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GIS-BASED MULTI-CRITERIA DECISION ANALYSIS (MCDA) FOR OPTIMAL SOLID WASTE DISPOSAL SITE SELECTION IN JALINGO METROPOLIS, TARABA STATE, NIGERIA

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Abstract

Rapid population growth and urban expansion in Jalingo Metropolis, Taraba State, Nigeria, have led to a significant increase in municipal solid waste generation, creating serious environmental and public health challenges. The absence of scientifically selected landfill sites has contributed to indiscriminate waste disposal, land degradation, and potential contamination of nearby water bodies. This study therefore aimed to identify environmentally suitable locations for solid waste disposal using a Geographic Information System (GIS)-based Multi-Criteria Decision Analysis (MCDA) framework. Four key criteria—road accessibility, proximity to drainage networks, buffers around built-up areas, and topographic conditions—were selected in accordance with environmental guidelines and international best practices for landfill siting. Spatial datasets, including QuickBird satellite imagery, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), and municipal geospatial datasets, were processed using ILWIS, ArcGIS, and IDRISI Taiga. The Analytical Hierarchy Process (AHP) was applied to determine the relative importance of the criteria, while Boolean overlay techniques were used to define constraint layers. A Weighted Linear Combination (WLC) model was subsequently employed to integrate the criteria and generate a landfill suitability map for the study area. The suitability analysis classified the study area into three categories: highly suitable, moderately suitable, and unsuitable zones for landfill development. Results indicate that 28% of the study area is highly suitable, 17% moderately suitable, and 55% unsuitable for landfill siting. Five potential sites were identified, with Site 3 ranked most suitable due to its accessibility, minimal environmental impact, and land availability. Sensitivity analysis confirmed the robustness of the model. Findings provide a scientific basis for evidence-based urban solid waste management, offering a practical decision-support tool for local authorities.

Keywords: Analytical Hierarchy Process, GIS, Jalingo Metropolis, Landfill Siting, Multi-Criteria Decision Analysis, Solid Waste Management

INTRODUCTION

Rapid population growth, urbanization, and economic development have drastically increased municipal solid waste (MSW) production globally. In developing nations, managing this waste is a critical challenge due to inadequate infrastructure, weak institutional capacity, and a lack of strategic planning (Ahmed *et al.,* 2022). Improper practices, such as open dumping and poorly sited landfills, lead to environmental degradation, groundwater contamination, and the spread of disease (Wanore *et al.,* 2023). Consequently, identifying environmentally sound landfill locations is essential for sustainable urban planning.

In Nigeria, inefficient waste management is particularly acute in rapidly growing urban centers. Many cities rely on uncontrolled dumping near residential areas, surface water, or agricultural land, posing significant risks to ecosystems and public health. These issues underscore the need for scientific approaches to identify disposal sites that minimize ecological and social footprints (Ahmed *et al.,* 2022; Chanda *et al.,* 2023).Traditional selection methods often rely on subjective decision-making and limited spatial analysis. However, Geographic Information Systems (GIS) have emerged as powerful tools for environmental planning. GIS allows for the integration and analysis of diverse spatial datasets, enabling planners to evaluate complex infrastructural and environmental factors systematically.

One of the most effective methods paired with GIS is Multi-Criteria Decision Analysis (MCDA). MCDA provides a structured framework to evaluate multiple, often conflicting criteria—such as proximity to roads, settlements, and water bodies—to rank alternative locations (Abubakar *et al.,* 2020). Within this framework, the Analytical Hierarchy Process (AHP) is frequently used to assign weights to factors through pairwise comparisons, reducing subjectivity (Elkhrachy *et al.,* 2023).

This study applies a GIS-based Multi-Criteria Decision Analysis (MCDA) framework to identify optimal solid waste disposal sites in Jalingo Metropolis. By integrating spatial datasets and environmental decision criteria within a GIS environment, the study aims to generate a landfill suitability map that supports evidence-based waste management planning. The findings are expected to provide practical guidance for urban planners, environmental managers, and policymakers seeking to improve solid waste management systems and promote environmentally sustainable urban development in Jalingo Metropolis and similar rapidly growing cities.

LITERATURE REVIEW

Landfill site selection has transitioned from manual, subjective methods to quantitative GIS-based frameworks (Sumathi et al., 2008). Recent studies have successfully employed AHP-weighted models (Elkhrachy *et al.,* 2023), Fuzzy AHP (Tella *et al.,* 2024), and Boolean logic. In Zambia, Chanda *et al*. (2023) utilized GIS-MCDA to classify landfill suitability based on slope, land use, and drainage systems. Similarly, research in Sudan demonstrated that integrating spatial constraints like transportation networks and settlement buffers provides a robust method for minimizing environmental risk (Ahmed *et al.*, 2022). In Ethiopia, Wanore *et al*. (2023) and Degefu and Asefa (2024) highlighted the necessity of incorporating geological and socio-economic factors into the decision-making process for industrializing zones.

In Nigeria, Oluwanimifise and Anyaeche (2025) found that in cities like Ibadan, only a small fraction of urban land meets the stringent requirements for sanitary landfills. Despite these advancements, Jalingo Metropolis has seen limited research in this area. Current practices in the city rely on conventional dumping without regard for long-term sustainability, making scientifically guided planning a critical necessity.

MATERIALS AND METHODS

Study Area

Jalingo Metropolis is located in northeastern Nigeria between latitudes 8°47′–8°55′ N and longitudes 11°18′–11°30′ E. The terrain is gently undulating, with elevations between 100 m and 200 m. The tropical climate features a wet season (April–October) and a dry season (November–March). Rapid expansion has created a complex landscape of dense settlements, agricultural land, and natural drainage, complicating waste disposal efforts (Olatunde *et al.,* 2025). Figure 1 shows the Map of Jalingo Metropolis.

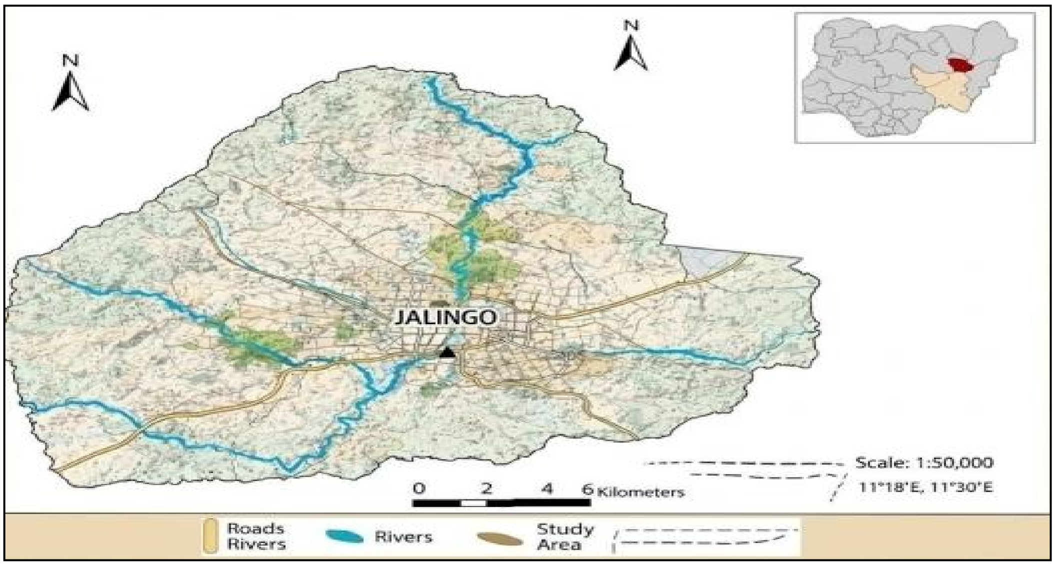

Figure 1: Map of Jalingo Metropolis
Source: Department of Surveying and Geoinformatics, Modibbo Adama University (MAU), Yola (2025)

Data Sources and GIS Processing

Spatial data were processed using ILWIS 3.7, ArcView 3.2a, and IDRISI Taiga. While these are older platforms, they are methodologically sound for standard operations such as buffering and overlay analysis. Table 1 presents the data sources used in the study and their corresponding applications.

Table 1: Data sources uses in the study area

Dataset	Source	Use
QuickBird Satellite Image	2014 archive	Land-use classification
SRTM DEM	USGS	Slope & elevation extraction
Road Network	OSM / LG data	Accessibility criterion
Drainage Map	Taraba Water Agency	Hydrological buffer
GPS Dumpsite Coordinates	Field survey	Validation

Source: Authors Research work (2025)

Ground verification was conducted using a Garmin 72 Global Positioning System (GPS) receiver to collect the coordinates of existing waste disposal sites within Jalingo Metropolis. These coordinates were integrated into the GIS environment to validate the results of the suitability analysis

Criteria Development and Weighting

Landfill site suitability was evaluated using four primary decision criteria, selected based on environmental guidelines and previous landfill siting studies (Oyinloye, 2003; Malczewski, 2006; Adewumi *et al.,* 2017). These criteria include:

1. Distance from residential areas (≥ 3 km)
2. Distance from major water bodies (≥ 1 km)
3. Distance from major roads (≥ 300 m)
4. Elevation between 100 m and 200 m

The Analytical Hierarchy Process (AHP) was used to weight these criteria. A pairwise comparison matrix was constructed, and the Consistency Ratio (CR) was calculated. A CR of 0.07 (less than the 0.10 threshold) confirmed the reliability of the weighting.

Suitability Modelling Using Weighted Linear Combination

After deriving the weights of the criteria using AHP, the Weighted Linear Combination (WLC) method was applied to integrate the standardized criteria layers within the GIS environment (Malczewski, 2006).

The WLC model combines weighted criteria according to the following relationship:

$$\text{Suitability Index (SI)} = \Sigma\,(W_i \times X_i) \qquad (1)$$

Where: W_i = weight of criterion i; and X_i = standardized score of criterion i.

The resulting suitability index map classified the study area into different suitability categories, including highly suitable, moderately suitable, and unsuitable zones.

The coordinates of existing dump sites obtained using GPS were then overlaid on the suitability map to evaluate whether current waste disposal locations correspond with environmentally suitable areas. Table 2 presents the criteria and weights used in the landfill suitability analysis.

Table 2: Landfill site selection criteria, Thresholds, and AHP Weights

Criterion	Derived Layer/Sub-layer	Threshold/ Buffer	AHP Weight	Justification
Residential Area	Built-up area buffer	≥ 3 km	0.45	Minimize health risks and conflicts with settlements
Water Bodies	Rivers, lakes, streams buffer	≥ 1 km	0.20	Prevent surface and groundwater contamination
Road Proximity	Road network buffer	≥ 300 m	0.25	Ensure accessibility for waste transport
Elevation / Topography	Relief / DEM-derived slope and height	100 m – 200 m above sea level	0.10	Avoid low-lying flood-prone areas
Derived layers	Drainage, Land use compatibility	Exclusion zones	Derived	Minimize ecological and social conflicts

Source: (Fieldwork, 2026)

Notes:

Four primary criteria (Residential Area, Water Bodies, Road Proximity, Elevation) were weighted using AHP, while, other layers are derived spatial layers to refine suitability modeling, and thresholds follow international guidelines and local environmental standards (Oyinloye, 2003; Malczewski, 2006).

Derived layers are integrated into the Weighted Linear Combination (WLC) GIS model for suitability classification. Although Table 3 above contains multiple analytical layers, these layers represent derived spatial datasets generated from the four core criteria, rather than independent decision criteria. For example, drainage buffers, settlement buffers, and road accessibility layers were derived from the main criteria to improve spatial modelling accuracy.

Analytical Hierarchy Process (AHP) Implementation

The Analytical Hierarchy Process (AHP) was applied to weight the landfill site selection criteria in a structured and transparent manner (Saaty, 1980). The process consisted of four steps:

Pairwise Comparison of Criteria: Each criterion was compared against the others based on relative importance for landfill suitability. Expert judgment and literature sources guided the comparison.

Weight Calculation: The eigenvector of the pairwise comparison matrix was normalized to obtain the relative weight of each criterion.

Consistency Check: The Consistency Ratio (CR) was computed to ensure reliability. CR < 0.10 indicates acceptable consistency.

Integration with GIS: The derived weights were applied to the standardized GIS layers using the Weighted Linear Combination (WLC) method to generate the landfill suitability map.

Table 3 depict pairwise comparison matrix of landfill selection criteria, while Table 4 shows the Normalized Weights and Consistency Ratio (CR).

Table 3: Pairwise Comparison Matrix of Landfill Selection Criteria

Criteria	Residential Area	Water Body	Road Proximity	Elevation	Row Sum
Residential Area	1.0	3.0	2.0	4.0	10.0
Water Body	0.33	1.0	0.5	2.0	3.83
Road Proximity	0.5	2.0	1.0	3.0	6.5
Elevation	0.25	0.5	0.33	1.0	2.08
Column Sum	2.08	6.5	3.83	10.0	

Source: (Fieldwork, 2026)

Table 4: Normalized Weights and Consistency Ratio (CR)

Criteria	Normalized Weight	Justification
Residential Area	0.45	Minimize health risks and conflicts with settlements
Water Body	0.20	Prevent contamination of surface and groundwater
Road Proximity	0.25	Ensure accessibility for waste transport
Elevation	0.10	Avoid low-lying flood-prone areas

Source: (Fieldwork, 2026)

If Consistency Ratio (CR) = 0.07 (<0.10), indicating acceptable consistency, and CR is given by equation (2)**:**

$$CR = \frac{CI}{RI} \quad (2)$$

Where; CI = Consistency index; RI = Random index and CI is deoted in equation (3):

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

In summary, Figure 2 shows GIS- MCDA Landfill Suitability Workflow that adopts a robust and applicable methodology in developing cities in Africa:

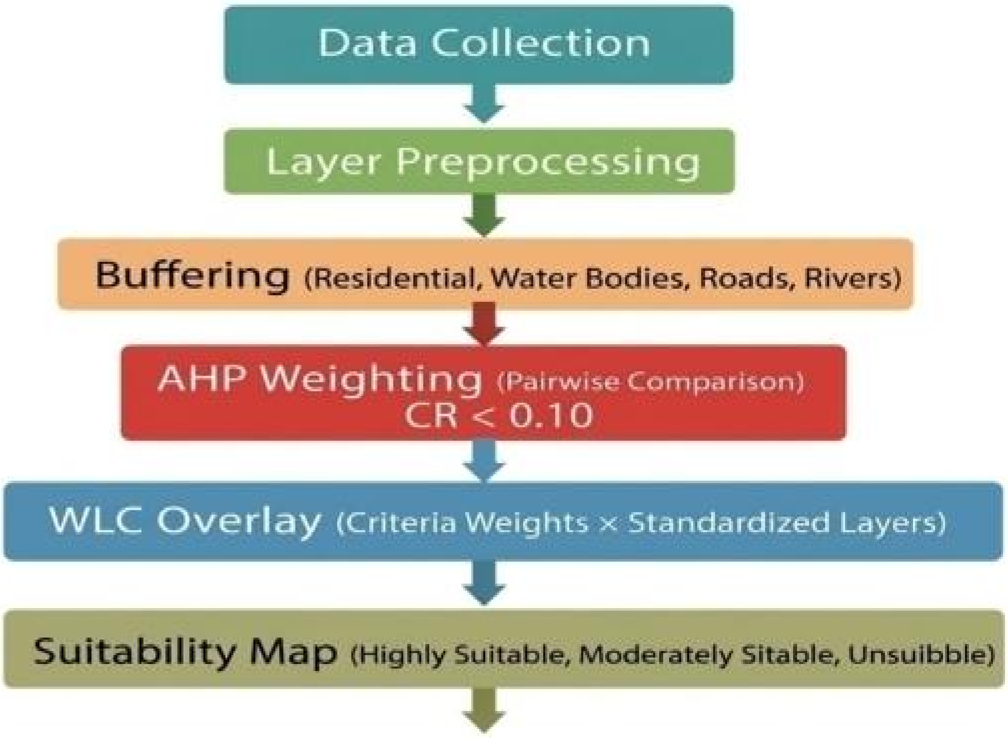

Figure 2: GIS-MCDA Landfill Suitability Workflow
Source: Fieldwork, (2026)

RESULTS

Spatial operations including buffer generation, polygon overlay, feature extraction, and spatial queries were conducted to derive landfill suitability in Jalingo Metropolis. The results are presented sequentially: thematic maps, composite suitability mapping, dumpsite verification, and sensitivity analysis.

Thematic Maps

Thematic layers were created and buffered according to the established criteria. The following layers were developed:

Buffered River and Built-Up Area Map: Residential areas and rivers were buffered according to thresholds (≥3 km from residential areas, ≥1 km from water bodies). The reclassified layer identifies areas environmentally suitable for landfill placement.

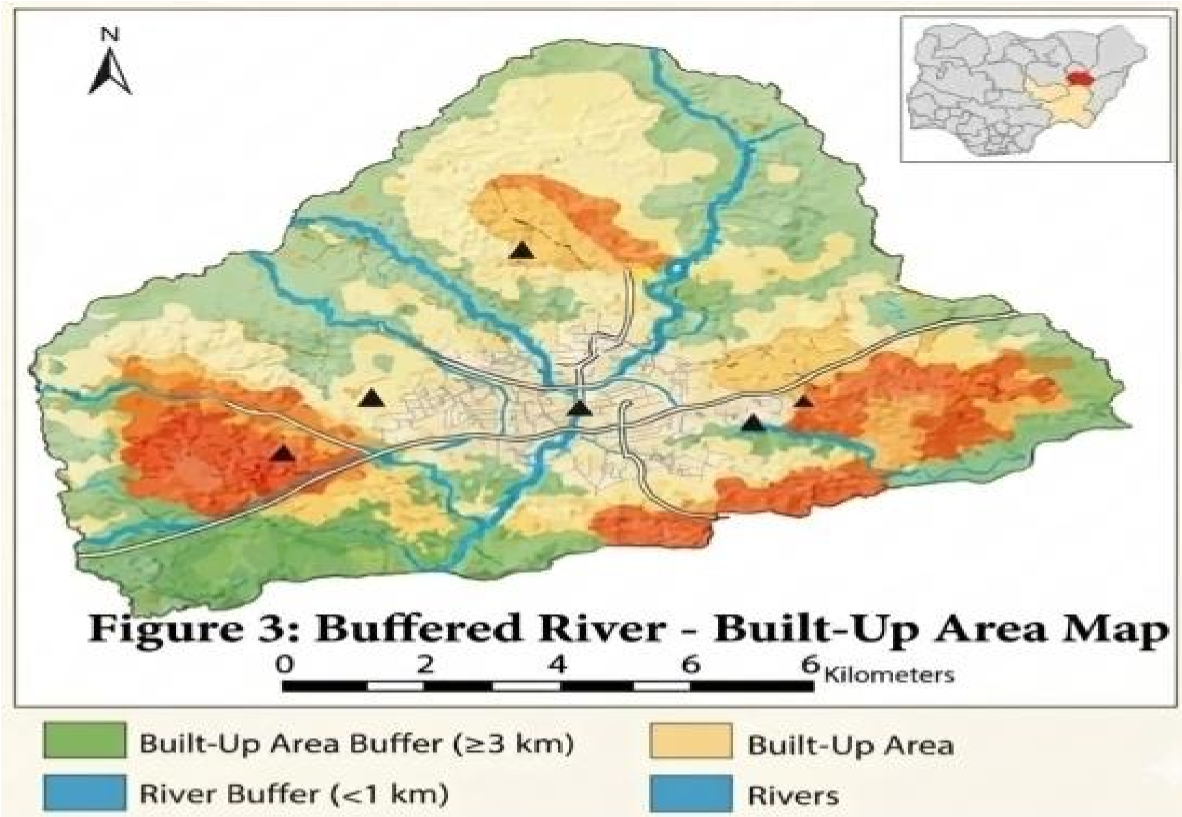

Figure 3: The reclassified buffered river-built-up area map
Source: Fieldwork (2026)

Buffered Road and Relief Map: Major roads and elevation were processed to produce accessibility and terrain suitability layers. Roads were buffered ≥300 m, and elevation was limited to 100–200 m above sea level.

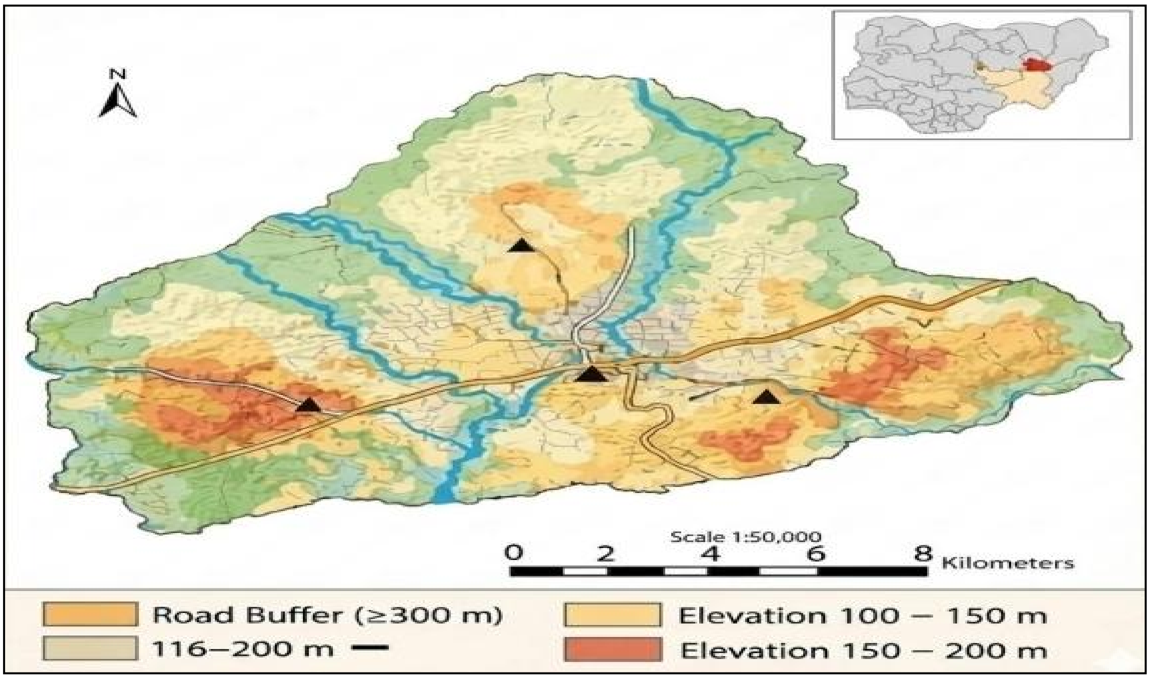

Figure 4: The reclassified buffered road-relief map
Source: Fieldwork (2026)

These thematic maps Figure 3 and Figure 4 form the basis for overlay and composite suitability analysis.

Composite Suitability Map

The weighted overlay (WLC) of the buffered and reclassified layers produced a composite landfill suitability map. Suitability classes were defined as shown in Table 5.

Table 5 : Suitability class, and Threshold description

Suitability Class	Threshold / Description
Highly Suitable (HS)	Areas meeting all primary criteria
Moderately Suitable (MS)	Areas partially meeting primary criteria
Unsuitable (US)	Areas failing one or more primary criteria

Source: Fieldwork (2026)

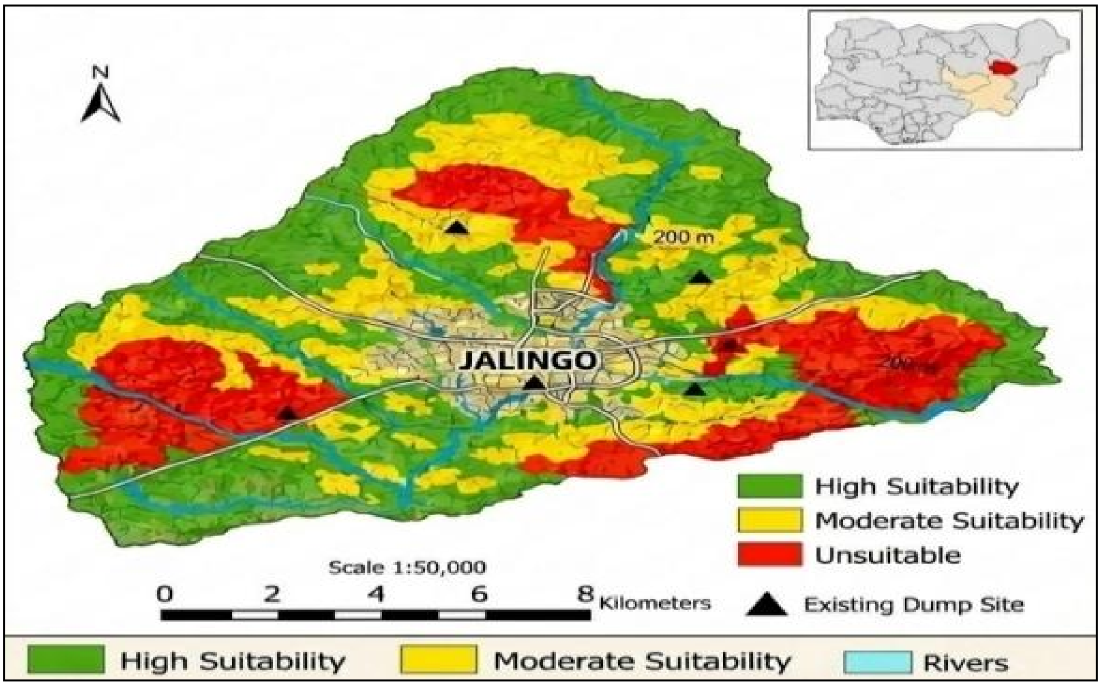

Figure 5: Composite Landfill Suitability
Source: Fieldwork (2026)

Figure 5 illustrates the spatial distribution of these suitability zones as Highly Suitable (HS); located mainly in the northwest and northeast of the metropolis; Moderately Suitable (MS); distributed along central periphery areas; and Unsuitable (US); which occupy dense settlements and drainage corridors.

Table 6 summarizes the area coverage of each class (Highly Suitable, Moderately Suitable, Unsuitable).

Table 6: Summary of the area coverage of each class

Suitability Class	Area (km²)	Percentage of Study Area (%)
Highly Suitable	0.035	28%
Moderately Suitable	0.021	17%
Unsuitable	0.072	0.072
Total	0.128	100%

Source: Fieldwork (2026)

Note: Area percentages are derived from raster cell counts and converted to square kilometers, reflecting the spatial distribution across the study area.

Dumpsite Verification

The locations of existing municipal dumpsites were overlaid on the composite suitability map for verification. All current dumpsites fell within the Unsuitable (US) zones, confirming poor planning and siting practices (Kontos *et al.,* 2005; Sener *et al* 2010;Aderemi and Folade 2012).. Table 7 depicts the geographical coordinates of the Potential Solid Waste Disposal Sites

Table 7: Coordinates of Potential Solid Waste Disposal Sites

Site	Latitude (N)	Longitude (E)	Notes
1	8.8790	11.1900	Moderately accessible
2	8.8850	11.2200	Adequate land availability
3	8.8900	11.2400	Most suitable: accessible, low environmental impact
4	8.8750	11.2000	Slightly elevated area
5	8.8700	11.2100	Peripheral zone with moderate suitability

Source: Fieldwork (2026)

Five potential landfill sites were identified within the Highly Suitable zones. Site 3 was ranked as the most suitable due to its proximity to major roads, minimal environmental impact, and available land. Figure 6 displays the existing dumpsites with their Lat/Long coordinates.

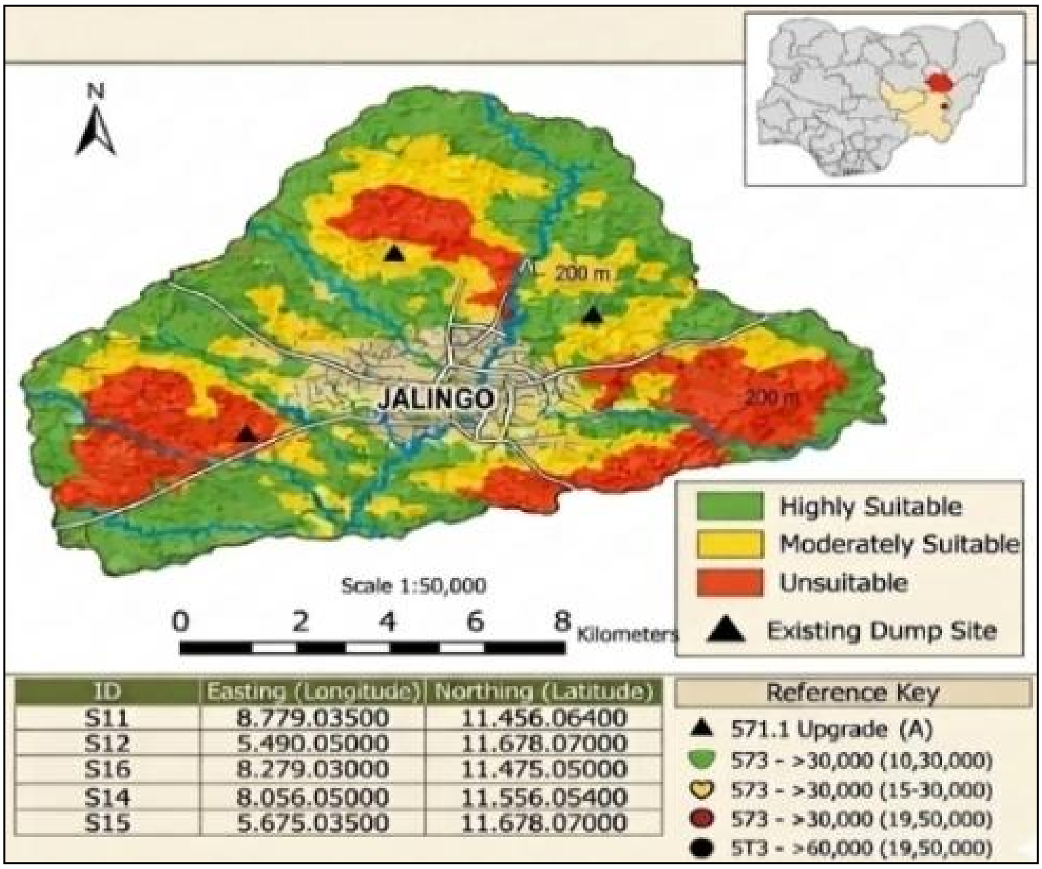

Figure 6: Dump site Verification Map of Jalingo and Vicinity, Taraba State, Nigeria
Source: Fieldwork (2026)

Figure 6 presents the suitability verification map, showing both potential sites and existing dumpsites.

Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the robustness of the model by varying individual criterion weights by ±10%. The spatial configuration of suitability zones remained largely stable. This signifies that highly suitable zones maintained their spatial integrity, confirming the robustness of the AHP-based weighting and WLC integration.This analysis demonstrates that minor variations in expert judgment do not significantly alter landfill suitability outcomes, providing confidence for planning decisions.

DISCUSSION

The GIS-based Multi-Criteria Decision Analysis (MCDA) approach applied in this study provided a systematic framework for identifying optimal solid waste disposal sites in Jalingo Metropolis. The results reveal critical insights regarding urban waste management, site suitability, and the applicability of spatial decision support systems in a developing-country context.

Interpretation of Landfill Suitability

The composite suitability map Figure 5 shows that approximately 28% of the study area is highly suitable, 17% is moderately suitable, and 55% is unsuitable for landfill development. The highly suitable zones are concentrated in the northwest and northeast, while dense urban settlements and drainage corridors are largely classified as unsuitable. These findings align with prior studies in Nigeria and other African cities, where urban expansion and proximity to water bodies limit safe landfill locations (Abdulwaheed *et al.,* 2024; Tella *et al.,* 2024 ; Sisay *et al.,* 2025).

The identification of five potential sites, with Site 3 being the most suitable, highlights the importance of integrating environmental, infrastructural, and topographic criteria in landfill planning. Site 3's location; proximate to major roads, outside sensitive ecological zones, and within the appropriate elevation range, ensures both accessibility and minimal environmental impact, consistent with international best practices (Malczewski, 2006; Degefu and Asefa, 2024).

Thematic Layer Analysis

The individual thematic layers (residential buffers, water bodies, roads, and elevation) demonstrate that environmental and infrastructural constraints strongly influence landfill site selection (See figures 3,4,5). Overlay analysis indicates that many existing dumpsites fall within unsuitable zones, corroborating findings from Kontos *et al*. (2005) and highlighting the need for evidence-based site selection in urban planning.

Residential area buffers effectively excluded high-density urban zones, reducing potential health risks, while, water body buffers ensured compliance with environmental standards, preventing groundwater contamination. Road and elevation analyses ensured accessibility and reduced flood risk, which is consistent with prior GIS-MCDA studies in Ilorin and Addis Ababa (Abdulwaheed *et al.,* 2024; Degefu and Asefa, 2024).

Robustness of the AHP-WLC Model

The AHP-based weighting of criteria, combined with the Weighted Linear Combination (WLC) approach, produced a robust suitability map. This aligns with prior MCDA applications in developing-country urban contexts, where robustness testing ensures that expert judgment does not disproportionately affect outcomes (Elkhrachy *et al.*, 2023; Tella *et al.,* 2024). The computed Consistency Ratio (CR = 0.07) further demonstrates that the AHP pairwise comparisons were internally consistent, validating the reliability of the derived weights.

Implications for Waste Management Planning

The findings of this study have several practical implications for urban planners, policymakers, and environmental managers:

a) Evidence-Based Landfill Siting: GIS-MCDA provides a transparent and scientifically justified framework for landfill location selection, which can reduce environmental and social conflicts.
b) Prioritization of High-Suitability Zones: Concentrating landfill development in highly suitable zones ensures compliance with environmental regulations and minimizes health risks.
c) Planning for Urban Expansion: Moderately suitable zones may serve as future expansion areas, but unsuitable zones (55% of the metropolis) should be strictly avoided for waste disposal.
d) Policy Integration: The approach provides a decision-support tool for local government authorities to implement strategic solid waste management, particularly in rapidly growing urban centers like Jalingo.

The results are consistent with other GIS-MCDA landfill siting studies in Africa and developing-country contexts. Abdulwaheed et al. (2024) identified limited suitable areas for landfill siting using GIS-MCDA, in Ilorin, Nigeria, demonstrating the constraints imposed by dense urbanization and water bodies. Degefu and Asefa (2024) did a study in Addis Ababa, Ethiopia and found that integrating multiple environmental and infrastructural criteria improves landfill selection even in data-limited environments. Also in Egypt, Elkhrachy et al. (2023) confirmed that AHP-weighted GIS overlays reliably identify optimal landfill sites, similar to the present study.These comparisons reinforce the generalizability of GIS-MCDA methods for urban solid waste management in developing cities.

CONCLUSION

This study applied a GIS-based Multi-Criteria Decision Analysis framework to identify environmentally suitable landfill sites in Jalingo Metropolis, Taraba State, Nigeria. The analysis integrated spatial datasets including road networks, drainage systems, settlement distribution, and terrain characteristics within a GIS environment. The results classified the study area into three suitability categories, revealing that 28% of the land area is highly suitable, 17% moderately suitable, and 55% unsuitable for landfill development. Five potential landfill sites were identified, with Site 3 emerging as the most suitable location based on accessibility and environmental safety.

The study demonstrates that GIS-MCDA provides a powerful and effective decision-support tool for landfill site selection and sustainable urban waste management planning. The methodology developed in this research can support policymakers, urban planners, and environmental managers in making informed decisions regarding waste disposal infrastructure.

Future research should incorporate additional criteria such as groundwater vulnerability, land ownership patterns, and socio-economic considerations to further improve landfill suitability assessment.

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