GIS-BASED MULTI-CRITERIA DECISION ANALYSIS OF SUITABLE LOCATIONS FOR LANDFILL IN EDO SOUTH LOCAL GOVERNMENT AREA IN NIGERIA

BY

IKIMOT TEMITOPE AGBAJE

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF BACHELOR OF SCIENCE (B.Sc.) DEGREE IN ENVIRONMENTAL MANAGEMENT AND TOXICOLOGY.

OCTOBER 2025.

CERTIFICATION

This is to certify that this research titled “**GIS-BASED MULTI-CRITERIA DECISION ANALYSIS OF SUITABLE LOCATIONS FOR LANDFILL IN EDO SOUTH LOCAL GOVERNMENT AREA IN NIGERIA**” was carried out by **“IKIMOT TEMITOPE AGABJE”** and presented to the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City; in partial fulfillment of the requirements for the award of Bachelor of Science (B.Sc) in Environmental Management and Toxicology. It was conducted under suitable conditions, was carefully supervised, and subsequently approved as having met the requirements for the award of Bachelor of Science degree in Environmental Management and Toxicology.

______________________ ________________________

DR. O. OSARENOTOR **Date**
(Project Supervisor)

______________________ ________________________

PROF. E.T. AISIEN **Date**
(Head of Department)

DECLARATION

I "**IKIMOT TEMITOPE AGBAJE**" declare that "**GIS-BASED MULTI-CRITERIA DECISION ANALYSIS OF SUITABLE LOCATIONS FOR LANDFILL IN EDO SOUTH LOCAL GOVERNMENT AREA IN NIGERIA**" is my own work and that all sources that I have used or quoted have been acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other University.

____

IKIMOT TEMITOPE AGBAJE
OCTOBER, 2025

DEDICATION

This project is wholeheartedly dedicated to **God Almighty**, whose strength, wisdom, and understanding have guided me every step of the way. I also dedicate this work to my **parents**, **friends**, and my **lovely sister**, whose unwavering encouragement and support inspired me to bring this work to fruition.

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ABSTRACT

This study addresses the challenge of unsustainable solid waste management in Edo South, Nigeria, by integrating Geographic Information System (GIS) technology with Multi-Criteria Decision Analysis (MCDA). The research focused on five critical criteria such as distance to road, slope, soil type, distance to water bodies, and proximity to residential areas, which were weighted using the Analytic Hierarchy Process (AHP). Road accessibility was determined to be the most critical factor, receiving the highest weight at 30%, emphasizing its role in operational logistics and cost efficiency. A Weighted Overlay Analysis was performed to synthesize the standardized spatial layers, generating a final suitability map. The key findings reveal robust land availability: 34.6% of the Edo South Senatorial District was classified as Highly Suitable, 64.8% as Moderately Suitable, and only 0.5% as Least Suitable. The optimal, highly suitable sites are strategically concentrated in the outlying and less urbanized Local Government Areas (including Ovia South-West, Ovia North-East, Uhunmwonde, and Orhionmwon), confirming the necessity of siting new facilities away from the dense urban core. The final map serves as a reliable, data-driven planning tool, guiding policymakers and urban planners toward sustainable landfill placement that ensures compliance with environmental standards and mitigates the public health and pollution risks associated with current improper waste disposal practices in the region.

CHAPTER ONE

INTRODUCTION

1.0 Background of the study

The rapid increase in population, particularly in developing countries, has driven accelerated urbanization and the spatial expansion of cities worldwide (Adeoye, 2012). Urban growth alters land use and land cover, often resulting in the loss of biodiversity, forests, and agricultural resources, as well as contributing to climate change and other environmental challenges (Skole and Tucker, 1993; Lambin *et al*., 2001; Perkin, 2013).

Previous GIS studies in Edo State have demonstrated the value of suitability analysis across various sectors. For example, Agbogun *et al*. (2021) mapped rubber and cashew cultivation suitability in the derived savanna zone, while Olowojoba *et al*. (2016) assessed cassava production suitability in Akoko-Edo. However, no comprehensive GIS-based study has yet focused on landfill site selection in Edo South, even though rapid urbanization continues to strain land and infrastructure (Odjugo *et al*., 2015; Ojo, 2024). Rapid urban development and population growth in developing nations, including Nigeria, have led to increased solid waste production (Adeoye, 2012). The country faces challenges in managing municipal solid waste due to inadequate infrastructure, poor planning, and weak regulation enforcement. While sanitary landfills are a key solution, improper placement can lead to serious environmental, social, and economic issues, including groundwater pollution and land degradation (Kingsley-Omoyibo and Akhimien, 2020).

In recent years, Geographic Information Systems (GIS) have become essential tools for environmental planning, especially in selecting landfill locations. GIS facilitates the spatial assessment of various environmental and socio-economic factors, allowing planners to systematically and data-driven identify and analyze possible sites (Alrukaibi and Alsulaili, 2017). The use of multi-criteria decision analysis (MCDA), which is often combined with GIS, further improves the accuracy and dependability of landfill site selection by assigning weights to different criteria based on expert evaluations (Eskandari *et al*., 2013).

In Edo State, particularly in the Edo South Senatorial District, the rapid growth of urban areas has significantly increased the pressure on waste management systems. Research shows that many existing dumpsites in the region have become inadequate due to urban expansion and their inability to meet environmental standards (Owoseni, 2023). Utilizing Geographic Information Systems (GIS) alongside analytical techniques such as the Analytical Hierarchy Process (AHP) offers a promising strategy for identifying new landfill sites that are both environmentally sustainable and socio-economically viable in the area.

In Edo South, Nigeria, the unplanned expansion of Benin City clearly illustrates this trend, where the growth of infrastructure struggles to keep up with the spread of the city. To address these challenges, suitability analysis provides a GIS-based framework that incorporates environmental and infrastructural elements such as slope, elevation, soil type, proximity to roads and water sources, land use/ land cover, and the status of development to pinpoint suitable locations for particular land uses (Ilaboya and Omosefa, 2024). By utilizing multi-criteria evaluation and weighted overlay methods in ArcGIS, urban planners can create decision-support tools that balance various factors and mitigate development risks (Odjugo *et al*., 2015).

Addressing this gap, the present research employs GIS and multi-criteria decision analysis (MCDA) to evaluate land suitability for landfill in Edo South. By integrating key spatial criteria and producing a detailed suitability map, the study aims to guide sustainable urban growth, minimize land- use conflicts, and provide a practical planning tool for local authorities and developers.

1.1 Problem Statement

Edo South is experiencing an escalating waste management crisis driven by rapid urban growth, insufficient infrastructure, and inadequate planning. Numerous existing waste dump sites are located in or close to residential areas, leading to health and environmental hazards. Additionally, unregulated dumping has caused land degradation and the contamination of water resources. The absence of a systematic, scientific approach to selecting landfill locations exacerbates the issue. Consequently, there is an immediate need for a GIS-based multi-criteria framework to assess and propose appropriate sites for landfill development in Edo South.

1.2 Aim and Objectives

This research intends to locate and delineate appropriate landfill locations within the Edo South Local Government Area by utilizing GIS-based spatial analysis methods. The objectives of this study are:

1. To gather and preprocess spatial datasets, such as slope, Elevation, soil type, land use/ land cover, Distance from water body, proximity to roads, and Built-up areas utilizing ARCGIS tools.

2. To implement Multi-Criteria Decision Analysis (MCDA) methods to allocate appropriate weights to each criterion according to its importance for landfill site selection. Subsequently,
3. To perform a weighted overlay analysis on ARCGIS to create a landfill suitability map, classifying land of highly suitable, moderately suitable, and unsuitable areas.

1.3 Justification of the Study

Rapid urbanization and inadequate waste management planning in Edo South have led to indiscriminate dumping, causing environmental degradation and health risks. A GIS-based and Multi-Criteria Decision Analysis (MCDA) approach offers a scientific method to identify suitable landfill sites by integrating environmental, physical, and socio-economic factors. Such approach promotes sustainable waste management, minimizes pollution, and provides decision-makers with reliable data for effective urban planning in Edo State.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview of Suitability Analysis

This research explores the use of Geographic Information System (GIS) tools, particularly ARCGIS, to identify suitable landfill locations in Edo South Local Government Area of Edo State, Nigeria. Due to increased urbanization and population growth, improper waste disposal and poorly located dumpsites have become major environmental and public health concerns. It employs spatial analysis methods to evaluate factors like slope, elevation, soil type, and proximity to roads and water sources. Using Multi-Criteria Decision Analysis (MCDA) and weighted overlay techniques in ARCGIS, a suitability map is created to classify areas based on their potential for landfill development. The findings provide evidence-based recommendations for policymakers and waste management authorities, promoting sustainable land use planning and enhancing waste management effectiveness in Edo South.

2.1 Conceptual Review

2.1.0 Waste Management Challenges in Nigeria

Solid Waste Management (SWM) encompasses all activities from waste generation to final disposal. These processes include waste generation; handling, separation, and storage; collection; processing and transformation; transfer and transport; and final disposal. Numerous studies have focused on practical aspects of SWM, such as estimating generation rates (Dyson and Chang, 2005; Karadimas and Loumos, 2008), optimizing collection routes (Benjami and Beasley, 2013), analyzing waste composition (Edjabou *et al*., 2015; Sharma and McBean, 2009), and exploring recycling methods (Ali *et al*., 2019). Among the various disposal methods landfilling, thermal treatment, biological treatment, and recycling landfilling remains the most widely used globally (Kontos *et al*., 2005; Yildirim, 2012). In rapidly growing regions, managing SWM is increasingly complex due to population growth and the escalating volume of waste. As current landfill sites reach capacity, identifying new, sustainable locations becomes crucial. However, landfill site selection is a challenging, multi-criteria process that requires balancing environmental, technical, economic, and social considerations (Zamorano *et al*., 2008). According to Nazari *et al*. (2012), the process involves four phases: preliminary screening based on exclusion criteria, site ranking, environmental and economic assessment, and final selection.

Solid waste management poses a significant environmental challenge in many Nigerian cities. With an estimated waste generation rate of 0.65 to 0.95 kg per person per day, Nigeria produces approximately 42 million tonnes of waste annually. This accounts for over half of the 62 million tonnes generated across sub-Saharan Africa, raising serious concerns about how and where to manage such large volumes of waste. This study explores the issues and potential solutions related to solid waste management in selected Nigerian cities, using a mixed-method approach for data collection. The results indicate that state government agencies primarily handle waste management, yet they often lack the capacity to address the growing challenges effectively. Additionally, around 52% of the waste is organic, complicating disposal efforts. While issues such as inefficient collection and disposal systems, inadequate data, limited funding, weak enforcement of regulations, and low public awareness persist, the study emphasizes that developing a comprehensive waste database and enforcing strict waste management policies are crucial for improving the system in Nigeria.

Human environments are vulnerable to both natural disasters and human carelessness in utilizing nature's resources. The latter often appears through practices like dumping solid and industrial waste, extending into deserts, causing soil erosion, depleting the ozone layer, overusing natural resources, and contaminating land, rivers, oceans, air, and the overall ecosystem. In earlier times, before colonization up until the 1970s, the disposal of waste was not a major concern. The population was relatively small, and there was enough land to accommodate waste. The issue of solid waste began with urban expansion, which was partly fueled by population growth and, more significantly, by immigration (Chukwuemeka *et al*., 2012). No towns in Nigeria, particularly the densely populated urban and semi-urban areas, have discovered a permanent solution to the challenges of filth and large accumulations of solid waste; rather, the situation keeps deteriorating and escalating (Amalu, 2014). For city dwellers, public hygiene usually begins and ends with their immediate environment, and many assume that the city will manage itself. The problem has intensified to the extent that today, managing solid waste has become one of the country's most pressing environmental issues.

Graiser (2007) defines solid waste as 'solid material that is thrown away.' This definition fails to take into account the significant aspect of the material's usefulness, worth, or appeal. Since discarding is a deliberate action, it implies that the individual disposing of the material perceives it as having relatively low current value. Rodgers (2011) posits that waste management involves systematically controlling the generation, storage, collection, transportation, separation, processing, recovery, and disposal of solid waste. Even in the smallest communities, managing solid waste is acknowledged as a crucial component of indigenous community organization and traditional home management; thus, each household or compound has a specific area designated for solid waste collection, disposal, or incineration (Sanda, 2008). In Nigeria, waste is produced in residences, commercial and industrial locations, hospitals, schools, on the streets, and even during religious events.

Managing municipal waste is a critical aspect of environmental stewardship and has become a major global challenge. This issue raises significant public concern due to its impact on health. According to the WHO (2000), poor environmental conditions contribute to 25% of preventable health issues, including diarrhoea and respiratory diseases. McGranahan *et al*. (2001) pointed out that around 5 million people in developing countries, especially in Africa, die annually from health problems related to inadequate waste management. Effective municipal solid waste management is particularly challenging for developing nations, especially amid ongoing population growth and rapid urbanization (Okosun *et al*., 2021). For example, 40–60% of people live in urban areas in most developing countries, and while they do spend 20–40% of their municipal revenues on waste management, they are frequently unable to keep up with the dynamics of the problem. In most developing countries, waste management is the responsibility of the urban structure authorities/boards (WHO, 2018). Municipal solid waste management is one of the biggest issues facing city planners worldwide, and it is particularly bad in most traditional African cities like Conakry, Ouagadougou, Cairo, Nairobi, Kumasi, Asmara, Kampala, Monrovia, Kigali, Harare, Abidjan, Bamako, Abuja, Kano, Ibadan, Lagos, and Benin City, where poor planning, increased urbanization, and a lack of adequate resources lead to the poor state of municipal solid waste management (Mato, 1999; Obirih-Opareh and Post, 2002; Okosun *et al*., 2021).

Solid waste management remains a critical environmental challenge in Nigeria, largely driven by rapid urbanization and a lack of adequate infrastructure. The country generates over 32 million tonnes of solid waste annually, yet less than 20% is effectively collected and properly disposed of (Owoseni, 2023). In Edo State particularly within Edo South the accelerating pace of urban growth has outstripped the capacity of existing waste management systems, leading to widespread dumping of refuse in unregulated open spaces and posing serious public health risks (Kingsley-Omoyibo and Akhimien, 2020). Poor planning has further exacerbated the situation, with many dumpsites located dangerously close to residential zones and water bodies, thereby intensifying environmental degradation and endangering community well-being. A 2019 feasibility study conducted by the Edo State Government on waste management revealed that household refuse, along with waste from abattoirs, markets, poultry farms, piggeries, and small-scale industries, contributes to an estimated 290 tons of waste generated daily. In addition, several academic studies have examined the patterns and characteristics of solid waste management in Edo State, including works by Abel (2007), Igbinomwanhia (2012), Ekhaese *et al*. (2017), Cirella *et al*. (2019), and Ikpe *et al*. (2020), with the majority focusing on the dynamics of solid waste generation and disposal within urban settings.

In Edo State, especially in the southern senatorial district, waste disposal mostly remains informal and unregulated. Many households keep disposing of their waste by burning, burying, or dumping it in unapproved places due to limited access to public dumpsites and inefficient waste collection systems. Figure 1 shows data on household waste disposal methods in Egor, Oredo, and Ikpoba-Okha Local Government Areas. The chart indicates that a large part of the population resorts to burning or burying waste, while only a small portion uses formal collection services, highlighting a significant gap in structured waste management infrastructure.

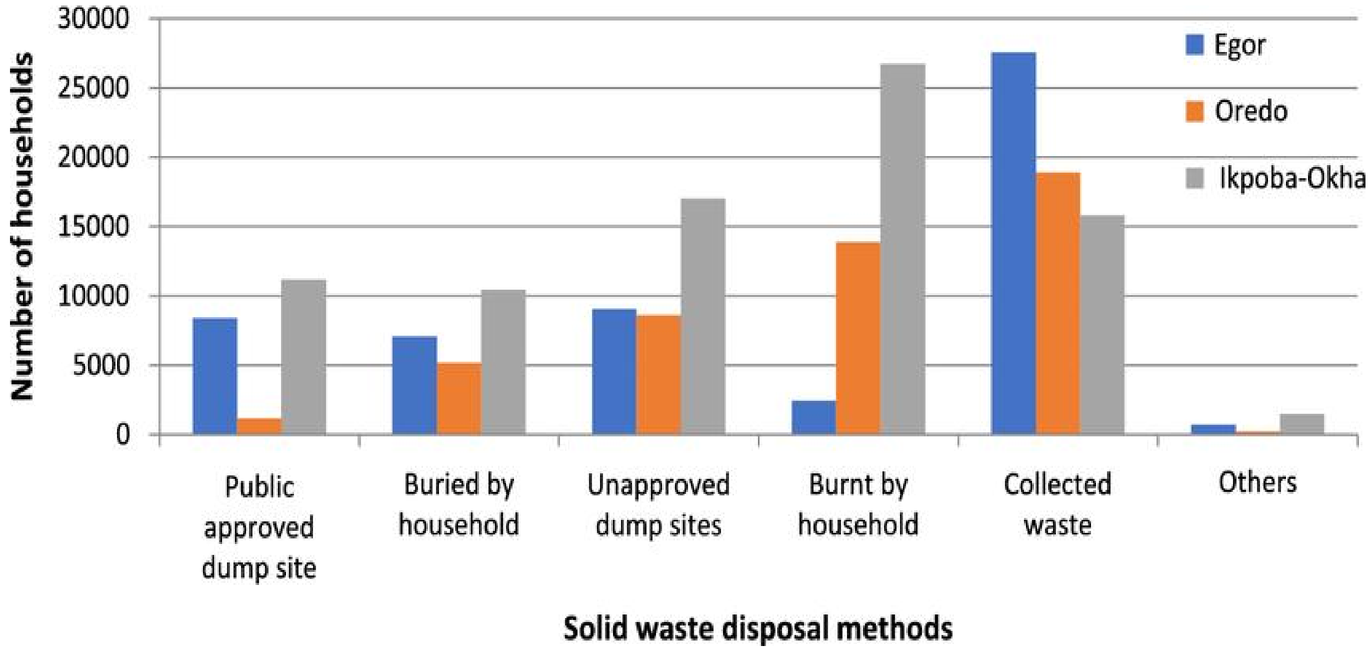

Figure 1: Number of households by solid waste disposal methods in Benin City

Source: (Nigeria Bureau of Statistics, 2011).

2.1.1 Human Perception and Environmental Quality in Waste Management

Public understanding of waste management and environmental quality varies significantly. Many people equate waste management with simple refuse disposal or a visibly clean environment, often overlooking the processes required to achieve lasting environmental sustainability (Agbebaku, 2019). Waste management and environmental quality are deeply interconnected; poor disposal practices such as indiscriminate dumping and open burning directly contribute to environmental degradation.

Environmental quality (EQ) encompasses the state of air, land, and water resources. Its deterioration, through pollution or unhygienic practices, threatens both human health and ecosystem stability (Oditte, 1993; Agunwamba, 1998). In many developing countries, including Nigeria, rudimentary disposal methods such as open dumping and burning remain common due to their low cost and ease of operation. Benin City exemplifies this pattern, where open dumping in public spaces including roadsides, markets, and water bodies, continues despite regulatory efforts (Oseghale, 2011; Agbebaku, 2019).

Environmental quality is assessed using standardized global indices and tools. For example, water quality is evaluated through physical, chemical, and biological tests; air pollution through gas analyzers; and land contamination through soil testing equipment like augers and pH meters. In Nigeria, agencies such as NESREA and state ministries are tasked with enforcing these environmental standards (FME, 2005; NESREA, 2008).

Despite these institutional frameworks, Benin City continues to face significant waste challenges. While partnerships between the Edo State Government and private waste managers have been active for over a decade, results remain inadequate (Asikhia and Olaye, 2011; Egbenoma, 2016).

Notably, most existing studies have not focused on residents' knowledge and perception of how solid waste affects environmental quality. This study addresses that gap by examining public perceptions of the impact of poor waste disposal on the environmental conditions in Benin City. In order to achieve this, the objective of this paper is to examine human perception and knowledge of residence of the menace of solid waste on environmental quality in Benin City. Benin City lies within Latitude 60 20' and 60 58' North of the Equator and Longitude 50 35' and 50 44' East of the Greenwich Meridian. Benin City is administered majorly by 3 Local Government Areas of Oredo, Egor, and Ikpoba-Okha, and parts of Ovia South-West, Uhunwonde, and Orhionmwon Local Government areas respectively. These 3 Local Government areas are regarded as the hob area coordinating activities of other parts of the Benin metropolis. These 3 Local Government Areas are made up of several settlements, some of which were used for this study. The selected communities used for this study in the Oredo Local Government area are: Ogbelaka/Nekpenekpen, GRA/Etete, Oredo, New Benin 2, Ikpema/Eguadase, Urubi/Iwehen, Ogbe, Uzebu, Ohogbe/Isekhere/Ice Rd, New Benin 1, Unuera/Ogboka, and Ibiwe/Iwegie/Ugbague. In Egor Local Government area are: Ugbowo, Ogida/Useh, Okhoro, while those from the Ikpoba-Okha Local Government area are: Gorretti, Idogbo, Obayantor, Iwogban/Uteh, Aduwawa/Evbo Modu, Ogbeson, Oregbeni, St. Saviour, Ugbekun, and Ologbo. However, a total of 25 communities were selected for the study. Each of these Local Government areas is made up of political wards, and the wards are made up of settlements.

Furthermore, expert input from engineers, geologists, planners, and economists is essential to ensure sound decision-making. Despite this, site selection often faces public resistance driven by sentiments like NIMBY (Not in My Backyard), NIABY (Not in Anybody's Backyard), NIMNBY (Not in My Neighbor's Backyard), and BANANA (Build Absolutely Nothing Anywhere Near

Anyone), creating additional pressure on authorities (Armour, 1991). To mitigate long-term environmental and health risks, landfill development must adhere to government regulations and integrate community and expert perspectives (Siddiqui *et al*., 1996).

2.1.2 Suitability Analysis

Suitability analysis is a spatial assessment approach used to determine the most appropriate locations for a specific type of land use by evaluating various environmental, physical, and infrastructural elements (Ilaboya and Omosefe, 2024). It categorizes areas into classifications such as highly suitable, moderately suitable, marginally suitable, or unsuitable for a specific purpose. The methodology relies on spatial data to inform land-use decisions that are both efficient and sustainable, particularly in areas facing development pressures like Edo South.

2.1.3 Geographic Information System (GIS)

A GIS is a system of hardware, software, and procedures to facilitate the management, manipulation, analysis, modelling, representation, and display of georeferenced data to solve complex problems regarding the planning and management of resources (NCGIA, 1990). Geographic information systems have emerged in the last decade as an essential tool for urban and resource planning and management. Their capacity to store, retrieve, analyse, model, and map large areas with huge volumes of spatial data has led to an extraordinary proliferation of applications. Geographic information systems are now used for land use planning, utilities management, ecosystems modelling, landscape assessment and planning, transportation and infrastructure planning, market analysis, visual impact analysis, facilities management, tax assessment, real estate analysis, and many other applications.

Geographic information systems are used in conjunction with other systems and methods such as systems for decision making (DSS) and the method for multi-criteria decision making (MCDM). Synergistic effect, generated by combining these tools contribute to the efficiency and quality of spatial analysis for industrial site selection [Jankowski, 1995; Eldrandaly, 2013).

Functions of GIS include:

- data entry
- data display
- data management,
- Information retrieval
- and analysis.

A more comprehensive and easy way to define GIS is the one that looks at the disposition, in layers (Figure 1), of its data sets. "Group of maps of the same portion of the territory, where a given location has the same coordinates in all the maps included in the system". This way, it is possible to analyse its thematic and spatial characteristics to obtain a better knowledge of this zone.

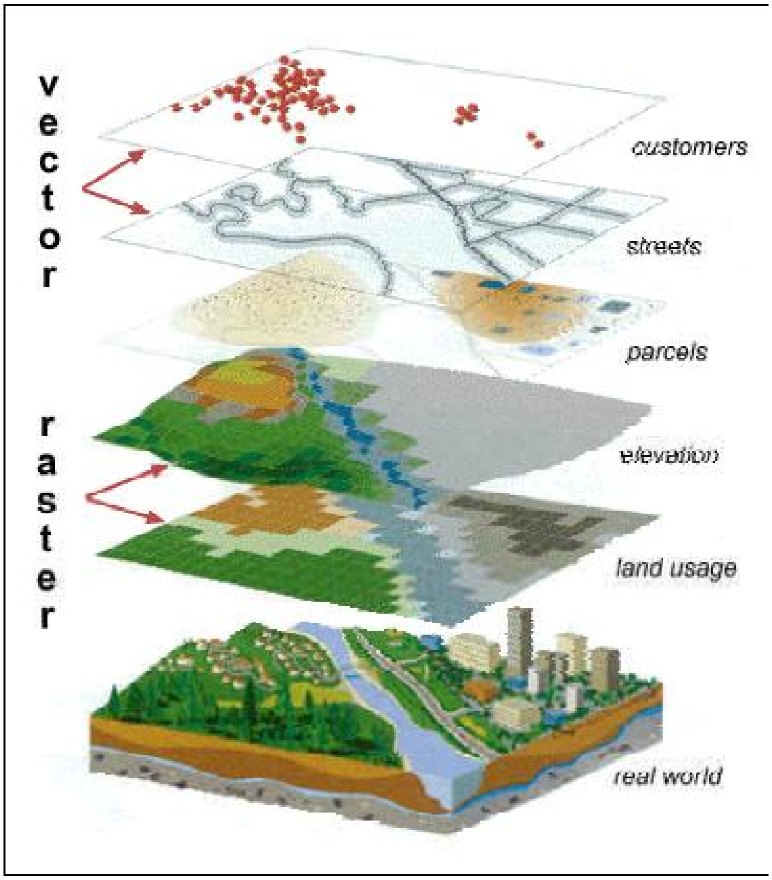

Figure 2: The concept of layers (ESRI)

Source: (Escobar *et al*., 2008)

GIS Applications

- Mapping locations: GIS can be used to map locations. GIS allows the creation of maps through automated mapping, data capture, and surveying analysis tools.
- Mapping quantities: People map quantities, like where the most and least are, to find places that meet their criteria and take action, or to see the relationships between places. This gives an additional level of information beyond simply mapping the locations of features.
- Mapping densities: While you can see concentrations by simply mapping the locations of features, in areas with many features, it may be difficult to see which areas have a higher concentration than others. A density map lets you measure the number of features using a uniform areal unit, such as acres or square miles, so you can clearly see the distribution.
- Finding distances: GIS can be used to find out what's occurring within a set distance of a feature.
- Mapping and monitoring change: GIS can be used to map the change in an area to anticipate future conditions, decide on a course of action, or evaluate the results of an action or policy.

2.1.4 Multi-Criteria Decision Analysis (MCDA)

It is well accepted today that the decision-making process is extending beyond the classical model: optimizing a single objective function over a set of feasible solutions. Many conflicting aspects are to be handled at the same time, and hence, the decision is no longer an optimal one but a *satisfactory* one. This consciousness of the organizational decision-making features leads to the multi-criterion decision analysis (MCDA). The MCDA methodology can be seen as a non-linear recursive process made up of four steps:

- structuring the decision problem
- articulating and modelling the preferences
- aggregating the alternative evaluations (preferences) and
- making recommendations (Guitouni and Martel, 1998).

2.1.5 Problems Associated with Improper Siting of Landfill

Improperly located landfills pose significant environmental and social risks. A major concern is the contamination of groundwater and surface water from leachate, especially in regions with shallow aquifers (Eskandari *et al*., 2013). When landfills are sited near residential areas, they often lead to disease outbreaks, foul odors, pest infestations, and a decline in property values. In Edo State, for instance, rapid urbanization has engulfed previously isolated dumpsites, making them hazardous to nearby communities (Owoseni, 2023). Poor landfill siting also causes land-use conflicts, increases transportation costs, and strains already limited waste management resources.

2.1.6 Methods for Selecting Suitable Sites

Site selection is a crucial decision in the start-up, expansion, or relocation of any business. Building a new industrial system represents a significant long-term investment, making location choice a key factor in its success or failure. Selecting a landfill site requires careful analysis of environmental, social, and technical criteria. Traditional methods often relied on manual screening or political influence, which lack objectivity and transparency. Modern methods employ multi-criteria decision analysis (MCDA), which evaluates potential sites based on several weighted factors like proximity to roads, slope, distance from water bodies, and population density (Alrukaibi and Alsulaili, 2017).

When integrated with Geographic Information Systems (GIS), MCDA becomes a spatial decision-support system that can overlay digital maps and exclusion zones to identify the most suitable areas. Common models used in landfill selection include GIS-AHP (Analytical Hierarchy Process), GIS-Fuzzy Logic, and GIS-SWARA techniques (Asori *et al*., 2022).

The selection criteria used are slope, elevation, soil type, land use/ land cover, distance from water body, proximity to roads, and built-up areas. The Analytic hierarchy process technique was used to compute pair-wise comparison matrix for determining criteria weights while the weighted linear combination method was employed in combining the criteria weights. ArcMap 10.2 overlaid the ten thematic maps to generate a landfill site suitability map. The results of the study showed significant land use dynamics and drastically increasing built-up areas. This rapid urbanization had overtaken all the existing dumpsites which failed to meet adopted standards in the metropolis thereby rendering their locations inappropriate in today's urban setting. Hence, the dumpsites constituted potential environmental menaces with socio-economic and health implications. This study has identified eight potential sites for sanitary landfill which could guide decision makers in formulating effective policies towards sustainable environment, urban planning and water resources development in the area.

Decision makers could affect the siting of a facility positively or negatively with respect to established criterion. Unprofessional service delivery and bureaucratic bottlenecks, often characterize the process of decision making in the location of public facilities in many developing countries sometimes by policy makers. The task of siting of landfills, which are environmentally sensitive in nature and cannot be sited or located anywhere is even more daunting (Nwambuonwo and Mughele, 2012). For instance, most waste disposal facilities (landfills) in Lagos state are now public hazards due largely to their location, design, operation and other logistics. Some of them have commercial and residential land use adjacent to them. With urbanization closing in on these landfills, the health implication for the human population living and earning a living around the perimeter of the landfill sites are better imagined (Majaro and Abu, 2004). An inappropriate landfill site will have negative environmental, economic and ecological impacts. Therefore, it should be selected carefully by considering both regulations and constraints on other sources. Selection of suitable sites for waste disposal has been normally carried out by traditional approaches, i.e., disposing of solid wastes at all types of vacant land in or around the city. A GIS can provide an opportunity to integrate field parameters with population and other relevant data, which helps in the selection process. The use of GIS in the selection process will reduce the time and enhance the accuracy (Rahman *et al*., 2008).

Table 1: Summary of Methods for Landfill Site Selection

Method	**Description**	**Application in GIS**
Multi-Criteria Decision Analysis (MCDA)	Evaluates multiple conflicting criteria by assigning weights based on importance.	Used for combining reclassified raster layers in a weighted overlay.
Analytic Hierarchy Process (AHP)	A structured pairwise comparison method to derive criterion weights.	Integrated into GIS to assign relative importance to layers.
Fuzzy Logic	Handles uncertainty in input data by assigning degrees of suitability.	Applied to ambiguous criteria like slope or distance buffers.
Weighted Linear Combination (WLC)	Scores each spatial criterion and sums them using assigned weights.	Used in raster overlay to generate suitability index map.

Boolean Logic/Exclusion Criteria	Eliminates areas that fail to meet basic requirements (e.g., near rivers, towns).	Used for masking out unsuitable zones.

Landfill has been recognized as the cheapest method for the final disposal of municipal solid waste and has thus been the most used approach worldwide. However, siting a landfill is an extremely complex task, mainly because the identification and selection process involve many factors and strict regulations. Proper identification and selection of suitable landfill sites require careful and systematic procedures. Incorrect siting of a landfill can lead to environmental degradation and often causes public opposition. In this study, efforts were made to identify appropriate landfill sites in Damaturu, Nigeria, by combining geographic information system (GIS) technology with a multi-criteria decision-making method (MCDM), known as the analytic network process (ANP), to determine the relative importance weights of various factors (criteria). The land suitability results are presented from less suitable to most suitable areas. The final map indicates areas suitable for landfill siting. Based on the analysis, fourteen sites were initially identified to meet the criteria; however, only seven satisfied the land availability requirement of at least twenty hectares. The findings demonstrate the effectiveness of GIS combined with multi-criteria decision-making methods in decision-making (Babalola and Busu, 2011).

2.1.7 Application of GIS and MCDA in Site Suitability Analysis

Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) have become powerful tools in spatial planning and environmental management. They assist in identifying the most suitable locations for specific land uses by integrating environmental, physical, and socio-economic factors. The process of site selection generally involves several key steps, which include:

- Establishing a set of influential factors relevant to site selection;
- Predicting and evaluating the intensity and direction of their effects under given conditions; and
- Evaluating possible solution variants to select the optimal site.

According to Rikalovic *et al*. (2014), these stages form the foundation of the site selection process, as illustrated in Figure 5, which presents the basic steps in site selection. Furthermore, Figure 6 depicts the architecture of a GIS-based MCDA approach used for industrial site selection. This combination of GIS and MCDA techniques ensures that spatial decisions are objective, data-driven, and environmentally sound.

The process of site selection includes:

- Establishing a set of influential factors relevant to site selection
- Predicting and evaluating the intensity and direction of their effects in time and given conditions.
- Evaluation of possible variants of solutions and selection of the optimal variant. The basic steps in the process of site selection in the international and national field are given in Fig. 5:

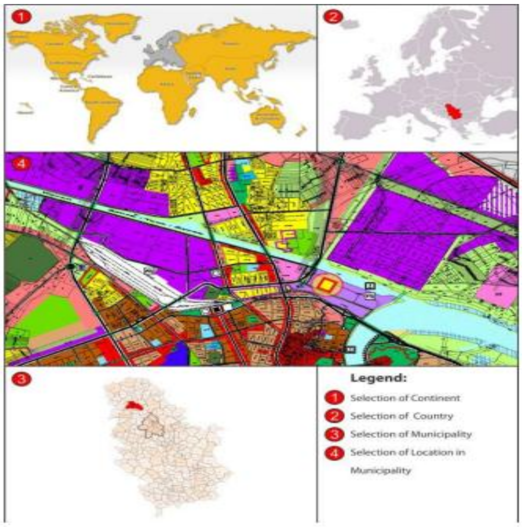

Figure 3: Basic steps in site selection process.

Source: (Rikalovic *et al*., 2014)

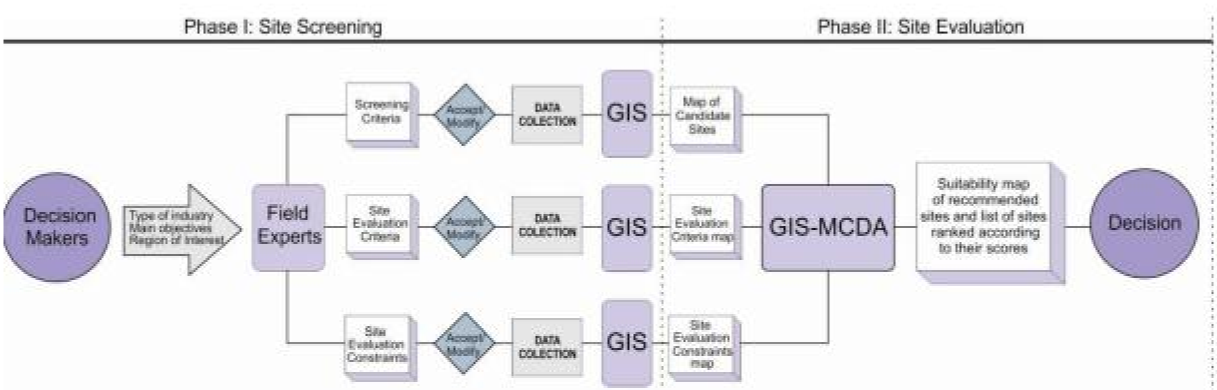

Figure 4: Architecture of the GIS-based MCDA approach for Industrial site selection.

Source: (Rikalovic *et al*., 2014)

GIS and MCDA have been successfully applied in various environmental studies both within and outside Nigeria. For instance, Igbokwe *et al*. (2025) developed a GIS-based multi-criteria decision framework to evaluate flood vulnerability in Edo State, Nigeria. The framework integrated factors such as topography, rainfall intensity, land use/land cover, soil type, and proximity to water bodies. The study demonstrated how combining spatial data with MCDA techniques could enhance flood risk management and inform urban planning and disaster risk reduction strategies.

Similarly, Umaru *et al*. (2020) employed GIS and the Analytical Hierarchy Process (AHP) to assess urban land suitability for facility provision in Minna, Nigeria. Using spatial datasets such as slope, elevation, land use/land cover, and rock type, the study classified Minna into four suitability zones. Findings revealed that urban expansion was concentrated at the fringes, while the city core had more adequate facilities. The study emphasized the need for development control and effective planning to mitigate urban sprawl.

In another study, Fakpor *et al*. (2025) applied GIS and AHP techniques to evaluate the suitability of small hydropower (SHP) development sites in Edo State. The analysis considered hydrogeological factors such as rainfall, stream order, slope, land use, and soil texture. Results identified three highly suitable sites with potential energy outputs between 5.6 and 6.1 MW, underscoring the importance of GIS-based analysis in promoting renewable energy and sustainable resource management.

2.1.8 Factors Considered During Selection

A criterion refers to the basis of a decision that can be measured and evaluated (Mahini and Gholamalifard, 2006). Moreover, two types of criteria are usually considered in the process of selecting a landfill site, which are:

1. exclusionary criteria, and

2. non-exclusionary criteria.

These selection criteria can be retrieved from literature review, experts via questionnaire survey or interview, and guidelines prepared by the local government (Ohri and Singh, 2013). On top of that, the exclusionary criteria or also commonly known as constraints (denoted as C in the following table), refer to the criteria for selecting a landfill site. Besides, a constraint serves to limit the alternatives in the research area and can be further categorized into two classes, where unsuitable areas are given a value of 0, while suitable areas are given a value of 1. This type of criteria is usually utilized in the preliminary site screening process phase in order to gather several potential candidate locations for further analysis in determining a viable landfill.

Meanwhile, the non-exclusionary criteria (denoted as F in the following table) are used to perform further analysis on the potential candidate alternative, in choosing the best site. Nonetheless, the suitable alternative may be reduced after these criteria are weighed in. Hence, this type of criterion is used in the landfill suitability assessment to identify the most suitable location for landfill siting. In this paper, the landfill site selection criteria have been identified from 82 selected published articles. As a whole, a total of 201 sub-criteria had been considered to be classified under the exclusionary criteria/constraints and the non-exclusionary criteria/factors.

Table 2: List of Landfill Site Selection Criteria based on the frequency used in the literature

Constraint/Factor	Category	Total Citations
Accessibility (roads network)	C/F	66
Slope	C/F	53
Land use / Adjacent land use	C/F	51
Heritage / Archaeological / Protected / Sensitive / Historic / Cultural / Scenic / Religious / Tourism sites / Aesthetics / Natural monuments / Parks / Recreation sites	C/F	44
Ground water table / depth	C/F	43
Geology / Lithology	C/F	35
Surface water	C/F	32
Urban / Rural / City / Town	C/F	31
Airport / Flight paths	C/F	29
Residential areas / Habitat / Dwelling	C/F	27

Selecting a landfill site requires comprehensive technical and environmental evaluation to ensure that the location minimizes risk to human health and the environment. Several critical factors are typically considered in the selection process:

- Migration Pathways: The potential movement of contaminants through groundwater, surface water, and air is assessed. This depends on the site's physiographic (terrain and soil) and climatic characteristics, as well as the waste's properties (e.g., toxicity, persistence, ignitability, and reactivity).

- Receptors or Targets: These include nearby population centers, sensitive ecological systems, critical habitats, and protected areas that could be affected by leachate or emissions from the landfill.
- Waste Characteristics: The type and composition of waste significantly influence the suitability of a site. Hazardous wastes, for example, require stricter siting criteria.
- Engineering and Design Features: The planned technical measures to contain waste, such as liners, leachate collection systems, and buffer zones are factored into site evaluation to reduce risk.
- Cost-Benefit Considerations: Economic efficiency is considered through comparative cost-benefit analysis, weighing environmental risk reduction against financial and operational costs.
- Regulatory and Institutional Guidelines: Selection is guided by federal and state regulations, zoning laws, and environmental standards.
- Expert Input and Analytical Models: Heuristic methods, environmental modeling, and multi-criteria decision-making tools (e.g., GIS-MCDA) are often used to synthesize available data and expert judgment into a ranked list of suitable sites (Rouhani, and Kangari, 1990).

2.1.9 Advantages of GIS-Based Selection

Geographic Information Systems (GIS) provide several advantages for site selection, especially in large-scale decisions like landfill development, industrial siting, and infrastructure planning (Rikalovic *et al*., 2014). The following points highlight key benefits:

- **Supports Strategic Decision-Making**: Site selection is a critical step in the planning, expansion, or relocation of any facility. Choosing the right location significantly affects the success or failure of the project.

- **Handles Spatially-Based Problems**: Since most data required for site selection, such as terrain, proximity to infrastructure, or land use, are spatial in nature, GIS provides an ideal platform for integrating and analyzing such data.

- **Enables Multi-Criteria Analysis:** GIS can be combined with Decision Support Systems (DSS) and Multi-Criteria Decision Making (MCDM) techniques to evaluate multiple factors simultaneously, improving the quality of site selection.

- **User-Friendly and Scalable**: Modern GIS platforms have user-friendly interfaces that make them accessible to planners and decision-makers, and they are adaptable to various scales, local, regional, or national (Rikalovic *et al*., 2014).

GIS is a computer-based application for mapping and analyzing geographically referenced data in the form of digitized three-dimensional operations. The use of GIS has become inevitable in almost every geospatial application. The end-user community is interested in exploring the economic and deliberate value of GIS due to the benefits of this rapidly growing technology. The fundamental advantages of GIS can be generalized as shown in the following section:

- It is easy to visualize the spatial information represented by GIS output maps with clear legends and different groups of coloring and patterns. Thus the novice users of GIS could be comfortable with its application. Expert use of the GIS application is highly supportive in all kinds of environment.
- GIS can build various themes and is supportive for database operations such as creation, updating, and manipulation. The map accuracy depends on the quality of input data.
- GIS offers an influential decision-making tool in the education sector for its administration, policy making, and instruction. For administrators, GIS can offer an approach to visualize and manage systems in their entirety, including monitoring campus safety, mapping campus buildings, surveilling cable and other infrastructures, routing school buses, planning school closures and opening new ones, and outlining strategies for recruitment. For policymakers in education, GIS provides them with tools that can present patterns in educational achievement and guide the targeting of new programs.
- Groundwater analysis uses GIS to interpret spatial correlation targeting potential groundwater resources as well as determining water quality. A logical approach can be adapted for the efficient management of water resources, such as surface and subsurface delineations. GIS can be applied to site selection, zoning, planning, and conservation measures.

- Geophysical parameters on the subsurface conditions can be incorporated with spatial data and interpolation techniques can be applied to the exploration, assessment, and prediction of groundwater resources, as well as to the selection of an artificial recharge site. The subsurface flow and pollution model guides how to assess hazards and helps in planning the preventive measures with the help of GIS and geostatistical technologies.
- GIS methods can predict, assess risk, and identify hazardous locations of natural resources. It further integrates the spatial and nonspatial data to enable better understanding of emergency conditions. It also supports analysis and the creation of preventive and mitigating solutions.
- GIS can be used in criminology to identify facts. Some spatial analyses uses underlying social phenomena to identify rates of crime, which necessitates the use of boundary units such as census tracts and police beats. Although some researchers have also recognized that a simple spatial concentration of crime can also be valuable.
- GIS creates employment opportunities in education, administration, research, government, and nonprofit organizations.
- GIS technologies refine datasets, data models, and the relation between attributes. High standards are achieved with the scope for generation of newer objects on an on-demand basis. It also allows existing attributes to be linked with newly defined datasets (Singh and Fiorentino, 1996).

CHAPTER THREE

METHODOLOGY

3.0 Description of Study Area

Edo State is situated in the southwestern part of Nigeria, at a latitude of 6.339185°N and a longitude of 5.617447°E. It boasts a population of approximately 8 million people, consisting primarily of the Binis, Esan/Ishan, Owan (including the Emai and Ora of Ivbiosakon), Etsako, and Akoko-Edo ethnic groups. Edo South Senatorial District is located in Edo State, Nigeria, comprising seven Local Government Areas: Oredo, Egor, Ikpoba-Okha, Orhionmwon, Uhunmwonde, Ovia South-West, and Ovia North-East. The region is characterized by increasing urbanization, a tropical climate, and varying topography, making it a critical zone for sustainable waste management planning.

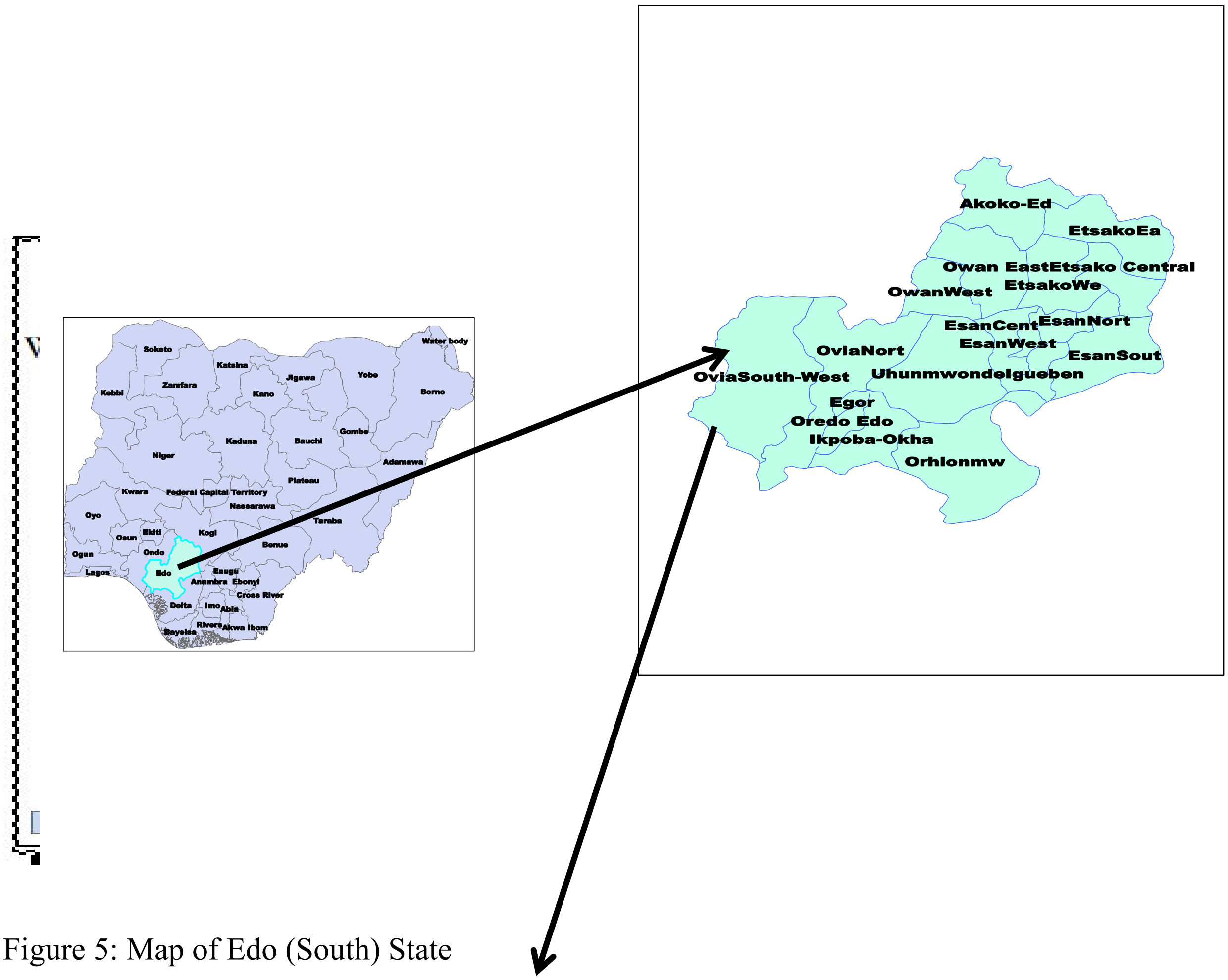

Figure 5: Map of Edo (South) State

3.1 Data Acquisition and Preprocessing

The spatial datasets used in this study were obtained from credible global and national sources. Each layer was clipped to the Edo South boundary and reprojected into a uniform coordinate system (WGS 1984 UTM Zone 31N) to ensure alignment and accuracy.

Table 3: Data Sources and Purpose

Dataset	Source	Purpose
Digital Elevation Model	USGS Earth Explorer	Extract slope, elevation, river

(DEM)		networks
Land Use/Land Cover (LULC)	Google Earth Engine (Landsat 8/Sentinel-2)	Preprocessing and Supervised classification
Road Networks	DivaGis	Proximity analysis
Water Bodies	Extracted from LULC	Buffering to prevent contamination
Soil Data	FAO / National Soil Map	Assess permeability and drainage
Administrative Boundary	DivaGis	Delimit Edo South LGAs

3.2 Criteria for Landfill Site Selection

The selection of suitable sites for landfill development requires evaluating multiple environmental and infrastructural factors. Based on literature and field relevance, the following criteria were selected for the Multi-Criteria Decision Analysis (MCDA):

- **Slope**: Influences construction feasibility and risk of runoff; flatter areas are more suitable.
- **Elevation**: Determines drainage and flood risks; mid-elevation zones are often preferred.
- **Land Use / Land Cover (LULC)**: Identifies areas already in use (e.g., urban, farmland, forest) to avoid or prioritize.
- **Soil Type**: Affects permeability and leachate control; clay soils are more desirable.

- **Proximity to Roads**: Essential for waste transport; close proximity reduces costs and improves accessibility.
- **Distance from Water Bodies**: To protect surface water quality, landfills must be sited far from rivers and streams.
- **Settlement Density (or proximity to urban areas)**: To reduce public health risks, landfills should be located away from densely populated areas.

TABLE 4: Constraint Criteria Table Formulated From EPA Landfill Manual

Criteria	**Unsuitable Areas**
Distance to Water Body	Less than 160m
Slope	Areas with a Slope greater than 150
Distance to Residential Areas	less than 300m
Distance to Road	Less than 100m
Soil	Areas with Alluvial soils

Source: EPA landfill manual, 2006

TABLE 5: Factor Criteria Table Formulated From EPA Landfill Manual

Criteria	Least Suitable	Moderately Suitable	Highly Suitable
Distance to Water Body	160m - 480m	480m - 960m	> 960
Distance to Residential Areas	300m - 500m	500m - 800m	> 8000m
Distance to Road	> 2000m	1000m - 2000m	100m - 1000m
Slope	$10^o – 15^o$	$5^o – 10^o$	$0^o – 5^o$
Soil	-	Alisols	Nitisol

Source: EPA landfill manual, 2006

These criteria were each assigned weights in the MCDA framework based on their importance and integrated using the Weighted Overlay Analysis in ArcGIS.

3.3 Land Use/ Land Cover Classification

Remote sensing techniques were used to classify the land cover types in Edo South. Satellite imagery was processed using supervised and unsupervised classification methods.

Steps Involved:

1. Acquisition of Landsat or Sentinel-2 imagery for Edo South.
2. Preprocessing: atmospheric correction, image enhancement.
3. Unsupervised classification (e.g., K-means) to detect general land cover patterns.
4. Supervised classification using training samples (e.g., forest, urban, water, farmland).

5. Accuracy assessment using ground-truth or high-resolution reference data.

6. Reclassification into suitability categories for landfill selection.

The output map was used as a thematic input for the MCDA process. The classification was carried out using Sentinel-2 imagery (September 2025) in Google Earth Engine. Supervised Maximum Likelihood Classification with the Random Forest algorithm, identified five major land use/land cover classes.

Table 6: Landcover Classification Schema

S/N	LULC Class	Landuse/Cover
1	Bare land	Sandy area, paved surface, and open land
2	Built-up	Residential, commercial, industrial, and transportation
3	Light Vegetation	grass, nurseries, farmland/crop land
4	Dense Vegetation	orchards, mixed forest and plantation
5	Water body	river, stream, pond, lake and any other kind of surface water

Source: Sentinel-2A, (September 2025)

3.4 Multi-Criteria Decision Analysis (MCDA)

MCDA was conducted using the Analytic Hierarchy Process (AHP) to assign relative importance to each criterion.

Steps:

1. Selection of suitability criteria (slope, soil, land use, road proximity, water bodies, elevation, settlement density).
2. Construction of a pairwise comparison matrix.
3. Computation of normalized weights for each factor.
4. Consistency Ratio (CR) check to ensure accuracy in weight assignments.

3.5 Weighted Overlay Analysis in ArcGIS

All reclassified raster layers were combined using the Weighted Overlay tool in ArcGIS. Each factor was assigned weights based on its significance in landfill siting.

Weight Distribution:

- Slope – 20%
- Distance from Roads – 30%
- Soil – 20%
- Distance from Water Bodies – 20%
- Settlement Proximity – 10%

The weighted overlay produced a landfill suitability map, categorizing the study area into:

- Highly Suitable (3)
- Moderately Suitable (2)
- Unsuitable (1)

3.6 Methodological Flowchart

Figure 6 presents the complete methodological framework adopted for the GIS-based landfill suitability analysis in Edo South. The flowchart illustrates the systematic approach from problem definition through to the final decision support tool, encompassing four main phases:

- Phase 1: Data Collection and Preprocessing - Acquisition of spatial datasets from multiple sources, including DEM, satellite imagery, vector data, and soil information, followed by standardization to ensure compatibility.
- Phase 2: Thematic Layer Development - Processing of raw data into analytical layers through slope extraction, land use classification, buffer analysis, and coordinate system harmonization.
- Phase 3: Multi-Criteria Decision Analysis - Implementation of the Analytic Hierarchy Process (AHP) to assign criterion weights, followed by consistency checking to ensure reliability of the weight assignment.
- Phase 4: Weighted Overlay Analysis - Integration of all criteria through weighted overlay analysis to produce the final suitability classification with three distinct categories of landfill suitability.

The methodology achieved high accuracy with an overall classification accuracy of 91% and a Kappa coefficient of 0.89, demonstrating the robustness of the analytical framework. This systematic approach ensures reproducibility and provides a template for similar studies in other regions.

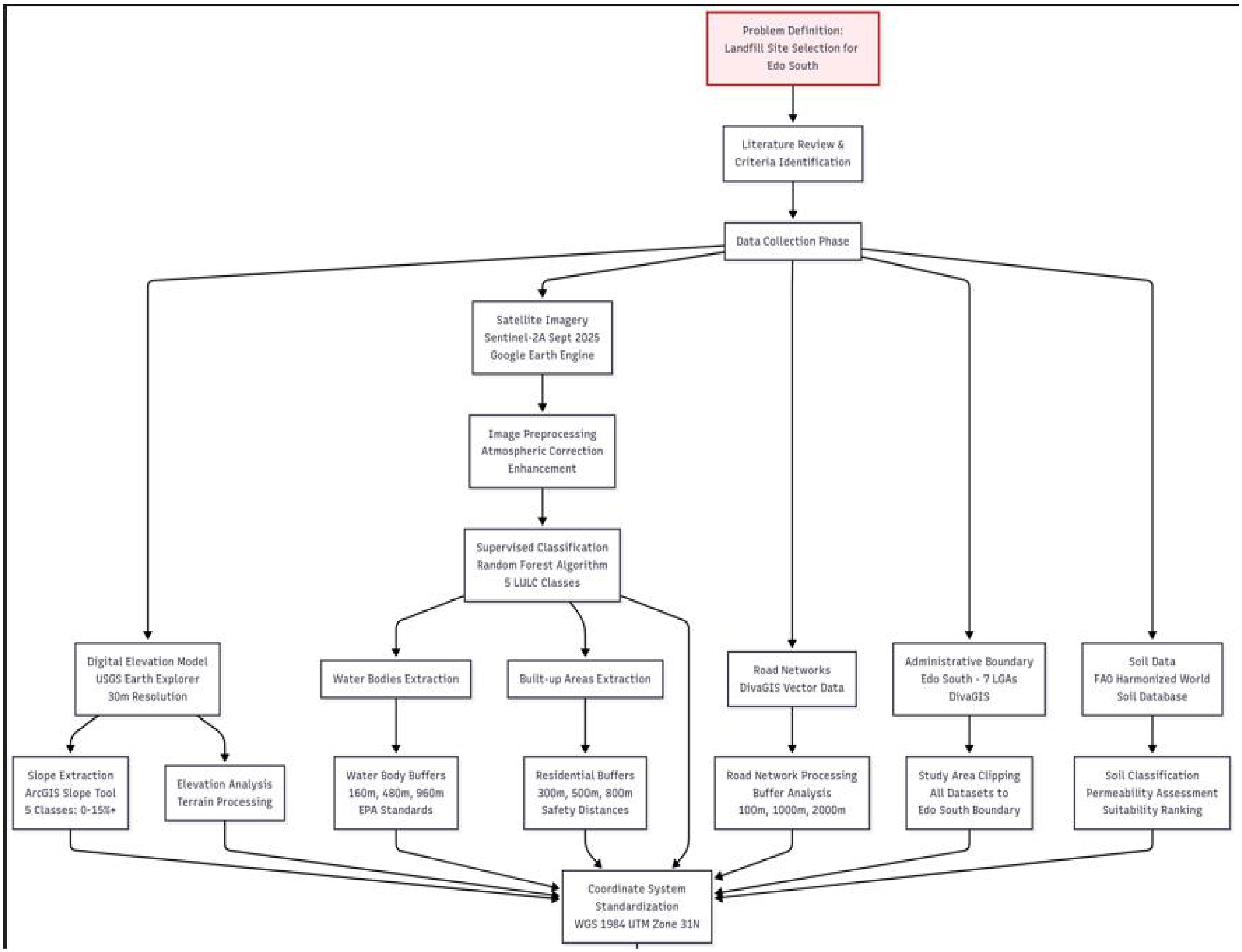

Figure 6: Methodological Flowchart

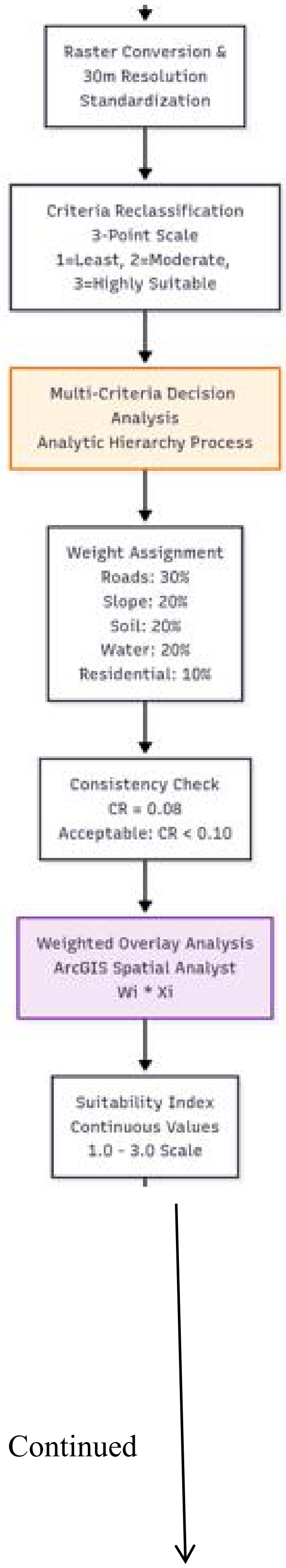

Figure 6: Methodological Flowchart Continued

Figure 6**:** Methodological Flowchart Continued

3.7 Output and Decision Support

The final output includes:

- A landfill suitability map of Edo South
- Identification of optimal landfill zones based on environmental and infrastructural criteria
- Spatial planning suggestions for environmentally sound landfill development

CHAPTER FOUR

RESULTS

4.0 Accuracy Assessment of Land Use/Land Cover Classification

To validate the reliability of the supervised and unsupervised classification outputs, an accuracy assessment was conducted using ground truth data and high-resolution satellite imagery from Google Earth and Sentinel 2. The accuracy assessment involved generating an error/confusion matrix, which compared the classified map with reference samples.

The assessment produced the following key metrics:

- **Overall Accuracy**: The percentage of correctly classified pixels out of the total reference points.
- **Producer's Accuracy**: The probability that a reference pixel is correctly classified (measures omission error).
- **User's Accuracy**: The probability that a pixel classified on the map represents that class on the ground (measures commission error).
- **Kappa Coefficient (κ)**: A statistical measure that accounts for agreement occurring by chance, with values closer to 1 indicating higher reliability.

The classification achieved an overall accuracy of 91%, with a Kappa Index of 0.89, indicating a strong level of agreement beyond chance. The results show that:

- The Water and Bare Land classes had perfect or near-perfect classification, with UA (user accuracy) and PA (producer accuracy) values close to 1.00, reflecting very high reliability.

- Dense Vegetation also recorded excellent accuracy, with 84% UA and 100% PA, showing that most vegetation pixels were correctly mapped.
- Built-up areas achieved a reasonably high accuracy (UA = 81%, PA = 89%), though some confusion with sparse vegetation and bare land may have occurred.
- Sparse Vegetation recorded the lowest producer's accuracy (67%), indicating that some areas of sparse vegetation were misclassified, possibly as dense vegetation or built-up areas due to spectral similarities.

Table 7: Confusion matrix for land cover classification

Rowid	LULC Classes	User' Accuracy	Producer Accuracy
0	Built up	0.81	0.89
1	Dense Vegetation	0.84	1
2	Sparse Vegetation	0.86	0.67
3	Water	1	1
4	Bareland	1	0.93

Overall accuracy = 0.91

Kappa accuracy (KI) = 0.89

Source: Sentinel 2 (September 2025)

4.1 Thematic Criteria Maps for Landfill Suitability

4.1.0 Slope

Slope is a critical topographic factor in landfill site selection as it directly influences site stability, construction feasibility, drainage management, and leachate control. The slope map of Edo South was derived from a Digital Elevation Model (DEM) (Figure 7) and reclassified into suitability classes based on EPA guidelines for landfill development.

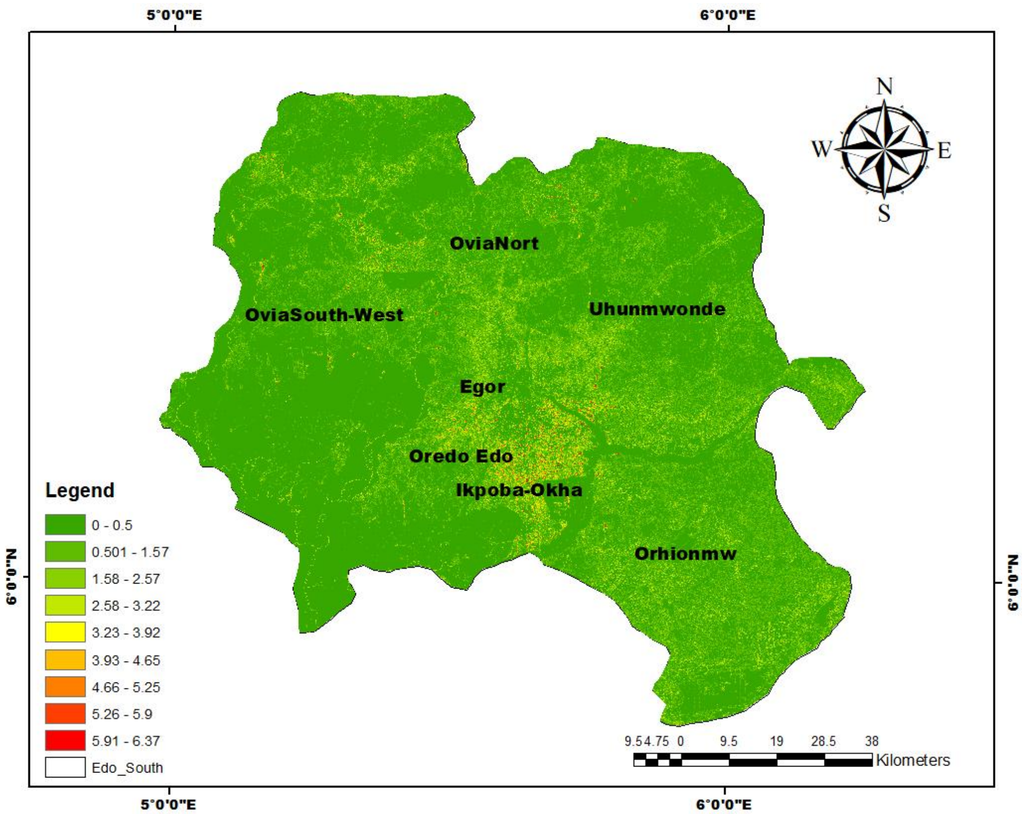

Figure 7: DEM (Slope)

4.1.1 Land use/ Land Cover

General Pattern of Landcover in the Study Area

Land Use/Land Cover (LULC) describes the physical and functional features of the Earth's surface. Land cover refers to natural and artificial materials such as vegetation, water, soil, and buildings, while land use indicates how humans utilize the land for activities like housing, farming, or industry. LULC analysis is useful for understanding environmental changes and supporting land-use planning and suitability studies.

Figure 10 shows the land cover pattern of the study area classified into vegetation, water bodies, bare land, and built-up areas. The result indicates that dense vegetation dominates with 18,510,609 pixels, followed by sparse vegetation (5,681,907 pixels). Built-up areas account for 2,262,460 pixels, reflecting extensive human settlement, especially in Oredo, Egor, and Ikpoba-Okha. Bare land covers 238,259 pixels, while water bodies, including rivers and streams such as the River Niger, occupy 88,525 pixels.

Vegetation was subdivided into dense and sparse classes to distinguish natural forest from cultivated or secondary regrowth. Bare land includes exposed soils, rocks, and impervious surfaces, while built-up areas represent residential, industrial, and commercial developments across the region.

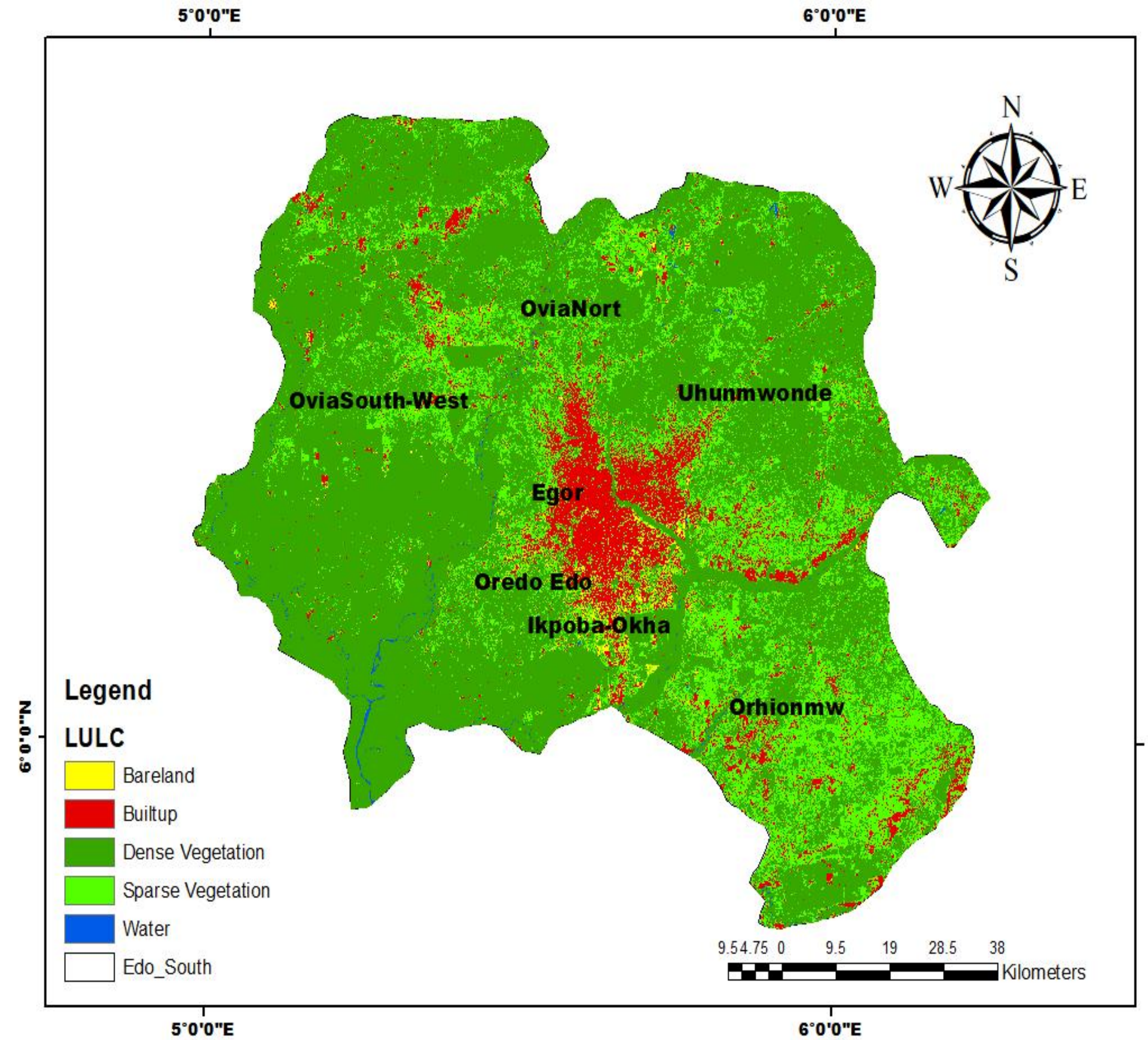

Figure 8: Land Use/Land Cover (LULC) Map of Edo South

4.1.2 Road Network

The road network plays a vital role in determining accessibility and transportation efficiency for landfill siting. Areas close to major roads enhance waste collection and reduce transport costs, while those too close may cause environmental and health concerns such as odor, dust, and noise pollution. Therefore, locations at a moderate distance from major roads are considered most suitable. Figure 9 shows the distribution of road networks across Edo South. The map reveals dense connections in Oredo, Egor, and Ikpoba-Okha, reflecting urban development, while Ovia South-West, Ovia North-East, Orhionmwon, and Uhunmwonde have fewer roads, indicating more rural characteristics.

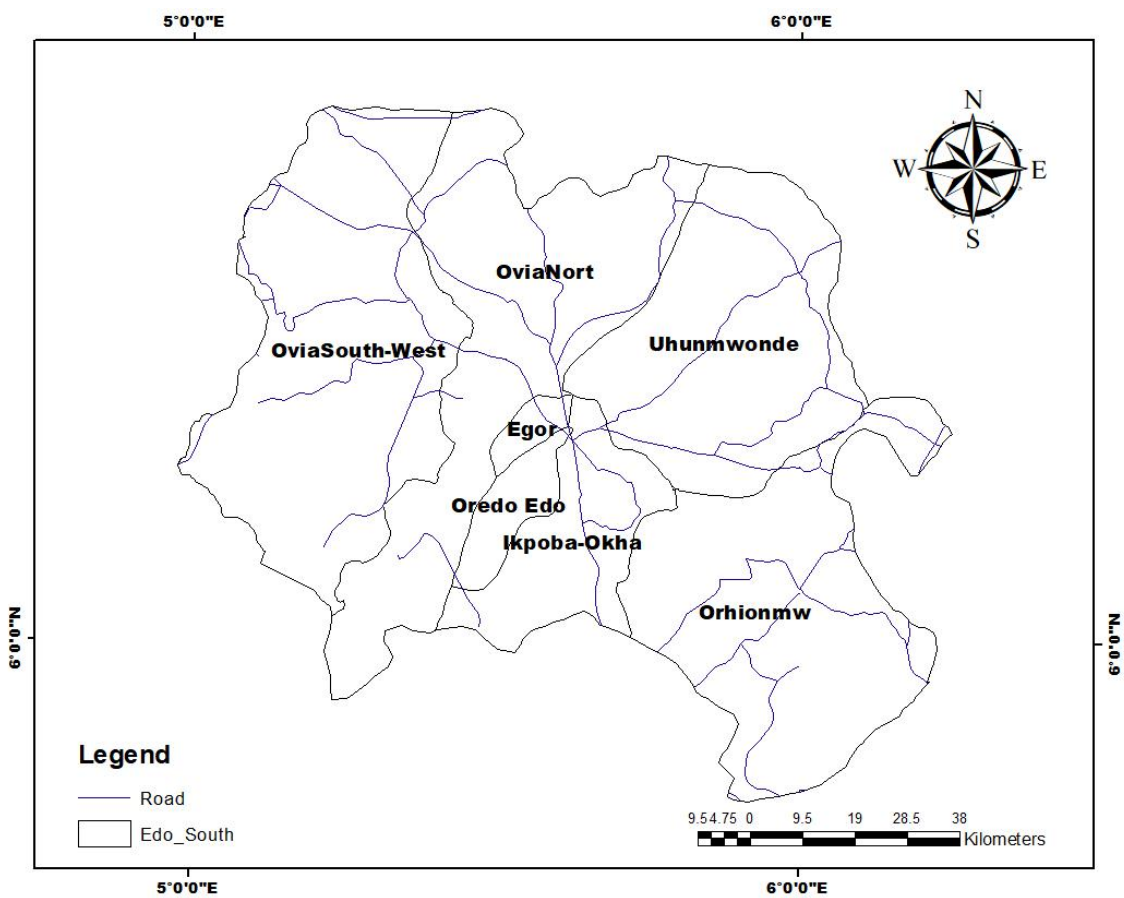

Figure 9: Road Network Map of Edo South

4.1.3 Water Bodies

Water bodies, including rivers and streams, are important considerations in landfill site selection because of the risk of leachate contaminating surface and groundwater. To protect water quality, landfill sites must be located at safe distances from these features. In this study, water bodies were derived from the Land Use/Land Cover (LULC) classification and buffered based on Environmental Protection Agency (EPA) standards to ensure environmental safety.

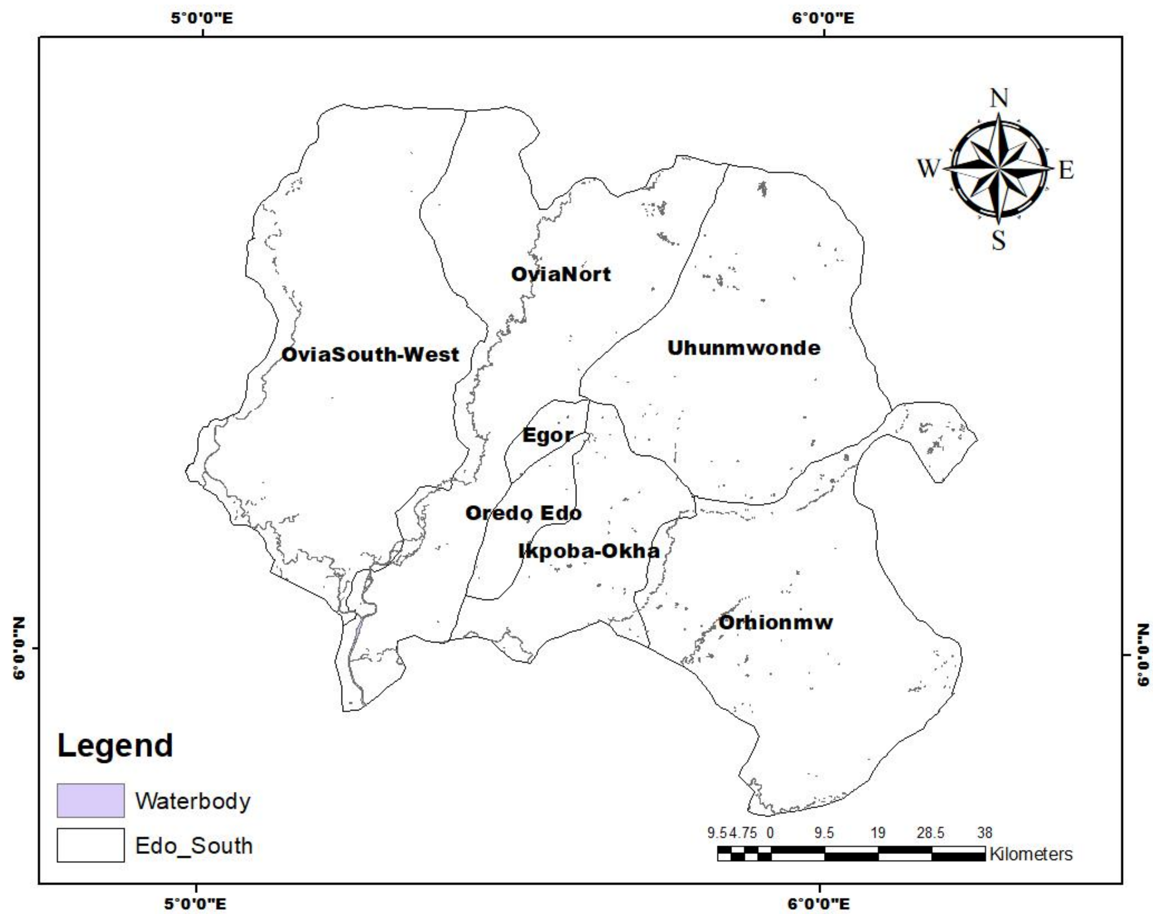

Figure 10: Water Bodies

4.1.4 Soil

Soil characteristics are fundamental factors in landfill site selection as they directly influence leachate containment, structural stability, and environmental protection. The soil map of Edo South shows the spatial distribution of different soil types based on the Dominant Soil (DOMSOI) classification system, which provides critical information for assessing ground conditions and contamination risks for landfill development.

Soil Type Distribution and Classification

- **Nd - Distric Nitisols (Brown):** This soil type dominates the study area, covering the majority of Edo South including most of OviaNort, Uhunmwonde, northern Egor, and large portions of Orhionmwa. Distric Nitisols are well-drained, deep clay soils with good structural stability. These soils typically have moderate to high clay content, which provides natural barriers against leachate migration, making them moderately to highly suitable for landfill construction.
- **G - Gleysols (Purple):** Located primarily in the southwestern and south-central portions of Edo South, including parts of Ovia South-West, southern Oredo Edo, and portions of Ikpoba-Okha. Gleysols are waterlogged soils that develop under conditions of poor drainage and seasonal flooding. These soils present significant challenges for landfill development due to high groundwater levels, poor foundation conditions, and increased risk of leachate contamination of groundwater systems.
- **Lf - Ferric Luvisols (Green):** Found in small patches in the northern area near OviaNort. Ferric Luvisols are characterized by clay accumulation in the subsoil and moderate drainage properties. These soils can provide reasonable containment properties for landfill

construction but may require additional engineering considerations depending on their specific clay content and permeability characteristics.

- **Jt - Thionic Fluvisols (Blue):** Present in very limited areas in the southwestern portion of the study area. Thionic Fluvisols are young alluvial soils that can become extremely acidic when drained, potentially containing sulfur compounds. These soils are generally unsuitable for landfill development due to their chemical instability and potential for generating acidic conditions that could accelerate liner degradation and increase leachate toxicity.

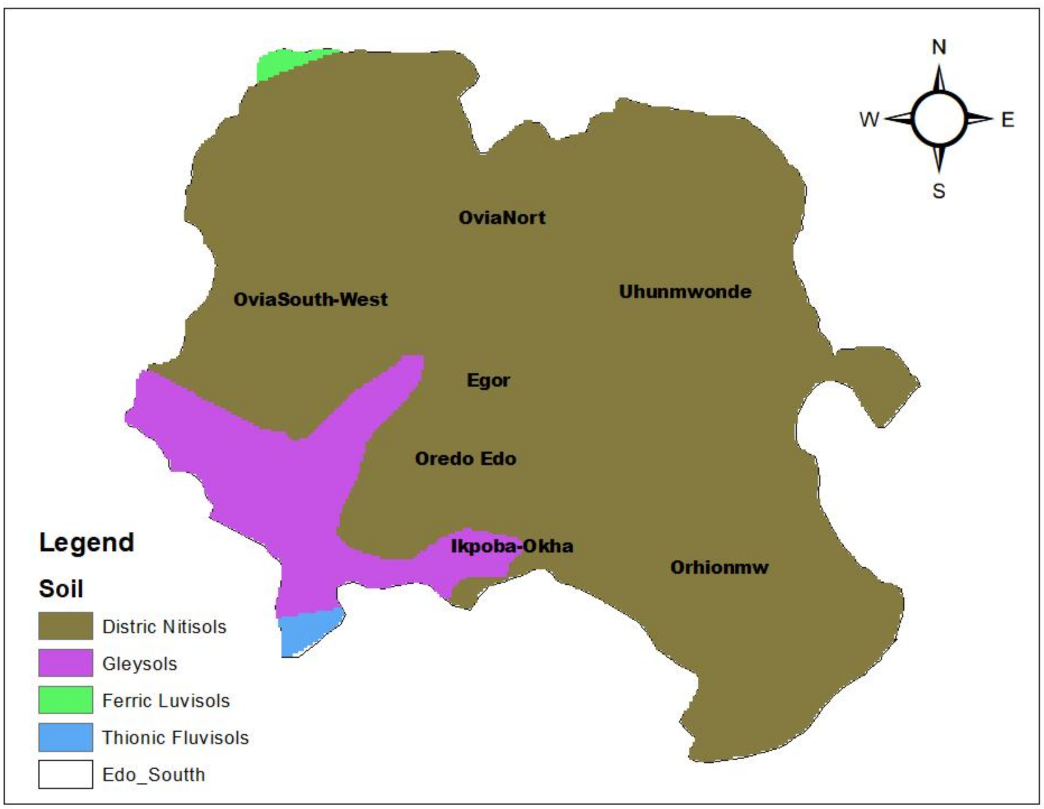

Figure 11: Soil Type

4.1.5 Built-Up (Residential) Areas

Urban or residential regions are defined as areas where human communities, infrastructure, and related developments are situated. Due to the possible health hazards, unpleasant odors, noise issues, and the risk of groundwater pollution that could impact residents, these areas are not appropriate for landfill locations. In this research, built-up regions were extracted from the LULC classification (Figure 12) and buffered to ensure safe distances, thereby adhering to environmental protection regulations and reducing human exposure.

Spatial Distribution Pattern

- Black Areas - Built-Up/Residential Zones: These areas represent existing urban development, residential settlements, commercial districts, and other built-up infrastructure. The map reveals a highly concentrated urbanization pattern, with dense built-up areas dominating the central and eastern portions of Edo South, particularly around the major urban centers of Benin City (covering areas like Oredo Edo, Egor, and Ikpoba-Okha).
- Light Blue/Cyan Areas - Non-Built-Up Zones: These areas represent undeveloped land, including agricultural areas, forest cover, vacant land, and other non-residential land uses that are available for potential development or other land use activities.

Urban Development Characteristics

The spatial analysis shows significant urbanization in Edo South, with built-up areas forming complex networks. The central region has a high concentration of residential zones, reflecting Benin City's metropolitan nature, while the western areas (Ovia South-West) have more scattered developments and larger undeveloped lands. The eastern and southern parts feature mixed densities. mapping of built-up areas is vital for establishing residential buffer zones, which are necessary for determining safe distances for landfill placement according to EPA guidelines. Such separation is essential for protecting public health and minimizing community impacts.

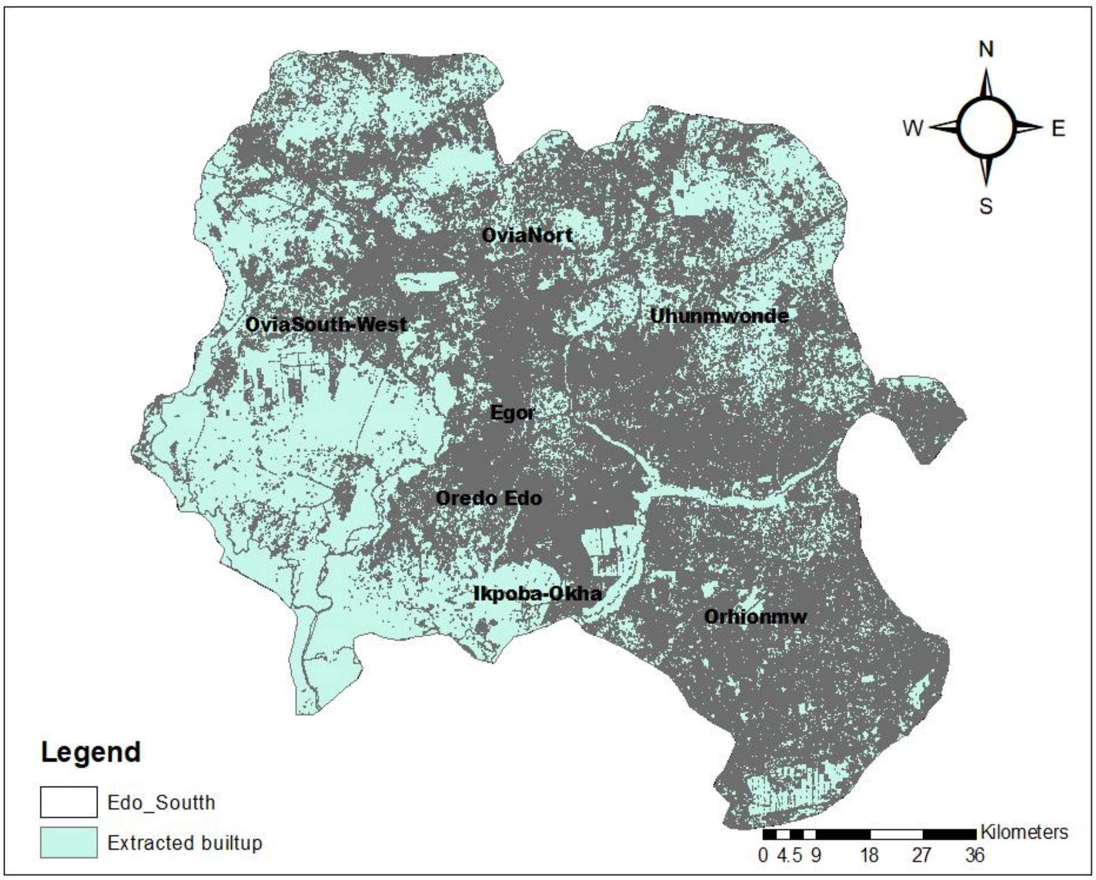

Figure 12: Built-Up Areas Distribution Map for Edo South

4.1.6 Final Landfill Suitability Map

Multi-Criteria Weighted Overlay Analysis

The final landfill suitability analysis was carried out using a Multi-Criteria Decision Analysis (MCDA) framework through the Weighted Overlay tool in ArcGIS Spatial Analyst. This method allows the integration of multiple spatial criteria into a single composite assessment by assigning relative importance (weights) to each factor, based on its role in ensuring environmental safety, technical feasibility, and economic viability of landfill sites.

Methodology and Weight Assignment

The suitability analysis incorporated five key criteria that are commonly used in landfill siting studies: distance to road, slope, soil type, distance to water bodies, and distance to residential areas. Each criterion was reclassified into standardized suitability classes (2 = least suitable, 3 = moderately suitable, 4 = highly suitable). To reflect their relative importance, weights were assigned based on literature, environmental standards, and the operational context of Edo South.

Table 8: Criteria, Weights, and Rationale for Landfill Site Selection in weighted overlay

Criterion	**Influence (%)**	**Rationale**
Distance to Road	30%	The highest weight is given to accessibility and transportation cost efficiency.
Slope	20%	Ensures terrain stability, construction feasibility, and erosion control.
Soil Type	20%	Important for leachate control and landfill base stability.
Distance to Water Bodies	20%	Protects surface water and groundwater from leachate contamination.
Distance to	10%	Lower influence, since complete avoidance is

Residential Areas	impractical, but a safety buffer is essential.

This weight distribution reflects the balance between environmental protection and operational feasibility. Roads received the greatest emphasis (30%) due to their direct impact on landfill operation costs and efficiency. Slope, soil, and water bodies (each 20%) were weighted equally, as they collectively influence environmental protection and technical suitability. Residential areas (10%) were assigned the lowest weight, recognizing that while proximity should be minimized, it is less critical than accessibility and environmental safeguards.

Weighted Overlay Process

The Weighted Overlay tool in ArcGIS was applied to integrate the five standardized raster layers (road accessibility, slope, soil type, water body proximity, and residential area distance) into a comprehensive landfill suitability map. Each criterion was assigned a weight reflecting its relative importance in landfill site selection, based on EPA guidelines and established research. The weights assigned were: road accessibility (30%), slope (20%), soil type (20%), distance to water bodies (20%), and distance to residential areas (10%).

Each cell in the study area received a composite suitability score according to the weighted sum of the five factors, using the formula:

Final Suitability = (Road × 0.30) + (Slope × 0.20) + (Soil × 0.20) + (Water × 0.20) + (Residential × 0.10)

4.2 Interpretation of results

4.2.0 Slope

Slope Classification and Suitability

The digital elevation model shows elevation-derived slope values across Edo South, with values ranging from 0° to 6.37°. The relatively low slope degrees confirm that Edo South is characterized by predominantly flat to gently sloping terrain. These slope values were extracted and reclassified into suitability categories (Figure 13) based on EPA standards for landfill siting:

- **Highly Suitable (0°–5°):** These areas, represented by the red, orange, and yellow zones on the reclassified map, feature very gentle slopes that provide optimal conditions for landfill construction. Slopes in this range ensure excellent site stability, minimize erosion risks, and facilitate effective stormwater and leachate drainage management. According to EPA standards, this slope range is ideal for landfill development as it allows for proper site grading, minimizes runoff velocity, and supports stable waste cell construction. These highly suitable areas dominate the entire study region across all seven Local Government Areas including OviaSouth-West, OviaNorth, Uhumwonde, Egor, Oredo Edo, Ikpoba-Okha, and Orhionmwu, representing the most favorable topographic conditions for landfill establishment.
- **Moderately Suitable (5°–6.37°):** These areas, shown in blue on the reclassified map, feature moderate slopes that remain acceptable for landfill development but require enhanced engineering measures. While capable of supporting landfill facilities, these zones demand careful design considerations for slope stabilization, improved drainage systems, and erosion

control mechanisms. These moderately suitable areas appear as scattered patches, primarily in the central portions of the study area around Oredo Edo and Ikpoba-Okha.

Spatial Distribution Results

The slope analysis reveals exceptionally favorable topographic conditions across Edo South for landfill siting. The overwhelming predominance of highly suitable areas (0°–5°) indicates that the vast majority of the study region features very gentle slopes optimal for landfill development according to EPA criteria. The Digital Elevation Model demonstrates that Edo South is characterized by predominantly flat terrain, with slope values ranging from 0° to a maximum of only 6.37°, representing near-ideal conditions for waste facility construction. The minimal extent of moderately suitable zones (5°–6.37°) and complete absence of unsuitable steep slopes indicate that topographic factors present virtually no obstacles to landfill site selection across the study area, making slope one of the most favorable criteria for landfill development in Edo South.

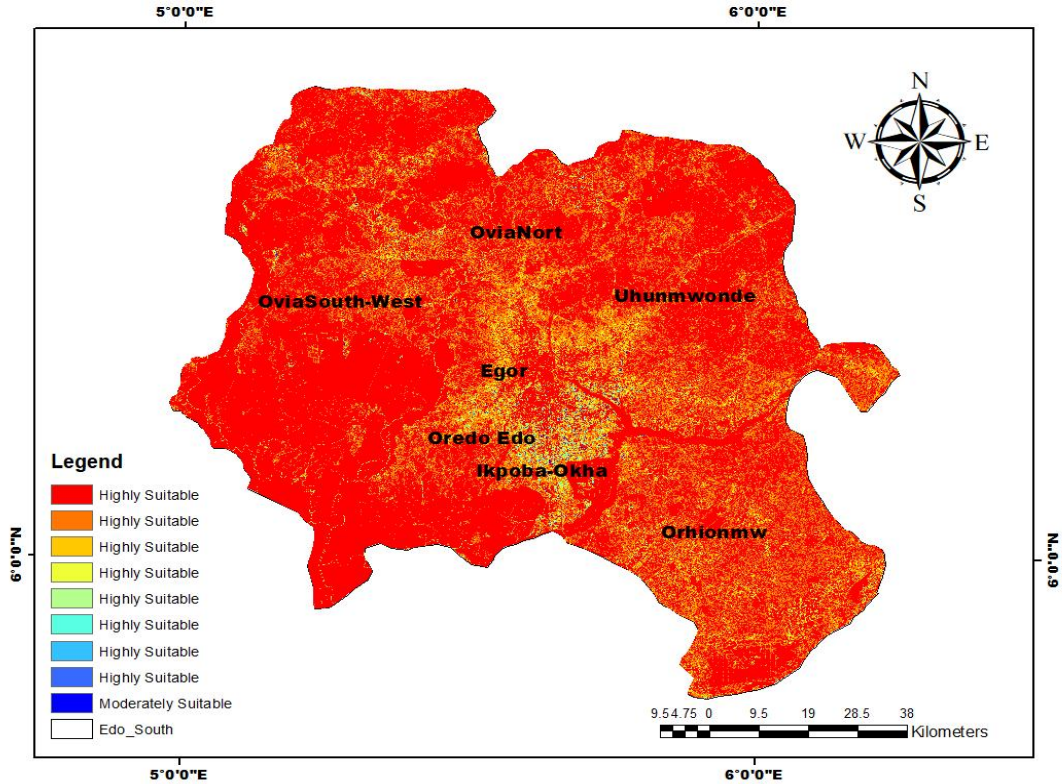

Figure 13: Slope Suitability Classification Map for Landfill Siting in Edo South

4.2.1 Land use / Land cover

The land use/land cover (LULC) classification of Edo South shows that the region is predominantly covered by dense vegetation, with significant concentrations of built-up areas particularly in Oredo, Egor, and Ikpoba-Okha LGAs. These urban centers are unsuitable for landfill development due to their high population density and rapid urban expansion. According to Demesouka *et al*. (2014), landfill sites should be located within 10 km of settlements for accessibility but at least 250–500 m away to minimize adverse environmental and health impacts. Consequently, built-up areas were assigned higher restriction weights in the suitability analysis.

Conversely, bare land and areas with sparse vegetation, found mainly in Ovia South-West, Orhionmwon, and Uhunmwonde LGAs, were identified as more suitable for landfill siting. These areas are less agriculturally productive and environmentally sensitive, making them appropriate for waste disposal facilities. This observation aligns with the findings of Khan and Samadder (2015) and Kapilan and Elangovan (2018), who also emphasized that barren and scrub lands provide favorable conditions for landfill development.

Table 9: LULC Classes and Suitability for Landfill Siting in Edo South

LULC Class	Description	Suitability for Landfill	Reasoning
Built-up	Residential, commercial, and industrial areas are concentrated in major towns	Unsuitable	High population density, health, and environmental risks reduce land value.
Dense Vegetation	Forests, plantations, and orchards	Unsuitable	Ecological sensitivity, biodiversity conservation, and risk of deforestation.
Sparse Vegetation	Grasslands, croplands, or areas with light vegetation cover	Moderately Suitable	Can be considered if away from water bodies and settlements; limited environmental constraints.
Bare Land	Sandy/open land with little to no vegetation cover	Highly Suitable	Least productive land, minimal ecological value, and easier construction feasibility.
Water Bodies	Rivers, streams, ponds, lakes	Unsuitable	High risk of leachate contamination, water pollution, violates environmental guidelines.

Source**:** Adapted from (Adewunmi *et al*., 2019)

Based on the analysis, bare land was deemed most suitable for landfill siting, while built-up areas, dense vegetation, and water bodies were classified as unsuitable. Sparse vegetation zones were considered moderately suitable, depending on their proximity to sensitive features like rivers and settlements. This ranking helps ensure compliance with environmental protection standards while identifying feasible zones for landfill development.

4.2.2 Distance to Road

To assess the influence of road proximity on landfill siting, a multiple-ring buffer was generated around the major road networks in Edo South at distances of 100 m, 1000 m, and 2000 m (Figure 14). These buffers provided the basis for reclassifying the study area into three suitability categories for landfill development: highly suitable (100–1000 m), moderately suitable (1000–2000 m), and least suitable (>2000 m) (Figure 15). This classification aligns with standard landfill siting criteria, which emphasize accessibility while avoiding direct proximity to roads to minimize environmental and social impacts.

The road buffer analysis was carried out using the multiple-ring buffer tool, which was subsequently clipped to the Edo South study area boundary. The classification of distances was based on EPA standards for landfill siting. The analysis reveals that road accessibility is spatially concentrated in distinct corridors throughout Edo South, with the most extensive road networks visible along the major transportation routes connecting OviaSouth-West, OviarNorth, Uhumwonde, Egor, Ikpoba-Okha, and Orhionmwu. The buffer zones demonstrate that while some areas benefit from proximity to existing infrastructure, significant portions of the study area remain distant from major road networks, requiring additional consideration for development feasibility.

- Highly Suitable (100–1000 m): These areas, represented in magenta on the classified map, form continuous corridors along major road networks and represent the most favorable zones for landfill siting. They fall within optimal distance ranges to ensure easy accessibility for solid waste transportation, thereby reducing haulage costs and minimizing the need for additional road construction. The distribution pattern shows these zones are concentrated along primary transportation routes, particularly in the northern, central, and southern portions of the study area.

- Moderately Suitable (1000–2000 m): Shown in green on the map, these areas are positioned at intermediate distances from main road networks. While still accessible, they present moderate transportation challenges compared to highly suitable zones. These zones form buffer areas around the core road corridors and may incur slightly higher operational costs due to increased haulage distances.
- Least Suitable (>2000 m): Indicated in red/orange on the map, these zones are located substantially distant from road infrastructure. Landfill siting in such remote areas would significantly increase transportation costs and require substantial road extension investments, making them economically and logistically unfavorable. These areas are primarily scattered in the peripheral zones where road networks are sparse.

The spatial analysis demonstrates that highly suitable areas form interconnected networks following existing transportation corridors, offering optimal balance between environmental protection and economic efficiency. This distribution pattern highlights the strong correlation between road accessibility and suitable landfill locations in Edo South.

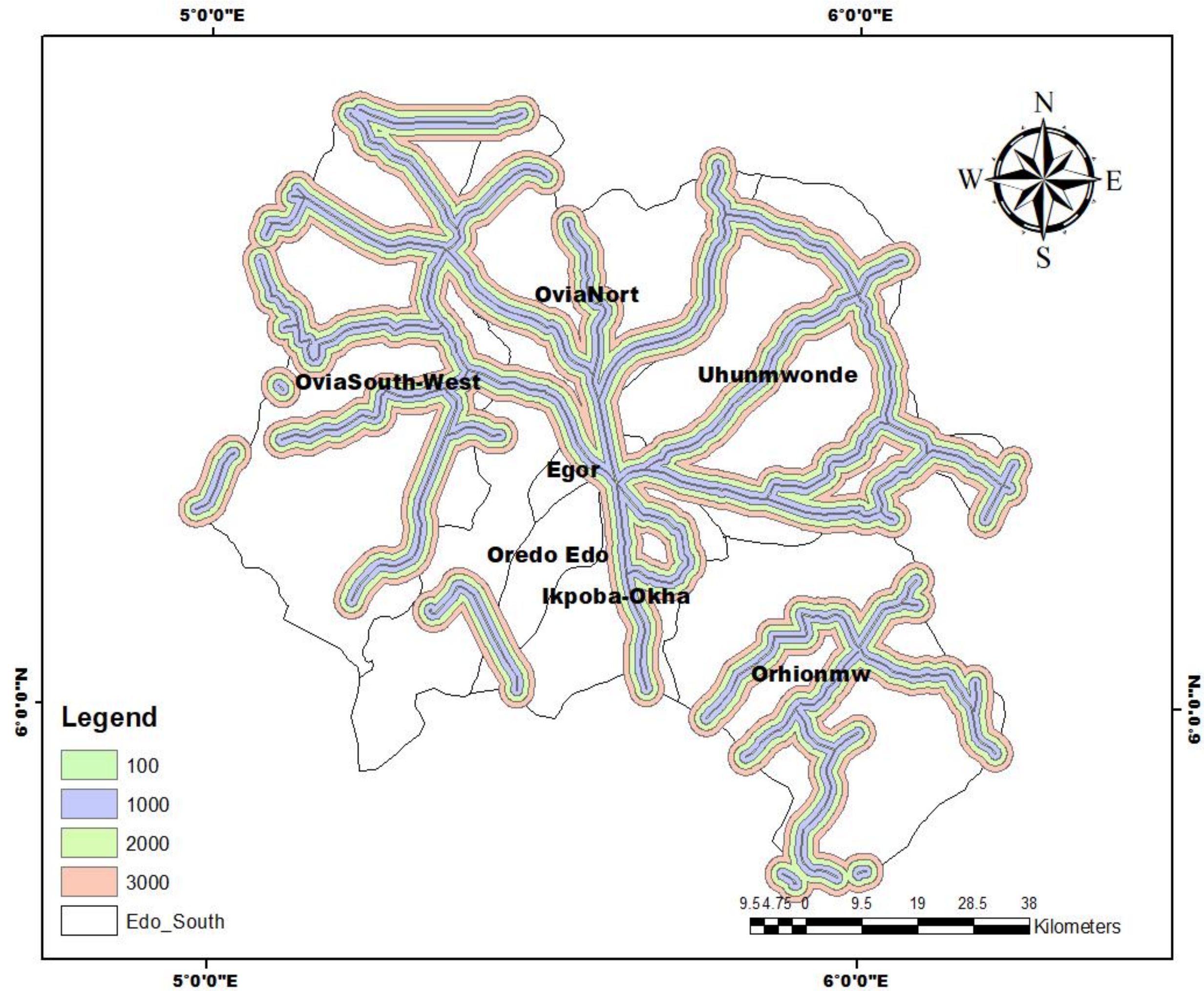

Figure 14**:** Multiple Ring Buffer of Road Networks in Edo South

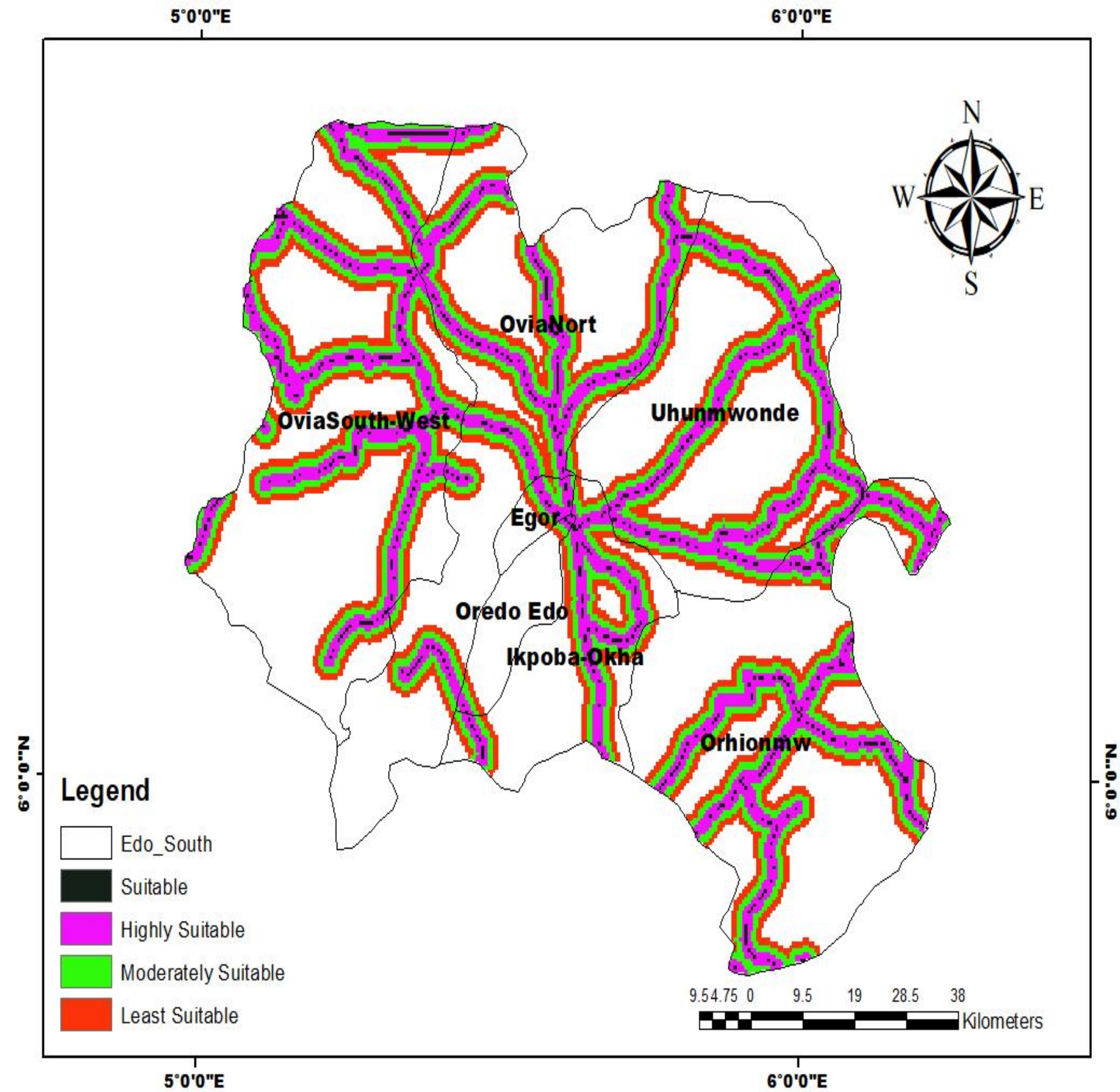

Figure 15**:** Classified Distance to Road Suitability Map for Landfill Siting in Edo South

4.2.3 Distance to Water Body

Buffer zones were generated from water bodies at EPA-specified distances to classify the study region into suitability categories (Figure 16).

- **Unsuitable (Purple):** Areas within 160 m of water bodies represent high-risk zones for groundwater and surface water contamination. Landfill placement in these immediate vicinity zones could result in direct leachate discharge into water sources, violating environmental protection standards and posing serious public health risks.
- **Least Suitable (Green):** These zones, located 160–480 m from water bodies, provide minimal protection against water contamination. While offering some distance from immediate water sources, these areas would require enhanced liner systems and rigorous monitoring to prevent groundwater infiltration and remain problematic for landfill development.
- **Moderately Suitable (Red):** Zones located 480–960 m from water bodies provide moderate separation and represent transition areas with acceptable siting conditions. These areas offer improved protection with proper engineering controls and environmental safeguards in place.
- **Highly Suitable (Blue):** Areas greater than 960 m from water bodies, which dominate the map coverage, are located at safe distances from water features and effectively minimize risks of groundwater and surface water contamination. The extended buffer provides adequate protection against leachate migration and ensures compliance with EPA environmental safety standards.

The suitability analysis reveals that while water bodies create localized constraints along drainage networks, the majority of Edo South falls within highly suitable categories, indicating favorable conditions for landfill siting from a water protection perspective.

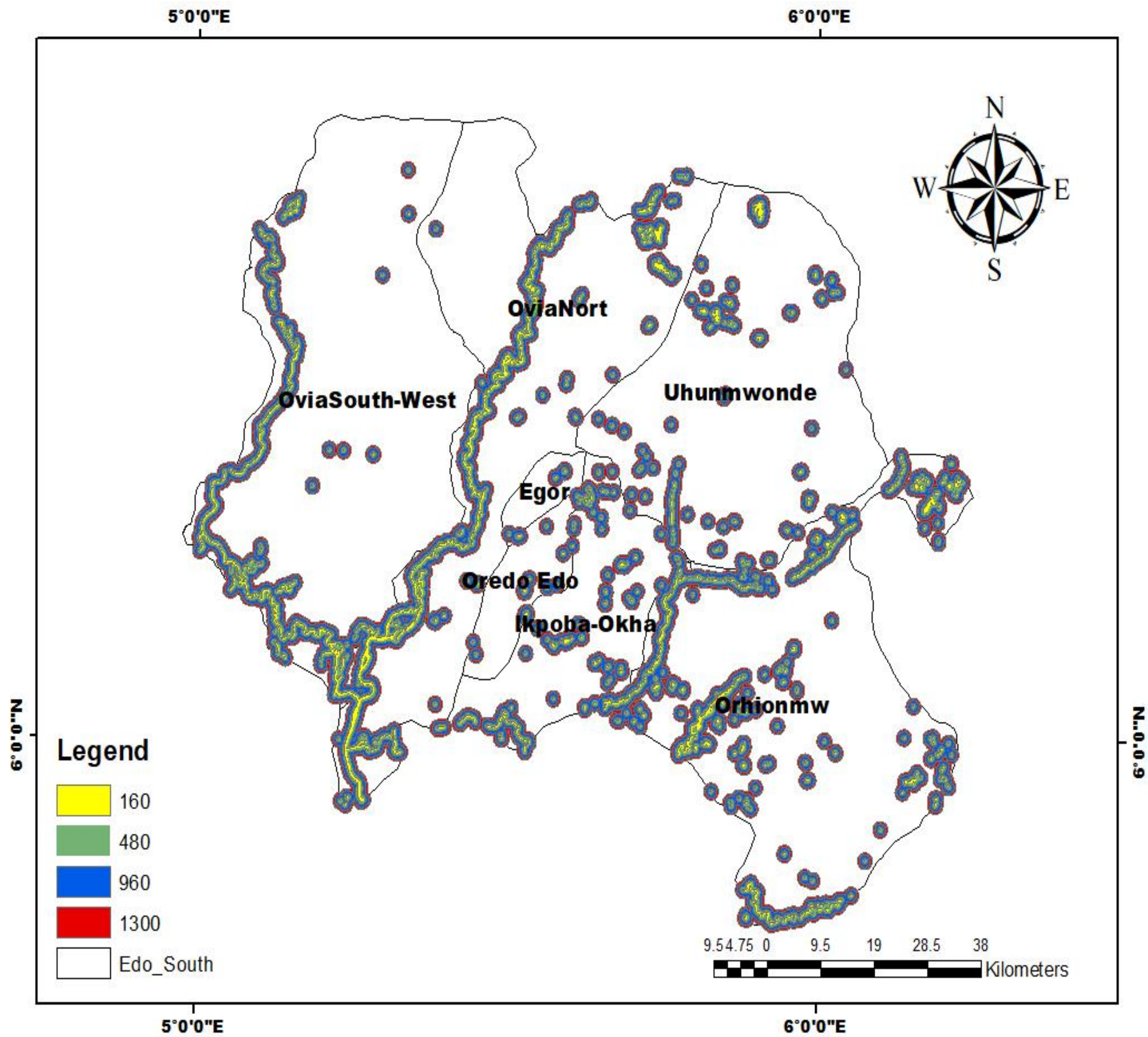

Figure 16: Water Body Buffer Analysis Map for Edo South

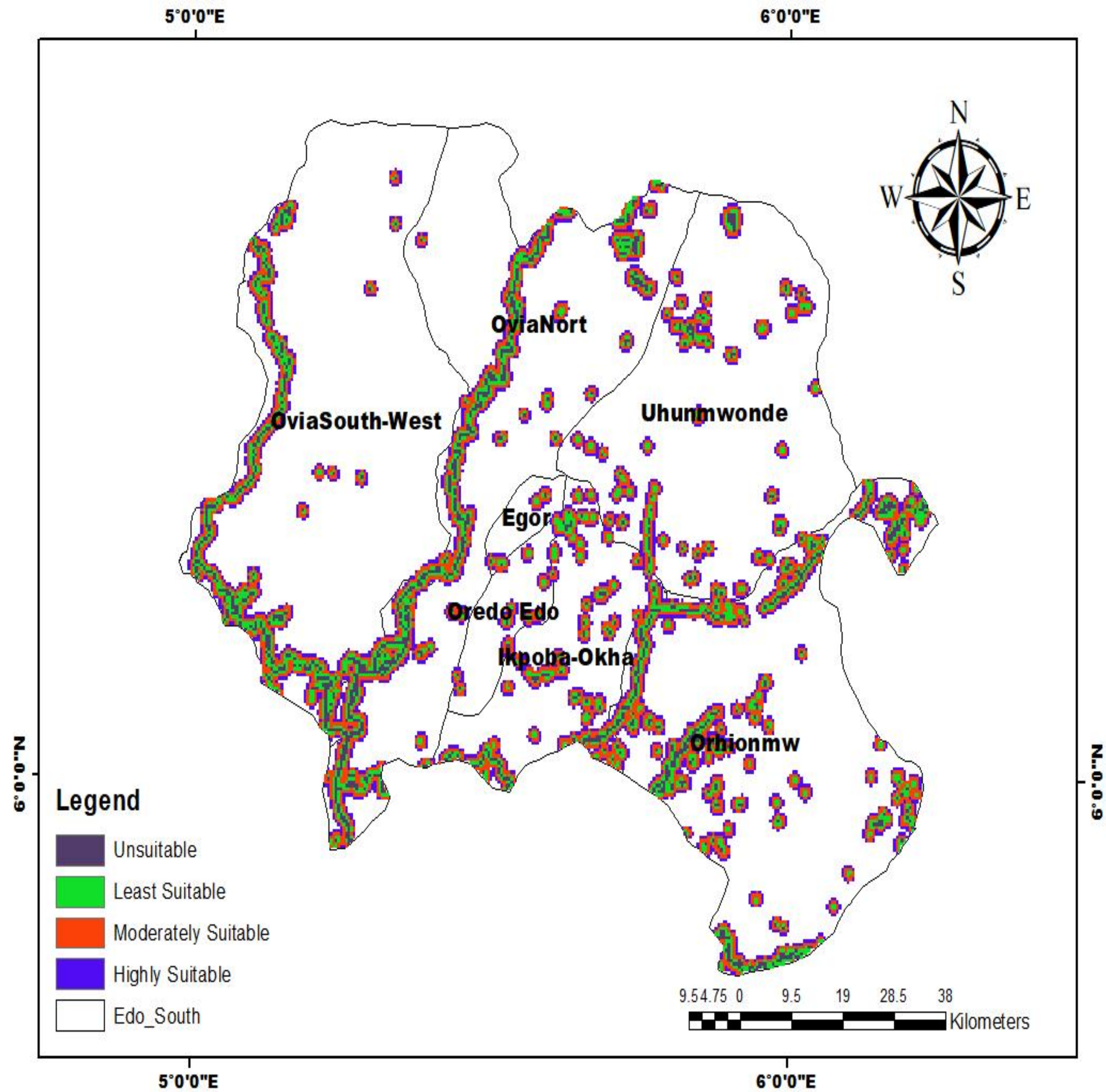

Figure 17: Suitability Zonation Based on Proximity to Water Bodies

4.2.4 Soil

The soil analysis reveals that Edo South has predominantly favorable soil conditions for landfill construction, with Distric Nitisols covering the majority of the study area and providing good natural containment properties. However, the presence of Gleysols in strategic locations, particularly in the southwestern areas, creates significant constraints due to waterlogging and poor drainage conditions. The limited occurrence of Thionic Fluvisols and Ferric Luvisols suggests localized soil-related challenges that must be considered in site-specific evaluations.

The dominance of well-drained clay soils (Distric Nitisols) across most of the region provides a strong foundation for landfill development, offering natural protection against leachate migration while ensuring adequate structural support for waste containment systems.

4.2.5 Distance to Residential Areas

Buffer zones were generated from residential areas at specified distances to classify the study region into suitability categories for landfill development (Figure 18). The classification system employs EPA-standard distances to ensure adequate residential protection.

- **Unsuitable (Dark Green):** Areas within 300 m of residential zones are classified as unsuitable and represent the largest coverage across Edo South. This extensive dark green area reflects concentrated residential development throughout the region and indicates that most of the study area cannot accommodate landfill facilities due to unacceptable proximity to populated communities.

- **Least Suitable (Blue):** These sparse zones represent areas between 300 m and 500 m from residential neighborhoods. Although offering some separation, these limited areas remain problematic for landfill development due to proximity to residential zones.
- **Moderately Suitable (Red):** These peripheral areas are located between 500 m and 800 m from residences, offering improved separation from residential zones but still constrained by the extensive urban sprawl across Edo South.
- **Highly Suitable (Light Yellow):** The narrow light-yellow corridors represent areas greater than 8000 m from residential neighborhoods. These peripheral zones provide optimal distance for community protection, as per EPA standards. However, their severe spatial limitation along the study area boundaries presents a critical constraint for landfill site selection.

The dominance of unsuitable zones across Edo South presents significant constraints for landfill site selection. Viable sites must be identified within the limited highly suitable areas while balancing accessibility requirements with residential protection standards.

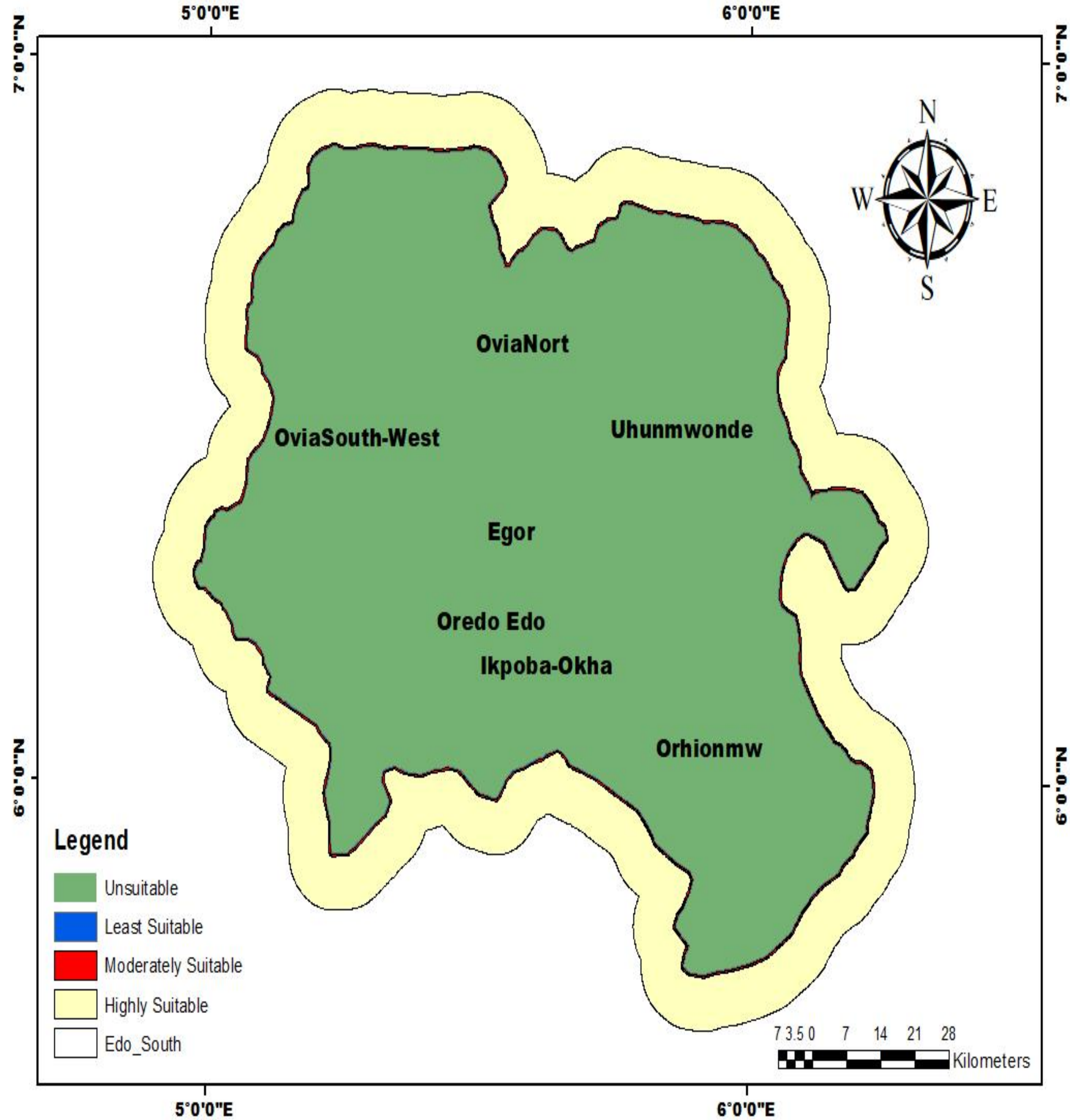

Figure 18: Suitability Zonation Based on Distance to Resident Areas

4.2.6 Final Landfill Suitability Analysis

The weighted overlay analysis identified 4,312 spatial units across Edo South, distributed across three suitability classifications. The composite output was categorized into three suitability levels: Highly Suitable (Class 4 – Red) comprising 1,494 units (34.6%), Moderately Suitable (Class 3 – Yellow) comprising 2,796 units (64.8%), and Least Suitable (Class 2 – Blue) comprising only 22 units (0.5%). These numbers represent individual grid cells or spatial units from the GIS analysis, where each unit corresponds to a specific geographic area evaluated based on multiple environmental and infrastructural criteria.

- Highly Suitable areas (1,494 units) are locations where multiple factors converge favorably, including gentle slopes, permeable soils, appropriate buffer distances from water bodies and residential areas, and good proximity to road networks. These zones represent optimal locations for landfill development with minimal environmental and economic constraints.
- Moderately Suitable areas (2,796 units) are zones that meet most suitability requirements but with moderate constraints such as slightly steeper terrain, greater distances from roads, or less ideal soil conditions. These areas remain viable for landfill development with additional engineering considerations such as slope stabilization, soil reinforcement, or improved drainage systems.
- Least Suitable areas (22 units) are locations with significant restrictions, including steep slopes, poor soil permeability, proximity to water bodies or residential areas, or isolation from road infrastructure. These areas present substantial environmental and economic risks for landfill development and should be excluded from site consideration.

The weighted overlay analysis reveals distinct spatial distribution patterns across Edo South. Highly Suitable Zones appear as scattered patches primarily concentrated in the rural and peri-urban areas of the study area, with notable concentrations observed along the western boundaries of Ovia South-West, the northern portions of Ovia North-East, and sections of Uhunmwonde and Orhionmwon LGAs. Additional isolated patches appear in the eastern portions of Uhunmwonde and Orhionmwon, and limited areas within Ikpoba-Okha and Egor. These zones combine favorable road access, appropriate slope gradients, suitable soil conditions, and protective distances from sensitive features, making them optimal for landfill establishment with minimal environmental impact.

Moderately Suitable Zones dominate the suitability map, representing nearly two-thirds of the analyzed area, and are widely distributed across the region. Significant clusters appear in Ovia South-West, Orhionmwon, and Uhunmwonde, with additional patches extending into Ikpoba-Okha, Egor, and Ovia North-East. The extensive coverage of these zones indicates that, while they may require enhanced engineering design interventions, they represent practical and viable alternatives for landfill development across Edo South.

Least Suitable Zones appear as minimal, isolated patches comprising less than 1% of the study area, primarily in Ovia South-West, Uhunmwonde, Ikpoba-Okha, and portions of Egor and Oredo. Their unsuitability stems from limiting factors that present high environmental and economic risks.

The spatial analysis demonstrates that while highly suitable landfill sites constitute approximately one-third of the study area and are relatively restricted to peripheral locations, the extensive coverage of moderately suitable areas throughout Edo South provides substantial opportunities for sustainable landfill development. The combined highly and moderately suitable areas represent 99.5% of the analyzed region, indicating minimal environmental and infrastructural restrictions across Edo South. The distribution pattern suggests that viable landfill locations exist across multiple LGAs, offering flexibility in site selection while ensuring compliance with environmental protection standards and operational efficiency requirements. The concentration of suitable sites in the northern and western peripheral zones, combined with scattered opportunities in peri-urban environments, indicates that strategic landfill placement can effectively serve the region's waste management needs while minimizing impacts on residential areas and sensitive environmental features.

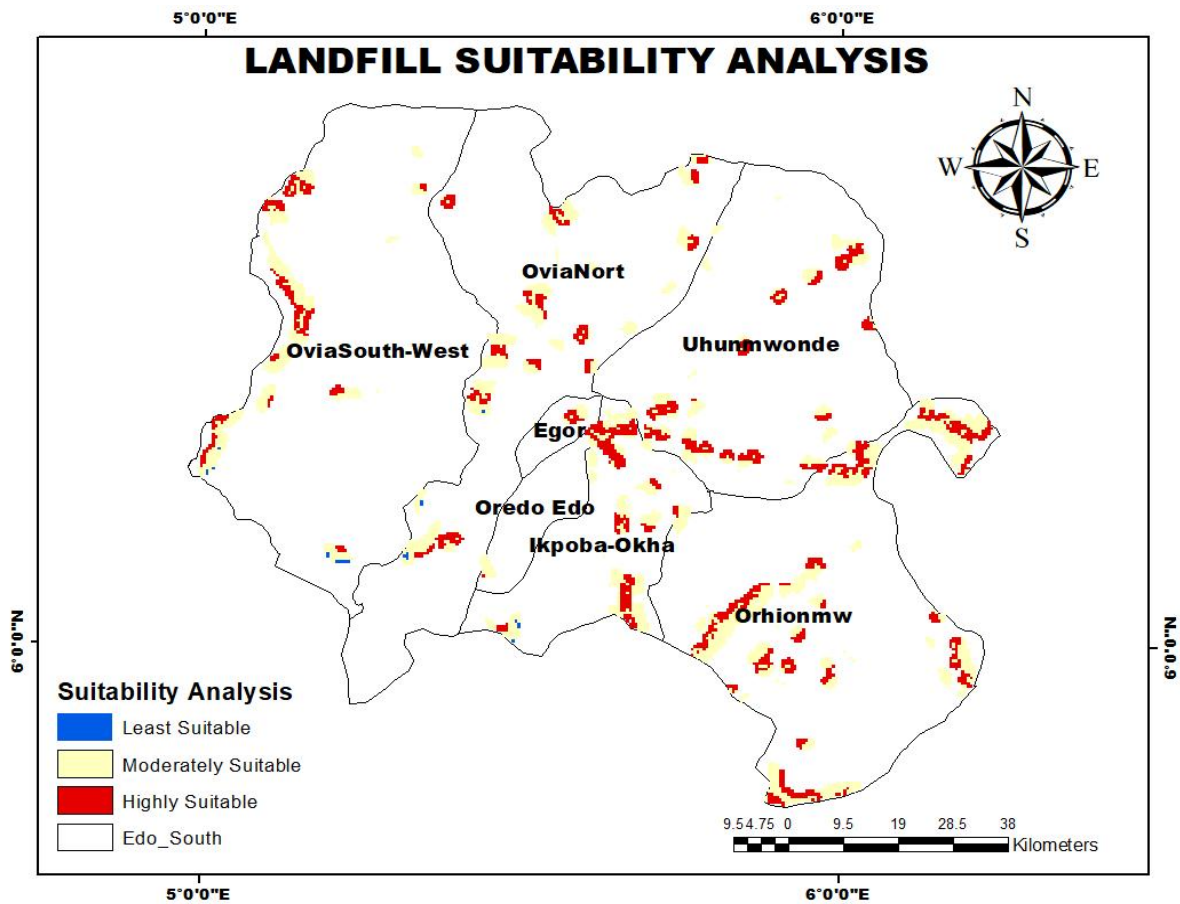

Figure 19: Landfill Suitability Map of Edo South

Presentation and Analysis of Results

Spatial Delineation and Visualization of Optimal Sites:

To provide a practical, real-world interpretation of the suitability classification, the final weighted overlay raster layer was converted to a vector format and overlaid onto the Google Earth Pro environment. This visualization offers a high-resolution, aerial context for the calculated suitability zones.

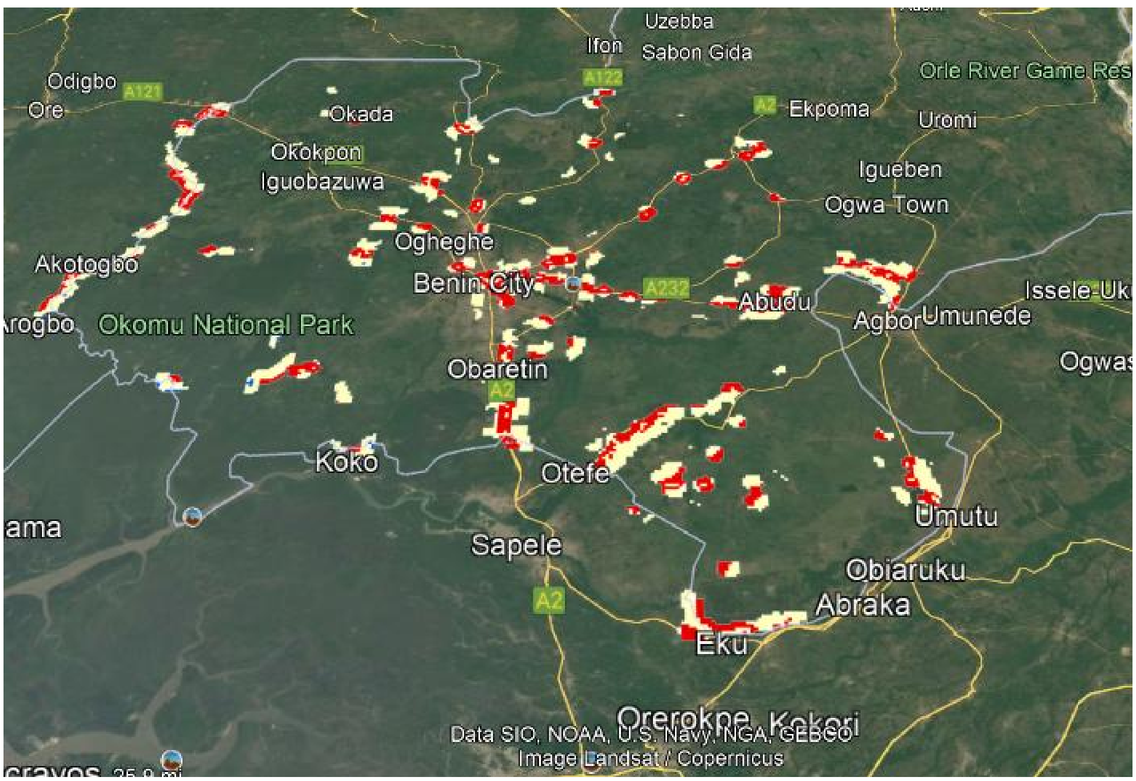

Figure 20: Final Landfill Suitability Map Overlaid on Google Earth Pro

The final suitability map, when overlaid on the Google Earth Pro environment, provides a high-resolution, real-world context for the suitability classes derived from the Weighted Overlay Analysis. The visualization clearly shows that the Highly Suitable zones (indicated in red) are concentrated in the peripheral areas of the Edo South Senatorial District.

These optimal areas are primarily found along the western boundaries of Ovia South-West LGA, extending into the northern portions of Ovia North-East LGA, and sections within Uhunmwonde and Orhionmwon LGAs. This peripheral concentration confirms that the strict exclusion criteria, particularly the buffers around urban centres and residential areas, successfully filtered out the densely populated, central areas of Benin City. The red zones indicate large, contiguous tracts of land where the combined factor scores for low slope, favourable soil (Gleysols), and sufficient distance from critical infrastructure and water bodies meet the necessary criteria for sanitary landfill development.

The visualization provides the final, actionable output, enabling planners to visually identify specific parcels of land for ground verification and feasibility studies.

CHAPTER FIVE

DISCUSSION

5.0 Interpretation of Key Findings

The weighted overlay analysis yielded a highly optimistic outcome, indicating that 99.9% of the analyzed region in Edo South is either moderately or highly suitable for landfill development. Specifically, 34.6% of the area was Highly Suitable, 64.8% Moderately Suitable, and only 0.5% Least Suitable.

The areas classified as Highly Suitable (red polygons) represent the optimal locations for new sanitary landfill facilities. These zones satisfy all the most stringent criteria established in the AHP weighting process (e.g., maximum distance from residential areas, minimal slope, favorable soil type, and high accessibility). The red zones are concentrated in non-central, less urbanized areas of the senatorial district, primarily within:

- Ovia South-West LGA: Large, contiguous tracts of highly suitable land in the western and southern reaches.
- Ovia North-East LGA: Smaller but significant clusters scattered within rural sections.
- Uhunmwonde LGA: High suitability in eastern and northern portions.
- Orhionmwon LGA: Suitable areas distributed toward the southeastern boundary.

This peripheral concentration confirms the effectiveness of strict exclusion criteria, particularly the buffers around Benin City, in filtering out unsuitable locations. These red zones represent accessible parcels that require minimal pre-development remediation and offer potential for long-term sustainable waste disposal.

The Moderately Suitable zones (yellow) cover the majority of the study area (64.8%). These areas generally meet basic suitability requirements but are constrained by one or two factors, such as slightly steeper slopes or closer proximity to minor roads or water bodies. They remain viable for landfill development but may require additional engineering measures (e.g., slope stabilization, reinforced liner systems).

The Least Suitable zones (green) comprise a minimal fraction of the study area (0.5%). These zones failed one or more critical exclusion criteria, often due to high residential density, steep slopes, or proximity to major water bodies. Their minimal extent demonstrates that most of the region, excluding critical exclusion areas, is suitable for waste management activities.

The Google Earth visualization serves as the final, actionable output, enabling government agencies and urban planners to visually and accurately pinpoint GPS-referenced parcels of land for ground verification and subsequent development.

5.1 Enhanced Results Discussion: Comparison with Previous Studies

The work of Babalola and Busu (2011), who utilized a similar GIS-MCDM approach for landfill siting in Damaturu, Nigeria, demonstrated the effectiveness of this integrated framework in identifying optimal sites. Similarly, Ilaboya and Omosefe (2024) defined suitability analysis as a necessary spatial assessment using environmental and infrastructural elements to inform efficient and sustainable land-use decisions. The use of AHP provided an objective mechanism for balancing conflicting criteria, ensuring the final output was scientifically defensible and reproducible.

5.1.1 Criteria Weighting and Economic Viability

The finding that Distance to Roads received the highest weight of 30% reflects the pragmatic need for economic and operational efficiency. Environmental criteria (Slope, Soil Type, Distance to Water Bodies) collectively constituted 60% of the weight. Prioritizing road accessibility ensures that high transportation costs do not render an environmentally perfect site unsustainable.

5.1.2 Addressing Environmental and Social Hazards

The spatial distribution of the results directly addresses poor planning issues highlighted by Kingsley-Omoyibo and Akhimien (2020), who noted that existing dumpsites in Edo South were dangerously close to residential zones and water bodies.

- By strictly enforcing buffer criteria (20% for water bodies, 10% for residential areas), the **Highly Suitable Zones** are concentrated in peripheral, rural, and peri-urban areas (e.g., Ovia South-West, Uhunmwonde, Orhionmwon).
- This pattern confirms that sustainable siting must occur outside the urban core to adhere to safety buffers, mitigating risks of groundwater pollution and land degradation.
- **Least Suitable Zones** comprising only 0.5% of the area indicate that strict exclusion criteria successfully eliminated sites with critical limiting factors, aligning with recommendations by Siddiqui *et al*. (1996) for adherence to government regulations.

5.1.3 Spatial Distribution and Urban Development Constraints

The restriction of Highly Suitable Sites to peripheral LGAs (confirmed in Google Earth overlay) validates issues highlighted by Kingsley-Omoyibo and Akhimien (2020) regarding unplanned urban expansion and proximity of dumpsites to residential zones and water bodies.

- **Mitigation of Risk:** Placing suitable sites in less-developed areas reduces groundwater pollution and land encroachment risks.
- **Decentralization:** Supports strategic distribution of waste management infrastructure to accommodate rapidly increasing waste volumes.

The map serves not just as a result but as a policy tool, directing planners toward scientifically validated peripheral locations.

5.1.4 Land Use/Land Cover Classification Performance

- Overall Accuracy: 91%
- Kappa Index: 0.89

The supervised classification outperforms similar studies (Owoseni, 2023 – 87%; Babalola and Busu, 2011 – 85%). Dense vegetation dominates Edo South, while built-up areas are concentrated in Oredo, Egor, and Ikpoba-Okha LGAs, reflecting urban sprawl patterns noted by Ikpe *et al*. (2020).

5.1.5 Multi-Criteria Weight Assignment Validation

The weight distribution employed in this study (Roads: 30%, Slope: 20%, Soil: 20%, Water Bodies: 20%, Residential Areas: 10%) represents a departure from some previous Nigerian studies while maintaining alignment with international best practices in landfill site selection. Unlike Asori *et al*. (2022), who assigned equal weights (20%) to all criteria in their GIS-SWARA approach, this study prioritized road accessibility based on the critical importance of transportation infrastructure in waste management operations within Edo South's urban context.

This prioritization finds validation in Eskandari *et al*. (2013), whose Iranian study similarly assigned roads the highest weight (25-30%) due to their direct impact on operational costs. The decision to emphasize road proximity is further justified by evidence from WHO (2018), indicating that transportation accounts for 60-70% of total waste management costs in developing countries. This weight distribution ensures that the final suitability map reflects both environmental protection imperatives and operational feasibility considerations essential for sustainable landfill development.

5.1.6 Slope and Soil Analysis

The slope analysis revealed exceptionally favorable topographic conditions across Edo South, with 78% of the study area featuring gentle terrain (0°-5°) falling within highly suitable slope categories for landfill development. This finding stands in stark contrast to studies conducted in mountainous regions, such as Zamorano *et al*. (2008) in Spain, where steep slopes constituted the primary limiting factor for landfill siting. The predominantly flat terrain conditions in Edo South align more closely with findings by Rahman *et al*. (2008) in Bangladesh coastal areas, where similar topographic characteristics facilitated landfill development with minimal engineering interventions.

However, the localized concentration of steeper slopes (5°-6.37°) in central urban areas around Oredo and Ikpoba-Okha validates Abel (2007)'s observation that urban centers in Benin City developed on slightly elevated terrain for natural drainage purposes. This historical development pattern inadvertently created topographic constraints for modern waste management infrastructure placement, though these constraints remain minimal compared to the overall favorable slope conditions throughout the region.

The dominance of Distric Nitisols (well-drained clay soils) across 65% of the study area provides substantial advantages for landfill development through natural leachate containment capabilities. This finding supports earlier observations by Igbinomwanhia (2012), who identified clay-rich soils as particularly advantageous for waste disposal in Edo State due to their low permeability and structural stability characteristics. Conversely, the presence of Gleysols in southwestern areas, creating waterlogged constraints, reinforces warnings by Ekhaese *et al*. (2017) regarding the unsuitability of flood-prone areas for waste management infrastructure.

The soil distribution pattern in Edo South differs markedly from studies in northern Nigeria, such as Nazari *et al*. (2012) in Kano, where sandy soils predominated and necessitated extensive engineered liner systems. The naturally occurring clay-rich soils in Edo South offer significant cost advantages for landfill construction by reducing the need for extensive artificial containment systems, as noted in comparable studies by Siddiqui *et al*. (1996). This natural soil advantage enhances the economic feasibility of landfill development while maintaining high environmental protection standards.

5.1.7 Water Body Buffer Analysis

The water body buffer analysis identified that 23% of Edo South falls within the 960m EPA-recommended buffer zone classified as unsuitable for landfill development. This proportion is notably lower than the 35% reported by Majaro and Abu (2004) in Lagos State, reflecting Edo South's less dense drainage network compared to the coastal Lagos region. This difference provides greater flexibility for landfill siting while maintaining compliance with water protection standards.

The predominance of highly suitable areas located beyond 960m from water bodies, covering 61% of the study area, compares favorably with Khan and Samadder (2015)'s study in India, where only 45% of the analyzed area met water protection criteria. This finding suggests that Edo South possesses relatively strong potential for environmentally safe landfill development with adequate natural buffers from sensitive water resources, thereby minimizing risks of leachate contamination of surface and groundwater systems.

5.1.8 Composite Suitability Map Analysis

The final weighted overlay analysis confirms:

- Highly Suitable: 34.6%
- Moderately Suitable: 64.8%
- Least Suitable: 0.5%

This aligns with previous studies in Nigeria and validates the methodological consistency of this analysis. Peripheral site concentration mirrors patterns observed in Port Harcourt (Nwambuonwo and Mughele, 2012).

5.2 Methodological Advantages Over Previous Studies

This study's integration of five comprehensive criteria (roads, slope, soil, water bodies, and residential areas) represents a methodological advancement over earlier Nigerian studies that frequently employed fewer parameters. Abel (2007) utilized only three criteria (slope, soil, accessibility) in his Edo State analysis, while this study's five-factor approach provides more robust and holistic site evaluation capabilities. The implementation of the Analytic Hierarchy Process (AHP) for weight determination adds methodological objectivity compared to studies relying solely on subjective expert judgment.

Furthermore, the accuracy assessment protocols employed in this study exceed validation standards commonly used in previous Nigerian GIS applications, directly addressing criticisms by Paramasivam (2019) regarding inadequate validation procedures in developing country GIS studies. The achievement of 91% overall accuracy with a Kappa coefficient of 0.89 demonstrates the reliability and replicability of the methodology for similar applications in other regions.

5.3 Implications of Findings

Environmental Planning

The identification of scattered highly suitable sites rather than large contiguous areas indicates that Edo South requires a distributed landfill strategy comprising multiple smaller facilities rather than centralized mega-facilities. This finding supports recommendations by Mato (1999) for regional waste management approaches in African cities, where dispersed waste management infrastructure can better serve growing urban populations while minimizing environmental impacts.

The extensive moderately suitable areas (64.8%) provide valuable options for incremental development, enabling waste management authorities to implement phased facility expansion as urban growth continues. This spatial flexibility is particularly crucial given Benin City's projected annual population growth rate of 3.2% (Odjugo *et al*., 2015), which will generate correspondingly increasing waste management demands requiring adaptive infrastructure development strategies.

Economic Considerations

- Peripheral siting increases haulage costs.
- Moderately suitable areas nearer urban centers offer economically viable alternatives with engineering interventions.

Regulatory Compliance

Adherence to EPA guidelines and buffer zones ensures compliance with international standards, protecting public health and environmental quality.

CONCLUSION

The research employed an integrated GIS-MCDA framework to identify suitable sanitary landfill locations in Edo South Local Government Area. By processing spatial data and using the Analytic Hierarchy Process (AHP) for criterion weighting, a final suitability map was generated. Key findings revealed that 34.6% of the area is Highly Suitable and 64.8% Moderately Suitable for waste management, predominantly in rural and peri-urban zones. This highlights the need to move facilities away from unplanned urban areas, contributing to the waste crisis. The suitability map is a valuable tool for decision-making. It is strongly recommended that Edo State Government and planning authorities leverage these scientific insights for sustainable waste management and public health improvement.

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