

Landfill Suitability Mapping for Waste Disposal Using Multi-Criteria Decision Analysis (MCDA) Method and GIS in Kaduna State, Nigeria

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Abstract

The study assessed the landfill site for waste disposal in Kaduna State using the Multi-Criteria Decision Analysis (MCDA) method. This method helped establish priority scales for each criterion. Additionally, the study utilized ArcGIS Pro software to overlay the given factors. As a result, the final landfill site map was generated and divided into five categories based on its suitability: unsuitable, less suitable, moderately suitable, suitable, and highly suitable. When the location of the major towns in Kaduna State was overlaid on the Suitability Index Map, it was revealed that only a few towns could serve as a landfill site, namely Atuma, Gimi, Idoh, Ikara, Sogaga, Pambeguwa, Garun Kurama, Idah, Jere, and Gidan Bahagu. In conclusion, integrating GIS and MCDA methodologies significantly reduces the time required and enhances the accuracy of the traditional landfill site selection process. The sensitivity analyses' outcomes on different MCDA methods further validate their effectiveness in identifying an appropriate landfill site for any specific region.

Keywords: Assessment, landfill, Multi-Criteria, Analysis & GIS

INTRODUCTION

Waste disposal is a critical aspect of modern society. With the increasing population and high consumption rates, the production of solid waste has become a significant issue in many developing countries. Landfilling is a commonly used method of waste disposal due to its cost-effectiveness and simplicity. However, selecting an appropriate landfill site is a crucial decision that requires careful consideration of various factors, such as economic, social, and ecological aspects (Shahabi, Keihanfard, Ahmad, & Amiri, 2013).

Solid Waste (SW) material is a combination of trash, waste, sludge, and other solid

garbage produced from human and other living things' activities. This waste is typically not reused or recycled and includes industrial, agricultural, commercial, and societal activities (Bilintoh and Stern, 2015). Solid Waste Management (SWM) is an essential part of the urban agenda in many developing countries.

Solid waste disposal is a challenging task that requires significant attention. The production of waste has increased significantly due to urbanization, high consumption rates, squatter settlements, and the Industrial Revolution. This has made waste management a critical issue

with a significant impact on many cities in developing countries (Haq, Xiwu and Guangyu, 2015).

The illegal disposal of waste, particularly in industrial and municipal areas within Kaduna metropolis and Nigeria as a whole, has become a significant concern for public health and the environment. Improper solid waste disposal has resulted in environmental pollution and posed various health challenges for individuals residing near these dumping sites. Inadequate treatment and disposal of solid waste in landfills or open dumps can lead to rainwater percolation through the waste materials, generating leachate, a contaminated liquid containing diverse pollutants. This leachate can have substantial environmental ramifications, infiltrating and contaminating surface water bodies, such as rivers, lakes, and streams, and permeating the soil, presenting a significant threat to groundwater quality. Pollutants from unmanaged waste degrade water quality, making it unfit for drinking, irrigation, and industrial use. The costs of water treatment increase and access to clean water becomes more limited, particularly for vulnerable communities. The presence of contaminants from improperly managed waste leads to the deterioration of water quality, rendering it unsuitable for consumption, agricultural purposes, and industrial applications. This, in turn, results in escalated expenditures on water treatment, ultimately restricting the accessibility of clean water, particularly for vulnerable communities.

Yongsi et al. (2008) The consequences of indiscriminate solid waste disposal include human exposure to environmental degradation, heightened risk of flooding,

obstruction of drainage systems, proliferation of infectious diseases including cholera, diarrhoea, and typhoid fever, as well as blockage of waterways resulting in the infestation of flies, ticks, and the breeding of mosquitoes responsible for the spread of diseases such as malaria.

To address this challenge, researchers have explored different methods for landfill site selection using advanced technologies such as Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA). GIS and MCDA are powerful tools that can be used to identify optimal landfill sites for waste disposal. By leveraging the capabilities of GIS and MCDA, decision-makers can gain valuable insights into various factors that influence the selection of landfill sites, such as proximity to urban areas, accessibility, environmental impact, and cost-effectiveness. With these insights, they can make informed decisions and develop effective policies to ensure sustainable waste management practices (Suman, 2012).

Aim and Objective

The research aims to use GIS and MCDA to identify optimal landfill sites. The educational program equips individuals with skills to assess spatial and non-spatial factors affecting site selection of landfill for waste disposal.

METHODOLOGY

Data

Data is a crucial component in GIS. The research used data from primary and secondary sources.

Table 1: Data and their Sources

Data	Sources
SRTM (DEM), 30m Resolution	USGS
Soil Map	Geological Survey, Kaduna
Geology Map	Geological Survey, Kaduna
Landsat Imagery 30m Resolution, Year 2024	USGS

Source: Author's work, 2024.

Preparation of Thematic Layers

The process of finding a suitable landfill site for waste disposal is complex and requires considering various factors that can influence the selection of a location. These factors include the proximity of the site to water bodies, geological characteristics, distance from roads, population density of the surrounding area, soil type, slope steepness, and existing land use.

To conduct a comprehensive study, a range of thematic layers were combined using ArcGIS Pro. The importance of each parameter was considered when integrating the thematic layers. A digital elevation model (DEM) with a resolution of 10 meters was used to determine the drainage and slope of the area, covering the entire study area for a detailed analysis of the land's topography.

Moreover, a soil and geological map of the study area was obtained from the Nigeria Geological Survey Agency, providing crucial information about the soil and geological characteristics of the area, which was vital for identifying potential risks or hazards associated with building a landfill site. All the datasets were processed to have a uniform projection system (Universal Transverse Mercator (UTM)) to ensure consistency and effective comparison.

Finally, all the data sets were stored in raster format for further analysis and interpretation. After considering all these factors and analysing the data in detail, the best possible location for the landfill site was identified, meeting all the necessary criteria and ensuring safe and effective waste disposal.

Image Classification

The satellite imagery that we have acquired has already been pre-processed by the US Geological Survey (USGS) National Centre for Earth Resources. The spectral bands used have a spatial resolution of 30m and have been layer-stacked to form a composite image of the study area. This image will be utilized for land use/land cover classification and image analysis. During this study, we will perform image classification to detect the LULC. This will be done using ENVI 5.0 through supervised classification. Additionally, we will use our field knowledge and refer to Google Earth images of the study area to conduct visual image interpretation.

Geo-referencing/Digitizing

The accurate georeferencing of the Geological and soil map of Kaduna state was achieved by establishing a correlation between precise points on the map and their corresponding points on the earth's surface using ArcGIS Pro 3.0. To digitize the map, the process of converting a Raster map to a

vector was performed using the same software. During the digitization process, roads, rivers, soil maps, and geology maps were all digitized to create a comprehensive database. Attribute information for each criterion was also included, which comprised the name of each criterion and its various types or classes.

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a commonly used approach for analysing decisions involving multiple criteria. It was developed by Saaty in 1988 to address such

Table 2: AHP Ranking and definition.

Ranking	Definition
1	Extremely less important
2	Very strongly less important
3	Strongly less important
4	Moderately less important
5	Equally important
6	Moderate important
7	Strongly important
8	Demonstrate important
9	Extreme important

Source: Adopted from Saaty (2005)

Landfill Suitability Modelling

To evaluate the suitability of a specific area for waste disposal through landfill, a reclassified layer (parameter) is assessed by assigning a weight to it. The resulting values of all cells are then added up to generate an output raster, which represents potential groundwater areas. Higher sum values indicate that the site is more suitable, while lower sum values indicate that it is less suitable for exploration. To determine the best landfill site for the study area being evaluated, each parameter class is assessed based on its importance relative to other classes in the layer. The summed-up cell values of all parameter classes are then used

problems. AHP employs a numerical scale ranging from 1 to 9 to determine the relative importance of each criterion. This is accomplished by employing a pairwise comparison method to assign scores and weights to each criterion (Ibrahim et al., 2018). When there are many criteria to consider during the decision-making process, using Analytic Hierarchy Process (AHP) can become difficult. To tackle this challenge, Saaty (2005) explains the definitions and scale values of each criterion to help understand its importance.

to create a final output raster, representing the optimal landfill site for waste disposal.

A suitable landfill site for waste disposal in the study area was produced by performing a weighted overlay using the raster calculator in ArcGIS Pro.

The equation used was modified from the DRASTIC Index and adopted from Khairul Anam *et al.* (2000), as shown below:

$$SS = G_r G_w + D_w D_{w_w} + D_r D_{r_w} + S_r S_w + St_r St_w + Lu_r Lu_w + Pd_r Pd_w$$

Where r= ratings

W= weight

SS= Site Suitability

Ge= Geology, Dw= Distance from
water, Dr= Distance from Road, S=

Slope, Pd=Population density, St=

Soil type, Lu= Land use/cover

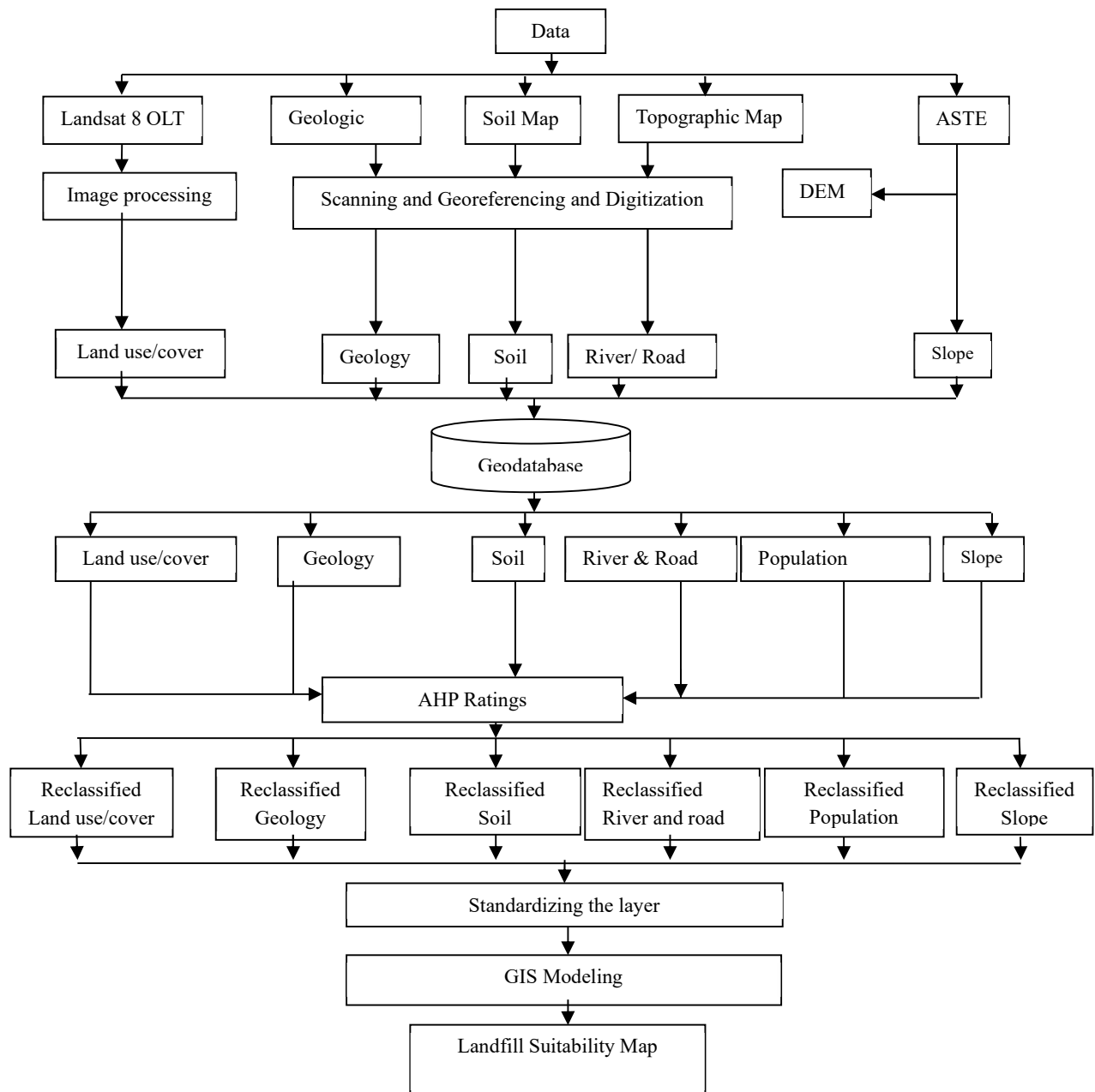


Figure 2: Flow diagram

Source; Authors work 2024.

Flow Diagram Digital Methodology

The flow diagram serves as a visual representation of the steps and procedure in sequence that was carried out. The flow diagram is noted with a shape, linked by

connecting arrow headlines. It gives a view of the process from start-up to finish. Below is the flow diagram for the method adopted in carrying out the suitability analysis of

potential dumpsites within the study location.

Landfill Siting Criteria

Population Density

Assessing the suitability of a location requires taking into account several factors, and one of the most critical ones is population density. Kaduna State has a total population of 9,032,200 people as of 2022, but it is essential to note that population

density varies significantly across different areas in the state. Kaduna South has the highest population density in the entire state, with 12,879/km² people residing in each square kilometre of land, followed by Kaduna North, with a density of 7,672/km² people per square kilometre. On the other hand, Birnin Gwari has the lowest population density, with only 61.05/km² people, closely followed by Kajuru, with a density of 72.76/km² people.

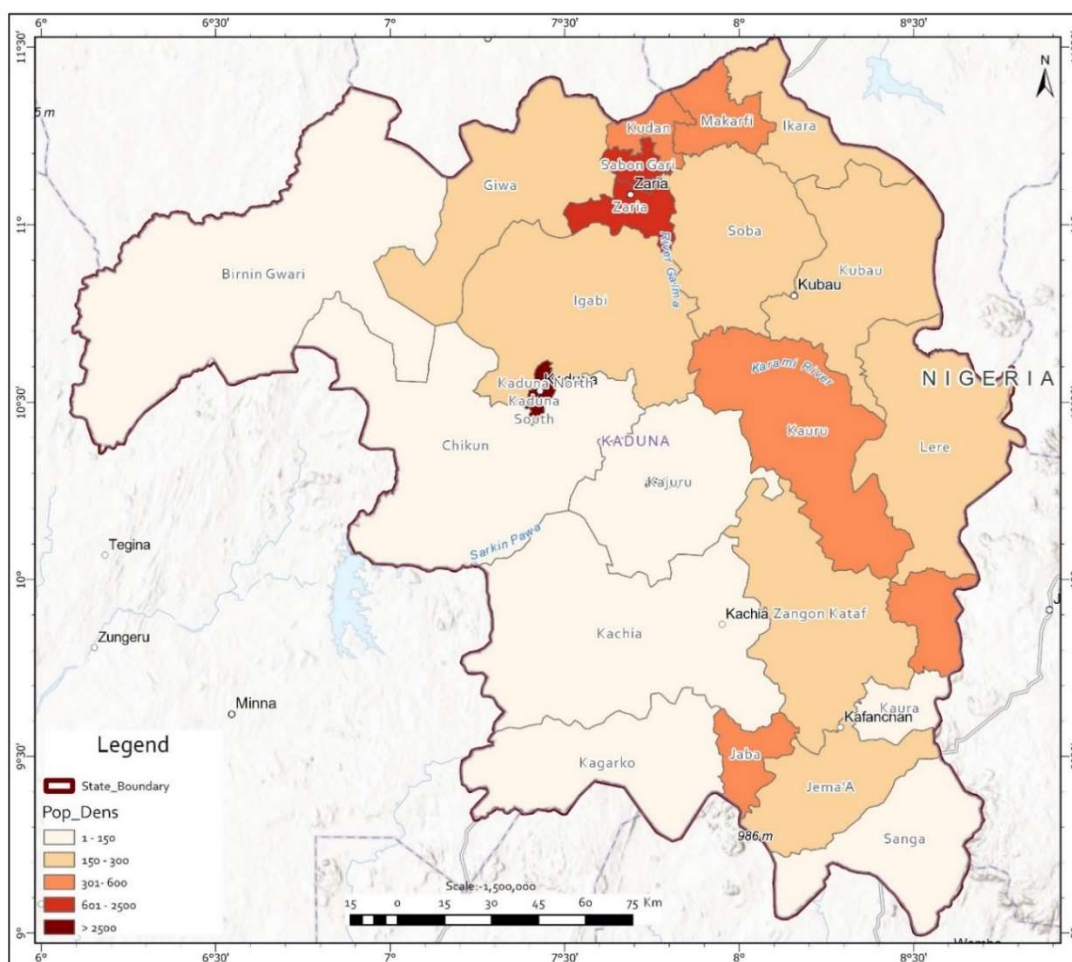


Figure 3: Population Density Map

Source; Authors work 2024.

Distance from Waterbody

When building landfill sites for waste disposal near water bodies such as rivers, lakes, streams, and ponds, there is a significant environmental hazard. This is

due to the possibility of leachate, a liquid that poses a significant threat to water bodies. This harmful liquid has the potential to cause extensive damage due to its contaminating nature. The resultant effects

of its contamination can be dire, ranging from the destruction of aquatic ecosystems to the adverse impact on human health. Therefore, necessary to take measures to mitigate the risk and ensure the sustainable management of waste. In order to minimize potential risks associated with landfills

close to waterbody, a multi-buffer analysis is employed which involve the creation of a safety zone with a minimum radius of 500 meters and a maximum of 2000 meters around each river in the study area so as to prevent any harmful effects on waterbody and environment.

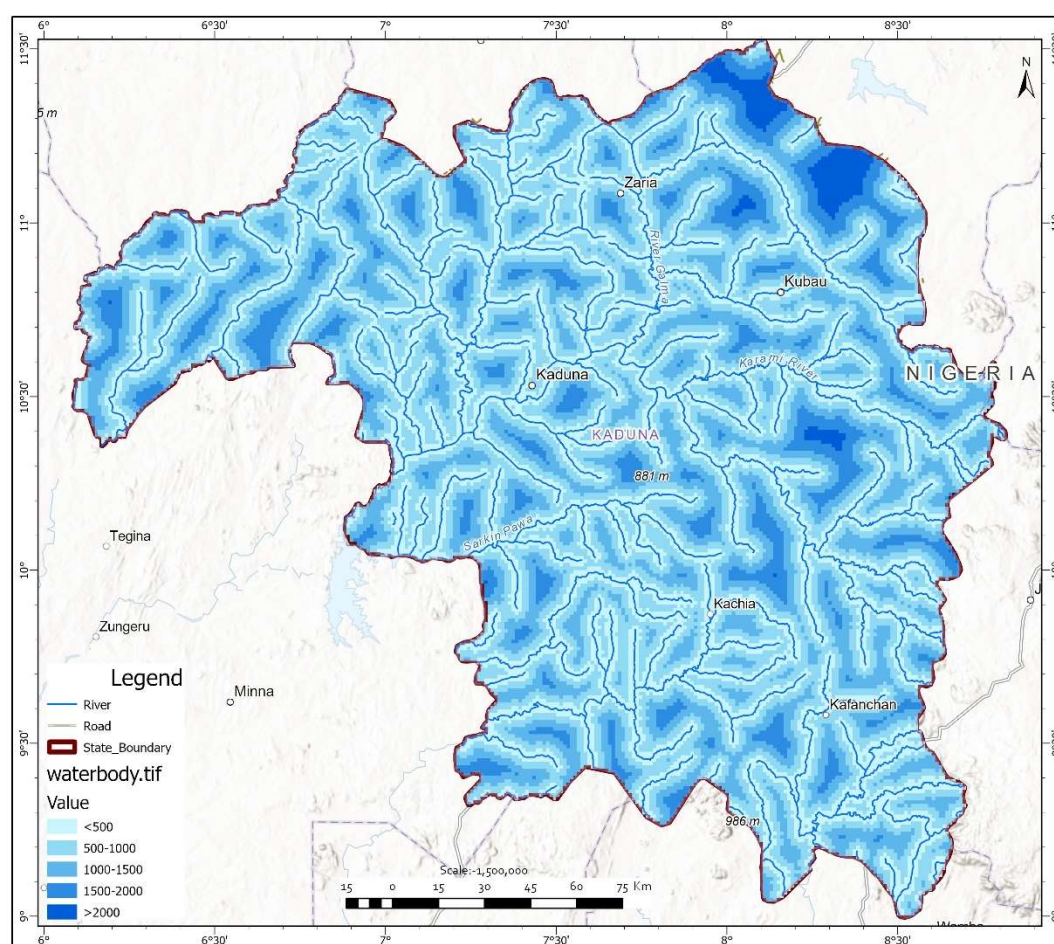


Figure 4: Distance from waterbody
Source; Authors work 2024.

Distance from Road

A Euclidean distance tool was used to examine the study area and create a buffer ring with distances of 100m, 200m, 300m, 400m, and 500m. The buffer distance was selected based on topography and infrastructure development. The study

emphasizes the importance of easy accessibility of the landfill site for waste collection and transportation vehicles. Areas close to roads are more accessible and favourable for a landfill site selection. The study highlights the need for careful consideration of factors that impact accessibility when selecting a landfill site.

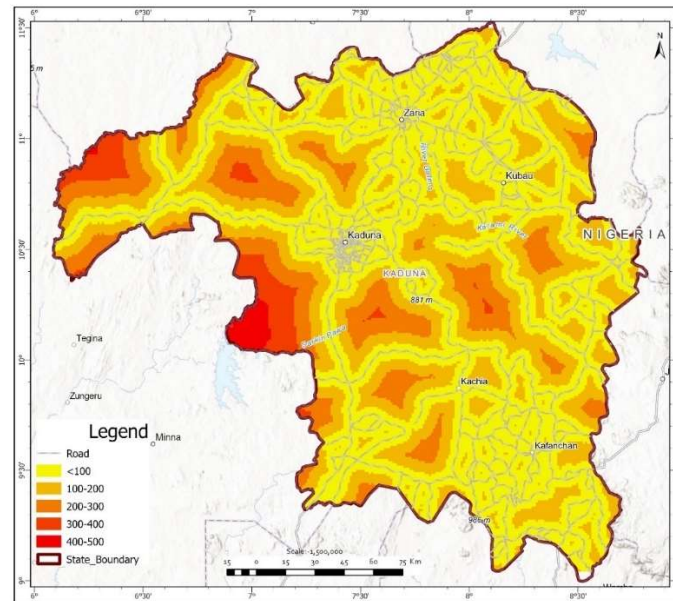


Figure 5: Distance from Road
Source; Authors work 2024.

Slope of the Study Area

To understand the terrain of the study area, a digital elevation model (DEM) of the study area that we obtained from the USGS website was analyzed. This analysis helped us create a slope map, which provided insight into the topography and the steepness in the terrain of the study area to identify a suitable location for a dump site.

Following the findings of Shamshiry et al. (2011), we aimed to identify an area with a gentle slope, while avoiding steeper slopes. Utilizing the data from the slope map, we were able to identify specific regions within our study area that possessed a gentler slope. This knowledge allowed us to make good decision regarding the location for the dump site.

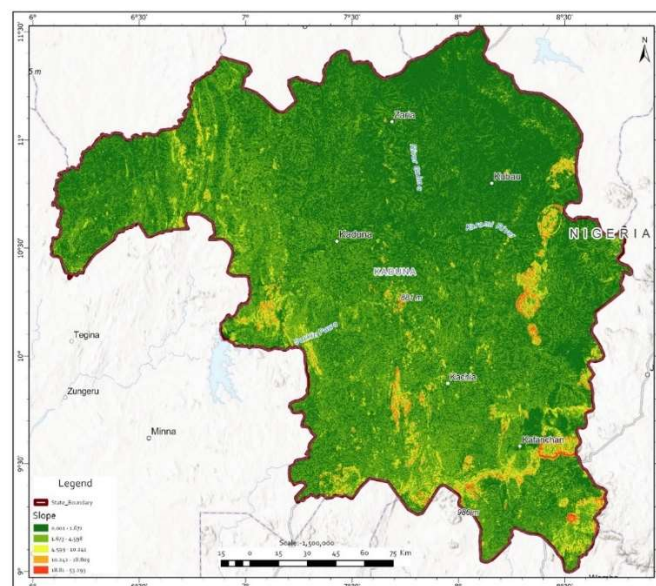


Figure 6: Slope Map
Source; Authors work 2024.

Land use/ Landcover.

The environmental impact of a refuse dump is significantly influenced by the surrounding land cover and land uses. Careful consideration of these factors is necessary to ensure that the refuse dump is located in a suitable area. For instance, the placement of a dump in forested areas can lead to deforestation and habitat destruction, whereas placing it in barren land may have minimal ecological consequences. It is important to note that different land uses exhibit varying degrees of sensitivity to

environmental impacts. Locating a refuse dump near residential areas, for example, can cause public health concerns and community opposition.

In order to identify areas that are less suitable for refuse dumps, it is imperative to have a comprehensive understanding of the current land use and the potential conflicts with existing activities or infrastructure. This information can inform the decision-making process and help ensure that the location of the refuse dump is appropriate and sustainable.

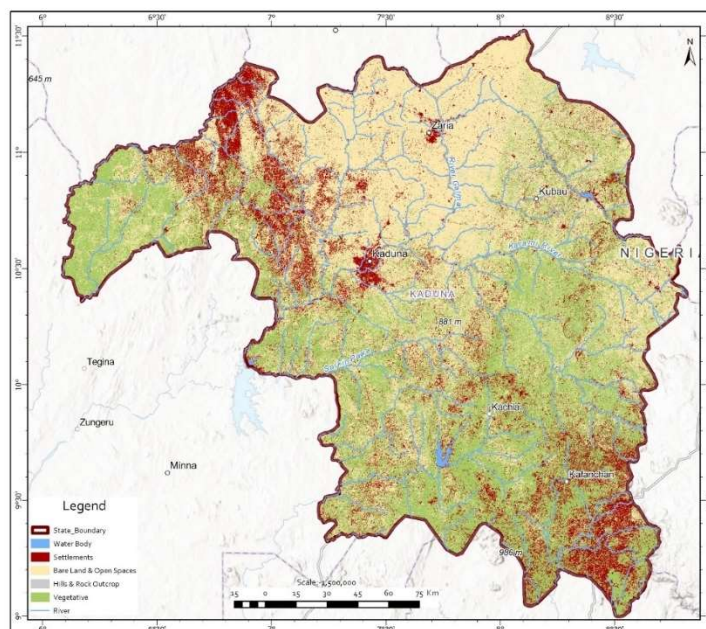


Figure 7: LULC map of the Study area
Source; Authors work 2024.

Soil Type

After examining the soil type of the study area, it was further sub classified into 3 Moderately Low permeable, Slow Permeable, very rapid permeable were by soil type like regosols, leptosol acrisols and fluvisols fall under the Very Rapid

Permeable, cambisols falls under moderately low permeable and under slow permeable we have the lixisols. By carefully observing these soil types and their various permeability zones is very important so as to ensure that the landfill for waste disposal is properly sited without causing any harm to the environment.

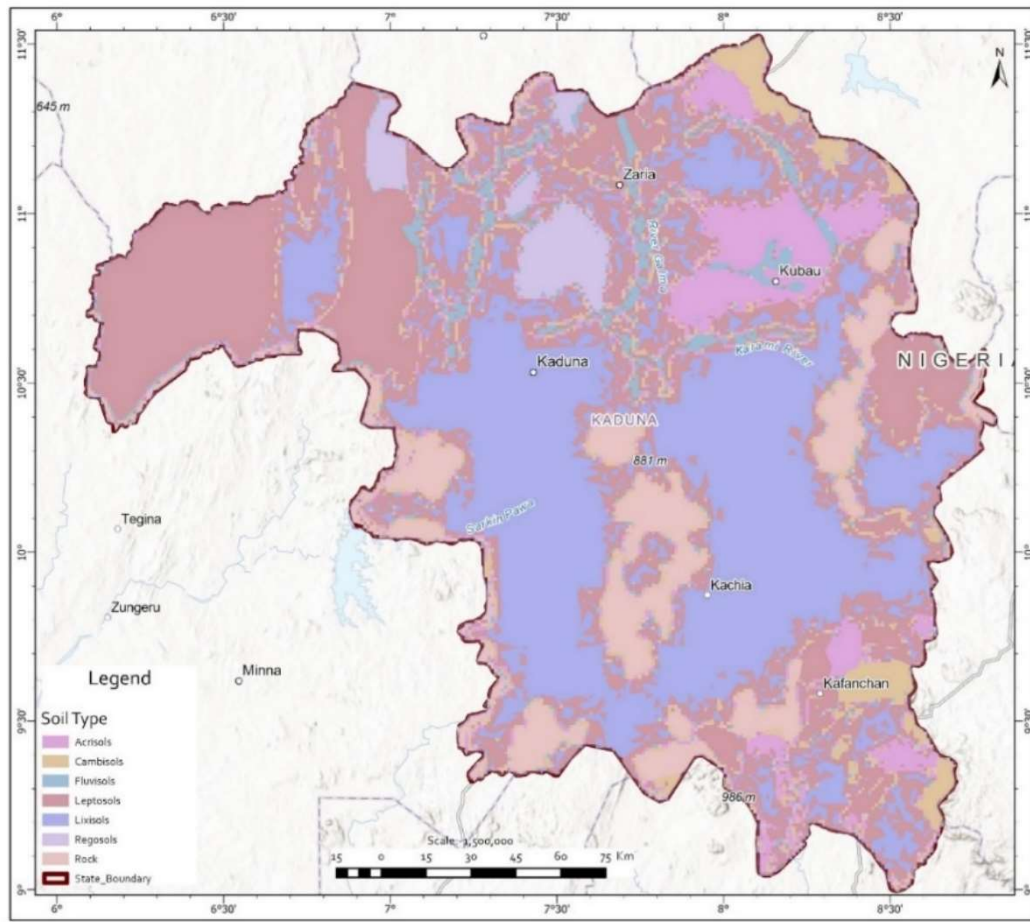


Figure 8: Soil type the Study area
 Source; Authors work 2024.

Geology

The geological examination of the study area was undertaken with the aim of ascertaining the rock formations present in the vicinity. After careful analysis of the geological features, it was determined that the area hosts a total of seven distinct rock formations, which can be further classified into three primary categories: sedimentary,

igneous, and metamorphic. The sedimentary rock group comprises alluvium, while the igneous group is composed of granite and rhyolite. The metamorphic group, on the other hand, encompasses quartzites and metasediments. This preliminary study provides a foundation for further research on the geology of the area.

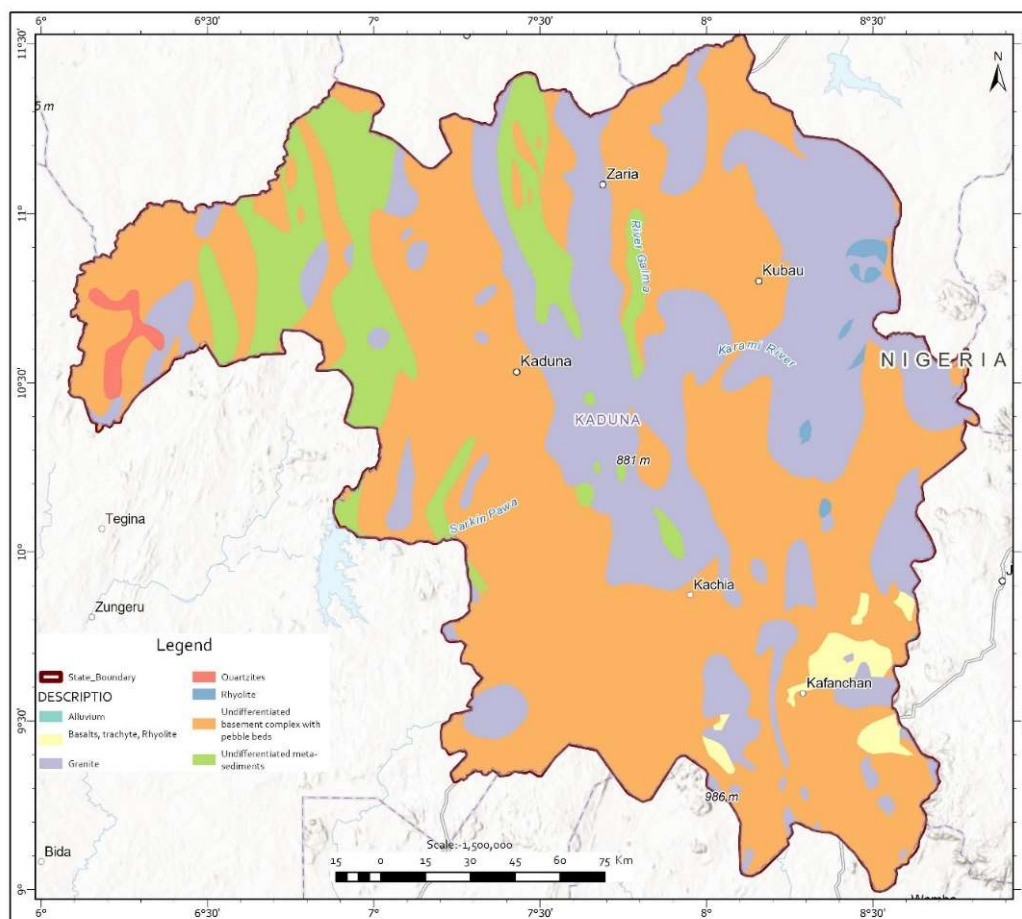


Figure 9: Geology of the Study area
 Source; Authors work 2024.

The MCDA (Multi-Criteria Decision Analysis) Analytic Hierarchy Process (AHP) Ratings Technique

The study utilized the MCDA (Multi-Criteria Decision Analysis) Analytic Hierarchy Process (AHP) Ratings Technique, which is a sophisticated method to establish priority scales for each criterion. To determine the relative importance of each criterion, the researchers used the pairwise comparison method via the AHP Excel template, a tool that simplifies the process of comparing and evaluating multiple criteria. The researchers rated the attributes of each factor based on a set of guidelines, procedures, and principles that

were carefully designed to consider their impact on groundwater accumulation and infiltration. The factors were then grouped based on the significance of their characteristics, and the key findings of the study were summarized in a table. Finally, the comparison process was concluded by assigning weights to each criterion, which were generated after the completion of the comparison process. Overall, this study provides a detailed and comprehensive analysis of the factors that affect the siting of landfill for waste dumping. It offers valuable insights into how these factors can be prioritized to make more informed decisions about managing this precious resource.

Table 3: Analytic Hierarchy Process (AHP) Ratings

Criteria	Class/ Buffer Zone	Rank
Distance to waterbody	< 500	1
	500-1000	5
	1000-1500	6
	1500-2000	7
	>2000	9
Distance to Road	<100	1
	100-200	2
	200-300	5
	300-400	7
	400-500	9
Slope	<1.672	8
	1.237-2.781	6
	2.782-4.598	4
	4.599-10.241	3
	10.242-18.809	2
LULC	Bare Ground	9
	Built Area	1
	Cropland	5
	Vegetation	7
	Water	1
	Rangeland	3
Geology	Sedimentary	5
	Igneous	6
	Metamorphic	4
Population Density	<150km ²	9
	150 km ² -300 km ²	7
	300km ² -600 km ²	6
	2500 km ² -2500 km ²	4
	>2500 km ²	2
Soil	Moderately Low permeable	9
	Slow Permeable	7
	Very rapid permeable	2

Source: Authors work, 2024.

Landfill Suitability model for waste disposal.

To locate a suitable landfill site for waste disposal, a comprehensive analysis was carried out using seven parameters and various siting criteria. We utilized Arc GIS

Pro software to overlay the given factors using the raster calculator. The final landfill site map was generated, and it was categorized into five groups based on its suitability: unsuitable, less suitable,

moderately suitable, suitable, and highly suitable.

After overlaying the location of the major towns in Kaduna State on the Suitability Index Map it was discovered that very Few

Towns could serve as a landfill Site this Towns consist of Atuma, Gimi, Idoh, Ikara, Sogaga, Pambeguwa, Garun Kurama, Idah, Jere, and Gidan Bahagu as shown in the figure bellow.

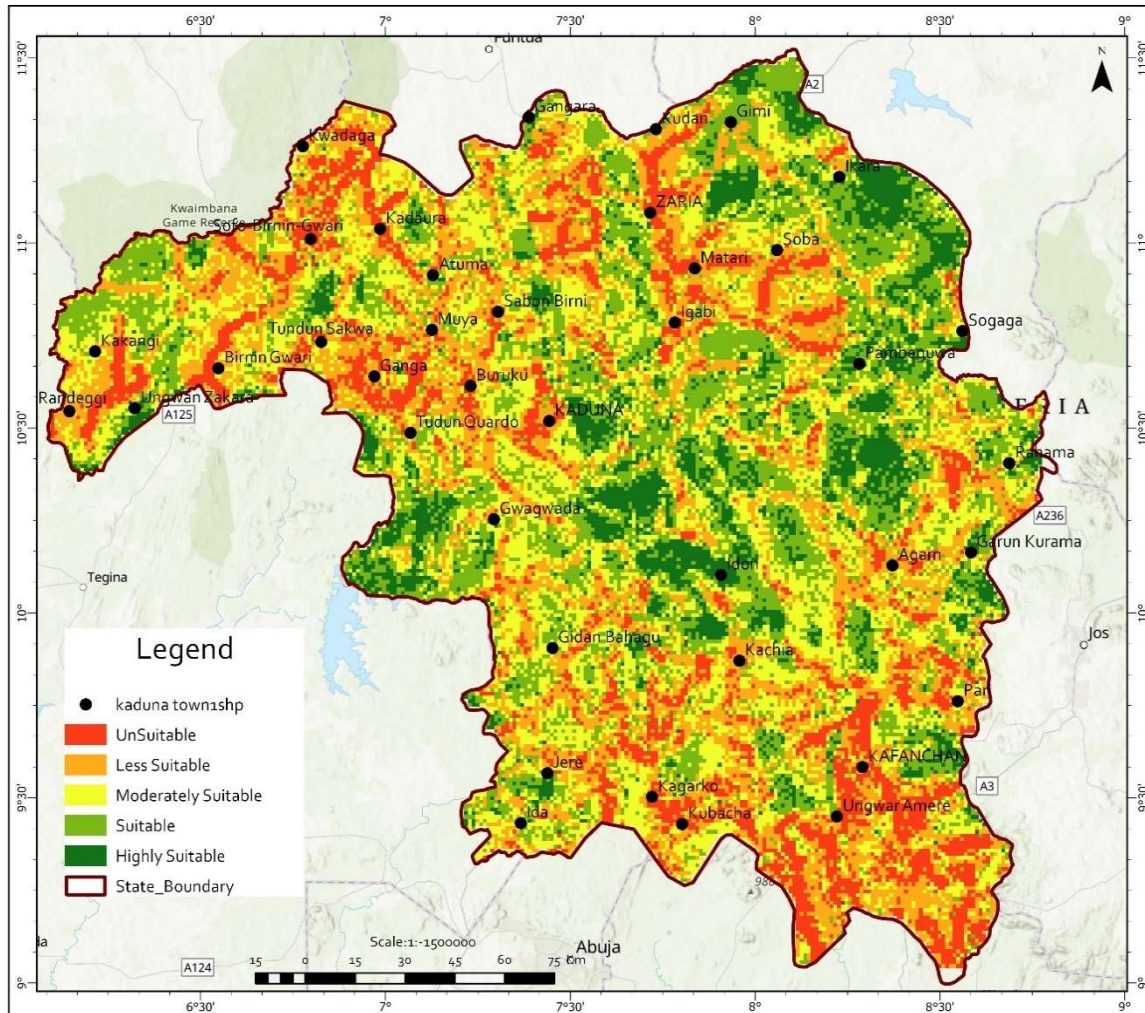


Figure 10: Landfill Suitability Map of the Study area
Source; Authors work 2024.

CONCLUSION

According to this study and other literature reviews, it has been established that the utilization of GIS and MCDA techniques has simplified the task of identifying suitable landfill locations for waste disposal. In contrast to the conventional landfill site selection process, the

integration of GIS and MCDA methodologies significantly minimizes the time required and enhances the accuracy of the procedure. The outcomes of the sensitivity analyses conducted on different MCDA methods further validate their effectiveness in identifying an appropriate landfill site for any specific region.

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