Journal of
Spatial
Information
Sciences

... JSIS

INTEGRATING FUZZY MULTI-CRITERIA DECISION-MAKING AND GIS FOR SUSTAINABLE LANDFILL SITE SELECTION IN RAPIDLY URBANIZING ILORIN CITY, KWARA STATE, NIGERIA

Gbemisola Olatunde, Ayo Babalola, Oyedapo Ademuyiwa Ipadeola, Temiloluwa Daniel Olatunde

JOURNAL OF SPATIAL INFORMATION SCIENCES ISSN: 2354-3361
VOL. 2, ISSUE 3, PP 151–162, 2025 **DOI:** https://doi.org/10.5281/zenodo.17203344
PUBLISHED 01-10-2025

www.journals.unizik.edu.ng/jsis

INTEGRATING FUZZY MULTI-CRITERIA DECISION-MAKING AND GIS FOR SUSTAINABLE LANDFILL SITE SELECTION IN RAPIDLY URBANIZING ILORIN CITY, KWARA STATE, NIGERIA

Gbemisola Olatunde[1], Ayo Babalola[1], Oyedapo Ademuyiwa Ipadeola[1] Temiloluwa Daniel Olatunde[2]

[1]Department of Surveying and Geoinformatics, University of Ilorin, Nigeria

[2]Department of Surveying and Geoinformatics, University of Benin, Nigeria

*Corresponding Author email: olatunde.g@unilorin.edu.ng

DOI: https://doi.org/10.5281/zenodo.17203344

Abstract

An effective landfill site is essential for sustainable solid waste management, particularly in urban areas experiencing rapid population growth. This study develops a decision support framework for landfill site selection by applying Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and weighted overlay techniques to evaluate potential landfill locations based on various factors. The study area covered Ilorin and its environs in Kwara State, Nigeria. The Fuzzy AHP was applied to determine the weights of relevant criteria, accounting for uncertainty in expert judgment. The weighted overlay technique was then used to integrate the various input criteria maps according to their assigned weights, thereby producing a landfill suitability map for the entire study area. The results of the findings show that 5% and 4% of the study area are unsuitable and less suitable, respectively, while 28% are moderately suitable, and 51% are suitable. On the other hand, 13% of the study area is highly ideal for landfill siting. The output suitability map was validated with two dumpsites. The old and decommissioned dumpsite at Ita Amo, which falls entirely within an unsuitable area, and the currently used site at Ago Aiyekale span both moderately suitable and suitable areas.

Keywords: *Waste management, Landfill, Multi-criteria decision making (MCDM), Fuzzy Analytical Hierarchy Process (FAHP), Geographic Information Systems (GIS).*

1.0 INTRODUCTION

Solid waste management remains a substantial challenge within many developing countries, particularly in rapidly urbanizing regions where population growth and consumption rates continue to escalate [1] [2] [3] [4]. Inefficient and indiscriminate waste disposal is often exacerbated by the inadequacies of existing waste management systems, posing significant environmental and public health risks [5]. Among various waste management methods, landfilling is the predominant technique due to its relative cost-effectiveness and operational simplicity [6] [7] However, landfill practices, especially in regions lacking robust technical, economic, and legal frameworks, present critical environmental and health challenges[8].

In rapidly urbanizing cities like Ilorin and its environs in Kwara State, Nigeria, existing waste management infrastructure struggles to keep pace with growing urban populations and increased waste generation. Consequently, effective landfill site planning and selection become imperative to ensure sustainable development and environmental protection [9].

Appropriate landfill siting requires the systematic consideration of multiple environmental, social, and economic factors [3] [10] [11] [12] [13]. The integration of geospatial technologies and advanced multi-criteria decision-making (MCDM) methodologies has transformed landfill site selection processes by providing structured frameworks to evaluate complex, conflicting criteria more effectively [14] [15] [16]

MCDM approaches, such as the Analytic Hierarchy Process (AHP), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), have long played essential roles in decision-making involving multiple criteria. However, their limitations in handling uncertainty and imprecision, particularly in linguistic expert judgments, have inspired the development of advanced fuzzy set-based methods [17] The Fuzzy Analytic Hierarchy Process (FAHP) enhances traditional AHP by incorporating fuzzy logic, enabling decision-makers to express comparisons in linguistic terms while accounting for uncertainty, thus yielding more reliable criterion weighting [18,19].

Geographic Information Systems (GIS), when combined with MCDM techniques, offer powerful tools for optimizing landfill site selection by overlaying multiple spatial criteria according to their weighted importance to generate suitability maps [20] [21] [22]. Among these techniques, weighted overlay analysis is a valuable GIS method that integrates raster datasets standardized to a common scale to facilitate multi-criteria evaluation.

This study develops a comprehensive landfill site selection framework for Ilorin and the surrounding areas in Kwara State, Nigeria, by applying FAHP for criteria weighting and a weighted overlay GIS technique. This integrated approach aims to provide decision-makers with a scientifically robust and practical tool to identify optimal landfill locations that balance environmental sustainability, socio-economic considerations, and urban growth dynamics.

2.0 THE STUDY AREA

The study area covers six Local Government Areas (LGAs) in Kwara State, Nigeria: Ilorin South, Ilorin East, Ilorin West, Asa, Moro, and Ifelodun. These LGAs form a rapidly urbanizing region and are central to the Ilorin Master Plan and the proposed Ilorin Smart City initiative, highlighting their strategic importance in regional planning and development. Geographically, the area lies between latitudes 8°30'N and 9°30'N and longitudes 4°00'E and 5°30'E.
Topographically, the landscape features gently undulating plains with elevations ranging from approximately 200 to 400 meters above sea level. This physiographic setting affects runoff, drainage, and soil characteristics, which are critical factors in assessing landfill site suitability. The region's diverse climatic, geological, and topographic attributes provide a comprehensive framework for evaluating landfill locations while accounting for environmental, social, and technical considerations unique to the area. The study area map is presented in Figure 1.

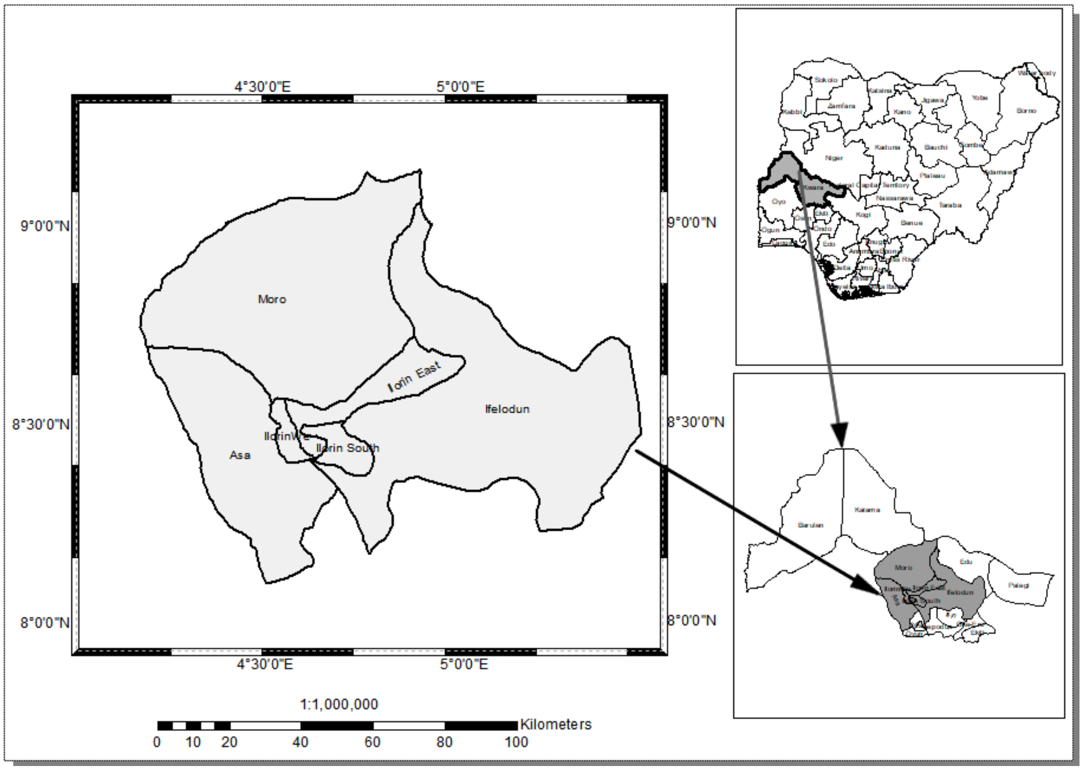

Figure 1: Study area

3.0 MATERIALS AND METHODS

3.1 Methods

This study employed a systematic, multi-criteria decision-making (MCDM) framework integrated with Geographic Information Systems (GIS) to identify optimal landfill sites within Ilorin and its environs in Kwara State, Nigeria. The approach combined environmental, social, and economic criteria, incorporating fuzzy logic to address uncertainties in expert judgments. Figure 2 presents a framework for landfill site selection.

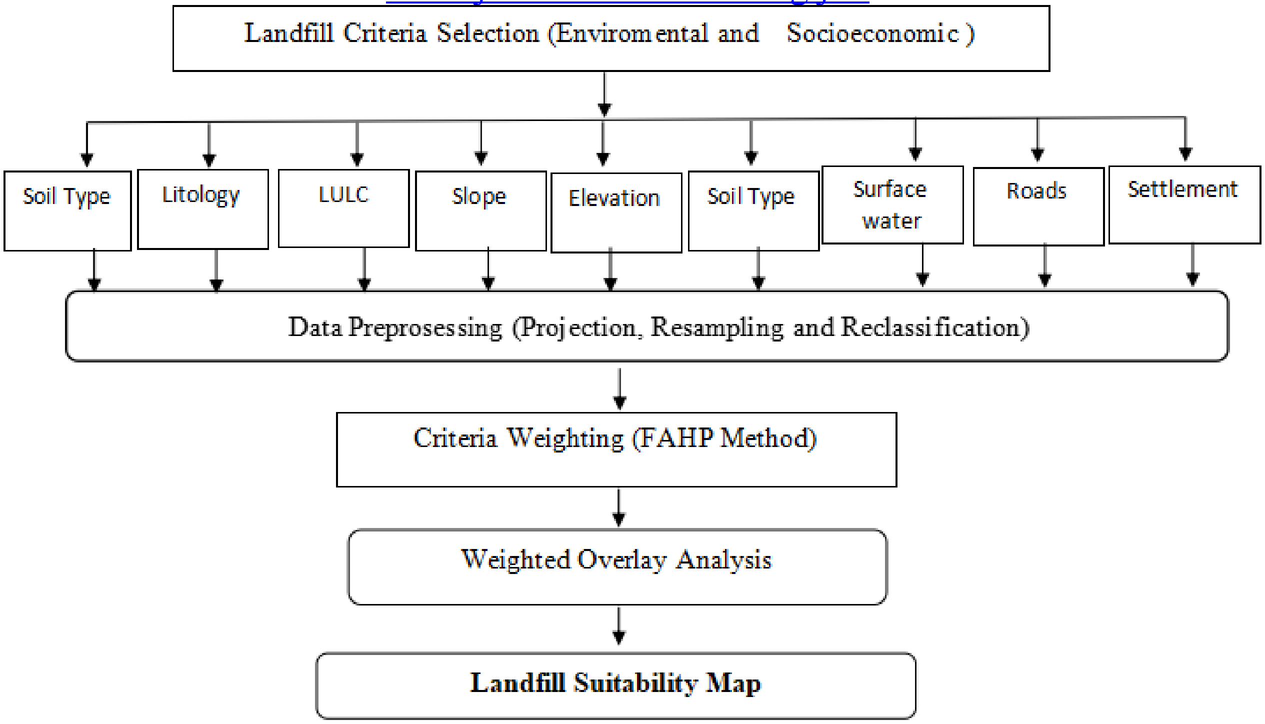

Figure 2: Framework for landfill site selection

3.2 Criteria Selection

Ten pivotal criteria influencing landfill suitability were selected following an extensive literature review and expert consultation. These criteria integrate environmental and socio-economic factors, including proximity to settlements, major and minor roads, water bodies, and rail lines; elevation and slope; land use and land cover (LULC); soil type; and lithology [3] [12]. These factors collectively ensure a balanced assessment of potential environmental impact, accessibility, and operational feasibility.

3.3 Data Acquisition and Processing

Spatial datasets were sourced from reputable repositories to encompass the required thematic layers. Elevation and slope data were derived from the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Digital Elevation Model (DEM) obtained via USGS Earth Explorer. Land use and land cover data were extracted from ESRI's global dataset at a 10-meter resolution. Soil data were acquired from the ISRIC Soil Information portal, while lithological information was obtained from the Africa Surface Lithology database powered by Esri. Hydrological features, transportation networks, and settlement data were retrieved from OpenStreetMap (OSM) [6] [13]. All spatial data layers were preprocessed in ArcGIS 10.8, involving coordinate system standardization to UTM Minna Datum Zone 31, resampling to a uniform 10-meter resolution, and reclassification into standardized suitability classes. This preprocessing ensured spatial compatibility and analytical consistency across all datasets used in subsequent analyses [10].

3.4 Fuzzy Analytic Hierarchy Process (FAHP) for Criteria Weighting

To accurately represent the relative importance of each criterion, the Fuzzy Analytic Hierarchy Process (FAHP) was applied. FAHP extends conventional AHP by integrating fuzzy logic, allowing decision-makers to express pairwise comparisons in linguistic terms to handle uncertainty and subjectivity effectively. Expert judgments were aggregated into pairwise comparison matrices, and fuzzy triangular numbers were utilized to calculate weights. The process culminated in a normalized weight vector reflecting the criteria's prioritized influence on landfill suitability [17] [18].

3.5 Weighted Overlay Analysis

Using the weighted overlay technique in GIS, reclassified raster layers corresponding to each criterion were combined according to their relative FAHP-derived weights. This multi-layer analysis generated a landfill suitability index map, classifying areas into five suitability categories: Unsuitable, Less Suitable, Moderately Suitable, Suitable, and Highly Suitable. The integration of weighted spatial layers enables comprehensive visual identification of optimal landfill locations considering multifaceted criteria [20] [21]. Suitability classification is shown in Table 1.

Table 1: Suitability Classification

Suitability Class	Class Number
Unsuitable	1
Less Suitable	2
Moderately Suitable	3
Suitable	4
Highly Suitable	5

3.6 Validation

The resulting suitability map was validated against existing landfill sites within the study area, specifically, the old, decommissioned dumpsite at Ita Amo and the operational site at Ago Aiyekale. This validation assesses the model's reliability by comparing identified suitability classifications with known site performance and characteristics [23].

4.0 RESULTS AND DISCUSSION

4.1 Criteria Weighting and Maps

Using the Fuzzy Analytic Hierarchy Process (FAHP), weights were assigned to ten criteria based on expert judgment (Table 2). Proximity to water bodies received the highest weight (25.15%), indicating its paramount importance in protecting water resources from contamination. This was followed by proximity to settlements (19.58%) and land use/land cover (LULC) (14.33%), reflecting concerns over environmental and social impacts. Elevation (7.64%) and lithology (7.26%) had moderate influence, while slope (6.04%), soil type (5.88%), and transportation factors, proximity to highways (5.52%), major roads (4.85%), and rail lines (3.76%) had lesser, but significant impacts on landfill suitability. The consistency ratio of 0.086 confirmed the reliability of the weighting process [3] [18]. The criteria maps are presented in Figures 3(a-j).

Table 2: Criteria Weights

Criteria	Weight (%)
Proximity to Water Bodies	25.15
Proximity to Settlements	19.58
LULC	14.33
Elevation	7.64
Slope	6.04
Litology	7.26
Soil_Type	5.88
Proximity to Highway	5.52
Proximity to Major Roads	4.85
Proximity to the Rail line	3.76

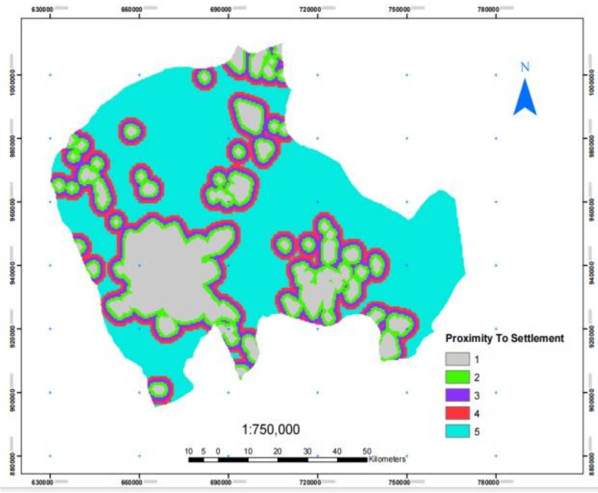

Figure 3a: Proximity of Settlement Map

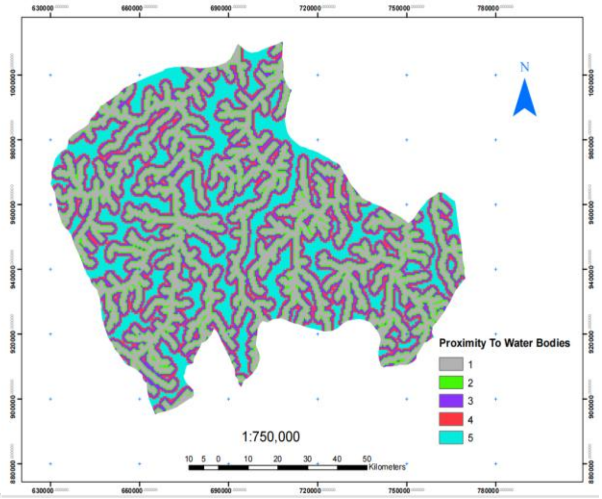

Figure 3b: Proximity to Water Bodies Map

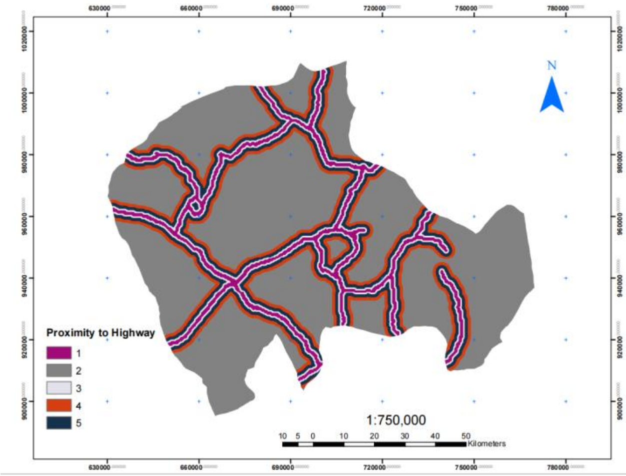

Figure 3c: Proximity to Highway Map

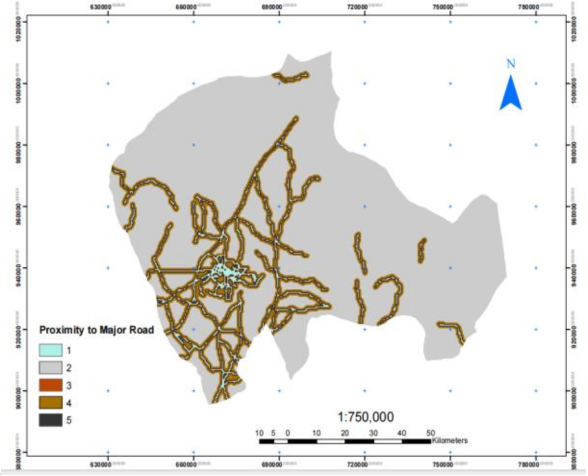

Figure 3d: Proximity to Major road Map

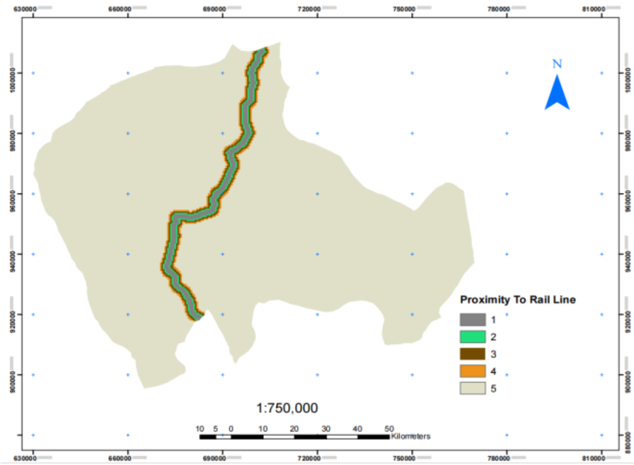

Figure 3e: Proximity to Rail Line Map

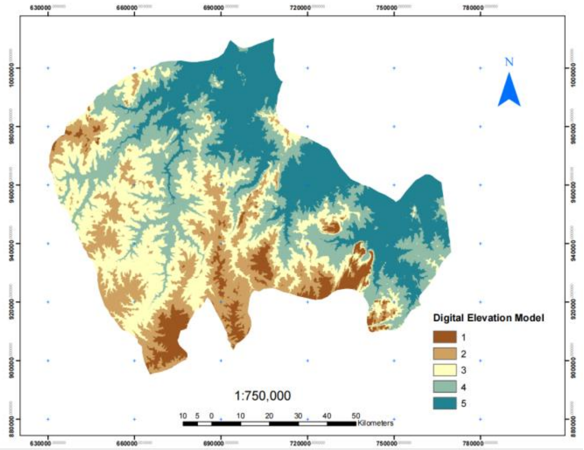

Figure 3f: Digital Elevation Model Map

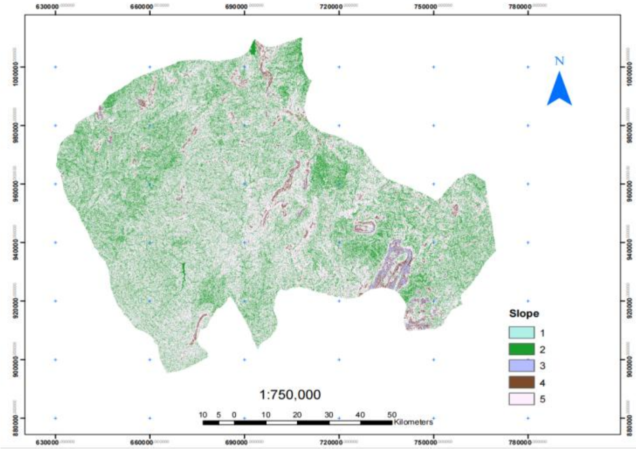

Figure 3g: Slope

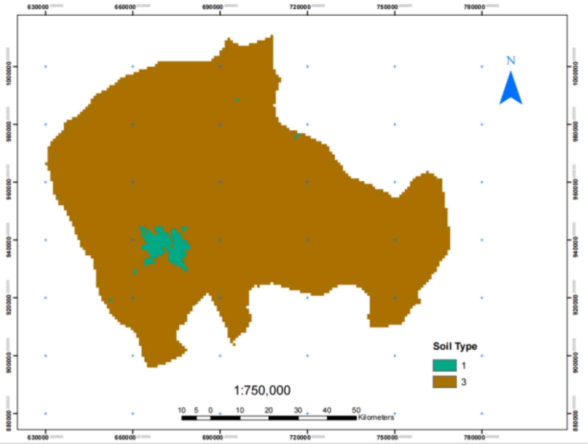

Figure 3h: Soil Type

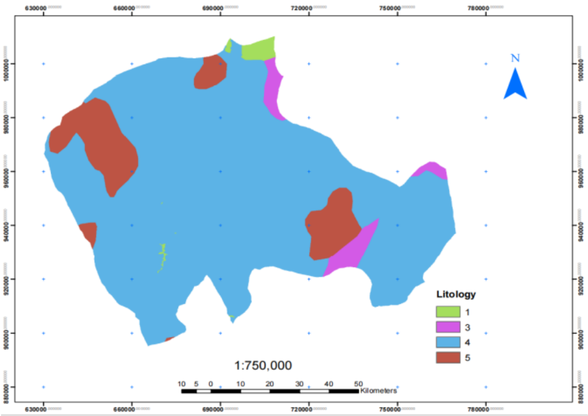

Figure 3i: Litology

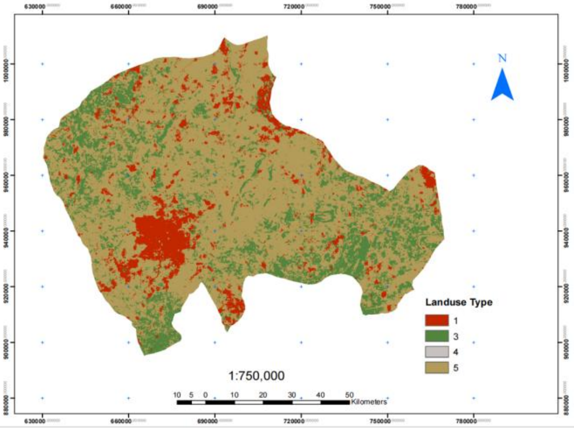

Figure 3j: Landuse Land cover(LULC)

4.2 Landfill Suitability Mapping

The GIS-based weighted overlay technique integrated the weighted criteria to produce a landfill suitability map (Figure 4). The area was categorized into five classes: Unsuitable (3.74%), Less Suitable (4.66%), Moderately Suitable (27.75%), Suitable (50.98%), and Highly Suitable (12.86%). Over 63% of the study area was deemed suitable or highly suitable for landfill development, suggesting substantial availability of potential sites across Ilorin and its environs. Moderately suitable zones may require further investigation or mitigation measures before development.

Table 3: Landfill Suitability Classification

Class	Suitability Class	Area COVERAGE (%)
1	Unsuitable	3.74
2	Less Suitable	4.66
3	Moderately Suitable	27.75
4	Suitable	50.98
5	Highly Suitable	12.86

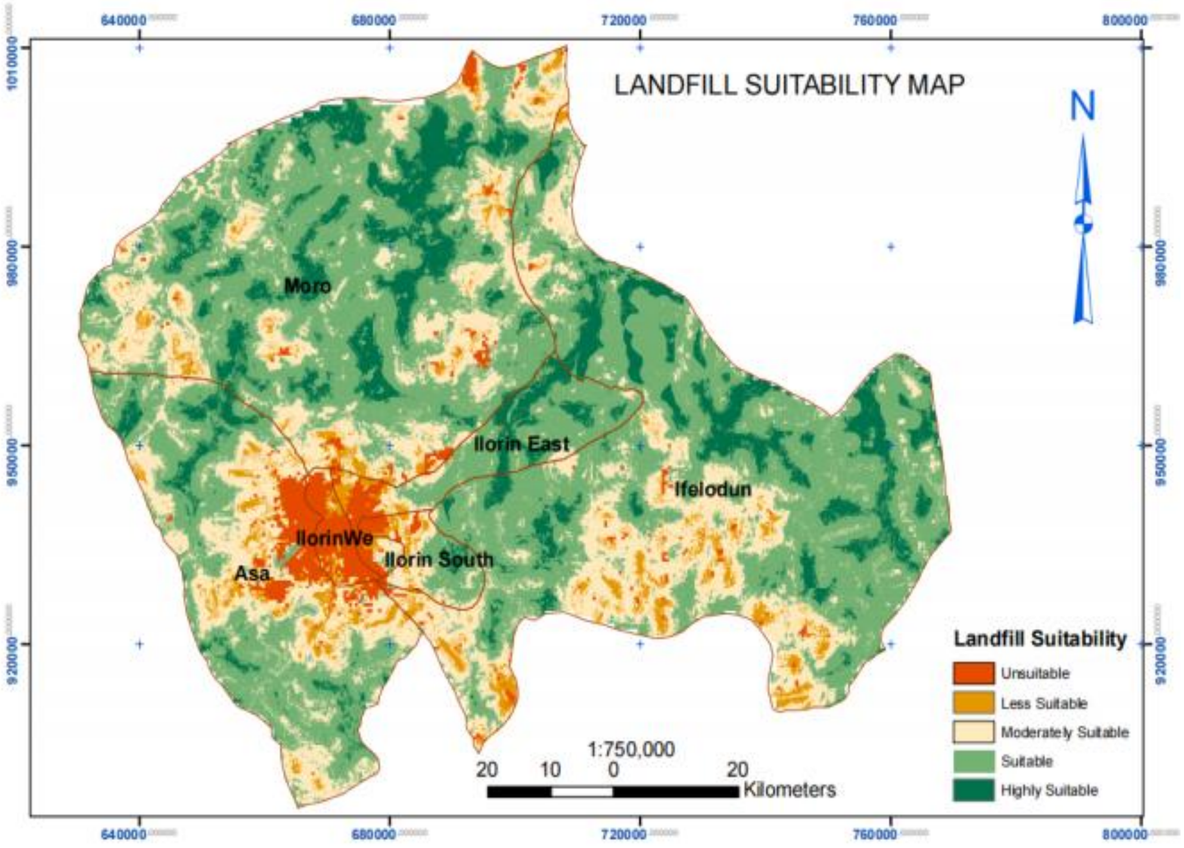

Figure 4: Landfill Suitability Map

4.3 Validation of Results

The model's practical validity was assessed by overlaying the suitability map with existing landfill locations. The old and decommissioned dump site at Ita Amo coincided with an unsuitable class, indicating historical challenges in siting. Conversely, the current operational landfill at Ago Aiyekale fell into moderately to suitable classes, affirming the model's accuracy in identifying viable landfill sites [13] [23].

4.4 Implications for Sustainable Landfill Planning

The study demonstrates that careful consideration of multiple environmental, social, and infrastructural factors is essential for sustainable landfill siting. Particularly, safeguarding water bodies and minimizing disruption to settlements must remain priorities. This integrated FAHP-GIS approach provides urban planners and waste management authorities in rapidly urbanizing regions with a scientifically robust tool for evidence-based decision-making, promoting environmental protection and community wellbeing.

5.0 CONCLUSION

This study successfully applied an integrated multi-criteria decision-making framework using the Fuzzy Analytic Hierarchy Process (FAHP) combined with Geographic Information Systems (GIS) to identify optimal landfill sites within Ilorin and surrounding areas in Kwara State, Nigeria. Ten environmental and socio-economic criteria were systematically weighted and spatially analyzed to produce a landfill suitability index map. The findings reveal that more than half of the study area is classified as suitable or highly suitable for landfill development, while a smaller proportion is moderately suitable or less appropriate. Proximity to water bodies, settlements, and land use patterns were identified as the most critical factors influencing site suitability, highlighting the need to minimize environmental contamination and social disruption.

Validation against existing landfill sites demonstrated the robustness of the model in distinguishing unsuitable from viable locations, supporting its practical applicability for informed decision-making. This evidence-based approach provides a replicable tool for sustainable landfill planning in rapidly urbanizing contexts, balancing operational feasibility with environmental protection and community welfare. Future work may extend this framework by incorporating additional environmental factors such as groundwater vulnerability, drainage infrastructure, and socio-political considerations to further refine site selection outcomes. Overall, the study contributes valuable insights and a scientific basis for effective solid waste management planning and landfill siting in Nigeria and comparable urban regions.

REFERENCES

[1] Sylvester, O., & Ikudayisi, O. (2021). An overview of solid waste in Nigeria: Challenges and management. *Jordan Journal of Earth and Environmental Sciences, 12*(3), 149–157. https://doi.org/10.5455/jjees.2020.12.3.15

[2] World Bank. (2022, February 11). Solid waste management. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste

[3] Abdulwaheed, A. A., Agboola, S. A., Moshood, B. B., Adeniyi, G., & Abdulsalam, M. A. (2024). Selection of suitable landfill site for waste disposal in Ilorin metropolis using geographical information system. *UNIOSUN Journal of Engineering and Environmental Sciences, 6*(1). https://doi.org/10.36108/ujees/4202.60.0171

[4] Raphela, T., Manqele, N., & Erasmus, M. (2024). The impact of improper waste disposal on human health and the environment: A case of Umgungundlovu District in KwaZulu Natal Province, South Africa. *Frontiers in Sustainability, 5*, Article 1386047. https://doi.org/10.3389/frsus.2024.1386047

[5] Ibikunle, R., Titiladunayo, I., Dahunsi, S., Akeju, E., & Osueke, C. (2021). Characterization and projection of dry season municipal solid waste for energy production in Ilorin metropolis, Nigeria. *Waste Management & Research, 39*(8), 1048–1057. https://doi.org/10.1177/0734242X20985599

[6] Ogunmakinde, O., Sher, W., & Maund, K. (2019). An assessment of material waste disposal methods in the Nigerian construction industry. *Recycling, 4*, 13. https://doi.org/10.3390/recycling4010013

[7] Yaashikaa P. R, Senthil Kumar P, Varjani S. Valorization of agro-industrial wastes for biorefinery process and circular bioeconomy: A critical review. Bioresour Technol. 2022 Jan;343:126126. doi: 10.1016/j.biortech.2021.126126. Epub 2021 Oct 19. PMID: 34673193.

[8] Osazee, I. T. (2021). Landfill in a sustainable waste disposal. *European Journal of Environment and Earth Sciences, 2*(4), 67–74. https://doi.org/10.24018/ejgeo.2021.2.4.165

[9] Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. A. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research, 29*, 58514–58536. https://doi.org/10.1007/s11356-022-21578-z

[10] Babalola, A., & Busu, I. (2011). Selection of landfill sites for solid waste treatment in Damaturu town-using GIS techniques. *Journal of Environmental Protection, 2*, 1–10. https://doi.org/10.4236/jep.2011.21001

[11] Ibrahim Mohammed, H., Majid, Z., & Bello Yamusa, Y. (2019). GIS based sanitary landfill suitability analysis for sustainable solid waste disposal. IOP Conference Series: Earth and Environmental Science, 220(1), 012056. https://doi.org/10.1088/1755-1315/220/1/012056

[12] Fernandez Nascimento, V., Loureiro, A. I. S., Andrade, P. R., Guasselli, L. A., & Ometto, J. P. B. (2020). A worldwide meta-analysis review of restriction criteria for landfill siting using geographic information systems. *Waste Management & Research, 39*(3), 409–426. https://doi.org/10.1177/0734242X20962834

[13] Oyedele, A. A., Omosekeji, A. E., Ayeni, O. O., Ewumi, T. O., & Ogunlana, F. O. (2022). Delineation of landfill sites for municipal solid waste management using GIS. *Journal of Human, Earth, and Future, 3*(3), 321–336. https://doi.org/10.28991/HEF-2022-03-03-05

ISSN: 2354-3361
DOI: https://doi.org/10.5281/zenodo.17203344

[14] Alkaradaghi, K., Ali, S. S., Al-Ansari, N., Laue, J., & Chabuk, A. (2019). Landfill site selection using MCDM methods and GIS in the Sulaimaniyah Governorate, Iraq. *Sustainability, 11*(17), 4530. https://doi.org/10.3390/su11174530

[15] Arabeyyat, O. S., Shatnawi, N., Shbool, M. A., & Al Shraah, A. (2024). Landfill site selection for sustainable solid waste management using multiple-criteria decision-making: Case study: Al-Balqa governorate in Jordan. *MethodsX, 12*, 102591. https://doi.org/10.1016/j.mex.2024.102591

[16] Awadhesh Kumar, Rana, N. K., & Kumar, A. (2025). Integration of multi-criteria decision model, analytic hierarchy process and geographic information system for landfill site selection: An overview of Varanasi City. *Current World Environment*. https://api.semanticscholar.org/CorpusID:275553454

[17] Kaya, İ., Çolak, M., & Terzi, F. (2019). A comprehensive review of fuzzy multi criteria decision making methodologies for energy policy making. *Energy Strategy Reviews, 24*, 207–228. https://doi.org/10.1016/j.esr.2019.03.003

[18] Emrouznejad, A., Ho, W., & Cahyono, S. T. (2022). *Fuzzy analytic hierarchy process* [Book].

[19] Varshney T, Waghmare AV, Singh VP, Meena VP, Anand R, Khan B. Fuzzy analytic hierarchy process based generation management for interconnected power system. Sci Rep. 2024 May 20;14(1):11446. doi: 10.1038/s41598-024-61524-2. PMID: 38769344; PMCID: PMC11106267.

[20] Sisay, G., Gebre, S. L., & Getahun, K. (2021). GIS-based potential landfill site selection using MCDM-AHP modeling of Gondar Town, Ethiopia. *African Geographical Review, 40*(2), 105–124.

[21] Saha, P., & Roy, M. (2024). Identification of municipal solid waste disposal sites for sustainable solid waste management in Cooch Behar Municipality, West Bengal: A RS-GIS based MCDA approach. *Waste Management Bulletin, 2*(3), 127–144. https://doi.org/10.1016/j.wmb.2024.07.004

[22] Mulualem, B., Ayenew, T., Tesfaw, G., & others. (2025). Geospatial and multi-criteria decision analysis for sustainable solid waste disposal site selection in Debre Tabor, Ethiopia. *Discover Sustainability, 6*, 475. https://doi.org/10.1007/s43621-025-01365-9

[23] Tella, A., Mustafa, M. R. U., Animashaun, G., et al. (2025). Data-driven landfill suitability mapping in Lagos State using GIS-based multi-criteria decision making. *International Journal of Environmental Science and Technology, 22*, 3181–3196. https://doi.org/10.1007/s13762-024-05803-5