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Application of Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP) in the Selection of a Suitable Sanitary Landfill Site for Solid Waste Disposal

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Abstract
Shortage of land for waste disposal and inappropriate dump sites is the biggest problems in the Niger Delta Area of Nigeria, Warri in particular. This problem has its negative impact on human and environment owing to the menace often caused by indiscriminate dumping of solid waste. The swamping nature of the soil and the irregular topographic nature of the land hinder the flow of accumulated water formed by rains. This makes runoff during the rainy season almost impossible leading to flood in most cases. To select an appropriate site for landfill, there is need to consider different alternative areas using numerous criteria's before making decision. In this study, geographical information systems (GIS) and analytical hierarchy process (AHP) were employed to analyze selected criteria's that can influence the selection of a suitable site for sanitary landfill application in Warri, Delta State, Nigeria. The selected criterions include; flood extent, stream, rivers, swampy areas, ground water, built-up areas, roads, slopes, airport, palaces and point of interests (POIs). Features of interest such as roads, built-up areas, swampy areas, rivers and streams in the SPOT 5 satellite imagery were converted to vector format by digitizing in order to create a geographic database dataset. Weighted Overlay Linear Combination for map superimposition was adopted while constraints and factors were employed as the criteria for decision-making process. Suitability rating value of 1 to 5 meaning; not suitable, least suitable, moderately suitable, highly suitable and mostly suitable was use as the final index for land suitability. Results of the weighted overlay revealed three potential sites within the study area and they include; site 1, site 2, and site 3 with 3.334, 5.418 and 47/582 hectares of land suitable for sanitary landfill applications.
Keyword: Sanitary landfill, weighted overlay, Suitability rating, geographical information systems (GIS), analytical hierarchy process (AHP)
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1. Introduction

One of the major problems in solid waste management is the selection of the appropriate site for waste disposal. Landfill Site Selection (LSS) in urban or rural areas is a critical issue for the planning process because of its enormous impact on the economy, ecology and the environmental health of the region (Chang et al., 2008). LSS is a difficult, complex process, which requires evaluation of many different criteria such as social, environmental and economic factors. The selection of sitting criteria obviously targets financial efficiency and minimization of environmental damage to natural resources and public health. In general, economic, environmental and social criteria are required on the first phase of evaluation. Economic criteria (distance to roads, slope, etc.) must be considered in sitting of landfills, which include the costs in relation with the development and operation of the site (Erkut et al., 1991). Environmental criteria (distance to surface waters, ground waters, etc.) are also very important due to the fact that the landfill may affect the ecology of the vicinity area (Kontos et al., 2003).

Furthermore, social/physical criteria (distance to residents, tourism destinations, etc), should be considered important factors since "Not in my backyard" (NIMBY) or "Not in anyone's backyard" (NIABY) phenomena are creating tremendous pressure on the decision makers dealing with LSS. It is obvious that establishing the physical criteria require comprehensive spatial information databases for the evaluation process (Chuang, 2001). Various spatial information layers such as settlements, road networks, slope, water resources, soil characteristics, etc. are used for site selection through successive spatial operations. For example, buffering, overlaying, updating and joining are the most commonly used for organizing spatial data within the process (Haaren and Fthenakis, 2011). Geographical Information Systems (GIS) have emerged as useful computer-based tools for spatial operations. It's a computer-based technology for collecting processing, managing, analyzing, modeling and presenting spatial data for a wide range of applications (Moeinaddini et al., 2010). Due to their ability to manage large volumes of spatial information from a various resource, GIS are ideal for site selection studies (Nikolakaki, 2003). It has been widely applied in the past for site selection studies (Haaren et al., 2011; Curtis et al., 2000; Woodhouse et al., 2000; Thomas, 2002**).** GIS is important because it not only reduces time and cost of the site selection but also provides a digital data storage for long term management and planning. As mentioned before, ideal site selection depends on several independent criteria such as social, economic and environmental. Thus, in addition to the GIS applications, one of the multi-criteria evaluations (MCE) methods has to be integrated for the achievement of an optimal result through site selection process. These methods can be evaluated as a major tool to assist decision makers, which divide the decision problems into smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner.

The integration of both GIS and MCE techniques improves decision making because it establishes an environment for transformation and combination of geographical data and stakeholders' preferences (Javaheri et al., 2006). GIS provide efficient manipulation and presentation of the data and MCE supplies consistent ranking of the potential landfill areas based on a variety of criteria (Sener et al., 2006). Among MCE techniques, Analytical Hierarchy Process (AHP) has been widely used in LSS in recent years. Lin et al. (2005) carried out an evaluation of solid waste management concerning the sitting of landfills. Jiang et al. (2000) identified a solid waste disposal site in Hyderabad city using AHP and GIS. (Al-Jarrah et al. (2006) focused on the problem of setting a new landfill using an intelligent system based on fuzzy inference. Sumathi et al. (2008) uses GIS and MCE analysis for the determination of the most suitable landfill site in Pondicherry, India Moeinaddini et al. (2010) presents a study that is called spatial multi-criteria evaluation (SMCE) that combines GIS and MCE methods for evaluating the suitability in Karaj. Guiqin et al. (2009) utilized spatial information technologies and AHP for LSS in Beijing, China.

2. Research Methodology

2.1 Description of Study Area

The study area is Warri in Delta state. Warri is one of the most important towns in Delta state, located in the South-South geo-political zone of Niger Delta Region of Nigeria. Warri is located within latitudes 5^0 28' 10.79" N to 5^0 37' 27.99" N and longitudes 5^0 40' 32.78" E to 5^0 51' 51.47" E which is 399.809km^2 by area. It is situated 48km upstream from the port of Forcados and at the terminus of road from Sapele and Ughelli. It has a navigable channel of water front of about 61meters. As a major industrial city in Delta state, on the Niger-Delta region bounded by Warri North LGA in the northern part of the state, in the west by Warri southwest LGA, in the east by Sapele LGA while in the south by Burutu LGA. There are creeks in the area such as Tori creek, Warri creek, and the major river. Warri is characterized by two major seasons namely, the rainy (wet) season and the dry season. The rainy season lasts from April to October which is a period of seven months. There is however a break in the rainy season by August after which it resumes and the rainfall becomes stronger. The dry season (harmattan) is short and starts from November to March. The effect of the short period of harmattan is minor and heavy down pour seldom occurs in the heart of the dry season. Warri experiences high annual rainfall of over 3,000mm, which is distributed throughout the year. The temperature is uniformly high with an annual means of 30^0C and very low daily range of 28^0C with relative humidity as high as 85%. The population of Warri has increased over the years. Warri metropolis is one of the rapidly growing cities in Nigeria with a population rising rapidly from 55,256 in 1963, 280,561 in 1980, and 511,074 in 1991 to 632,243 in 2006 and estimated to be 930,000 in 2016 (Tajuddin, 2003). The satellite imagery of Warri, Delta State is shown in Figure 1

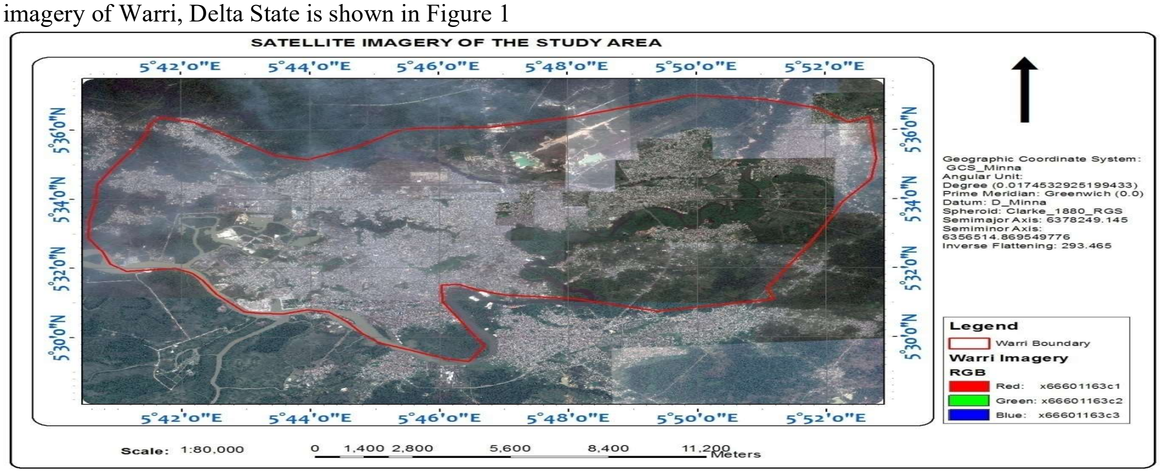

Figure 1: Satellite imagery of Warri, Delta State (Adopted from Google Earth)

2.2 Data Collection

All datasets obtained was classified for the landfill selection. Some of the factors considered for selecting the disposal sites and their buffers were sourced from literature survey. In this study, five different datasets presented in Table 1 were used for this study.

Table 1: Data used for the study

S/N	Data	Source	Purpose
A	Shuttle Radar Topographic Misssion Digital Elevation Model (SRTM-DEM)	Office of the Surveyor General of the Federation (OSGOF)	Delineation of flood plain extent and slope
B	Daily Rainfall Data	Nigerian Meterological Agency (NIMET}	100 years Flood extent
C	SPOT 5 (2.5m resolution)	Office of the Surveyor General of the Federation (OSGOF)	Production of thematic maps for roads, streams, built-up areas, swampy areas, rivers
D	Adminisrative Map	Ministry of Land and Survey, Delta State.	Digitization of Warri boundary
E	Survey Data	Differential Global Positioning System (DGPS)	Groundwater analysis

2.3 Data Analysis

2.3.1 Analytic Hierarchy Process (AHP)

For this study, the pair-wise comparisons for eleven criteria were conducted based on a comparison between the criteria and their importance to appropriately sitting a landfill. Based on this (11 x 11) matrix, excel tools were used while the mathematical formula for AHP was adopted from Haas et al., (2012) as follows:

For a matrix of pair-wise alternate, we have:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \tag{1}$$

To Sum the values in each column of the pair-wise matrix we employed

$$C_{ij} = \sum_{i=1}^{n} C_{ij} \tag{2}$$

Normalized pair-wise matrix was generated by dividing each element in the matrix by its column.

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} = \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \tag{3}$$

To generate weighted matrix, the sum of normalized column of matrix was divided by the number of criteria used

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} = \begin{bmatrix} W11 \\ W12 \\ W13 \end{bmatrix} \tag{4}$$

For consistency analysis, constituency vector $\lfloor Cvi_j \rfloor$ was calculated by first multiplying the pair-wise matrix by the weights vector then by dividing the weighted sum vector with criterion weight.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix} \tag{5}$$

$$Cv_{11} = \frac{1}{W_{11}}\left[C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}\right] \tag{6}$$

$$Cv_{21} = \frac{1}{W_{21}}\left[C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}\right] \tag{7}$$

$$Cv_{31} = \frac{1}{W_{31}}\left[C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}\right] \tag{8}$$

Maximum eigenvalue $[\lambda]$ was calculated by averaging the value of consistency vector.

$$\lambda = \sum_{i=1}^{n} Cv_{ij} \tag{9}$$

Consistency Index $[CI]$ was employed to measure the deviation as follows;

$$CI = \frac{\lambda - n}{n-1} \tag{10}$$

Consistency Ratio CR (< 0.1) employed to check the consistency of the comparison was calculated as thus:

$$CR = \frac{CI}{RI} \tag{11}$$

Where; RI is the random inconsistency indices which was obtained from the works of Saaty, (2008) presented in Table 2

Table 2: Random Inconsistency Indices (RI) (for n = 1- 10)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

N; is the number of comparisons.

2.3.2 Application of Geographical Information Systems (GIS)

Geographical Information Systems (GIS) have emerged as useful computer-based tools for spatial operations. It's a computer-based technology for collecting processing, managing, analyzing, modelling and presenting spatial data for a wide range of applications. Due to their ability to manage large volumes of spatial information from a various resource, GIS are ideal for site selection studies (Nikolakaki, 2003). In general, criteria can be classified as factors and constraints. A factor is a criterion that enhances the suitability of a specific alternative for the activity under consideration. A constraint limits the alternatives under consideration while it classifies the areas into two classes: unsuitable (value 0) or suitable (value 1). Since there are many constraints according to the criteria selected, GIS-based constraint mapping was developed to eliminate unsuitable sites for each criterion and to narrow down the amount of the area for further analysis. The various criteria were created in layers in GIS environment and structured in a geo-database to ensure consistency of the data during spatial analysis.

2.3.3 Criteria for landfill site selection

A set of criteria was developed by combining an intensive literature review and expert knowledge. Some criteria such as flood extent, stream, rivers, swampy areas, ground water, built-up areas, roads, slopes, airport, palaces and point of interests (POIs) were identified for the study area. Features of interest such as roads, built-up areas, swampy areas, rivers and streams in the SPOT 5 satellite imagery were converted to vector format by digitizing in order to create a geographic database dataset. All the datasets used for this work were projected to Universal Transverse Mercator Zone 31N in WGS 1984 datum. This study adopted Weighted Overlay Linear Combination. The decision-making process criteria used for this work are constraints and factors. Constraints were used to eliminate certain spatial objects from consideration. Factors were criteria which were grouped into themes. Suitability rating is a scale that assesses the suitability of parcel of land for a particular purpose. The suitability rating is dependent on the constraint. Suitability rating value of 1 to 5 was adopted in this study; value 1 means not suitable, 2 means least suitable, 3 means moderately suitable, 4 means highly suitable and 5 means mostly suitable. The work flow for this work is presented in Figure 2

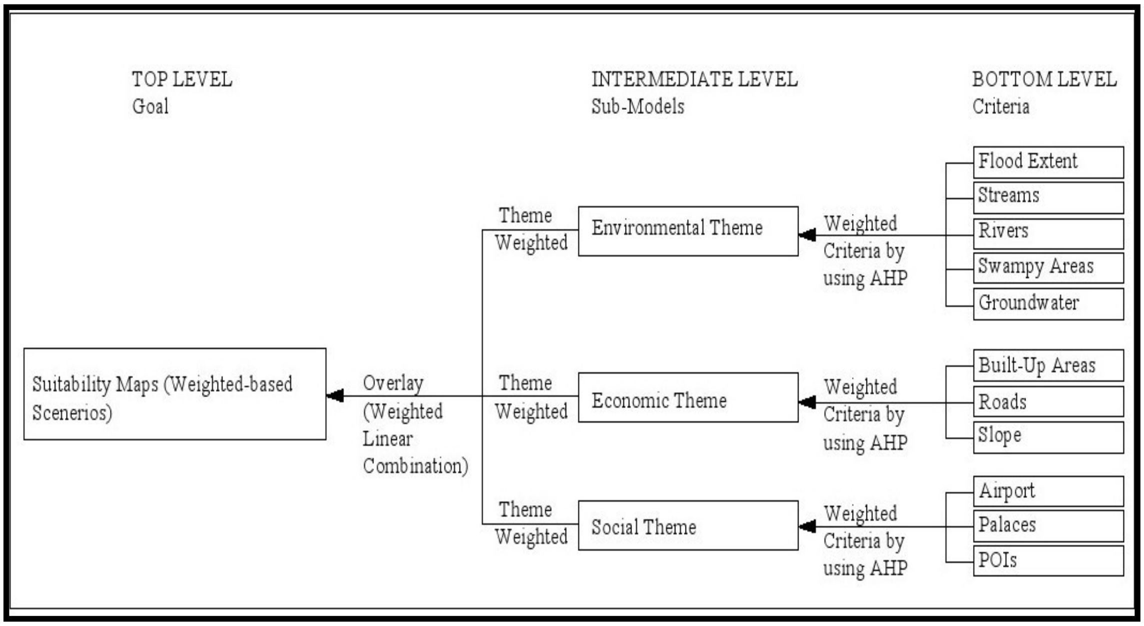

Figure 2: Workflow of the study

3. Results and Discussion

3.1 Result of digitization/flood extent

The features that were digitized within the study area are presented in Figure 3. The representation of each feature is shown in the legend of the map. Each digitized feature was buffered and converted to raster format. The raster format of each feature becomes the thematic map for that feature which was used for weighted overlay analysis. The flood extent for 100 years return period for the study area is presented in Figure 4. The locations that will be affected by flood are represented as shaded polygon feature. This flood extent was buffered and converted to raster format. The raster format was used for weighted overlay analysis

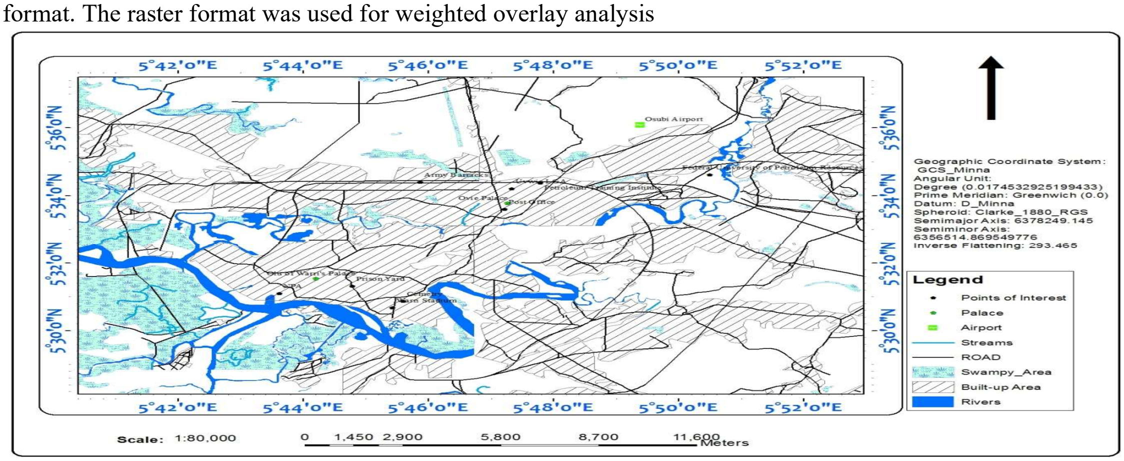

Figure 3: Map showing the digitized features within the study area

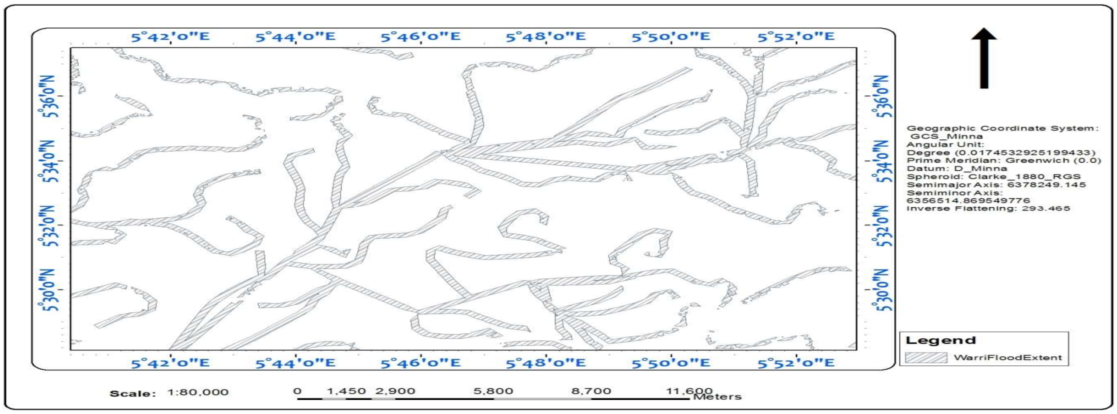

Figure 4: Map showing the flood extent of 100 years return period within the study area

3.2 Result of AHP Priority Ranking

Result of AHP priority ranking for the environmental theme is presented in Table 3

Table 3: AHP Priority Ranking for Environmental Theme

S/N	Factors	Priority (%)	Rank
1	Flood extent	40.3	1
2	River	24.4	2
3	Stream	13.7	3
4	Swamp area	13.7	3
5	Groundwater table	7.9	5
Consistency Ratio CR = 0.7%			

From the result of Table 3, it was observed that flood extent is the most important factor while groundwater table is the least important factor within the theme. Flood extent is twice more important than river; five times more important than groundwater table; and three times more important than stream and swampy area. The consistency ratio is less than 10%, therefore the ranking is valid. The percentage priority served as the percentage of influence for performing weighted overlay analysis. Result of AHP priority ranking for the economic theme is presented in Table 4

Table 4: AHP Priority Ranking for Economic Theme

S/N	Factors	Priority (%)	Rank
1	Built-up area	54.0	1
2	Slope	29.7	2
3	Roads	16.3	3
CR Consistency Ratio = 1.0%			

From the result of Table 4, it was observed that built-up area is most important while road is least important. Built-up area is three times more important than roads and twice more important than slope. The percentage of priority was used in performing weighted overlay analysis for the economic theme in Arc GIS 10.1 environment. Result of AHP priority ranking for the social theme is presented in Table 5

Table 5: AHP priority ranking for social theme

S/N	Factors	Priority (%)	Rank
1	Airport	67.4	1
2	Palaces	22.6	2
3	Points of Interest	10.1	3
Consistency Ratio CR = 9.0%			

The priority Table presented in Table 5 shows that airport is three times more important than points of interest and twice more important than palaces. The consistency ratio is within the permissible range; therefore, the ranking is valid. The percentage of priority was used in performing weighted overlay analysis for social theme.

3.3 Results of Thematic Map Generation

3.3.1 Thematic Map for Environmental theme

Results of all the thematic maps of the factors within the environmental theme (flood extent, streams, rivers, swampy areas and groundwater table) in raster format and their AHP priority ranking served as input data to generate weighted overlay analysis map for environmental theme. This theme is presented in Figure 5.

3.3.2 Thematic Map for Economic theme

From the imagery, the center of the study area is highly built-up while towards the boundary has various virgin lands and mangroves. Costs of development and maintenance of landfill site becomes indispensable. At the same time, the farther the landfill site to the source of waste generation (built-up areas), the more the transportation cost. It means the closer the landfill is to the road, the more its suitability while the farther the landfill to the road, the lesser its suitability. The slope of a land is considered an economic factor in construction of a landfill as high sloped lands are more difficult to be managed and therefore will be more costly.

The raster format of all the thematic maps of the factors within the economic theme (built-up areas, slope and roads) in raster format and their AHP priority ranking served as input data in Arc GIS environment in order to perform weighted overlay analysis for this theme. The result of the economic theme is presented in Figure 6

3.3.3 Thematic Map for Social theme

The raster formats of all the factors within the social theme (POIs, palaces and airport) in raster format and their AHP priority ranking served as input in performing weighted overlay analysis in Arc GIS environment. The result of the social theme is presented in Figure 7

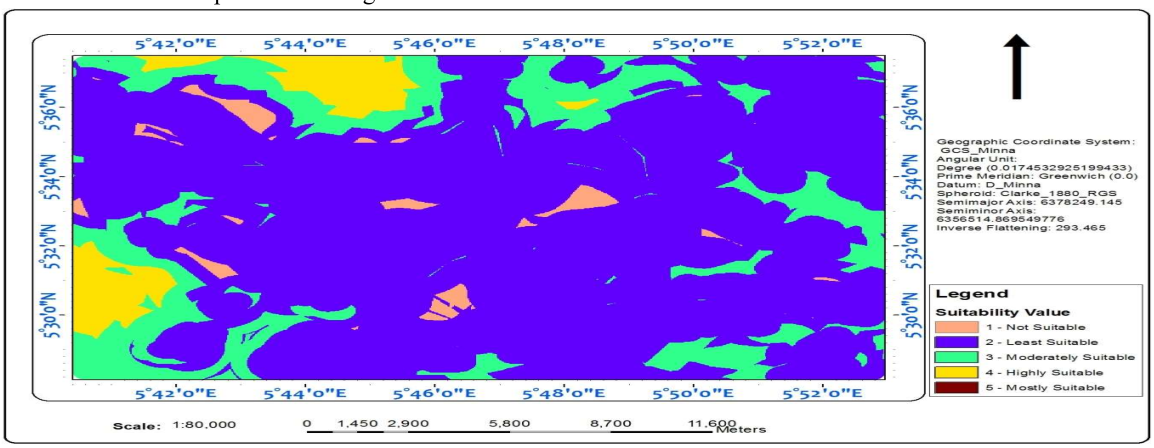

Figure 6: Map showing the economic theme of the study area

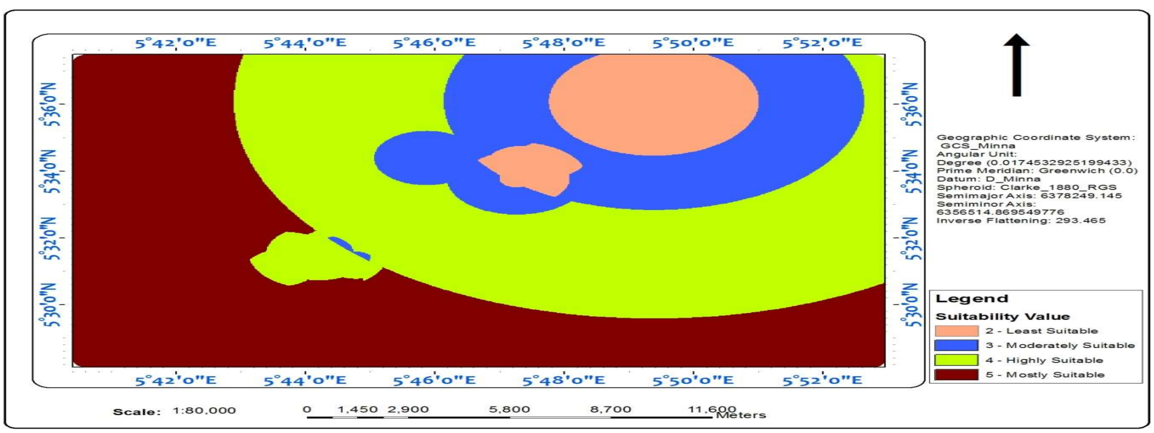

Figure 7: Map showing the social theme of the study area

3.4 Results of Weighted Overlay Analysis for Different Scenarios

The weighted overlay analysis for the scenario I, II and III were performed in this section and their results are presented in Figures 8, 9 and 10 respectively. The results of the different scenario show the areas within the study area that are suitable and not suitable for landfill selection. The regions with green represent the suitable site while the region with blue colour represents the not suitable for each scenario. Scenarios I, II and III have 20, 17 and 19 candidates' sites respectively that are potential suitable landfill locations. It was observed that most of the suitable regions were outside the Warri boundary. The suitable regions for each scenario within Warri boundary were digitized and were overlaid on one another using the intersect tool of the analysis tools in Arc GIS environment in order to know the common suitable regions that span through all the three scenarios within the study area. The common suitable sites or regions represent the best suitable site for all the scenarios. The best site within Warri is presented in Figures 11 and 12 respectively. After the overlay, three potential sites were discovered within Warri.

Site 1, 2 and 3 has 3.334, 5.418 and 47.582 hectares of land suitable for landfill site within Warri.

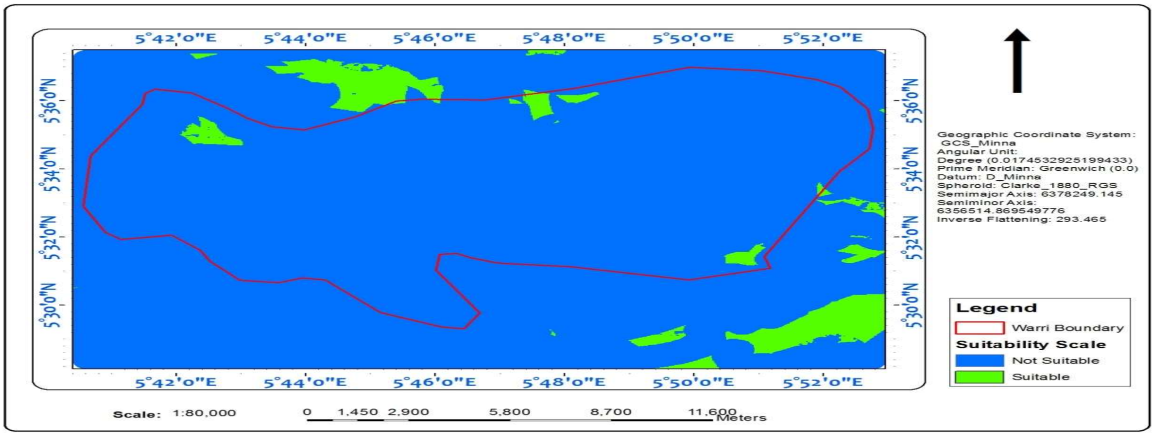

Figure 8: Map of Scenario I

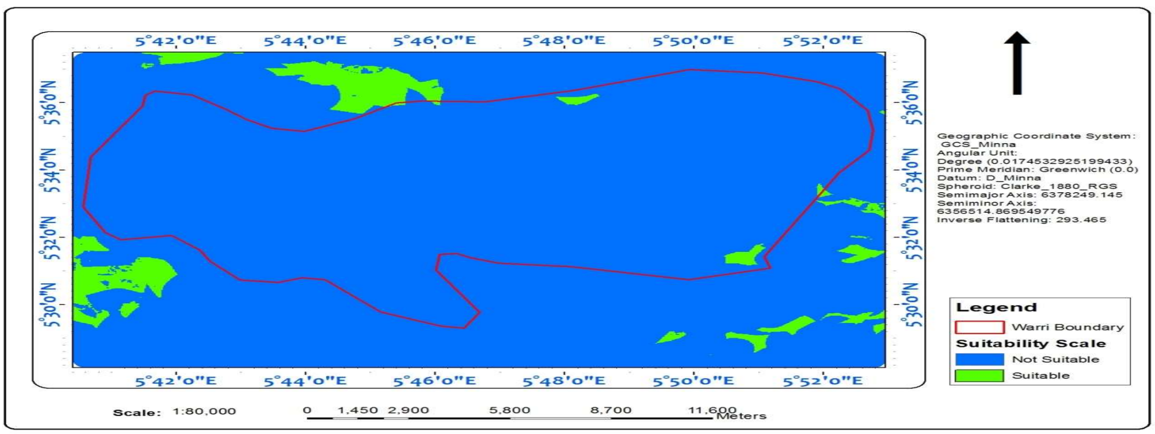

Figure 9: Map of Scenario II

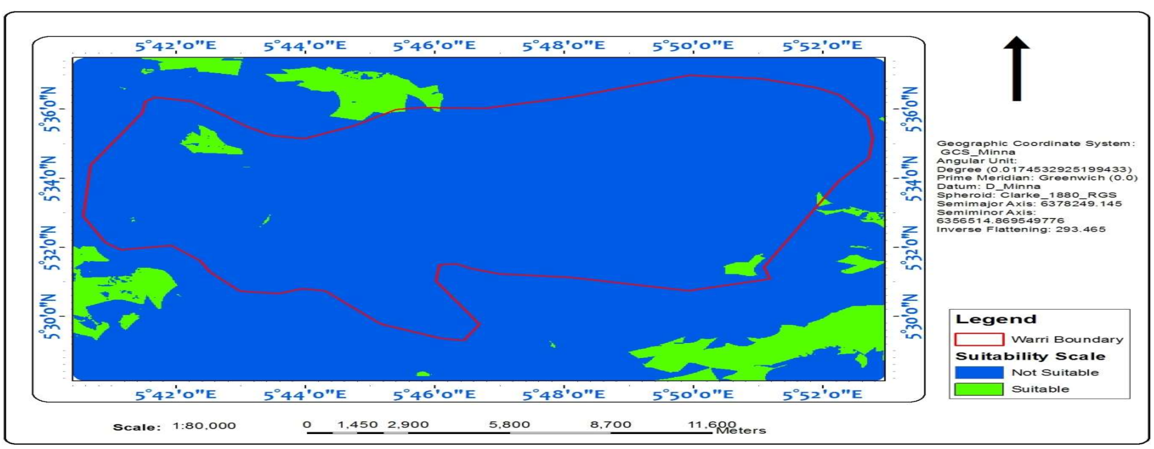

Figure 10: Map of Scenario III

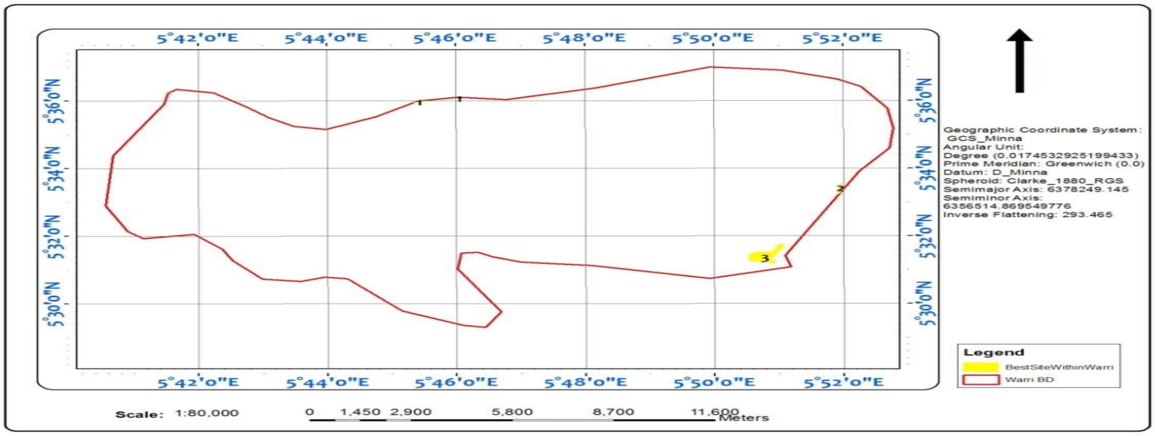

Figure 11: Map showing the best locations for landfill sites within Warri

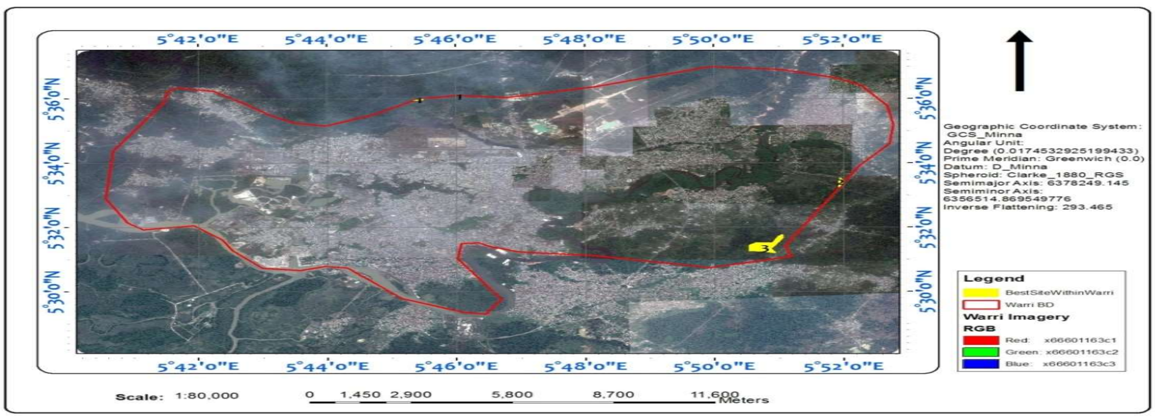

Figure 12: Map showing the satellite imagery of the best locations for landfill sites within Warri

Based on the result of Figures 11 and 12, three potential sites were discovered within Warri and they include; site 1, site 2 and site 3 with 3.334, 5.418 and 47.582 hectares of land suitable for landfill site within Warri.

4. Conclusion

The increasing generation of MSW is one of the greatest challenges faced by governmental authorities. In order to mitigate the impacts on the environment and public health, a claim, which requires a fast decision-making process regarding the final disposal of the MSW, motivates this study. Research findings show that GIS-MCDM featuring a well-structured architecture and the computational power, improves the application potential in urban and regional planning, and gives essential support to the decision-maker in the assessment of the waste management problem so that a higher level of understanding can be reached in regard to environmental decisions. The analysis was successful in selecting potential landfill sites for the study area. MCDM method smoothly incorporated the information provided by experts leading to fulfill the ranking of the five different criteria. Overall, GIS thus offered the means to identify three potential landfill sites based on well-defined criteria, which were later ranked according to the preferences provided by experts that were based on their experiences and knowledge of the dynamics of the study area.

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