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Suitability Analysis in Determining Optimal Landfill Location Using Multi-Criteria Evaluation (MCE), GIS & Remote Sensing

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ABSTRACT

Most of human activities often result in numerous wastes as their by-products. Rapid and uncontrolled urban expansion, poor planning, lack of adequate financial support just to mention a few often lead to poor management of municipal solid waste (MSW) in most cities, especially in developing countries like Nigeria. Similarly, changes in consumption patterns worldwide have resulted in a sporadic increase in commercial, industrial and household wastes thereby causing serious environmental and health hazards. However, with various waste management techniques in developed economy which is being adopted by developing nations, waste dump sites still manifest physically in developing countries as the primary means of waste disposal. In Lagos Metropolis, there are challenges in handling the various legal and illegal waste dump sites and in adopting holistic approach to the management of wastes by the state agency in-charge of waste disposal. This paper examines the locations of the existing dump sites, and adopts Geographic Information Systems (GIS), Remote Sensing technology and Multi-Criteria Evaluation (MCE) technique to carry out suitability mapping of optimal locations for Landfills within Lagos Metropolis. For the optimal site selection, fourteen different criteria were identified and each criterion was weighted using MCE. Finally, based on transportation and minimum area criteria requirements using overlaying and buffering analysis, the suitability map was generated. The map revealed four classifications as: "unsuitable (96.0%)", "least suitable (0.4%)", "moderately suitable (1.0%)", and "most suitable (2.6%)".

KEYWORDS: *Solid Waste, Landfill, Geographic Information Systems (GIS), Remote Sensing, Multi-Criteria Evaluation (MCE)*

I. INTRODUCTION

In Nigeria like other developing countries, proper solid waste management is one of the undaunted monster that is confronting various municipal authorities as it has posed threats to lives and the environmental. Indiscriminate disposal of effluent and toxic waste have endangered healthy living. Diseases transmission, fire hazards, odour nuisance, atmospheric and water pollution, aesthetic nuisance and economic losses are some of the problems associated with improper management of solid waste (Nwambuonwo and Mughele, 2012). **Solid** waste means any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant or air pollution control facility and other discarded materials including solid, liquid, semi-solid, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations and from community activities but does not include solid or dissolved materials in domestic sewage, solid or dissolved materials in irrigation return flows or industrial discharges that are point sources. Some of these wastes can be recycled while others are discarded and disposed of properly (New York State Department of Environmental Conservation, 2010). A suitable disposal site must have environmental safety criteria and attributes that will enable the wastes to be isolated so that there is no unacceptable risk to people or the environment. Criteria for site selection include physical, socioeconomic, ecological and land-use factors. Different tools and techniques are being developed for solid waste disposal site selection in developed countries. Out of these, landfilling is the most common method used in many countries (Yesilnacar and Cetin 2005). In modern times, finding a site to locate undesirable facilities is becoming a significant problem in the planning sector (Erkut and Moran, 1991). In particular, the sitting of landfills is an issue due to prevalent "not in my backyard (NIMBY)" and "not in anyone's backyard (NIABY)" concerns from the public. Sitting of landfills is important because of the imperative nature of landfills due to the expanding population and the corresponding volume of garbage (Kao and Lin, 1996).Despite the existence of solid waste dumpsites, the problem of waste management has continued to be a menace in developing countries such as Nigeria. Lagos being the commercial nerve centre of Nigeria with a fast population growth, the problem of waste management is still a huge monster that is plaguing the city. The concerted efforts of State Agency in charge of waste management (Lagos Waste Management Authority, LAWMA) in tackling this menace are yet to achieve the desired result. There is still need to ensure effective and efficient disposal of both residential and industrial wastes in Lagos. To assist in achieving effective and efficient waste management, this research is aimed at the determination of: (i) suitable optimal site for landfills in Lagos State, and (ii) waste optimal planned collection route using Geographic Information Systems (GIS), Remote Sensing technology and Multi-Criteria Evaluation (MCE) technique. Existing dump sites were considered, fourteen non-exclusionary and exclusionary criteria (geomorphology, underground water depth, wetland, mangroves, land-use, surface waters, drainage, forest and vegetation, rivers, slope, roads, settlements and airport) were examined, Analytical Hierarchy Process (AHP) was used to assign weights, maps were overlaid and buffering technique was used to carry out suitability evaluation. Transportation needs for effective waste management were discussed and a typical *shortest-path* route from waste collection site to the landfill site was created in a GIS environment for efficient transferring and transporting of solid wastes.

Study Area

Lagos Metropolitan Area (3,345Km^1) spreads over much of Lagos State. Lagos is the most populous conurbation in Nigeria with 7,937,932 inhabitants at the 2006 census as a result of heavy migration from all parts of the country as well as from outside the country. It is currently the second most populous city in Africa (*after Cairo*), and currently estimated to be the second fastest growing city in Africa (7th fastest in the world), immediately following Bamako. Formerly the capital of Nigeria, Lagos is a huge metropolis which originated on islands separated by creeks, such as Lagos Island. The city is the economic and financial capital of Nigeria. The multi-ethnic nature of the place made it hard to get a good grip on the place. The city of Lagos lies in south-western Nigeria, on the Atlantic coast in the Gulf of Guinea, west of the Niger River delta, located on longitude 3° 24' E and latitude 6° 27' N. There are two major urban islands of Lagos in Lagos Lagoon, Lagos Island and Victoria Island (Lagos Travel Guide, 2014).The lagoons provides places of abode and recreation, means of livelihood and transport, dumpsite for residential and industrial discharges and a natural shock absorber to balance forces within the natural ecological system. The Lagos Lagoon consists of three main segments: Lagos Harbour, the Metropolitan end and Epe Division (Oyenekan, 1988).

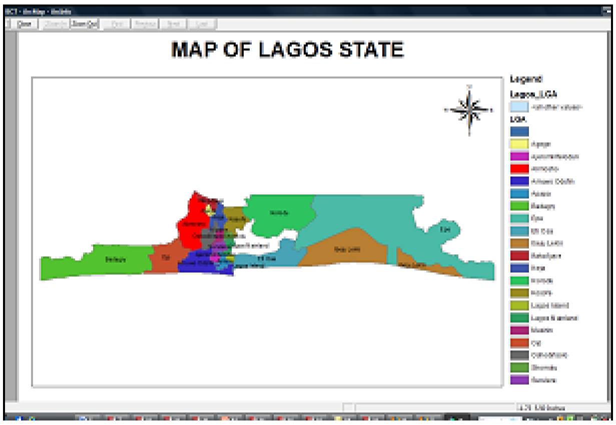

Fig. 1. Showing the map of Local Government Areas in Lagos State.

II. SOLID WASTES GENERATION AND MANAGEMENT

2.1 Solid Wastes Generation

Generally, municipal solid waste is defined as waste arising from human activities in household, commercial and institutional areas that are useless or unwanted. The knowledge of the sources and types of solid wastes, along with data on composition and rates of generation, is basic to the design and operation of the functional elements associated with the management of solid wastes. Sources of solid wastes in a community are, in general, related to the land use and zoning. Tcholobanogous et al (1993) gave a description of sources and types of solid wastes within a community (Table 1).

Table 1. Sources and types of solid wastes within a community (Tcholobanogous et al, 1993).

Source	Typical facilities, activities, or locations where solid waste is generated	Types of Solid Wastes
Residential	Single family and multifamily, detached dwellings, low, medium, and high-rise apartments, etc	Food wastes, paper, cardboard ,plastics ,textiles, leather, yard wastes, wood, glass, tin cans, aluminium, other metals, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yards wastes collected separately, batteries, oil, and tires), household hazardous wastes.
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc	Paper, cardboard, plastics, wood, food waste ,glass, metals, special wastes, hazardous wastes, etc.
Institutional	School, hospitals, prisons, governmental centres.	As above in commercial
Industrial	Construction, fabrication, light and heavy manufacturing, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap material, etc. Non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazard wastes.
Agricultural	Field and farms	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes.
Public Areas	Streets, parks, recreation areas.etc	Special wastes, rubbish.

Like in most developing countries, scientific data are scare and very scanty. The data on waste generation in Lagos till date is still scanty. However, the estimated wastes generated/tonnes in Lagos are shown in Table 2:

Table 2. Development of Waste Generation and Management in Lagos (LAWMA, 2008).

Year	Area	Population	Generation Rate per Day	Ton/Day	Trucks
1945	>200km^2	40000	0.1(E)	4+	1
1967	1200km^2	1,500,000	0.12 (E)	180	6(2 trucks)
1976	10000km^2	3,200,000	0.2	640	100(35 trucks)
1990	35000km^2	5,000,000	0.25	1,250	210(70trucks)
2006	<40000km^2	18,000,000	0.4	7,200	1200(400-500 trucks)
2008	<40000km^2	18,000,000	0.5	9,000	1500(550-600 trucks)
2015	<60000km^2	23,000,000	0.7	16,100	2500(800 trucks)
2020	<60000km^2	30,200,000	0.7	21,140	(1,057 trucks)

2.2 Solid Waste Management

Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes. Integrated solid waste management includes the selection and application of suitable techniques, technologies and management programmes to achieve specific waste management objectives and goals Tchobanoglous and Kreith, 2002). Solid waste management technologies entails: 1) Source reduction, 2) Recycling, 3) Waste transformation and 4) Landfilling.For most industrialized nations today, solid waste management is a multibillion dollar business which is also crucial to survival, unlike in developing countries where solid wastes create losses. The conditions, issues and problems of urban waste management in the industrialized and developing worlds are different. Though the developed countries generate larger amounts of wastes, they have developed adequate facilities, competent government institutions and bureaucracies to manage their wastes. Developing countries are still in the transition towards better waste management but they currently have insufficient collection and improper disposal of wastes. Disposal of wastes is commonly done by dumping (on land or into water bodies), incineration or long term storage in a secured facility. All these methods have varying degrees of negative environmental impacts with adverse environmental and health risks if wastes are improperly disposed or stored. (Longe and Balogun, 2010).

For Nigerian cities, including Lagos Metropolis, waste removal is one of the most pressing issues and not a new problem. Most Nigerian cities consist of heaps of refuse in street corners, side-walks to mention but a few. As at 1977, Lagos was described as the dirtiest capital city in the World to host FESTAC 77.Several government agencies emerged to manage waste until the transformation of Waste Disposal Board to Lagos State Waste Management Authority (LAWMA) in 1991 with the mandate of collection and disposal of municipal and industrial waste in the State and improved commercial services to the State and Local Governments. From 1994, LAWMA started the private sector participation (formal / informal) in waste management in the State (Rugiramanzi, 2013). However, illegal dumping of waste into water and land environment by cart pushers and individuals alike has necessitated the review of waste management and disposal system in the State. In readiness for the Lagos Metropolitan Development Governance project supported by the World Bank, Lagos State restructured the Lagos State Waste Management Authority in 2005.

2.3 Existing Landfill Operations in Lagos State

There are three (3) major landfills (Fig. 2) and three (3) temporary sites serving Lagos State. The major landfills fall within the case study. The major landfills and their capacities are shown in Table 3.

Table 3. Major Landfill Sites in Lagos Metropolis (LAWMA, 2008).

Name		**Location**	**Coordinates**		**Average daily tonnage**	**Approximate Waste Received (%)**	**Size (Hectares)**	**Residual Life Span (Years)**
			Latitude (N)	**Longitude (E)**				
Olushosun		Ikeja Local Government (L.G.). Situated at Ojota / Oregun	6.5911	3.3814	211,667.33	35	42	20
Abule-Egba		Alimosho L.G. Located within Agbado Oke-Odo LCDA	6.6411	3.3027	97,611.67	80	10.5	8
Soluos	Soluos II	Along Lagos State University – IBA Road	6.5703	3.2537	53,178.33	Over 70	7.8	5
	Soluos III	Along Lagos State University – IBA Road	6.5703	3.2537	53,178.33	Over 70	5	5

Their pictoral view are shown below.

Olushosun Abule-Egba Solous

Fig. 2. Major Landfills in Lagos.

Other Satellite (minor) Landfill Sites comprise of Owutu (Ikorodu L.G.), Sangotedo (Eti–Osa L.G.) and Temu (Epe L.G.) dumpsites. These sites serve as back–ups for the three major landfill sites, and also have an advantage of proximity. They are temporary sites and fall outside the scope of this study area,

2.4 General Criteria for Selecting Potential Sites for a Solid Waste Landfill

International practices always account for environmental, economic, social, and technical factors in the construction of landfills. Landfill designers are primarily concerned with the viability of a site. To be commercially and environmentally viable, a landfill must be constructed in accordance with specific rules, regulations, factors and constraints which vary from place to place or from country to country. These specific rules, regulations, factors, and constraints must cover: geomorphology, land value, slope and proximity to recreational areas (Dorhofer and Siebert, 1996; Erkut and Moran, 1991; Lin and Kao, 1999). In summary, Chang et al, 2007 gave the following criteria for specifying the best site for a landfill:
(i) Distance from historical sites, ancient areas and including international museums should not be less than 1 Km; (ii) Keep the distance from well-water or water supply for manufacturing g not less than 1 Km away, (iii) Keep the distance from the road not less than 750 m away, (iv) Keep the distance away from rivers of not less than 1 Km, (v) In addition, the landfill should be situated at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odour, noise, and decrease in property value. Urban buffers may range from 150 m to 5 Km, and (vi) Moreover the selected area shouldn't often flood.

III. METHODOLOGY

Siting a sanitary landfill requires a substantial evaluation process in order to identify the best available disposal location, that is, a location which meets the requirements of government regulations and minimizes economic, environmental, health, and social cost (Siddiqui et al. 1996). In this research, the following steps were taken to determine the best locations for siting landfills in Lagos Metropolis.

3.1 Data Acquisition and Image Processing

In GIS, availability of data is crucial. In this work, a comprehensive body of secondary information related to environmental (streams network and wetlands), socio-cultural (municipal development area, historic and important conserved sites and land use), and economic factors (road network, land slope, soil cover, and geology) were collected and produced in a digital format.

Sources of data include primary and secondary sources:
Primary Data- Spatial and Aspatial data of the existing dumpsites were obtained from the field.
Secondary Data:- these include: Average daily waste generated per tonnage dumped at the existing dump sites obtained from Lagos Waste Management Agency (LAWMA); Lagos State Land Use map from Land Use Department of the Lagos State Ministry of Environment; LandSat imagery for Lagos Metropolis from GLCF; and Height data of the study area from SRTM (shuttle radar topography mission); Lagos State Local Government Administrative Map from LASPPDA; and Lagos road network map from the Department of Surveying & Geoinformatics.

3.2 Data Compilation and Processing

The acquired data (both primary and secondary) were processed, and plotted in a GIS environment with their attributes attached:
1. Features Extraction- Acquired Landsat imagery was processed using ENVI 4.5 (Fig. 3) and transformed in WGS 1984 UTM Zone 31N.

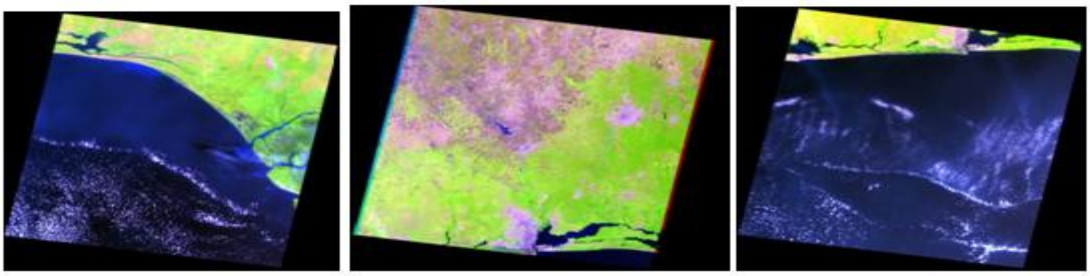

Fig. 3. The Three (3) Landsat Images covering the entire Lagos State.

For better land use classification of the study area, the acquired Land Use Map of Lagos State was overlaid on the processed Landsat imageries and five (5) distinct feature classes were identified out: (i) Built up areas, (ii) Water bodies, (iii) Forests and other vegetation, (iv) Wetlands, and (v) Mangroves.The Land Use Map of Lagos State and Lagos State mosaicked aerial photography were used to assist feature location and identification. Region of Interest (ROI) was specified for each feature class during the supervised classification. Feature extractions were carried out based on the five (5) identified classes (Figs. 4a and 4b).

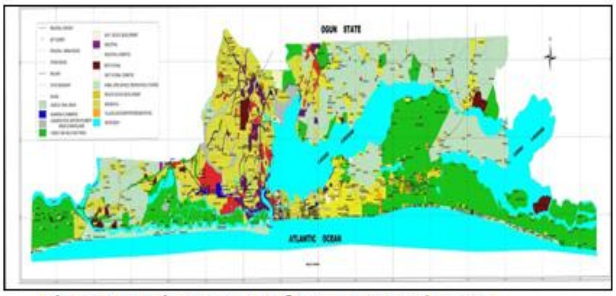

Fig. 4a Land Use map of Lagos State (Lagos State Land Use Department, 2002)

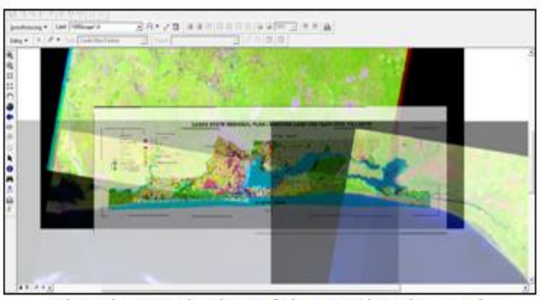

Fig. 4b. Overlaying of the Landsat imageries and the existing land use map.

Post-classification was carried out to vectorize classified areas and the vectorized features were exported as shape files to ArcMap. Feature trimming was carried out. The three Landsat imageries (Fig. 3) were merged using similar feature edge-matching technique and overlaid on a boundary map of Lagos Metropolis. Water bodies were extracted (Fig. 5).

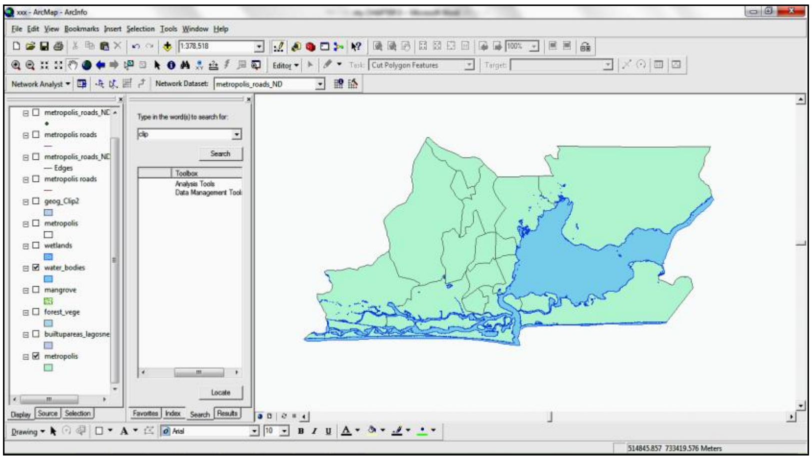

Fig. 5. Water Bodies classification within Lagos Metropolis.

2. Spot Heights Extraction- Spot heights were acquired from SRTM (Shuttle Radar Topography Mission) data (*GeoTIFF* and *HGT*, Fig. 6) and processed.

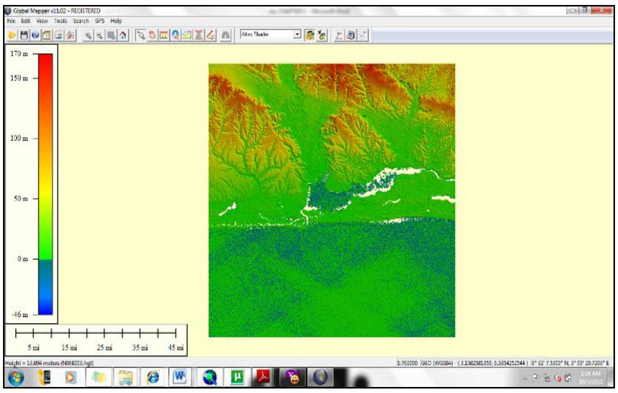

Fig. 6. *hgt* SRTM data covering Lagos State and some part of the Atlantic Ocean.

The XYZ grid data were later converted to a .dbf (database file), plotted as points on ArcMap and clipped to fit in the boundaries of Lagos Metropolis.

3.3 Criteria and Restriction Parameters for Landfill siting in Lagos State

According to Lagos Waste Management Authority (LAWMA), the simple preliminary guidelines used for landfill site selection includes: (1) Size of area/capacity, (2) Distance to populated areas, (3) Distance to sensitive water resources, and (4) Hydrology and Hydrogeology.Since an optimal landfill location must comply with all Federal and State Governments' regulations, therefore, location restriction criterion, which varies depending on environmental and climatic regional factors must be considered. With a little modifications in this work, the Land Use Department of Lagos State Ministry of Environment agreed with the criteria used in Dhaka City [Table 4].

Table 4. Criteria and Restriction Parameters for Landfill siting
(Mohammad, Kidokoro and Syed, 2009)

Criterion	**Parameter**	**Criterion**	**Parameter**
Distance from water bodies	300 – 500m	Distance from urban area	500 – 2000m
Distance from forest, park, etc.	50 – 500m	Distance from roads	50 – 100m
Distance from well	500 –1000m	Haul distance	30 – 45m
Soil permeability	< 10 **-** 6cm/sec.	Slopes	< 15 – 20%

In this work, fourteen non-exclusionary and exclusionary criteria were considered. Non-exclusionary criteria (Factors) were classified into two groups: (i) Biophysical factors (i.e. biological and physical environmental related factors) and (ii) Socio-economic factors (human related activities). The Biophysical factors include: geomorphology, underground water depth, wetland, mangroves, land-use, surface waters, drainage, forest and vegetation and rivers; while the socio-economic factors include: slope, roads, settlements (i.e. residential area) and airport. Constraints for the Biophysical factors are: (i) the waste disposal site cannot be built on landslides which are active or may become active in the future, (ii) the waste disposal site can only be constructed in areas which do not have an important economic or ecological value, (iii) areas should have sufficient size/capacity to be used as a waste disposal site for a prolonged time, and (iv) the waste disposal site must be close as possible to existing roads for saving road development, transportation, and collection costs. Details on the exclusionary criteria with respective buffer distances are discussed in Section 4.2. Three decision criteria, using buffering (proximity) techniques, were considered for suitability evaluation: (i) Stream proximity, (ii) Urban proximity, and (iii) Road proximity. The decision criteria were analysed for sensitivity of land suitability (Effat and Hegazy, 2012; Rugiramanzi, 2013).

3.3Multi-Criteria Evaluation (MCE)

According to Mohammad, Kidokoro and Syed (2009), Multi-Criteria Evaluation is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. In this process, multidimensional geographical data and information were aggregated into one-dimensional values for the alternatives. Landfill site selection by GIS is a multi-criteria evaluation (MCE) process and generally has four steps: (i) Criterion establishment, (ii) Standardization of factors, (iii) Establishment of factors weight, and (iv) Weighted linear combination. With a weighted linear combination, factors were combined by applying a weight to each followed by a summation of results to yield a suitability map i.e.

$$S = \sum w_i x_i \quad \text{……….……………………………….. (1)}$$

where, S = suitability, w_i = weight of factor i, x_i = criterion score of factor i.
The procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints, i.e.

$$S_{i,j} = \left(\sum_{x=1}^{p} f_x\, w_x \prod_{y=1}^{q} r_y\right)_{i,j} \quad \text{……….………………………….. (2)}$$

where $S_{i,j}$ = land suitability of cell i for the land use type j, f_x = attribute of factor x at cell i, w_x = weight of the factor x, p = number of factors f, r_y = attribute of constraint y at cell i, q = number of constraints r.

Using a weighted linear combination in MCE, the weights summed to 1. AHP being a multi-objective, multicriteria decision-making technique was used to assigning weights to all the factors and to control the level of risk and trade-off for the alternatives. In the AHP, weight was derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The AHP hierarchical structure is shown in Figure 7. The AHP results were thereafter integrated into GIS for better analysis to determine optimal landfill site suitability (Mendoza, 1997**)**. Flowchart for the MCE optimal suitable site selection is shown in Figure 8 (Saaty, 1980).

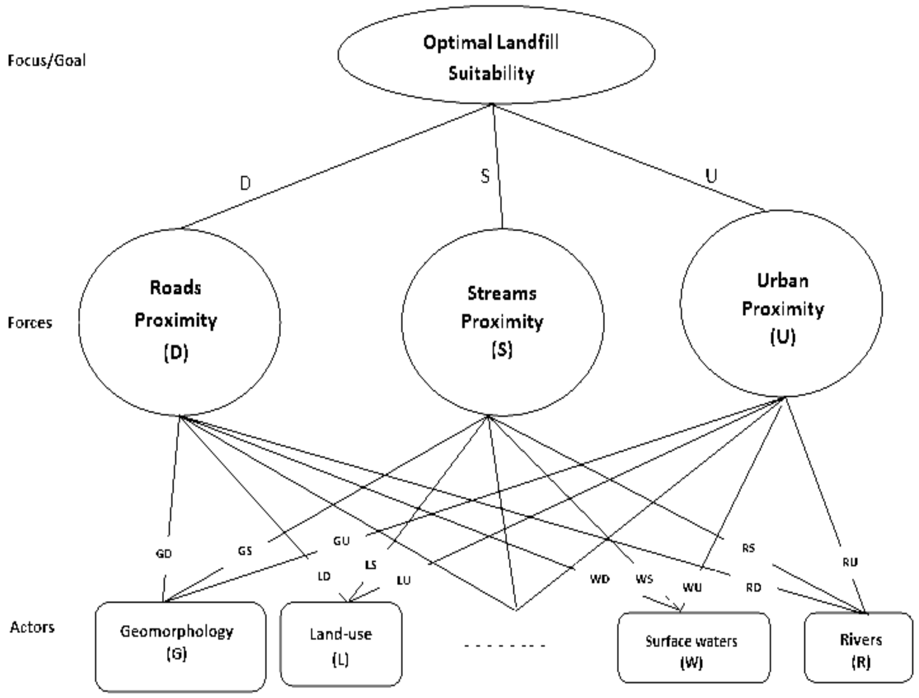

Fig. 7. AHP Hierarchical Structure of Ranking of all Factors (Saaty, 1980).

Factor Maps

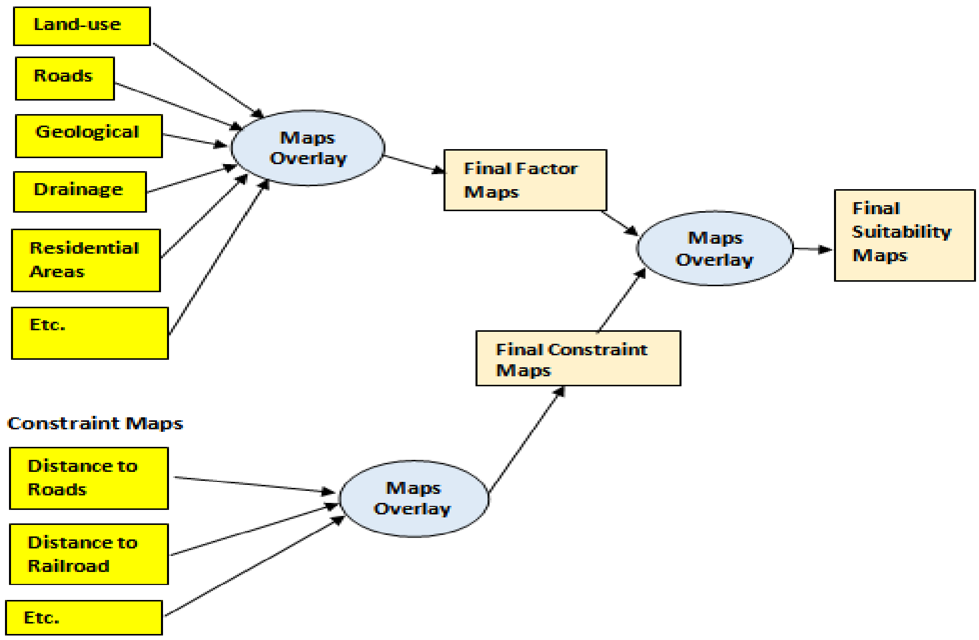

Fig. 8. Multi-criteria Evaluation (MCE) Model Flowchart.

IV. RESULTS GENERATION AND ANALYSIS

Results on creation of factor maps, eliminating unsuitable areas and selecting most suitable site are shown below:

4.1 Creation of Factor Maps

The AHP Pairwise Comparisons for the Biophysical factors' Scores for Geomorphology = 0.595; Depth of the underground water = 0.246; Wetland = 0.099 and Mangrove = 0.059. The Eigen Value (λ max.) i.e. Average = 4.192; CI = 0.064 and while Consistency Ratio = 0.071.
Similarly, the AHP Pairwise comparison for the Proximity Criteria Scores revealed that Stream Proximity (S) = 0.724; Urban Proximity (U) = 0.193; and Road Proximity (D) = 0.083. The Eigen Value (λ max.) i.e. Average = 3.066; CI = 0.033 and while Consistency Ratio = 0.057.

All the factors (geology, residential areas, forest and other vegetation, etc.) were used to create the factor maps:

- **Geological Criteria-** Geological map derived for the study area is shown in Figure 9a (Alluvium [Light Blue], Benin Formation [Yellow] and Ilaro Formation [Pink]).
- **Wetlands-** Wetlands map of the study area is shown Figure 9b.
- **Mangroves-** The areas classified as mangroves in the study area are shown Figure 9c.
- **Drainage-** The drainage system of the study area is shown in Figure 9d.
- **Surface Water-** Figure 9e shows the rivers network in the study area.
- **Forests and other Vegetation-** The areas classified as forests and vegetation in the area are shown in Figure 9f.
- **Slope-** Slope map shown in Figure 9g.
- **Road Network Map-** Lagos road network map is shown in Figure 9h.
- **Residential Areas-** The map of residential areas was derived from the land use map as shown in Figure 9i.
- **Airports-** The location of the airport is shown in Figure 9j.
- **Railroad Map-** Lagos railroad map (Fig. 9k) as obtained from the Dept. of Surveying & Geoinformatics.

Some of these factor maps are shown in Figures 9a - 9k.

Some of the Biophysical factors:

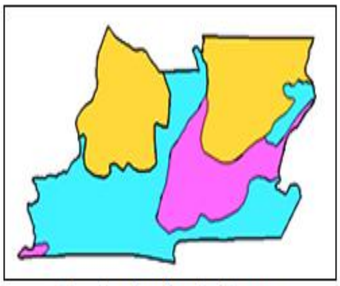
Fig. 9a.Geological map.

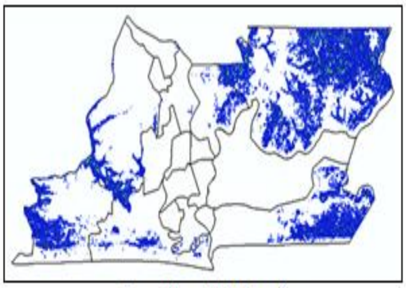
Fig. 9b. Wetlands.

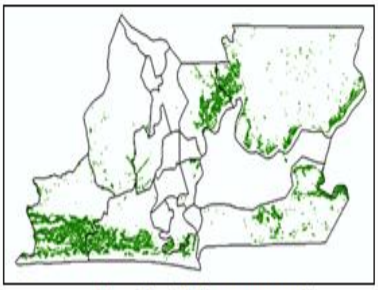
Fig. 9c. "Mangrooves".

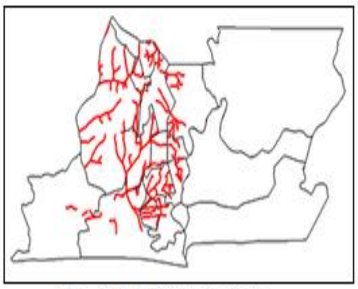
Fig. 9d. Drainage map.

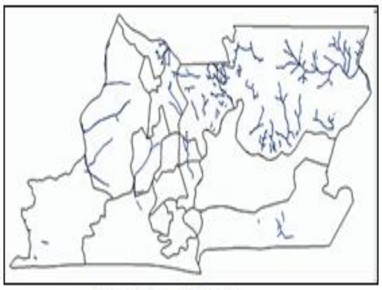
Fig. 9e. Rivers.

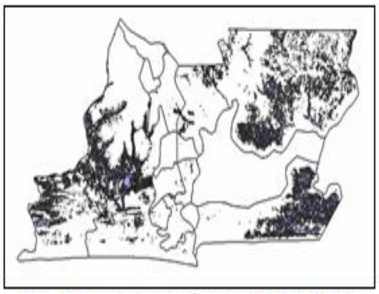
Fig. 9f. Forests and other Vegetation.

Some of the socio-economic factors:

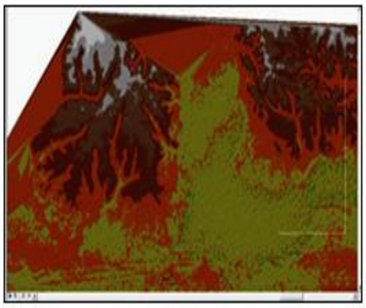

Fig. 9g. "Slope" Map

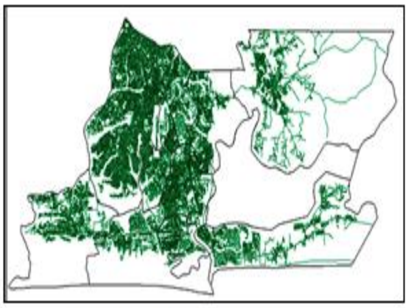

Fig. 9h. Road network

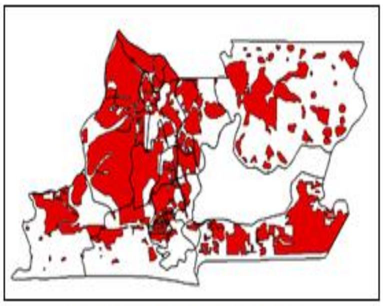

Fig. 9i. "Residential Areas".

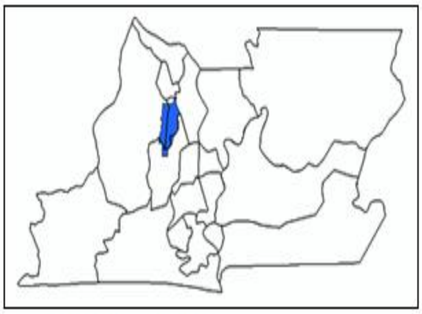

Fig. 9j. Airport.

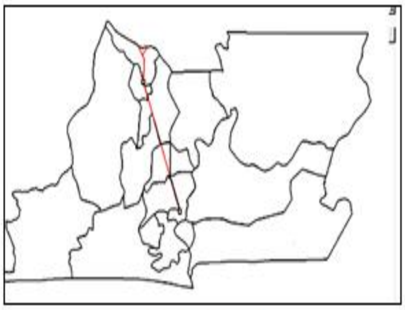

Fig. 9k. Railroad.

4.2 Analysis and Buffering

In the AHP Pairwise Comparisons for the Biophysical factors, Geomorphology was given highest priority (0.595), while Mangrove got the least rating of 0.059. Similarly, AHP Pairwise Comparisons for the Proximity Criteria; Stream Proximity (S) got the highest priority (0.724), while Road Proximity had the least 0.083. Analysing the Factor Maps, unsuitable areas were screened out by imposing exclusionary buffer criteria within the GIS environment thus leading to the creation of Buffer Maps. The analysis and the buffer maps are discussed below:

- **Wetlands and Mangroves-** Are not ideal for landfill locations since hazardous solutes from the landfill can easily endanger (i.e. pollute) nearby rivers and other water bodies, hence they are just factored out (Figure 10a).
- **Drainage-** Landfill must avoid areas with leachate flow contaminations. There is need to avoid the impact of drainage system failure. Therefore, a buffer distance of 100m from the drainage network was considered safe in this study (Fig. 10b).
- **Surface Water-** Surface water (rivers) is very important because of its ecological balance to all the human activities and as a natural resource. Rivers can be endangered by the landfill because of leachate thus bringing a great pollution to the river. A buffer distance of 100m from the river was considered for landfill location (Figure 10c).
- **Forests and other Vegetation-** Forests and other Vegetation areas are not suitable as landfill sites; hence they are just factored out.
- **Slope-** A low slope is required to minimize erosion and water runoff. A low slope also facilitates the construction of the site to be much easier and with lower costs. Furthermore, the slope map of Lagos Metropolis area was not utilized because based on the Lagos State Contour Map, almost all parts of the study area comprise low gradient that ranges from 9% to 15%.
- **Road Network Map-** Road network generally comprised of four main roads with the highest hierarchy being expressways and the lowest is local roads. This region has a good network system and access to landfills anywhere in this area is possible (Fig. 10d). For landfill siting, the suitable distance from road network is within 100m buffer in order to meet environmental requirement, property protection and pollution reduction). (Cointreau, 1996).
- **Residential Areas-** Locating a landfill away from urban land areas is noted for several reasons, including aesthetics, odor, noise, decrease in property value and health concerns. To define a limit around urban areas that would protect the population from landfill hazards (such as scavenging animals and strong odour) and using the NIMBY ("Not in my backyard") approach, a buffer of 500m is established (Fig. 10e). (Chang et al, 2007 and Dikshit et al., 2000).

- **Airports-** A landfill should not be situated around the regulatory zone of an airport authority. The site shall not be 3km nearer to the airport area. Therefore, a 3km buffer was used as a criterion for selecting suitable landfill site (Fig. 10f).
- **Railroad Map-** Since railroads and roads have similar transportation characteristics, therefore, to avoid any conflict with transportation along the rail system buffer distance of 100m was employed (Fig. 10g).
- **Geological Criteria-** Leachate migration from the landfill could be a potential source of surface and groundwater contaminations (Rugiramanzi, 2013). In Figure 9a, only 3 major soil types were identified (Alluvium [Light Blue], Benin Formation [Yellow] and Ilaro Formation [Pink]). The Ilaro formation is basically sedimentary formation found mostly under and around water bodies hence was classified as unfit. The remaining Alluvium and Benin formation consist mainly of clay, and clay can serve as a very good support due to its low permeability. The unsuitable geological area was factored out (Fig.11a).

Some are graphically shown in Figures 10a – 10g and 11a.

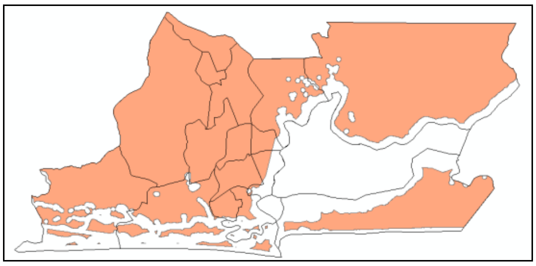
Fig. 10a. Unsuitable areas due to "Wetlands".

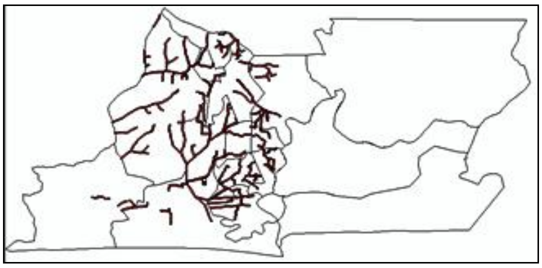
Fig. 10b. 100m buffer from the Drainage.

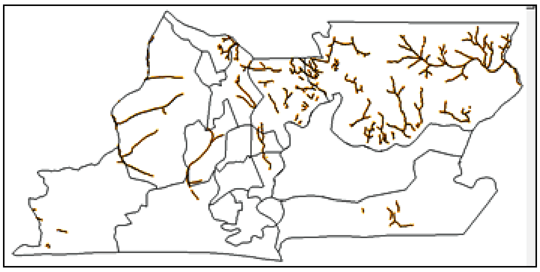
Fig. 10c. 100m buffer from the Rivers.

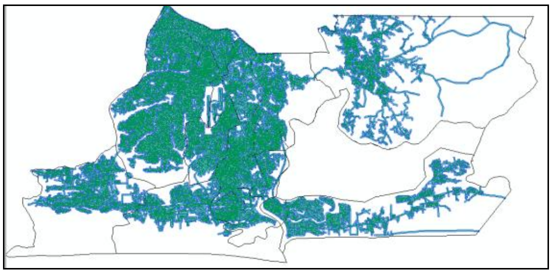
Fig. 10d. 100m buffers from the Roads.

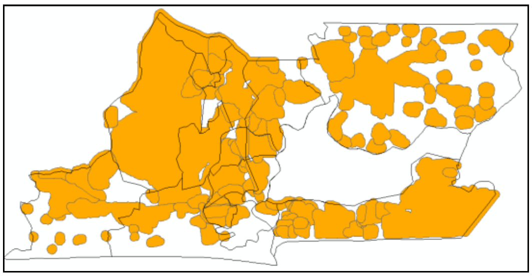
Fig. 10e. 500m buffers from the Residential Areas.

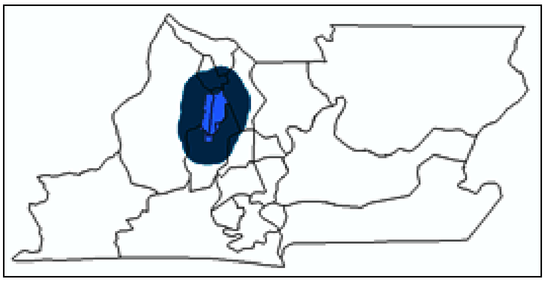
Fig. 10f. 3km buffer from the Airport.

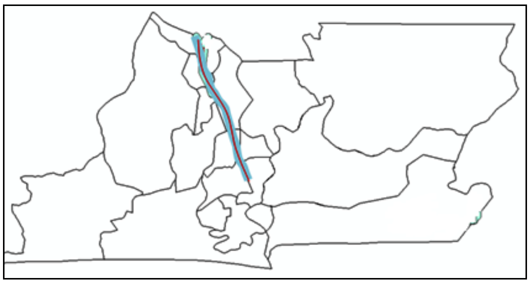
Fig. 10g. 100m buffer from the Railroad.

After applying the exclusionary criteria, decision factors, standardization of factors, and weighting of factors, using multi-criteria evaluation (MCE) for land suitability analysis, weighted linear combination (WLC) method, as discussed in Section 3.4, was adopted to obtain the final suitability map.

4.3 Optimal Landfill Location Determination through Objectivity

The factors, the buffers and the constraint maps were used in form of negative mapping. This was carried out by factoring out the constraints from the map of the study area until areas suitable and optimal for locating landfills are left (Mohammad, Kidokoro and Syed, 2009):

[1] The map of the study area was subtracted from the map of the unsuitable Geology (Fig. 11a).
[2] The resulting map (Fig. 11a) of suitable geology was overlaid on the map showing the water bodies with buffer distance, and negative mapping was also carried out to obtain a map showing areas not within the Water Bodies criteria and with suitable "Geology" (Fig. 11b).
[1] The wetlands map is then overlaid on the resulting map (Fig. 11b) to obtain the areas suitable under the Wetlands criteria (Fig. 11c).
[2] The mangrove map is overlaid on the resulting map (Fig. 11c) to obtain the areas suitable under the Mangroves criteria (Fig. 11d).
[3] The rivers map is overlaid on the resulting map (Fig. 11d) to obtain the areas suitable under the Rivers criteria (Fig. 11e).
[4] This procedure was repeated for other criteria to select areas suitable under the Vegetation, Residential Areas and Airports criteria (Fig. 11f).

Fig. 11a. Excluding unsuitable. Geology

Fig. 11b. Excluding "Water bodies" but with suitable "Geology'

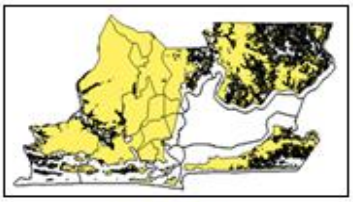

Fig. 11c. Excluding "Water bodies" and "Wetlands" but with suitable "Geology",

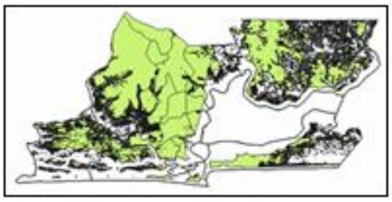

Fig. 11d. Excluding "Water Bodies", "Wetlands" and "Mangroves" but with suitable "Geology",

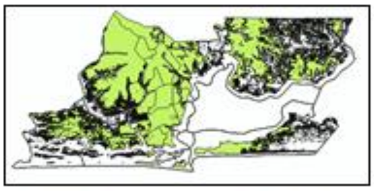

Fig. 11e. Excluding "Water Bodies", "Wetlands", "Mangroves", "Forests", and "Rivers" but with suitable "Geology",

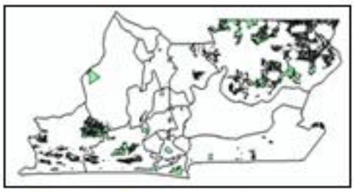

Fig. 11f. Excluding "Water bodies, "Wetlands", "Mangroves", "Forests", "Rivers", "Vegetation", "Residential Areas" and "Airports" but with suitable "Geology

Finding the best suitable areas depends upon the objectives or goals of the land suitability analysis. In this study, transportation of wastes and potential sites' space availability (≥ 10Hect.) were considered during land suitability analysis:

4.3.1 Transportation Scheduling and Routing Principle in Waste Management

No matter the methods of eliminating unsuitable areas, ranking suitable sites and selecting the most suitable landfill site, as mentioned in Section 3.3 a major determinant is the transportation costs. Therefore, the landfill site should be placed as close as possible to existing roads for saving road development, transportation, and collection costs.A "Planned Collection Route [PCR]", (Fig. 12), will ensure a productive and economical service. It will: (i) serve as map-based detailed route configurations and collection schedules for the selected collection system, and (ii) make citizens to be aware of the collection schedule (e.g. regular weekly schedule). Efficient routing and rerouting of solid waste collection vehicles will decrease labour, equipment and fuel costs, and increase customer satisfaction by making pick-up predictable. The size of each route must therefore depend on: all service points, all one-way streets, any culs-de-sac and areas that do not require a service. Since the amount of waste collected per stop depends on: distance between stops, loading time, traffic conditions and method of collection, therefore, the following rules for routing must be followed: (1) routes should not be fragmented or overlapping; (2) the collection route should start as close to the garage or motor pool as possible taking into account heavily travelled and one-way streets; (4) collection from heavily travelled streets should not be carried out during rush hours; (5) collection routes should be planned to maximize vehicle capacities; and (6) for the convenience of householders it is preferable to maintain a regular routine, to ensure their waste is ready for collection (CSIR, 2014 and TALG, 2008). For the present waste disposal in Lagos; (1) there is no strictly designed collection schedule; (2) sometimes for two (2) weeks the collectors may not collect waste in some areas whereas the local cart pushers have been sent away from the roads by the State Government; (3) in the course of discharging their duties, the waste collectors always stay (block) the roads even during rush hours hindering other commuters rushing to work, claiming that nobody can arrest them because they are on "essential duty"; (4) sometimes when wastes are not collected bills are brought for payment; and (5) the collectors do litter the roads at the point of collection and the routes to the dumpsite. In this research, since the shortcomings mentioned above are still prevalent, to minimize transportation costs, a typical optimal route from the collection centre to the landfill site was created using **"Shortest-Path" Algorithm** (Fig. 13).

After all the factors have being erased from the base map of the area by negative mapping, criterion on proximity of the land fill site to roads was carried out. A 100m buffered road network map of Lagos Metropolis was overlaid on Figure 11f to determine which of the areas to be chosen as potential sites (Fig. 14).

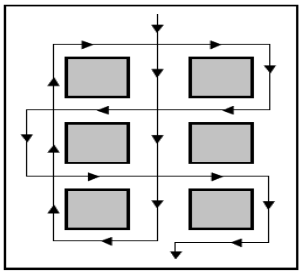

Fig. 12. PCR Collection Route from Two Sides of of the road (CSIR, saved 2014).

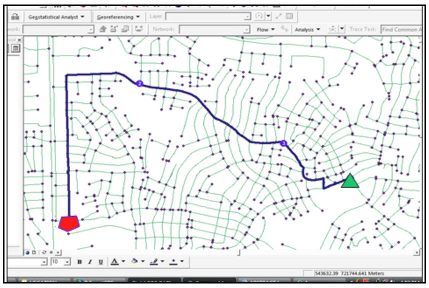

Fig. 13. A typical Waste Optimal Planned Collection Route (WOPCR).

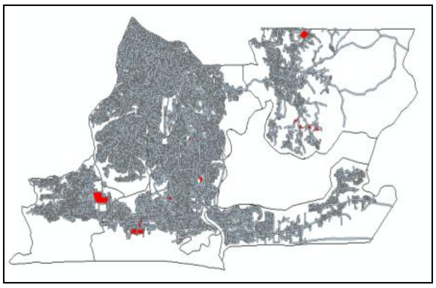

Fig. 14. Final Potential Sites meeting the 100m proximity to Roads criteria

4.3.2 Size of Land Space

The final suitability map was produced based on potential sites of which suitability ranges between 10–25hectares, in terms of land space. Three major locations were finally selected (Fig. 15).

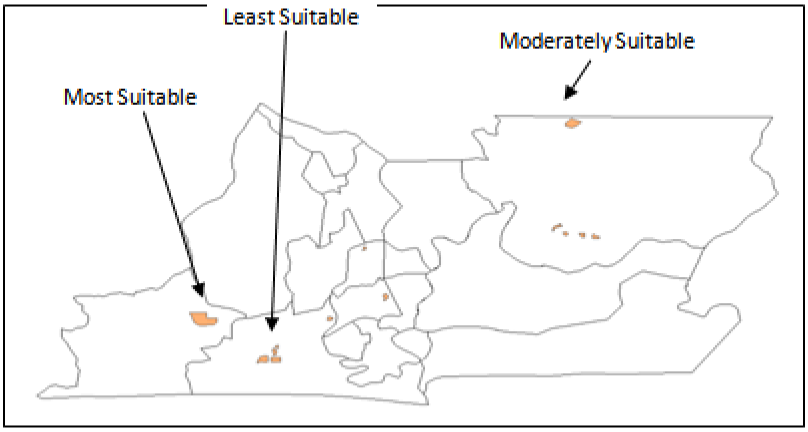

Fig. 15. Result of query showing potential areas meeting the 10-25 Hectares minimum area criteria. All other locations are "unsuitable".

The final suitability map revealed four classifications: "unsuitable (96.0%)", "least suitable (0.4%)", "moderately suitable (1.0%)", and "most suitable (2.6%)".

V. CONCLUSION

Solid waste management is an obligatory function of the urban and local government authorities. However, a poorly sited landfill will result in health hazard and socio-economic and environmental degradations (Nwambuonwo and Mughele, 2012).In this study, the utilization of GIS, Remote Sensing and MCE in identifying suitable and optimal landfill locations in Lagos Metropolis was carried out. Highly suitable locations were determined based on predefined parameters, most especially space availability and transportation planned collection routes (PCR). The selected locations will minimize social conflict, environmental and economic impacts. With the fourteen factors considered, the final suitability map revealed four classifications with most part of the study area “unsuitable” for landfilling. Therefore, with increasing annual growth in urban population and the rapid pace of urbanization in Lagos Metropolis, the existing deficiencies related to solid waste management (SWM); such as use of inefficient tools by contractors, non-punctuality of contractors, creating congestion during peak traffic periods and inadequate transportation of wastes; need to be quickly addressed. Rules governing transportation scheduling and routing in waste management must facilitate safety, ease and speed of collection. Clear government policies and competent bureaucracies for management of solid wastes are needed urgently to resolve these deficiencies.

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