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Site Suitability Study for Solid Waste Dumpsite Selection Using Geospatial-Based Multi-Criteria Analysis in Yenagoa, Bayelsa State Nigeria

Eteh Desmond Rowland[1*], Francis Omonefe[2], Jonathan Lisa Erebi[1]

[1]*Department of Geology Niger Delta University, Wilberforce Island, Amassoma Bayelsa State Nigeria*
[2]*Department of Physics Niger Delta University, Wilberforce Island, Amassoma Bayelsa State Nigeria*

***Corresponding Author:** Eteh Desmond Rowland, Department of Geology Niger Delta University, Wilberforce Island, Amassoma Bayelsa State, Nigeria.*

ABSTRACT

Solid waste dumping is a major environmental problem in the Yenagoa metropolis because as the city develops, most solid wastes are not dumped in suitable areas. These give rise to the objective of this study for the selection of a suitable area for the solid waste dumpsite. The following data Analysis is Landuse/land cover, Settlement, Place, Borehole, Roads, River, Drainage, Slope, and DEM as determining factors to find an appropriate site for a solid waste dumping site. The maps were prepared by applying Multi-Criteria Analysis Methods (MCAM) using Geographic Information System (GIS) and Remote Sensing techniques for overlay and suitability analysis. The final suitability map was prepared by overlay analysis on Arc map and leveled as high, moderate, less suitable, and unsuitable regions of the study area were determined. The results indicate that only 1.86% of the total study area (Dark brown) is most suitable for solid waste disposal, 37.87% of the total study area (Purple) is moderately suitable, 56.10% of the total study area (Yellow) is less suitable and lastly the unsuitable area or restricted areas for solid waste disposal is 4.17% (Light green). The highly suitable locations for dumpsites are far away from any water sources and other variables put into analysis. They are located in the south-west and Northcentral of the town and are dry agricultural areas, bare land, and grass land with 0-10% slope. zones, bare land, and grassland with 0-10% inclination or slope. Consequently, the ability to utilize GIS and remote sensing innovation for the successful distinguishing of suitable solid waste dumping site will minimize the environmental risk and human health problems.

Keywords: *Dumpsite, geospatial, Solid waste,multi-criteria analysis.*

INTRODUCTION

Disposing of solid waste is a difficult issue in both Rural and Urban settlements because most garbage or debris is disposed of in sites that are not suitable. A few nations are attempting to build up legitimate waste management frameworks with regards to expanding populace and urbanization (Sener, et al., 2006). Waste is any material discharged from human activities, which makes adverse impacts on human wellbeing and the environment.

Informal garbage removal can create serious tainting of surface and groundwater through adsorption of unwanted and harmful chemicals stored in solid wastes and air contamination, as well as the release of methane, spreading of diseases by different vectors like birds, insects, and rodents. However, the waste management system of Yenagoa metropolis in Bayelsa is not satisfactory, because debris or garbage disposal site for this citydoes not consider the environmental factors. Lack of solid waste collection centers and disposal locations such as land filling are among the solid waste management problem in Yenagoa, as a result, solid waste is disposed of in gutters, streams, pits, undeveloped plots, and farmlands. A heterogeneity of issues including infection of water, invitation of bugs and rodents to the residence, and increasing the risk of flooding because of obstructed or blocked drainage, canals, or gullies can be brought about by uncontrolled unloading and ill-advised waste handling (Ersoy & Bulut., 2009).According to several kinds of literature, the components to be considered as measures for determination of appropriate dumpsite destinations comprise of general wellbeing, the geography of the territory, hydrology, topography, and climate of the region, proximity to the residential and industrial areas, the distance to and from the city, the weather of the area, the drainage system of the area, cost and the future land use of the area. (Ahmed & Suryabhagavan., 2019; Yesilnacar & Çetin., 2007; Panepinto& Zanetti., 2018;Lober., 1995).

A proper location suitable for dumping solid waste that is far away from environmental resources, residential areas, water bodies, roads, faults, and settlements is essential in managing solid waste disposal (Baban& Flannagan.,1998).

Integrating Geographic Information Systems (GIS) and remote sensing techniques to select the best possible solid wastes dumping site is a recent essential technology (Leaoet al., 2001). Geographic Information Systems (GIS)plays a great role in solid waste management because very large aspects of its planning and operations are highly dependent on spatial data (Lober., 1995).

Therefore, GIS is now a tool that not only reduces the time and cost of the site selection but also provides a digital data bank for future monitoring programs of the site (Changet al., 2008).

The Study Area

The study area consists of two Local Government Areas within the Bayelsa state. These local Governments are Yenagoa and Ogbia. These areas lie within longitudes 6012'0"E and 6o25'30" E of the prime meridian and Latitudes 4o52'30"N and 5o03'00"N of the equator within the coastal area of the recent Niger Delta. (Fig.1). Bayelsa state is located within the Niger Delta basin in the southern part of Nigeria and covers an area of 170km. The area lies within the freshwater swamps, back swamps, deltaic plain, alluvium, and meander belt geomorphic unit of the Niger Delta (Akpokodje, 1986). The Niger Delta is an alluvial plain and consists of the modern and Holocene delta top deposits (Amajor, 1991). The fine-grained silts and clay overlying the basal sandy sequence is often referred to as the near surface aquitard. The thickness of the aquitard varies between <5 to about 15m, and due to the varying extent of clay, silt, and fine sands, the permeability of the aquitard is highly heterogeneous (Amajor, 1991).

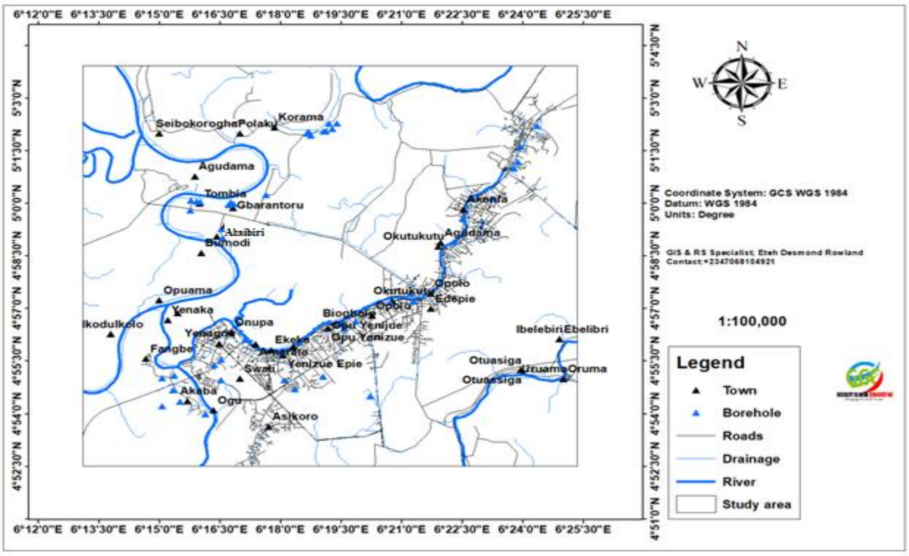

Figure1. *Study area map*

According to Akpokodje (1986), the groundwater flows from North to South in the region. The Niger Delta consists of three main subsurface lithostratigraphic units (Short &Stauble, 1967). From top to bottom they are Benin, Agbada, and Akata Formations. The Benin Formation which is fluvial in origin is the main aquifer in the study area. The water table in many areas of the Niger Delta is close to the surface but subject to seasonal variations. In the dry season, the water table is about 4 - 6 m. During the rainy season, the water table rises significantly, in some cases, the ground surface is flooded. Groundwater is the main source of drinking water for over 80% of the population in the study area.

Data and Methods

The data for this study were acquired from the internet, LANSAT images with a spatial resolution of 10m. The study used a spatial multi-criteria analysis technique to recognize the most suitable debris or garbage site. The Landuse /land cover, Settlement, Place, Borehole, Roads, River, Drainage, Slope, and DEM details are collected from the study area. The weight age analysis for each parameter is done by a Pair wise comparison matrix on a 9-point continuous scale. Various thematic maps are prepared for each parameter by classifying each into four categories. Classifications were done on various layers and the values were assigned ranging from most suitable to unsuitable.

The reclassification of the layers wasin1's, 2's, 3's, and 4's scoring framework, where 1 is unacceptable or unsuitable, 2 less suitable, 3 moderately appropriate, and 4 profoundly appropriate or highly suitable after distance computation was done, individually or respectively. The thematic maps are then overlaid using GIS software. The overlay analysis is done and the layers are classified into four categories namely unsuitable, less suitable, moderately suitable, and most suitable.

RESULTS AND DISCUSSION

Geospatial analysis using Arc GIS was conducted to identify the most suitable sites for the waste dump in Yenagoa metropolis, Bayelsa State. The analysis uses Landuse /land cover, Settlement, Place, Borehole, Roads, River, Drainage, Slope, and DEM to determine or find an appropriate site for solid waste dumping and the results are discussed as follows:

Land Use/Land Cover

The Landuse/land cover is the natural and human landscape that may be exposed by the threats imposed from the effect of dumpsite (Dorhofer& Siebert., 1998).

The landuse/land cover of this study area was analyzed from the satellite image. By reviewing different literature, it was advisable to select land that is occupied by grasses for solid waste disposal (Higgs., 2006; Lin& Kao., 1998; Malczewski., 1997). The Landuse/land cover result gotten from this study areaas summarized in table 1 is classified as follows: water bodies (3.25%), Built-up areas (20%), Vegetation (41.5%), bare soil (35.3%).

Hence, vegetation occupied the highest percentage of the total area. The land which is covered by bare soil and vegetation accounts for about 76.8% of the total area (Fig.2).

The vegetations and bare soil lands indicated by green and red color respectively are the most suitable area for a solid waste dumping site.

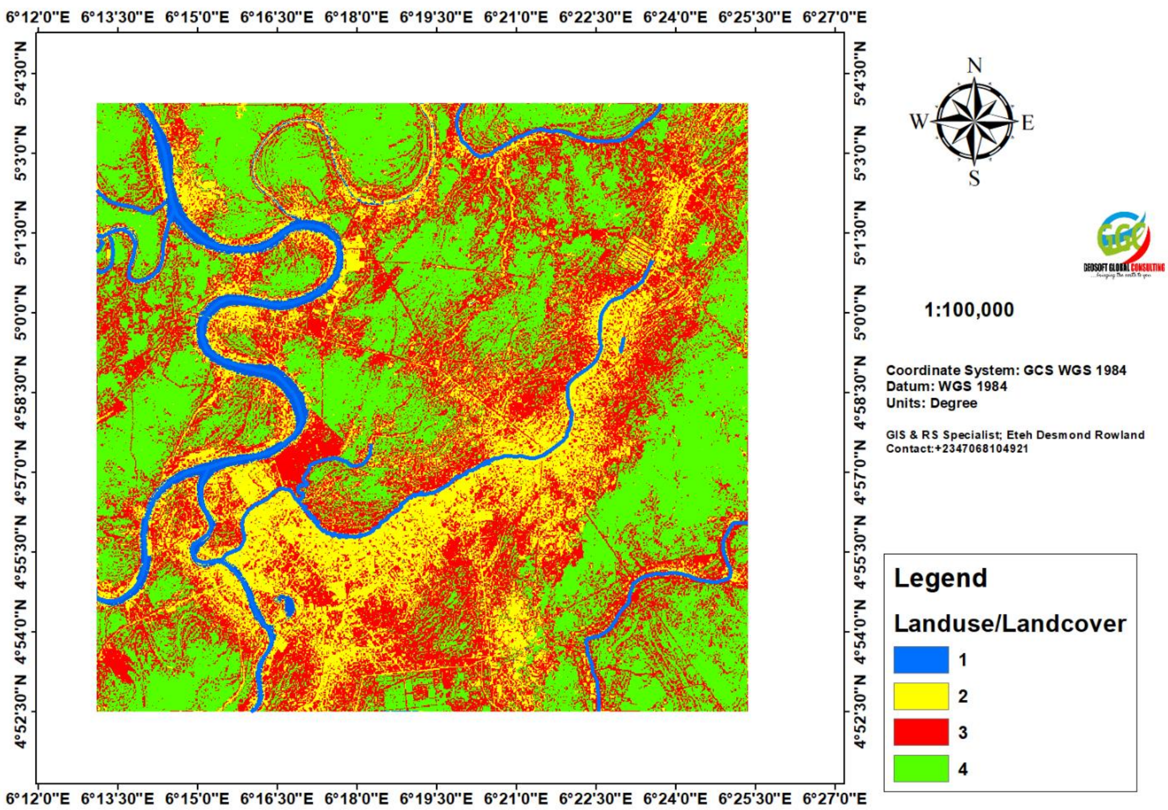

Figure2. *Land use/land cover map of the study area*

Table1. *The Landuse/land cover waste dumpsites suitability result from the study area*

Landuse/land cover	Level of suitability	Value	Area (km^2)	Percent of total area (%)
Water bodies	Unsuitable	1	15.55	3.253
Built up	Less suitable	2	95.39	19.96
Bare soil	Moderate suitable	3	168.51	35.26
Vegetation	High suitable	4	198.47	41.53

The total Area under investigation covers477.92km2where the total highly suitable and recommended site for solid waste disposal is 198.47km2.

Roads

According to previous studies and standards, the dumpsites should be located at least 500 m and above from any major highways, city streets, or other transportation routes (Sener, et al., 2006).

In other words, Debris or garbage dumpsites must be situated at an appropriate location not far away from the streets network to encourage transportation and thusly to lessen relative expenses (Changet al., 2008). 2000 m distance from main roads was buffered. The results were reclassified as unsuitable, less suitable, moderately suitable, and highly suitable which is assigned to Values 1, 2, 3, and 4 respectively (Fig. 3).

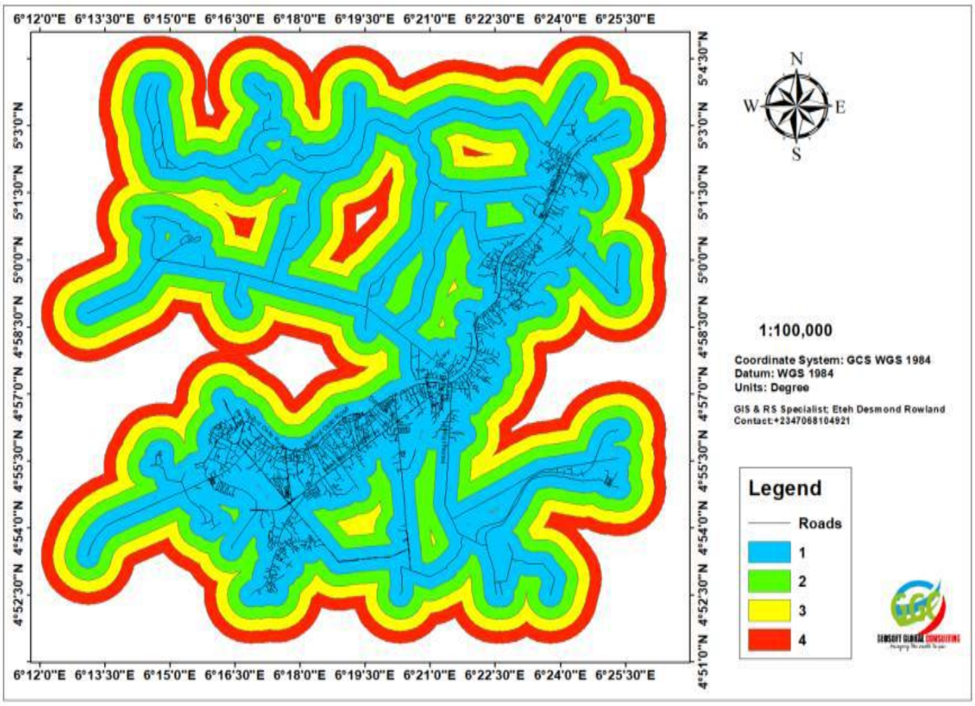

Figure3. *Buffer distance map from the main road*

The buffered distance within 500 m (blue) was considered unsuitable, the distance starting from 500 to 1000 m (green) was considered less suitable. The buffered distance within 1000 – 1500 m (yellow) was considered moderately suitable. Lastly, the highly suitable site for dumpsite location away from the road is at a distance between 1500-2000 m. From the results as summarized in table 2, the area highly suitable for solid waste dumping with the class of value 4 is15.1% from the total buffered distance of this study. The land that is unsuitable for solid waste dumping site by referring to distance from the road is 43.1% of the total area (Table 2 and Fig.3).

Table2. *Distance from main road and area coverage suitability levels.*

Distance to the road (m)	Level of suitability	Value	Area (km2)	Percent of total area (%)
500	Unsuitable	1	233.51	43.49
1000	Less suitable	2	126.18	23.50
1500	Moderate suitable	3	96.21	17.92
2000	High suitable	4	81.07	15.10

Settlement

For urban settlement, the safe distances for dumpsite location are put at around5000 m. But for rural settlement, 2000 m were put as criteria (Dorhofer& Siebert., 1998).

In this study, the 2000 m distance from the settlement was buffered and the2000 m distance was reclassified as Unsuitable, Less suitable, Moderate suitable, and Highly suitable (Fig 4).Unsuitable distance from settlements falls within 0 to 500 m (Blue), less suitable is from 500-1000 m (Yellow), moderate suitable is from 1000 to 1500 m (Red) and most suitable area is from 1500 to 2000 m (Horse-blood). The result from the settlement buffer map in the study area shows that the unsuitable area covered the highest portion as compared to other levels of suitability.

The portion highly suitable for dumpsite covers 23.1%while the unsuitable area covers 27.3% of the total area (Table 3). The class values were given based on the level of suitability from the lowest to the most suitable area used at the time of weighted overlay (Tables 3).

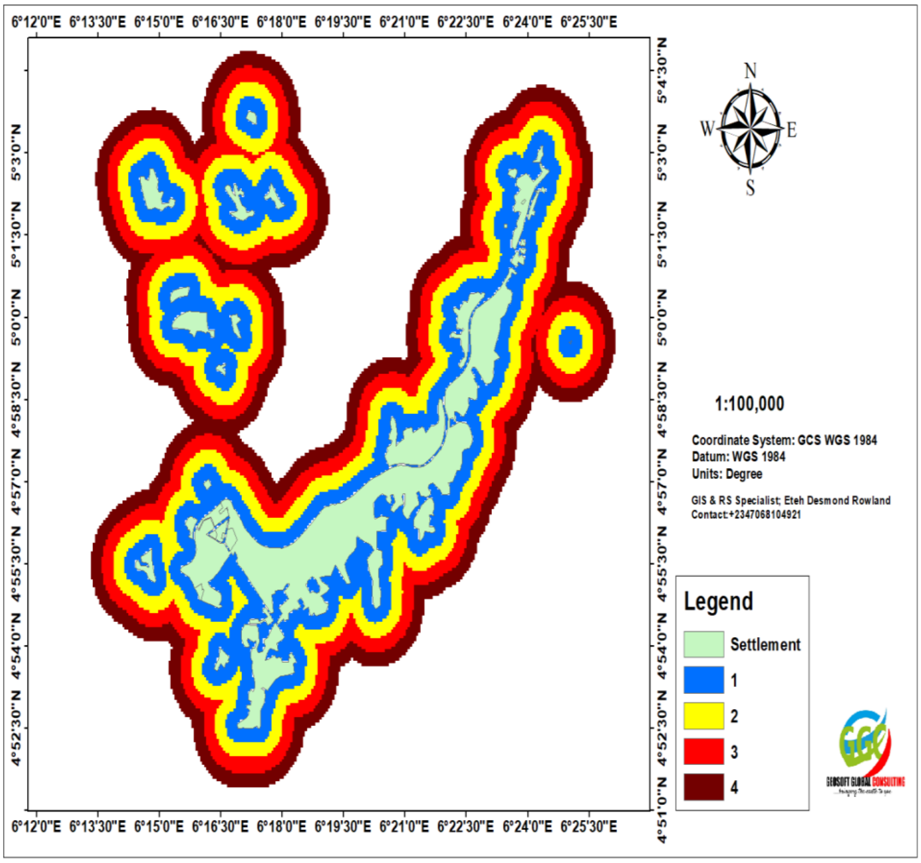

Figure4. *Suitability map for settlement*

Table3. *Settlement area coverage suitability levels*

Distance to Settlement (m)	Level of suitability	Value	Area (km2)	Percent of total area (%)
500	Unsuitable	1	72.55	27.31
1000	Less suitable	2	65.80	24.77
1500	Moderate suitable	3	66.09	24.87
2000	High suitable	4	61.24	23.05

River

Lands far away from lake and river banks are more preferred for solid waste dumping sites (Gomez-Delgado & Tarantola 2006). Hence, in other to maintain the environmental health of these rivers, at least 2000 m buffered distance should be ringed through straight-line calculation (Delgado et al. 2008).

From the result obtained in this study, four different zones were specified considering the relative distance from the rivers (Tables 4; Fig. 5).

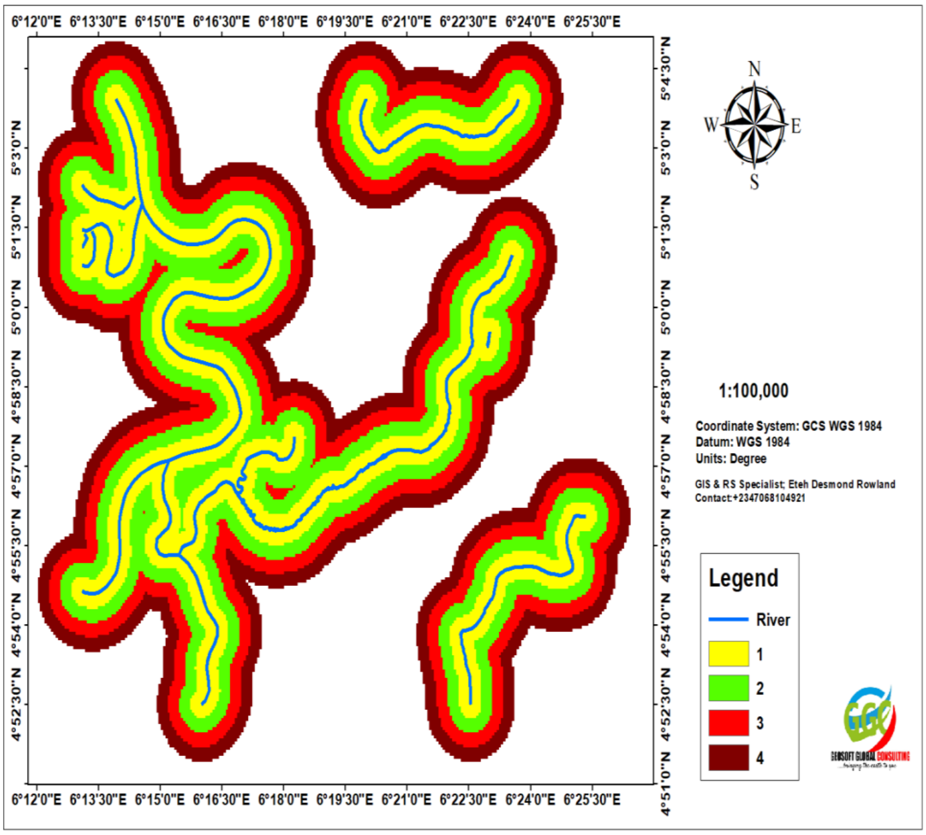

Figure5.*Suitability map for rivers*

The results were reclassified as unsuitable, less suitable, moderately suitable, and highly suitable assigned to Values 1, 2, 3, and 4 respectively. The buffered distance within 500 m (yellow) was considered unsuitable, the distance starting from 500 to 1000 m (green) was considered less suitable. The buffered distance within 1000 – 1500 m(red) was considered moderately suitable and lastly, the highly suitable site for dumpsite location away from the river is at a distance between 1500-2000 m (Horse-blood). From the results as summarized in table 2, the area highly suitable for solid waste dumping with the class of value 4 is22.7% from the total buffered distance of this study. The land that is unsuitable for solid waste dumping site by referring to distance from the road is 28.1% of the total area.

Table4. *River coverage suitability levels*

Distance to River (m)	Level of suitability	Value	Area (km^2)	Percent of total area (%)
500	Unsuitable	1	104.78	28.11
1000	Less suitable	2	96.88	25.99
1500	Moderate suitable	3	86.40	23.18
2000	High suitable	4	84.70	22.72

Slope

The appropriate slope for constructing a dumpsite is about 8–13o because too steep of a slope would make it difficult to maintain (Lober., 1995).

With slopes above 13o, an environment is created where decreased infiltration, contaminants can travel greater distances from the dumping area (Ersoy & Bulut., 2009). In the study area, the slope is too steep and a weighting of 10 is taken if >15o slope and 0 if <15o slope.

For this study, a Slope lesser than 10ois considered the lower slope and it is highly suitable than the land with a higher slope greater than 80o. Different research shows that areas with high slopes will have a high risk of pollution and potentially not a good site for dumping (Ahmed & Suryabhagavan., 2019). The majority of the study area falls under the slope class of >80o which covers 85% of the total study area. According to Sener et al. (2011) and Leao et al. (2001), the land with a slope less than 10o is highly suitable for solid waste dumping.

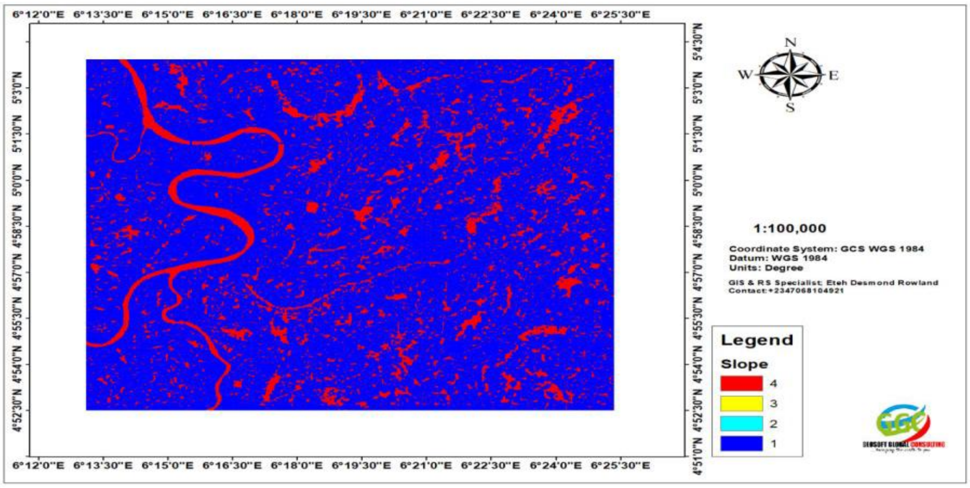

Figure6. *Suitability map for slope*

Table5. *slope coverage suitability levels.*

Slope (⁰)	Level of suitability	Value	Area (km^2)	Percent of total area (%)
>80	Unsuitable	1	406.38	85.06
50-80	Less suitable	2	0	0
50-10	Moderate suitable	3	0	0
<10	High suitable	4	71.38	14.94
			477.76	

Depending on this, only 14.9% of the total study area is suitable for the solid waste disposal site. Base on this result, it shows that slope is not a significant criterion for solid waste dumping site selection in the Yenagoa metropolis and this also means that the city is very steep in its topography (Table 5 and Fig.6).

Place

The specifiedplaces in this study include schools, churches, mosques, parks, and others. A dumpsite should not be located close to sensitive areas listed above to a limit of 2,000 m buffer surrounding (Delgado et al. 2008). When the distance increases the suitability also increases (Table 6). The buffered distance within 500 m (green) was considered unsuitable, the distance starting from 500 to 1000 m (purple) was considered less suitable. The buffered distance within 1000 – 1500 m(orange) was considered moderately suitable. Lastly, the highly suitable site for dumpsite location away from the road is at a distance between 1500-2000 m (Fig 7). From the results as summarized in table 7, the area highly suitable for solid waste dumping with the class of value 4 is27.7% of the total buffered area of this study. The land that is unsuitable for solid waste dumping site by referring to distance from the road is 12% of the total area.

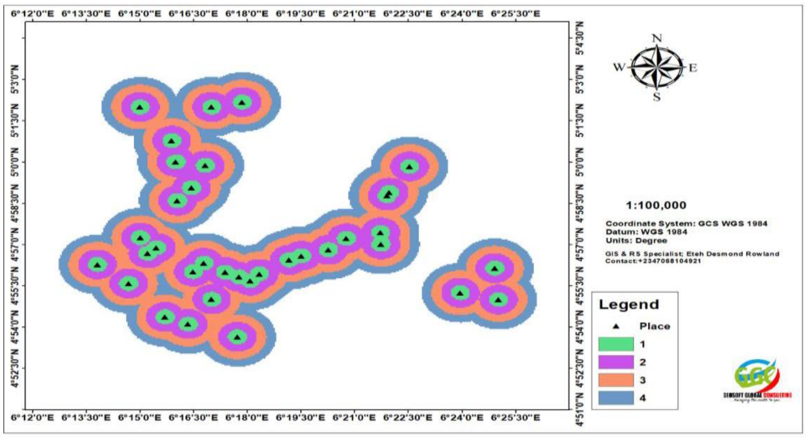

Figure7. *Suitability map for the place*

Table6. *Place coverage suitability levels.*

Distance to Place (m)	Level of suitability	Value	Area (km^2)	Percent of total area (%)
500	Unsuitable	1	25.91	12.02
1000	Less suitable	2	61.87	28.71
1500	Moderate suitable	3	67.99	31.55
2000	High suitable	4	59.71	27.71

Borehole

A dumpsite must not be situated close to any surface streams, lakes, waterways, wells, or wetlands (Bilgehanet al., 2010). Closeness to wells was a significant basis for accessing the dumping site. Dumpsites make toxic gases and leach ate that make them unsatisfactory to be in the vicinity to water wells (Baban& Flannagan.,1998). For this reason, a 3000 m buffer was placed using the function in GIS software, which will be used to generate the buffer around all wells. The depth of the wells in the study area varies between 20 and 30 m. The results as summarized in Table 7, shows that the area highly suitable for solid waste dumping with the class of value 4 is36.3% of the total buffered distance of this study. The land that is unsuitable for solid waste dumping site by referring to distance from well and streams is 9.4% of the total area.

Table7. *Borehole coverage suitability levels*

Distance to Borehole (m)	Level of suitability	Value	Area (km^2)	Percent of total area (%)
500	Unsuitable	1	28.13	9.48
1000	Less suitable	2	53.63	18.07
2000	Moderate suitable	3	107.23	36.12
3000	High suitable	4	107.85	36.33

The buffered distance within 500 m (horse-blood) was considered unsuitable, the distance starting from 500 to 1000 m (yellow) was considered less suitable. The buffered distance within 1000 – 1500 m(green) was considered moderately suitable. Lastly, the highly suitable site for dumpsite location away from boreholes is at a distance between 1500-2000 m (Blue) see Fig 8.

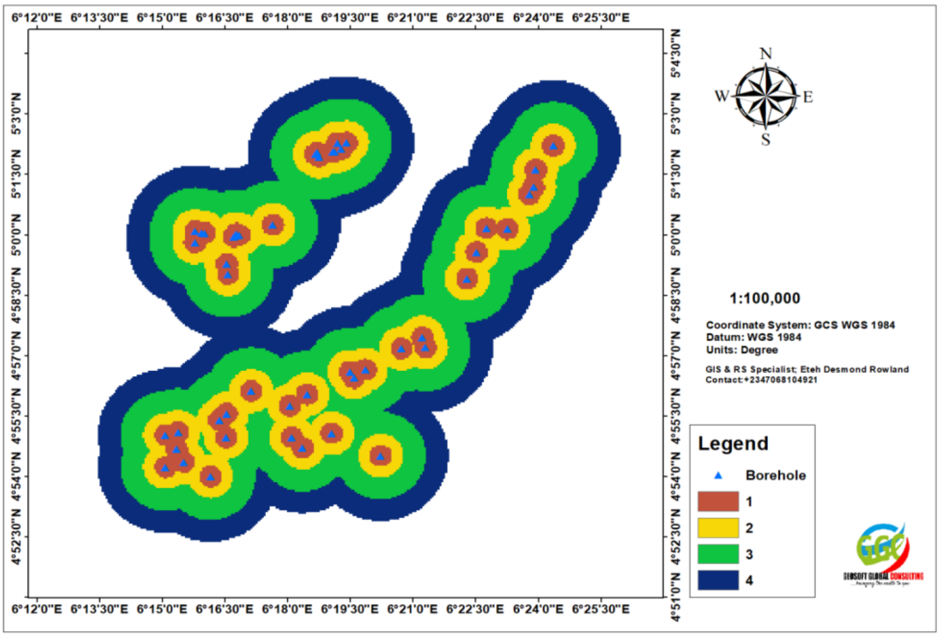

Figure8. *Suitability map for Borehole*

Drainages

Drainages are important in every city or town. Blockage of drainages due to waste and dirt can cause serious environmental hazards. Therefore, a dumpsite must not be located within 100 m of irrigational drainages or canals (Leaoet al., 2001). In this study, a weighting of 10 is then applied for every 100 m away. The result shows that only 10% of the total area is highly suitable for dumpsite location (Fig. 9 and Table 8).

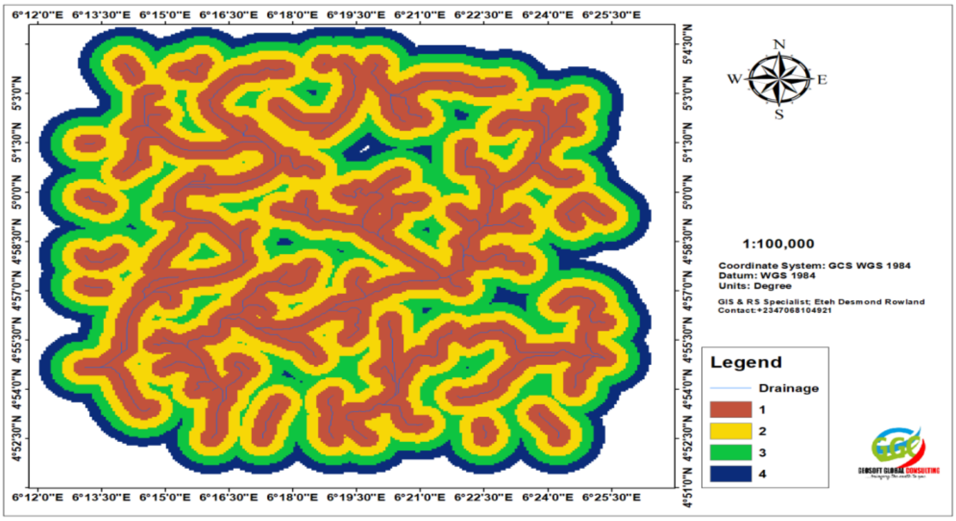

Figure9.*Suitability map for Drainages*

Table8. *Drainagecoverage suitability levels*

Distance to Drainage (m)	Level of suitability	Value	Area (km^2)	Percent of total area (%)
500	Unsuitable	1	224.14	38.18
1000	Less suitable	2	195.34	33.28
1500	Moderate suitable	3	109.35	18.63
2000	High suitable	4	58.20	9.91

Digital Elevation Model

The study area comprises flat land with two natural ground slopes. One of the natural ground slopes is found from north-south to south-south, which follows the general flow direction of the River Niger. Another natural ground slope follows the north-east to southwest direction. As a result, the elevated land lies in the West and Northern parts of the study area. The general ground elevation of Yenagoa City and its adjoining area varies from 0.5 m to 50 m above AMSL (Average Mean Sea Level). The spatial distribution of the different elevated classes and the area under different elevated land classes are shown in Fig. 10 and Table 9.

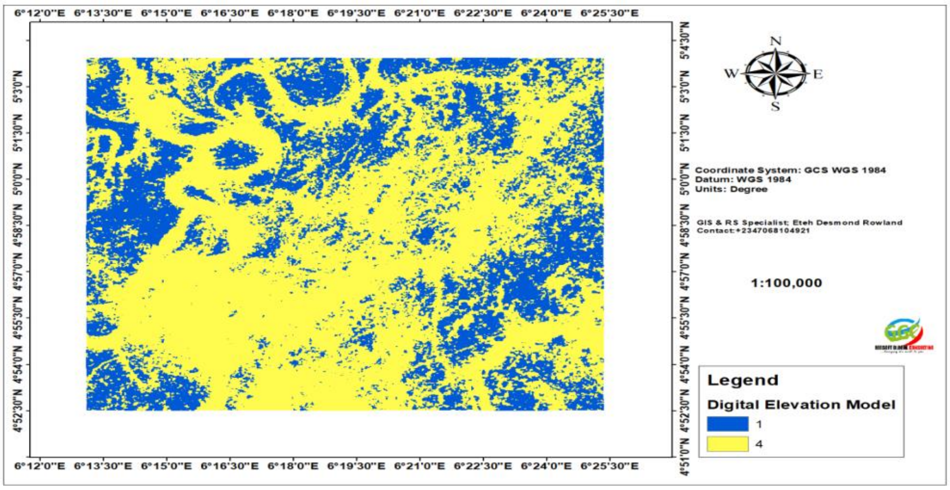

Figure10.*Suitability map for Digital Elevation Model*

Table9. *Digital Elevation Model coverage suitability levels*

Digital Elevation Model (m)	Level of suitability	Value	Area (km^2)	Percent of total area (%)
40-10	Unsuitable	1	154.79	32.40
<10	High suitable	4	322.98	67.60

The site selection for solid waste disposal dumping site involves the comparison of different options based on environmental, social, and economic impact (Solomon., 2012).

Hence, based on experience and likely impact on the surrounding environment, different weights were assigned to all the parameters.

The bigger the weight, the more significant is the model in the general utility. The weights were created by giving a sequence of pair wise comparisons of the general significance of variables to the suitability of pixels for the activity being estimated. The procedure by which the weights were produced follows the logic developed under the Analytical Hierarchy Process (AHP). Weight rates were given based on a pair wise comparison 9-point continuous scale (Table 10).

This pair-wise comparison was then analyzed to produce weights that sum to 1. The consistency ratio of this study indicated that 0.03 was acceptable(Table 11).

If the consistency ratio is less than or equal to 0.1, it signifies an acceptable reciprocal matrix (Panepinto & Zanetti., 2018). The factors and their resulting weights were used as input for the multi-criteria evaluation (MCE) module for the weighted linear combination of overlay analysis.

Table10. *Pairwise comparison in a 9-point continuous scale*

	Landuse/land cover	Settlement	Place	Borehole	Roads	River	Drainage	Slope	DEM
Landuse/land cover	1								
Settlement	0.5	1							
Place	0.3333333	0.5	1						
Borehole	0.25	0.333333333	0.5	1					
Roads	0.2	0.2	0.25	0.333333	1				
River	0.1666666	0.2	0.25	0.333333	0.5	1			
Drainage	0.1428571	0.166666667	0.2	0.25	0.333333	0.5	1		
Slope	0.125	0.142857143	0.16666666	0.2	0.25	0.333333	0.5	1	
DEM	0.1111111	0.125	0.14285714	0.166667	0.2	0.25	0.333333	0.5	1

1/9, Extremely; 1/7, very strongly; 1/5, strongly; 1/3, moderately; 1, equally; 3, moderately; 5, strongly; 7, very strongly 9, extremely

Table11. *Weights derived by calculating the principal eigenvector of the pair wise comparison matrix*

Factor	Eigenvector weight	Percentage (%)
Landuse/land cover	0.308517747	30.85177473
Settlement	0.219210875	21.92108746
Place	0.154897808	15.48978075
Borehole	0.109190263	10.91902634
Roads	0.072566838	7.256683789
River	0.053447538	5.344753769
Drainage	0.037138692	3.713869246
Slope	0.026037746	2.603774583
DEM	0.018992715	1.899271451

Consistency ratio = 0.035, consistency is acceptable

Finally, the suitability map was produced by weighting all the parameters with their respective percent of influence and overlays. Table 11 summarizes their factors, their values, and weights. As indicated by the level of significance, they have the function of choosing appropriate solid waste dumping site. After the overlay examination of the given factors the accompanying appropriate solid waste dumping site map was made (Fig. 11). The final map (Fig. 11) has four colors (classes): Light Green, Yellow, Purple, and Dark Brown. The most suitable area for solid waste dumping site is marked by Dark brown color shaded (class 4).

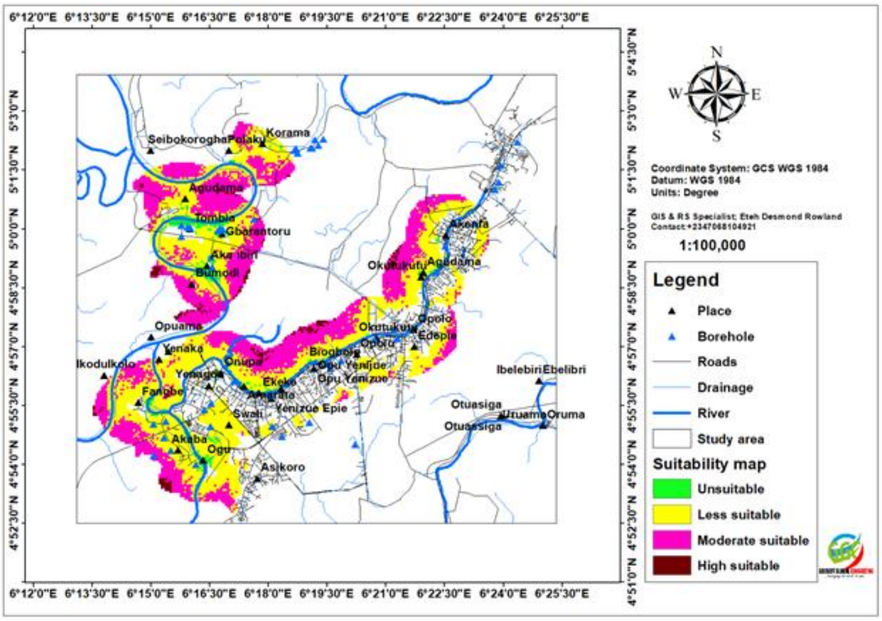

Figure11. *Final suitability map*

Out of the total area of the study site, only1.9% fall under this category. The Purple color represents a moderate suitable area (class 3) and it covers an area of 37.9%. The area which is shaded by yellow color covers 56.1% representing less suitable class and the remaining 4.1% falls under unsuitability class 1 (Table 13). The suitable areas for solid waste dumping site fall on the South-west and North-central part of the town (Fig. 11). The highly suitable areas for solid waste disposal are significantly at the optimum distance from Settlement, Place, Borehole, Roads, River, and Drainage. Moreover, suitability, for slope analyses had shown that slopes less than 10% are more suitable to minimize environmental impacts.

Table12. *Final suitability mapcoverage levels*

Final suitability map	Value	Area (Km^2)	Percent of total area (%)
Unsuitable	Light green	4.27	4.17
Less suitable	Yellow	57.44	56.10
Moderate suitable	Purple	38.77	37.87
High suitable	Dark brown	1.91	1.86

CONCLUSION

The findings from this study have shown that GIS and remote sensing can analyze, evaluate, and take critical decisions in waste management related issues. The analysis from this study has taken Landuse /land cover, Settlement, Place, Borehole, Roads, River, Drainage, Slope, and DEM as determining factors to find an appropriate site for solid waste dumping site. The results have shown that only 1.86% of the total study area (Dark brown) is most suitable for solid waste disposal, 37.87% of the total study area (Purple) is moderately suitable, 56.10% of the total study area (Yellow) is less suitable and lastly, the unsuitable area or restricted areas for solid waste disposal is 4.17% (Light green).The highly suitable locations for dumpsites are far away from any water sources and other variables put into analysis. They are located in the south-west and North central of the town and are dry agricultural areas, bare land, and grass land with 0-10% slopezones, bare land, and grass land with 0-10% inclination or slope.

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