nigeria: Public Health Implications, *Archives of Environmental and Occupational Health*. 65(1), 21-26.

Saka, G.O. (1997). *Strategies for Solid Waste Management*. Paper presented at the Workshop on Environmental Pollution and Management, Ikeja Lagos, Held at the Lagos Airport Hotel, Ikeja.

Saaty, T.L. (1980a). *The Analytic Hierarchy Process*: McGraw-Hill.

Saaty, T.L. (1980b). How to make a decision: The Analytic Hierarchy Process,*European Journal of Operational Research,* 48, 9-26.

Senkiio, C.S., Ramos, A.P.M, Simões, S.J.C. & Mendes, T.S.G. (2022). Multi-criteria analysis and logistical grouping method for selecting areas to consortium landfills in Paraiba do Sul river basin, Brazil, *Environmental Earth Sciences*, 81(8), DOI: 10.1007/s12665-022-10354-4.

Shah, S.A, Musvi, S.H.A, Tameez, A. & Alam, M. (2019) Analyzing site suitability for solid waste disposal through GIS multi-criteria decision-making hierarchy process, 3Ciencias, special issue 07(65), DOI: http://dx.doi.org/10.17993/3ctecno.2019.

Siddiqui, M.Z., Everett, J.W. &Vieux, B.E. (1996). Landfill siting using geographic information systems: a demonstration. *Journal of Environmental Engineering*, 122-126, 515-523.

Thomas, R.M. (2002). GIS-based decision support system for brownfield redevelopment, *Landscape and Urban Planning,* 58(1):7-23, DOI: 10.1016/S0169-2046(01)00229-8.

WHO (World Health Organisation) (2000). Air quality guidelines for Europpe, *WHO Regional Publication European Series,* No. 91, World Health Organisation Regional Office for Europe, Copenhagen.

Woodhouse S., Lovett A., Dolman P.& Fuller R. (2000). Using a GIS to select priority areas for conservation, *Computers, Environment and Urban Systems,* 24(2), 79-93. (DOI): 10.1016/S0198-9715(99)00046-0.