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GIS-BASED COMPARATIVE ASSESSMENT OF SUITABLE SITES FOR LANDFILL IN AKURE SOUTH LOCAL GOVERNMENT AREA, ONDO STATE, NIGERIA

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Abstract

In Akure South, the accumulation of waste has been steadily increasing due to the rise in industrial and economic activities, posing a significant challenge in solid waste management within the Local Government Area (LGA). The primary aim of this research is to identify the most appropriate approach for assessing landfill suitability, utilizing the weighted overlay technique alongside the analytic hierarchy process (AHP). To achieve this, ASTER Digital Elevation Model, FAO soil data, and Landsat 8 imagery were employed to analyze various factors. The AHP pair-wise comparison module was utilized to assign weights to the factors for both the AHP plugin technique and the weighted overlay method. Careful consideration was given to determining the weights for the weighted overlay technique. Subsequently, a suitability map was generated, categorizing sites into highly suitable, suitable, moderately suitable, less suitable, and unsuitable. The findings reveal that the most suitable landfill sites are predominantly located in the south-east and north-west regions of Akure South LGA. Furthermore, this study advocates for the adoption of the AHP plugin technique as it proves to be more efficient in identifying the most suitable sites, thus enhancing the effectiveness of landfill management in the area.

Key Words: *Landfill, Weighted overlay, Analytical Hierarchical Process, GIS*

Introduction

Waste comprises tangible, non-free flowing substances that arise from human activities (Finck and Mueller, 2023). A significant increase in waste volume in urban areas, largely driven by rural-urban migration, exacerbating existing solid waste challenges in these communities. Mismanagement of waste poses environmental threats, contributing to illness and fatalities (Hyacinthe, 2023; Zhao *et al*., 2024). In Nigeria, urbanization drives daily waste generation, with further increases projected (Maton *et al*., 2016; Abdulraheem *et al*., 2023). Population growth due to industrialization and urbanization complicates waste management, particularly in cities like Akure South, where waste production rises alongside industrial and economic activities. The high population density and daily waste production in urban areas necessitate proper waste management to safeguard both the environment and public health (Moruff, 2014; Ezeudu *et al*., 2021).

Effective waste disposal, encompassing sorting, storage, collection, and transportation, is hindered by rapid urban expansion, leading to faster accumulation and disposal of waste than can be adequately managed or processed. This issue is particularly acute in African slums, where open dumping is a common practice (Adomako, 2013; Asabere, 2020). In Nigeria, open dumping, roadside disposal, and gully water usage persist due to financial and administrative limitations (Osumgborogwu and Chibo, 2017; Idowu, 2023; Ummulkhair, and Emigilati, 2023). The Solid Waste Management Office in Ondo State identifies urban sprawl as a major hurdle for waste management with Akure South's population projected to grow from 353,211 in 2006 to 553,400 by 2022, escalating waste management issues.

Waste disposal poses a significant challenge, requiring the planning of routes for waste transportation from residential and commercial sources to transfer stations, along with the monitoring of landfill sites (Singh *et al*., 2014). Hence, it is crucial to consider multiple factors in the decision-making process for siting sanitary landfills, utilizing geographic information systems (GIS) to process and manipulate extensive spatial data. According to Thoso (2007), with the increasing abundance of geographic information, more efficient site selection methods are necessary, potentially reducing the time traditionally spent on site selection.

Several articles were examined concerning landfill site selection, presenting various methods, results, and conclusions. Mekuria *et al.* (2019) conducted research on landfill site selection in Northwest Ethiopia, utilizing five criteria: geology, land use/land cover, slope, distance from drainages, and distance from road networks. They employed the Weighted Overlay method to identify suitable environments for landfill siting, prioritizing criteria based on their environmental risks. Sites were chosen with consideration given to proximity to existing roads, avoiding excessive closeness or distance to minimize new road construction. Gentle slopes were favored to facilitate landfill construction and excavation.

Additionally, Gontte (2023) utilized buffer and distance layers (roads, rivers), land use and land cover data, and physical parameters such as soil texture, built-up area, fault/lineament, slope, and lithology to develop an AHP-based method for landfill siting. Akintorinwa, and Okoro (2019) noted in their article that areas underlain by migmatite-gneisses are preferable for landfill sites, provided they are situated over a competent rock of limited permeability, which greatly reduces the likelihood of groundwater contamination, whether chemically or microbiologically. Similarly, Basavarajappa *et al.* (2014) concluded that the presence of less impermeable soil and a gneissic terrain is crucial in site selection to prevent effluents and toxic wastes from seeping into the environment, utilizing the AHP method for their assessment. Mussa and Suryabhagavan, (2021) applied the AHP method and determined that 2.2% of the study area is highly suitable for solid waste disposal sites, with 6.4% being suitable, 0.6% moderately suitable, 5.6% less suitable, and 85.2% considered unsuitable for waste disposal in Logia town.

Vergara and Tchobanoglous (2012) argue that effective planning and regulation of waste disposal is essential to mitigate adverse environmental impacts. The primary objective of waste management is to maintain a safe environment. Various methods of waste management exist, including landfilling, composting (recycling into fertilizer), and recycling for energy generation. Arıkan *et al*. (2017) highlight a preference for certain waste management practices over others. For instance, methods such as reuse, recycling, composting, and energy recovery through incineration are often favored over landfilling due to the latter's potential for unhygienic conditions and inefficiency, leading to significant health risks through air pollution when mismanaged. The objectives of solid waste management include ensuring environmental safety, pollution prevention, and greenhouse gas emission reduction (Jaya, 2004). Solid waste management requires active participation from various stakeholders to maintain clean, safe, and aesthetically pleasing urban environments.

Additionally, it was observed that the Analytical Hierarchical Process (AHP) was among the primary methodologies employed. This study adopted both AHP and weighted overlay methods to determine the most effective approach for site selection in Akure South Local Government Area (LGA). The objective of this study was to identify an appropriate landfill site and determine the optimal method for assessing landfill suitability. This involved the use of Weighted Overlay technique, a recent AHP plugin technique, and a combination of both methodologies, while comparing and providing rationale for each approach.

The Study Area

Akure South Local Government Area is situated in Ondo’s central senatorial district, alongside five other LGAs. It encompasses the capital city of Akure and stands as the most populous LGA in the State, recording a population of 353,211 during the 2006 census, out of the total of 18 LGAs in the state. Geographically, it is within the coordinates that range from 790820m N to 809277m N in the north and 733726 m E to 752139 m E in the east (Figure 1). The terrain is approximately 250 meters above sea level, covering a land area of 331 km^2 with an average elevation of 353 meters. It shares boundaries with Akure North Local Government Area to the northeast, Ifedore Local Government Area to the northwest, and Idanre Local Government Area to the south. Akure South LGA experiences a tropical climate characterized by distinct rainy (April - October) and dry (November - March) seasons. Temperatures typically range from 21°C to 29°C, accompanied by relatively high humidity levels averaging around 80%. Annual precipitation varies from 1150 mm in the northern parts to 2000mm in the southern regions.

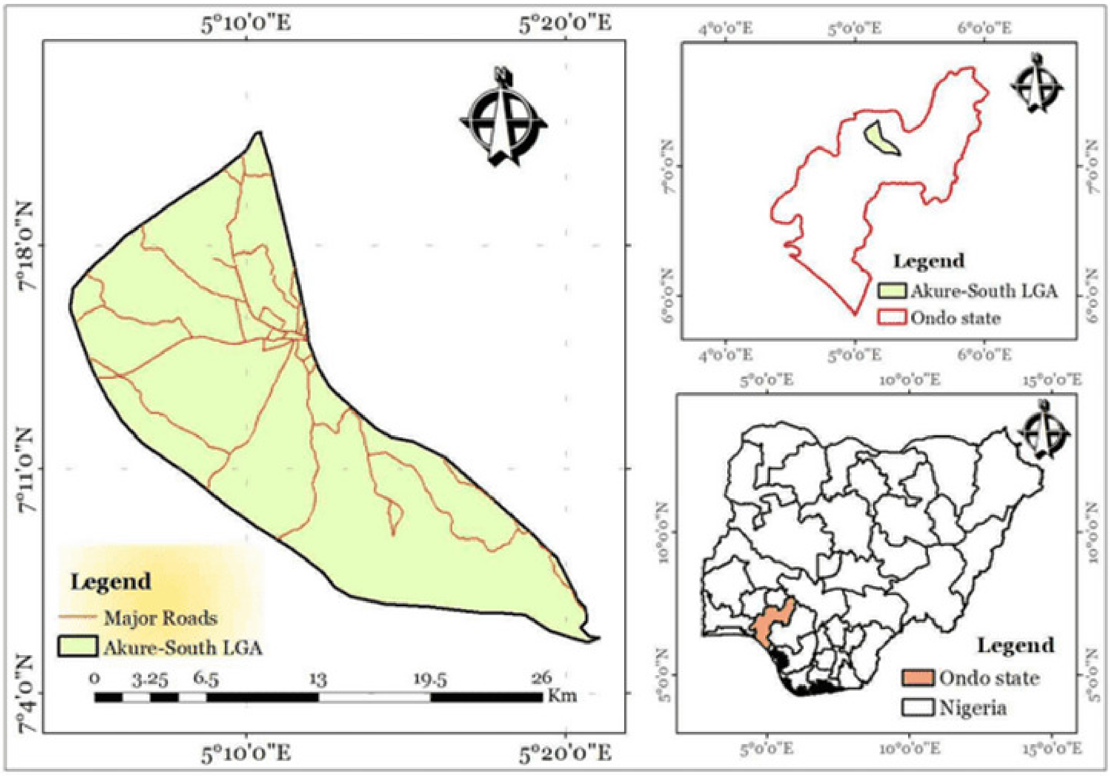

Fig. 1: Akure South Local Government Area

Materials and Methods

Seven criteria were used to identify suitable landfill sites: slope, aspect, stream network density, landuse/land cover, lithology, distance to road, and soil. Data utilized in the research comprises Landsat-8 imagery, FAO soil database, ASTER DEM, and road network data from open street map (Table 1). Thematic maps for each criterion were generated using this data. Spatial analysis tools in ArcGIS 10.8, such as the Euclidean distance tool, were used to calculate stream network density and road distances. Landsat-8 OLI imagery with a 30m resolution provided land use/land cover maps via supervised classification in ArcMap 10.8. A 30m DEM extracted topographic details like slope, aspect, and elevation, while lithology data from Nigeria's Geological Map was digitized to create a lithology layer. The DEM also facilitated stream network density mapping using ArcGIS hydrology tools. All thematic layers were converted to 30m x 30m raster format projected into UTM zone 31. Categorized raster layers were then analyzed to identify optimal and non-optimal sites. Reclassified layers were analyzed with the ArcMap AHP plugin and the Weighted Overlay method to generate final maps of suitable landfill locations, enabling a comparative evaluation to determine the most suitable site location.

Based on the analytical hierarchical process (AHP) created by Thomas L. Saaty in 1970, factors of equal importance are scored as 1, while significantly more important factors are scored as 9 (Table 1 for a summary). The ArcGIS AHP plugin was installed, activated, and integrated into the ArcMap environment for computing the selected criteria.

Table 1: Pair-wise comparison

Intensity of pair wise comparison	Definition
1	Equal importance
2	Equal to Moderate importance
3	Moderate importance
4	Moderate to Strong importance
5	Strong importance
6	Strong to Very strong importance
7	Very strong importance
8	Very to Extremely strong importance
9	Extremely strong importance

A comprehensive analysis can be generated through the weighted overlay method using a consistent value scale for input layers, with weights assigned based on empirical techniques and expert judgment (Table 2). In this study, weighted overlay analysis was applied to factors like stream network density, land use/land cover, road network, slope, lithology, aspect, and soil, creating a site sensitivity index. Weights were assigned to thematic layers based on their relevance to site suitability.

Table 2: Weighted Overlay Measurement scale

Rank	Suitability Value
1	Unsuitable
2	Less suitable
3	Moderately suitable
4	Suitable
5	Highly suitable

Slope

Slope is a critical factor in landfill site selection influencing soil moisture, erosion rates, surface runoff, and the potential for groundwater contamination. The slope significantly impacts the construction of landfill sites, steeper slopes and high slope gradient increase construction costs due to higher material, technology, and labor demands. Ali and Ahmad (2020) suggest that slopes exceeding 4–5 degrees are unsuitable, with medium-altitude locations preferred. Following reclassification, 28.74% of the area is highly suitable, 33.83% suitable, 24.92% moderately suitable, 10.49% less suitable, and 2.02% unsuitable. These categories correspond to approximately 94 km², 111 km², 81 km², 34 km², and 7 km², respectively (Table 3, Figure 2).

Table 3: Slope reclassification

Slope in percent	Suitability value	Area in sq.km	Percent
0 - 4.5	5	94.4028	28.74
4.5 - 7.98	4	111.1293	33.83
7.98 - 12.16	3	81.8838	24.92
12.16 - 18.62	2	34.4754	10.49

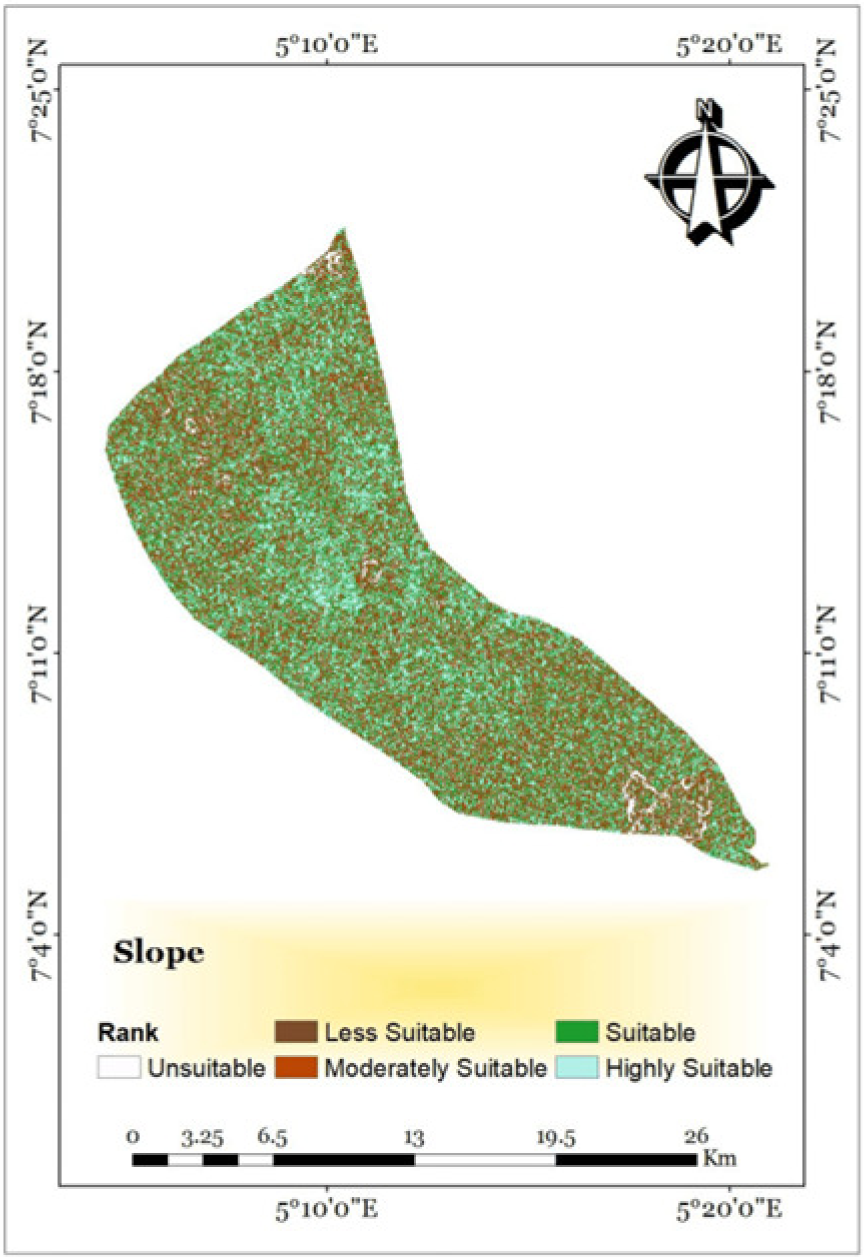

Fig. 2: Slope of the study area

Aspect

Upon analyzing the speed and direction of wind within the study area, it was revealed that the prevailing wind direction is primarily from the South (S) and Southwest (SW), with regions having this aspect demonstrating the least suitability. Reclassification identified 12.04% of the area as highly suitable, 12.06% as suitable, 24.65% as moderately suitable, and 12.05% as less suitable, with 39.2% classified as unsuitable (Figure 3).

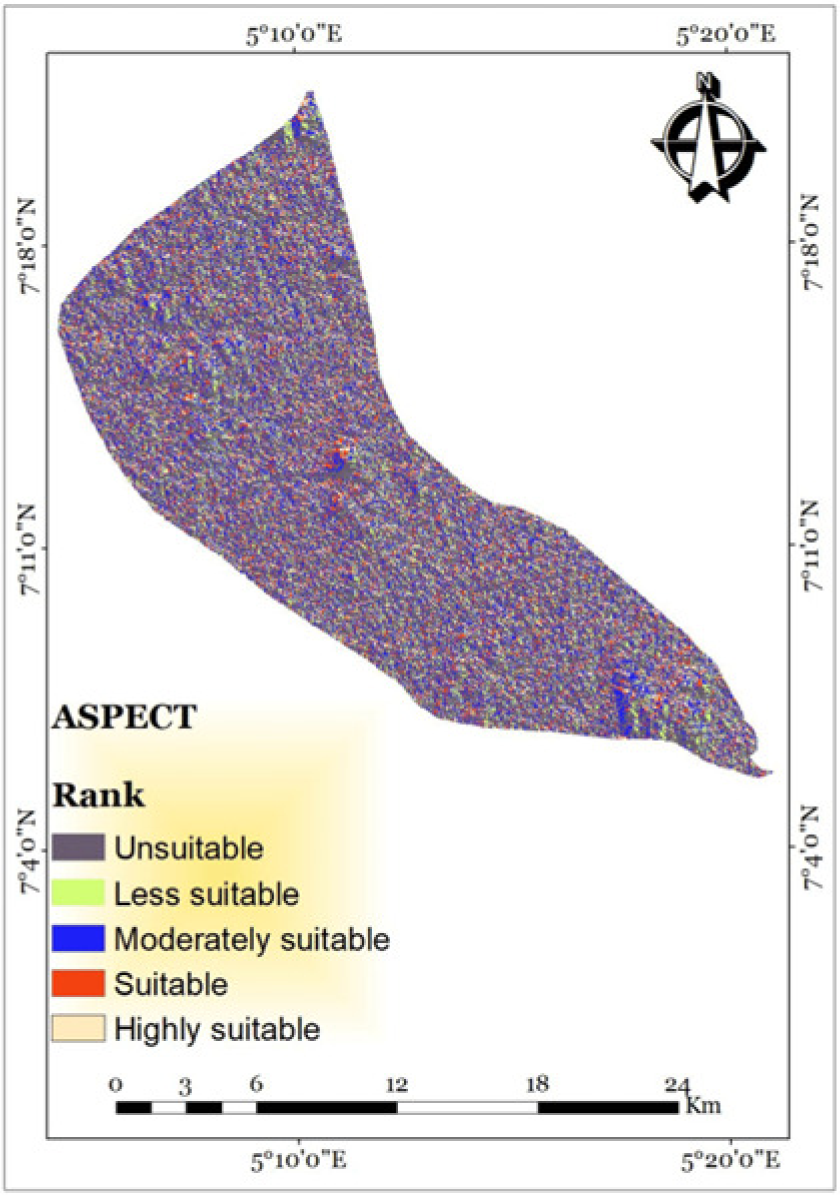

Fig. 3: Aspect of the study area

Stream Network Density

The disposal of solid waste near or into rivers and streams poses ecological and health risks to both humans and animals, as they rely on water from these polluted sources. When landfills are situated in close proximity to water bodies, there is an increased likelihood of leachate contaminating both groundwater and surface water, which is undesirable. Hence, landfill sites should be located farther away from surface water sources. Reclassification identified 2.57% (8.44 km²) as highly suitable, 1.21% (3.9 km²) suitable, 0.98% (3.21 km²) moderately suitable, and 18.30% (60.09 km²) less suitable, with 76.94% (252.60 km²) deemed unsuitable (Table 4, Figure 4).

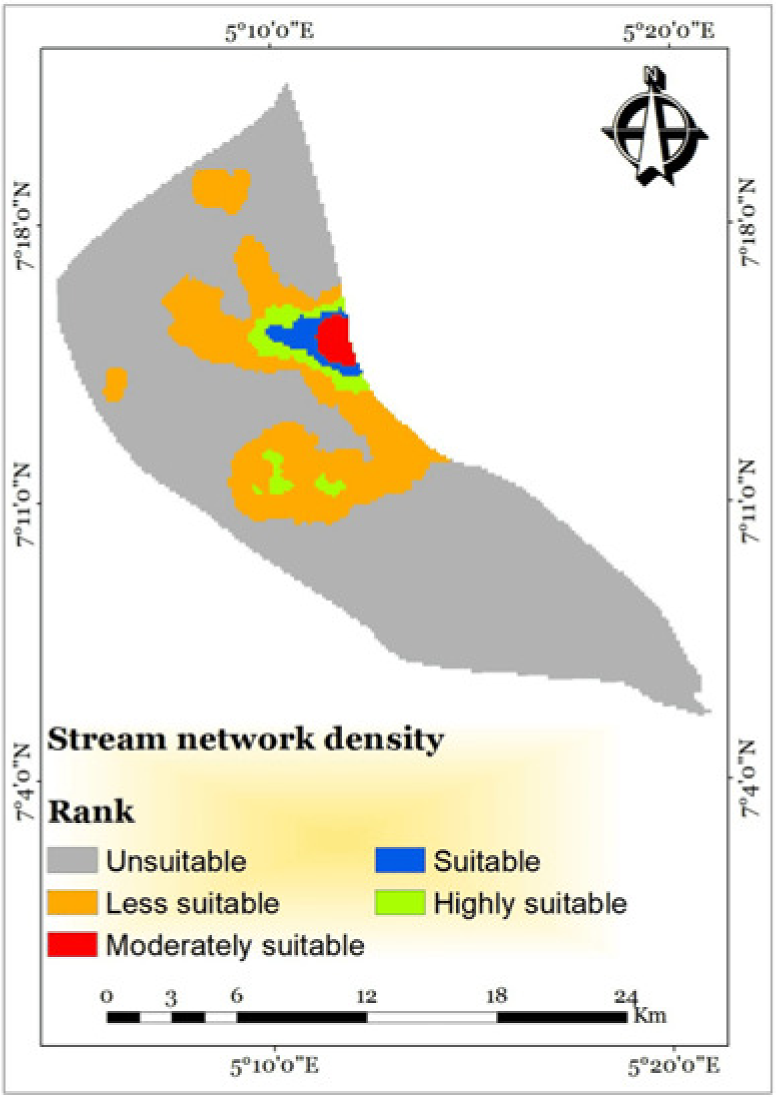

Fig. 4: Stream Network Density

Table 4: Stream density reclassification

Stream network Density	Suitability value	Area (Squared Km)	Percent
0 – 100	1	252.5958	76.94
100 – 200	2	60.0885	18.30
200 – 300	5	8.4375	2.57
300 – 400	4	3.9645	1.21
400 – 600	3	3.213	0.98

Land Use/Land Cover

After completing the image classification process, five land use/land cover classes were identified and reclassified based on proximity to urban centres and densely populated areas. Bare ground, covering 19.16% of the area, was deemed most suitable with a value of 5, while crops and residential areas, covering 18.18%, received the lowest suitability value of 1. Thick vegetation, the most common land cover type, accounted for 25.11%, mainly on the town's outskirts (Figure 5).

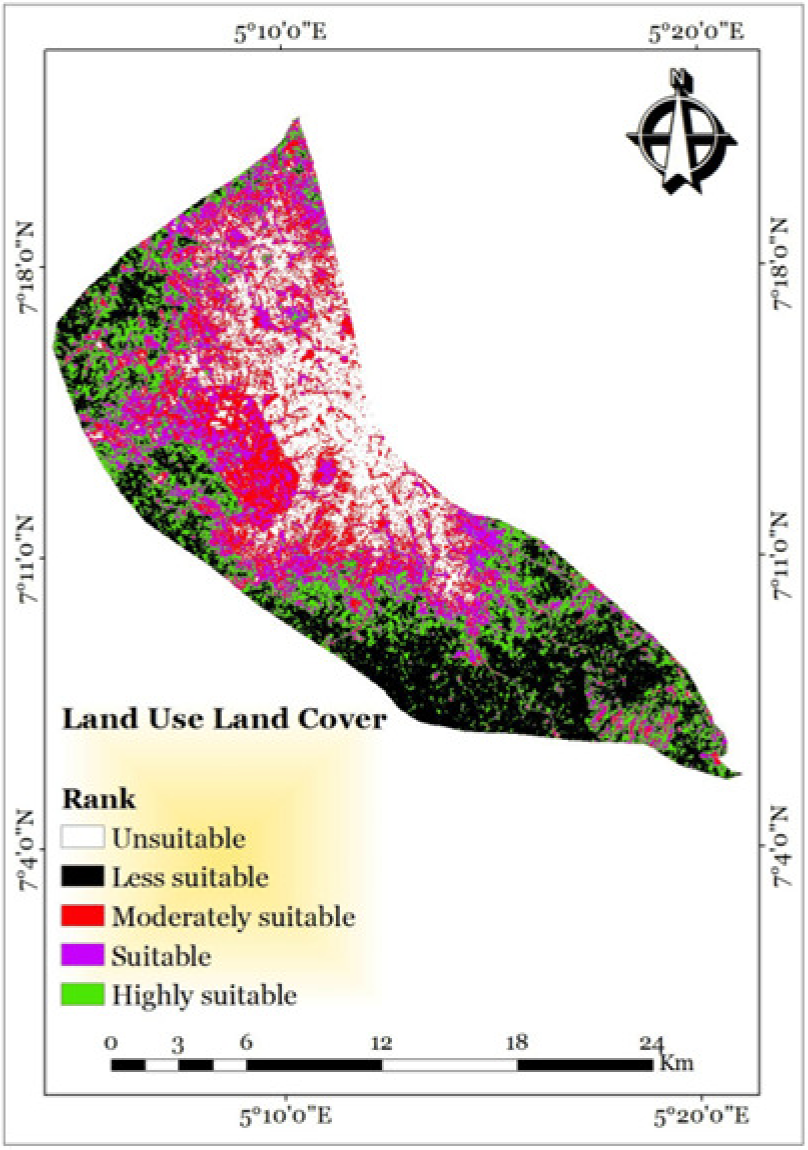

Fig. 5: Land Use land cover

Lithology

Suitability for landfill sites was determined by factors like weathering, fracturing, and porosity to minimize groundwater contamination risks. Granite-gneiss, covering 18.74% of the area, had the lowest risk and the highest suitability value of 5. Fine-grained biotite granite, making up 71.8%, was assigned a suitability value of 4, while areas with the lowest biotite granite content (4.11%) received a value of 1 (Figure 6).

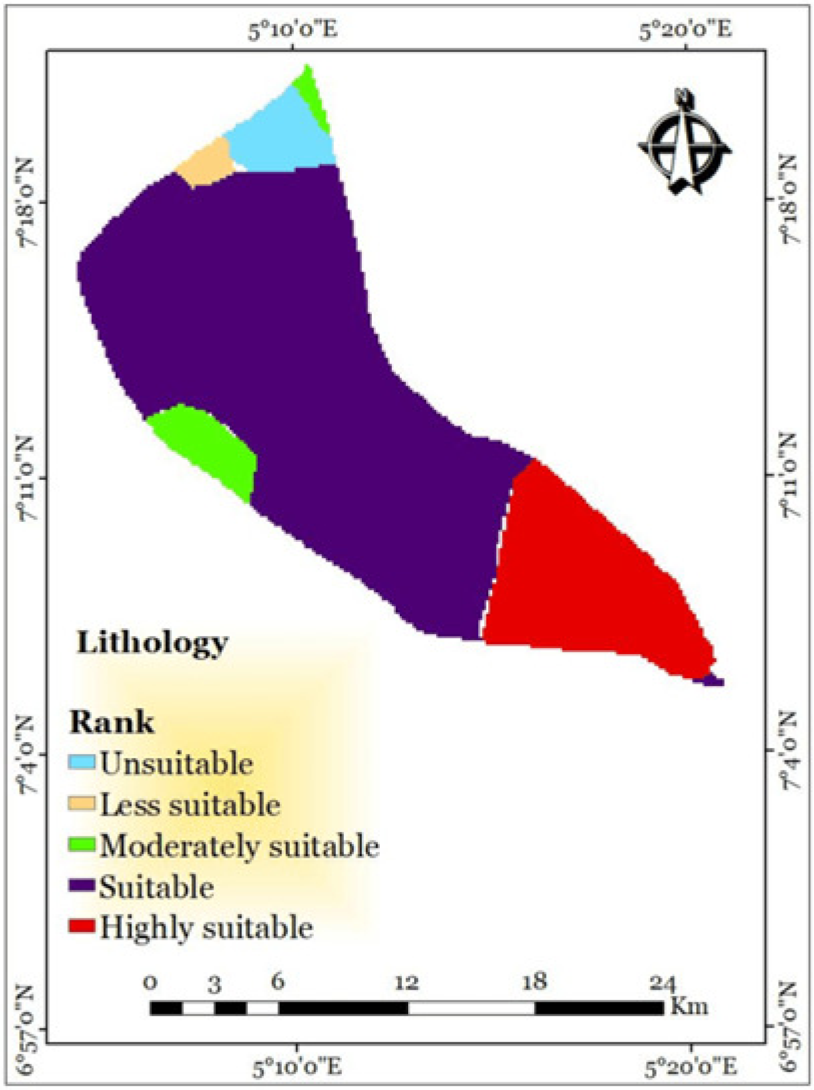

Fig. 6: Lithology

Distance to Road

Proximity to roads is essential for landfill site suitability, ensuring ease of transportation while maintaining a safe distance of at least 300 meters from major roads, town streets, or other transportation routes to prevent public health risks. Optimal placement ensures ease of transportation from households or transfer stations to disposal sites, thus it's preferable to locate landfills at a distance greater than 300 meters from roads. Reclassification identified 12.7% of the area within 300 meters as highly suitable, 5.7% at 400 meters as suitable, 5.2% at 500 meters as moderately suitable, 27.9% at 200 meters as less suitable, and 48.5% at 100 metres as unsuitable (Figure 7).

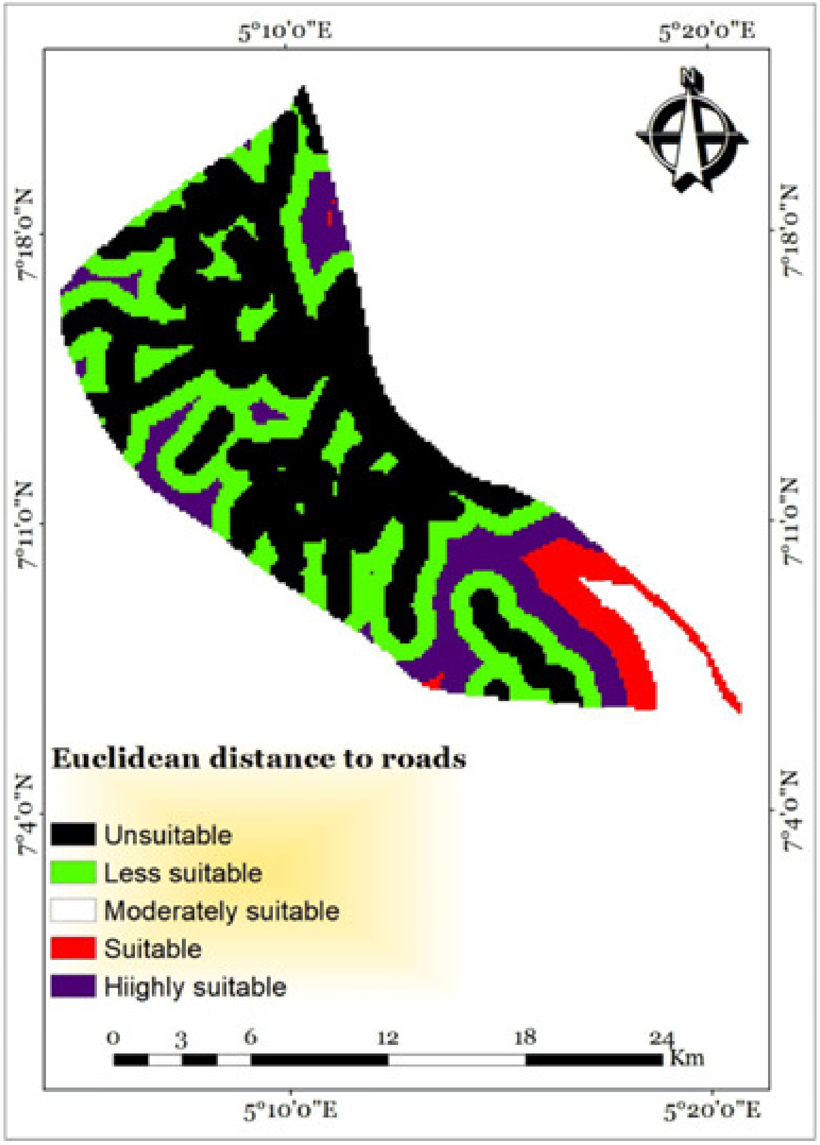

Fig. 7: Distance to Road

Soil

The predominant soil type in the study area is Orthic luvisol, accounting for 77.9% of the total area. This soil type is commonly found in forested landscapes and is characterized by loamy tills originating from the underlying bedrock, typically forming in the Ae and Bt horizons. The second most prevalent soil type is Chromic luvisol, which features a sandy-loam texture and reddish coloration, making it conducive for cultivation with nutrient-rich topsoil but low levels of organic matter. Chromic luvisol covers 15.9% of the study area. The third soil type, Lithosol, comprises chiefly unweathered or partly weathered rock fragments and is often found in steep slopes, covering 6.2% of the study area. Physical characteristics of the study area play a significant role in selecting potential sites for solid waste disposal. As soil permeability increases, the suitability of a site decreases due to the higher likelihood of groundwater pollution. Based on these factors, approximately 6.2% of the total area is deemed suitable for solid waste disposal sites, while 77.9% is classified as unsuitable (Figure 8).

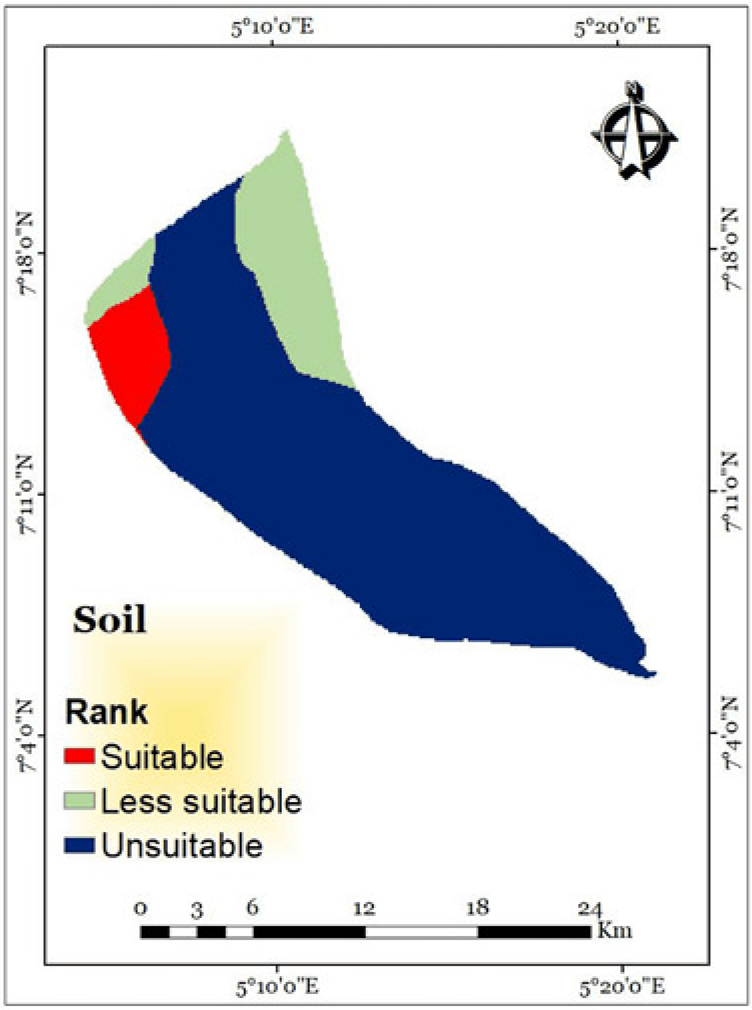

Fig. 8: Soil of the study area

Assigning Weights to Criteria for Suitable Site Selection for Landfill

In the GIS-Based Multi-Criteria Evaluation (MCE) methodology, one essential aspect involves assigning weights to criteria for each factor map. The objective of weighting in the landfill site selection process is to indicate the significance or preference of each factor concerning its impact on landfill siting.

Results

Suitability analysis evaluates, compares, and ranks potential sites based on selected criteria and methods.

Analytical Hierarchical Process (plugin) Method

In AHP, weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved at a time, in determining suitability. Accordingly, all possible combinations of two factors were compared based on expert judgment to prepare a pair-wise comparison matrix from which the module calculates a set of weights and consistency ratio. This ratio is very important as it shows any inconsistencies that may have arisen during the pair-wise comparison process. The result for pairwise comparison among lithology, road network, slope, aspect, stream density, LULC and soil are shown in Table 5.

Table 5: Pairwise Comparison

Layers	Lithology	Road Network	Slope	Aspect	Stream Density	LULC	Soil Texture
Lithology	1	3	6	6	5	1	1
Road Network	1/3	1	4	4	3	1/3	3
Slope	1/6	¼	1	1	½	1/6	1/2
Aspect	1/6	¼	1	1	½	1/6	1/2
Stream Density	1/5	1/3	2	2	1	1/5	2
LULC	1	3	6	6	5	1	4
Soil	1	1/3	3	2	½	¼	1

The AHP plugin in ArcMap assigned the following weights: 27.126% for lithology, 16.057% for distance to road, 3.848% for slope, 4.065% for aspect, 8.048% for stream density, 9.813% for soil, and 31.043% for land use/land cover (Table 6). With a consistency ratio of 0.065 (below 0.1), the results are deemed reliable. The analysis shows that 41.36 km² (12.89% of the total area) is highly suitable for landfill, mainly in the South-East and North-West regions (Figure 9). Additional areas classified as suitable and moderately suitable cover 93 km² and 32 km², respectively (Table 7 and Figure 9).

Table 6: AHP generated Weights and Weight percentage

Layers	**Weights**	**Weights (%)**
Lithology	0.2713	27.13
Road Network	0.1606	16.06
Slope	0.0385	3.85
Aspect	0.0407	4.07
Stream Density	0.0804	8.04
LULC	0.3104	31.04
Soil	0.0981	9.81
	1.0	100

Table 7: AHP plugin suitability values

Suitability Value	**Area in sq.km**	**Percent**
Unsuitable	4.1094	1.28
Less suitable	79.1982	24.67
Moderately Suitable	103.1049	32.12
Suitable	93.1959	29.04
Highly suitable	41.3586	12.89

Table 8: Weighted Overlay suitability values

Suitability Value	**Area in sq.km**	**Percent**
Unsuitable	1.6812	0.52
Less suitable	92.8458	28.84
Suitable	195.876	60.86
Highly suitable	31.4478	9.77

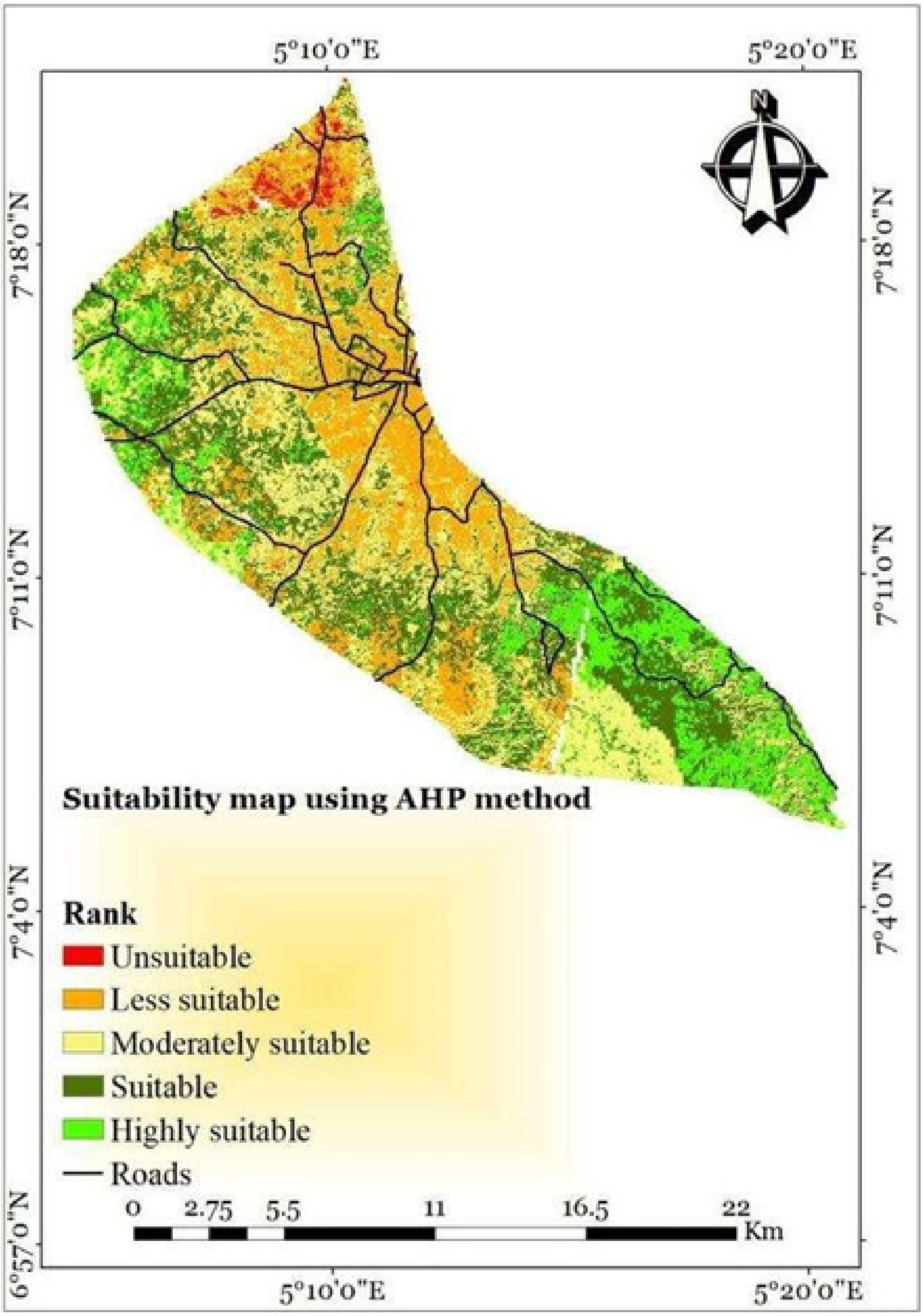

Fig. 9: Landfill suitability map using the AHP method

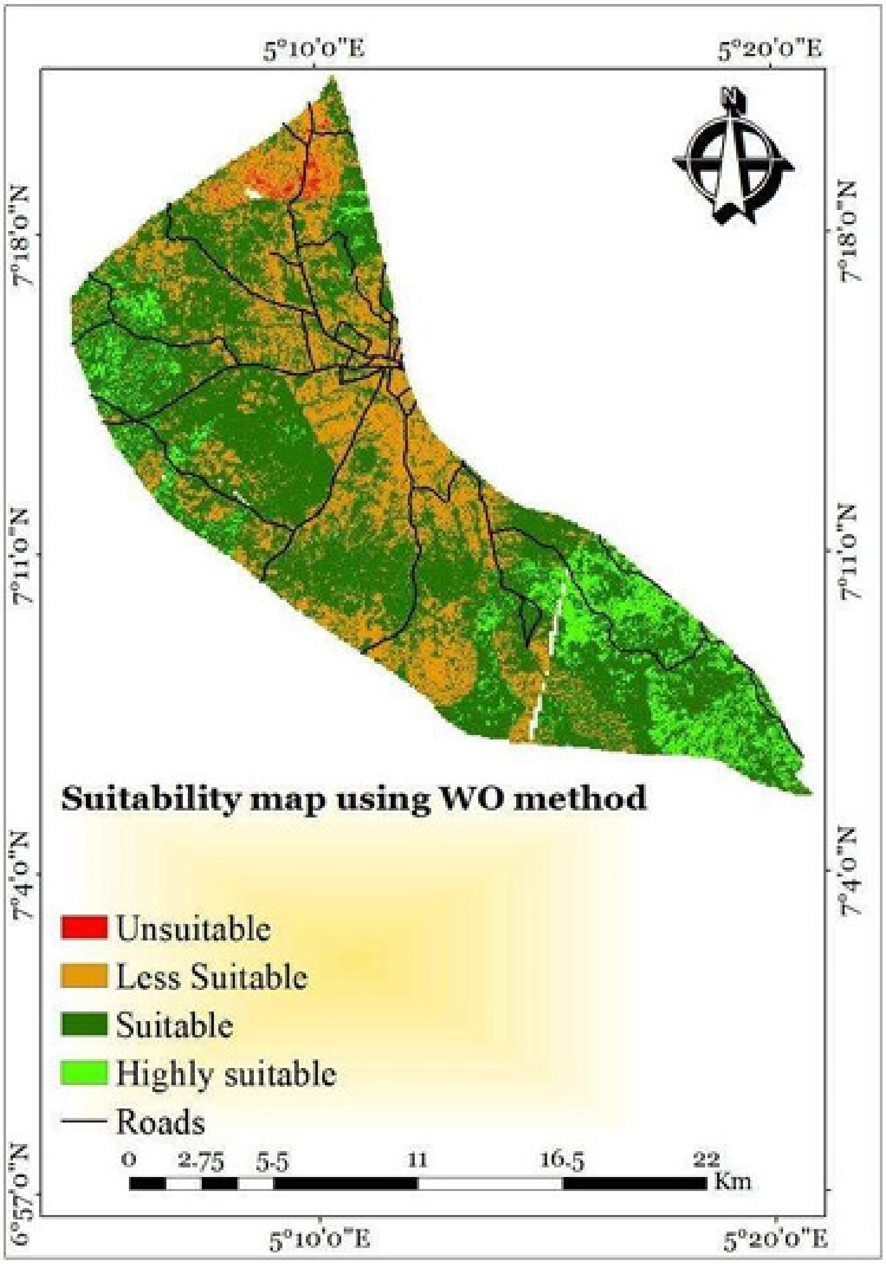

Fig. 10: Landfill Suitability Using Weighted Overlay (WO)

Integration of Weighted Overlay method with AHP for Landfill Suitability

When selecting a site for solid waste disposal, various factors such as environmental, social, and economic impacts are compared among different options. Through weight calculation, the relative importance of each parameter was determined for all criteria, including land use/land-cover, lithology, soil, road, stream network density, slope, and aspect maps. The significance of a criterion in the overall assessment increases with a larger weight.

The overlay analysis was conducted using AHP-derived weights rounded to whole numbers, the overlay analysis assigned 27% to lithology, 16% to road distance, 4% each to slope and aspect, 8% to stream density, 10% to soil, and 31% to land use/land cover. Table 9 shows 193 km² were classified as suitable and 36 km² as highly suitable. Figure 11 shows that the highly suitable areas for landfill are concentrated in the southeast and northwest regions of Akure South LGA.

Table 9: WO and AHP suitability value

Suitability Value	Area in sq.km	Percent
Unsuitable	1.9125	0.59
Less suitable	90.8451	28.23
Suitable	192.8529	59.92
Highly suitable	36.2403	11.26

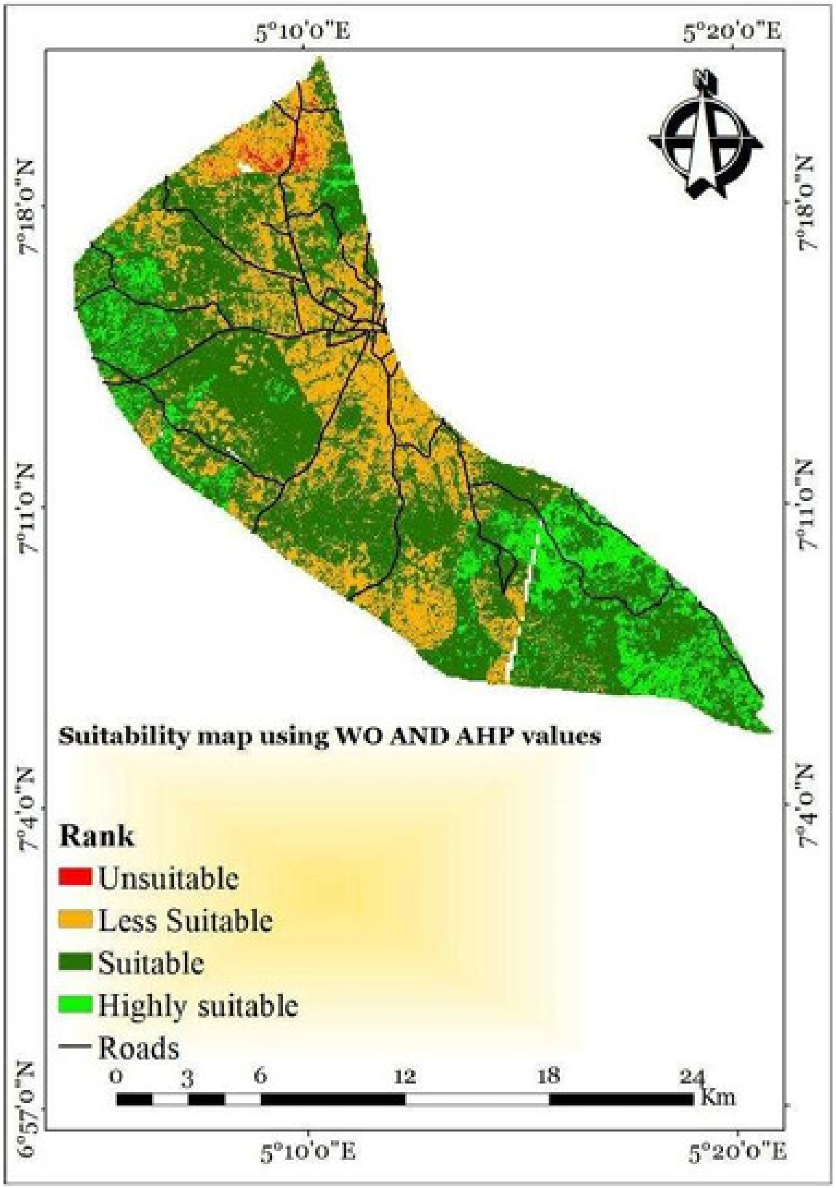

Fig. 11: Landfill suitability using the integration of WO and AHP method

Discussions and Conclusion

The findings revealed that highly suitable zones cover 10%, 13%, and 12% of the study area for the weighted overlay method, AHP technique, and their integration, respectively. Suitable zones encompass 60.86%, 29.04%, and 59.92%, while unsuitable areas account for only 0.52%, 1.28%, and 0.59%, respectively. The AHP plugin proved more efficient in generating the landfill suitability map for Akure South LGA. Unlike the weighted overlay method, which relies on subjective judgment of the decision maker for weights, the AHP plugin considers the interrelationship among criteria, offering a detailed five-class suitability map compared to the four-class map from the weighted overlay method. Integrating both techniques provided a suitability map based on AHP values and weighted overlay analysis, ensuring environmental, social, and economic criteria were met in highly suitable areas. This approach facilitates site evaluation, comparison, and prioritization.

The following conclusions were drawn: the AHP plugin approach demonstrated greater efficiency in identifying highly suitable areas and guiding efforts toward detailed field studies compared to the weighted overlay method for landfill site selection in Akure South Local Government Area. Mussa and Suryabhagavan, (2021) also observed this in their study of solid waste dumping site selection using GIS-based multi-criteria spatial modeling: a case study in Logia town, Afar region, Ethiopia. However, in situations where the plugin is not readily available, integrating both techniques- utilizing AHP-generated values as weights in the weighted overlay tool- can also identify suitable landfill areas. Having observed the inadequacies in the waste management system of Akure South LGA, which can be described as poorly managed, the AHP plugin approach can serve as a suitable method for landfill site selection in areas with similar characteristics. This approach enables decision-makers to conduct thorough analyses and address waste management challenges effectively. The relevant authorities should devise solid waste disposal strategies while considering social, economic, and environmental factors to enhance the solid waste management system's effectiveness.

References

Abdulraheem, K.A., Adeniran, J.A., Aremu, A.S., Yusuf, M.N.O., Yusuf, R. O., Odediran, E.T., ... & Du, M. (2023). Quantifications and predictions of sectoral pollutants emissions in Nigeria from 1980 to 2050. *Environmental Monitoring and Assessment*, 195(3): 398.

Adomako, J.A.A. (2013). *Urbanisation of the Rural Landscape: Assessing the Effects and Coping Mechanisms in Peri-Urban Kumas* (Doctoral dissertation).

Akintorinwa, O.J. and Okoro, O.V. (2019). Combine electrical resistivity method and multi-criteria GIS- based modeling for landfill site selection in the Southwestern Nigeria. *Environmental Earth Sciences*, 78: 1-16.

Ali, S.A. and Ahmad, A. (2020). Suitability analysis for municipal landfill site selection using fuzzy analytic hierarchy process and geospatial technique. *Environmental Earth Sciences*, 79(10): 227.

Arıkan, E., Şimşit-Kalender, Z.T. and Vayvay, Ö. (2017). Solid waste disposal methodology selection using multi-criteria decision making methods and an application in Turkey. *Journal of Cleaner Production*, 142: 403-412.

Asabere, S.B. (2020). *Urbanisation, Land Use and Soil Resource: Spatio-Temporal Analyses of Trends and Environmental Effects in Two Metropolitan Regions of Ghana (West Africa)* (Doctoral dissertation, Dissertation, Göttingen, Georg-August Universität, 2020).

Basavarajappa, H.T., Parviz, T., Manjunatha, M.C. and Balasubramanian, A. (2014). Integration of geology, drainage and lineament on suitable landfill sites selection and environmental appraisal around Mysore city, Karnataka, India through remote sensing and GIS. *Journal of Geomatics*, 8(1): 120.

Ezeudu, O.B., Agunwamba, J.C., Ugochukwu, U.C. and Ezeudu, T. S. (2021). Temporal assessment of municipal solid waste management in Nigeria: Prospects for circular economy adoption. *Reviews on Environmental Health*, 36(3): 327-344.

Finck, M. and Mueller, M.S. (2023). Access to Data for Environmental Purposes: Setting the Scene and Evaluating Recent Changes in EU Data Law. *Journal of Environmental Law*, 35(1): 109-131.

Gontte, A.T. (2023). *Solid Waste Disposal Site Selection Using Gis-Based Multi-Criteria Decision Analysis Techniques: A Case of Areka Town, Wolaitta Zone, Ethiopia* (Doctoral Dissertation, Hu).

Hyacinthe, K.K. (2023). *Waste Management Problems and Solutions in Anyama,* Cote d'Ivoire.

Idowu, A. (2023). *Innovative Solutions to Waste Management: A Case Study of Lagos State, Nigeria* (Doctoral dissertation, Hochschule Rhein-Waal).

Maton, S.M., Dabi, D.D., Dodo, J.D. and Nesla, R.A. (2016). Environmental hazards of continued solid waste generation and poor disposal in municipal areas of Nigeria. *Journal of geography, environment and earth science international*, 6(3): 1-10.

Mekuria, T., Muralitharan, J. and Ali, Y. (2019). GIS and remote sensing based suitable site selection for solid waste disposal: A case study of Gondar Town, Northwest Ethiopia. *Journal of Academia and Industrial Research (JAIR)*, 8(2): 38-44.

Moruff, M. (2014). Space, population and waste management in Ibadan. *He Journal of Pan African Studies*, 7(4): 175-194.

Mussa, A. and Suryabhagavan, K.V. (2021). Solid waste dumping site selection using GIS-based multi-criteria spatial modeling: a case study in Logia town, Afar region, Ethiopia. *Geology, Ecology, and Landscapes*, 5(3): 186-198.

Osumgborogwu, I. and Chibo, C. (2017). Environmental laws in Nigeria and occurrence of some geohazards: A review. *Asian Journal of Environment and Ecology*, 2(4): 1-12.

Singh, J., Laurenti, R., Sinha, R. and Frostell, B. (2014). Progress and challenges to the global waste management system. *Waste Management and Research*, 32(9): 800-812.

Thoso, M. (2007). *The construction of a geographic information system (GIS) model for landfill site selection* (Doctoral dissertation, University of the Free State).

Ummulkhair, H. and Emigilati, A.M. (2023). Unlocking the Value of Waste: A Case Study of Minna Metropolis. *Journal of inclusive Cities and Built Environment*, 3(5): 27-38.

Vergara, S.E. and Tchobanoglous, G. (2012). Municipal solid waste and the environment: a global perspective. *Annual Review of Environment and Resources*, 37: 277-309.

Zhao, T., Gao, Y., Zhan, W., Sun, H., Zhang, T., Li, L., ... & Tian, Y. (2024). Municipal solid waste (MSW) under the population shrinking and aging: Spatio-temporal patterns, driving forces, and the impact of smart city development. *Journal of Cleaner Production.* 434(7): 140124.