Vol. 10 No. 2 (2026): Journal of Contemporary Social Research
Journal Link: https://aa.unij.co.uk/index.php/jcsr / Pub. Link: https://aa.unij.co.uk/index.php/jcsr/issue/view/12

GIS- and Remote Sensing-Based Identification of Suitable Agricultural Waste Landfill Sites for Climate-Smart Agriculture in Ilorin, Nigeria

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DOI: https://doi.org/10.5281/zenodo.23168429

Abstract

Lack of a designated landfill for agricultural waste management (AWM) in Ilorin municipalities led to indiscriminate disposal of agricultural waste within the city and the only existing Sokoto-Ayekale general solid waste dumpsite, posing environmental and public health risks while undermining climate-smart agriculture (CSA). The study identifies suitable landfill sites for AWM by integrating Geographic Information System (GIS), Remote Sensing (RS), and Multi-Criteria Decision Analysis (MCDA) to locate environmentally and climate-resilient sites. Spatial data employed for the study include Shuttle Radar Topography Mission (SRTM), Landsat 9 imagery, Digital Elevation Model (DEM), road networks, waterbodies, built-up areas, soil quality, slope, and geology, which were processed in ArcGIS 10.3 to develop constraint thematic suitability maps. The Analytical Hierarchy Process (AHP) was employed to derive criterion weights, and the Weighted Linear Combination (WLC) was used to generate the map. AHP consistency ratio (CR) was used to validate the model's consistency (CR=0.016), which falls within the acceptable CR <0.1. The AHP weighted results were 0.41, 0.2, 0.14, 0.10, 0.08, and 0.07 for waterbodies, built-up area, slope, soil quality, geology, and road network, respectively. Maps were created for each criterion, reclassified, and integrated using the weighted linear combination method to generate an overall AWM suitability map. The study identified four potential locations for AWM. Approximately 507.23 km² are unsuitable, 1204.21 km² are marginally suitable, 4899.28 km² are moderately suitable, and 2021.7 km² are highly suitable for AWM landfill development. The findings present a scientifically based decision-support framework to guide policymakers, environmental agencies, and urban planners in developing sustainable AWM strategies that minimize environmental risk while advancing climate-smart agriculture.

Keywords: Agricultural waste, Climate-smart agriculture, Landfill, Suitability, Sustainability

INTRODUCTION

Agricultural waste management (AWM) is a critical issue globally, particularly in developing countries such as Nigeria, where rapid population growth and high demand for agricultural products have led to a significant increase in waste generation. This makes it imperative to adopt sustainable waste management practices (Maji et al., 2020). In this study, agricultural waste (AW) refers to the residual fraction of waste from agricultural operations that cannot be feasibly recycled, composted, reused, or recovered for energy due to contamination, disease risks, technological or technical limitations, or economic constraints (Abhilash et al., 2021; Lackner & Besharati, 2025). Circular economy (CE) promotes waste prevention, reduction, reuse, recycling, anaerobic digestion, and energy recovery as preferred AWM strategies; landfill disposal remains a quintessential component of integrated AWM. Developing countries' inadequate infrastructure, paucity of investments in waste-to-energy technologies, and poor segregation practices hinder the full implementation of CE approaches in support of CSA. Thus, a significant portion of the generated agricultural waste (AW) and residuals, including pesticide- or herbicide-contaminated, crop residues, mould-infested grains, unincinerable carcasses, and ash from biomass burning or incineration, among others, still requires disposal in engineered landfills after CE resource recovery options have been exhausted. Rather than conflicting with the CE approach, scientifically selected landfills complement sustainable AWM by identifying environmentally safe locations for the disposal of generated AW residual that cannot be economically recovered or recycled.

The first organised public waste management system can be traced back to the Roman Empire; the purpose of waste collection and disposal was to protect the health of inhabitants and improve the aesthetic appeal of their territories (World Bank, 2018). Management of waste in developing countries is gaining more attention as a result of increase in generation with no or a lack of proper management (Hantoko et al., 2021). An environment polluted by solid waste hinders the ability of nature to provide basic resources such as quality air, water and land. Also, improper solid waste management can limit the environment from performing its basic functions such as replenishing resources, carbon sink, waste assimilation, and recycling potency of nature (Brandão et al., 2021; Kraham, 2017). Nature has the ability to replenish itself back to its pristine form, but due to man's anthropogenic activities the ability is impaired (Goudie, 2018; Ødegaard, 2022). The rate at which waste is generated exceeds the rate of self-cleansing by nature through natural processes without input from man (Mitra et al., 2026). Therefore, nature's ability is impaired, and humans are at the receiving end of the adverse effects of their actions. Air, water and land could be polluted due to improper solid waste management. Developing nations and the poor are usually exposed to the impact of these effects (Berneji et al., 2026; Mishra et al., 2026). According to Paul (2022), environmental impacts such as air pollution and acid rain that could result from improper solid waste management have no clear boundary and transcend beyond the region in which they are generated.

The need for a dedicated AW landfill suitability assessment (LSA) is particularly important in Ilorin, Kwara State, where increasing agricultural production and demand have resulted in growing volumes of agricultural AW. Despite the city's strategic role as an agricultural and commercial centre in North-Central Nigeria, there is no designated landfill specifically developed for AWM. Instead, AWs are disposed of at the government-designated Sokoto-Ayekale general solid waste dumpsite or through indiscriminate dumping. Indiscriminate disposal of AW is one of the major causes of environmental degradation and public health concerns. These wastes may contain a mixture of AW, such as pesticides, herbicides, animal waste, processing residues, weeds and grasses, and general AW that are susceptible to burning, and their exposure poses a threat to human and animal health (Nalwanga et al., 2023; Padmanabhan, 2019). Major risks and impacts of mismanaged AW in the environment, as described by Kumari et al. (2020), include air pollutants such as carbon dioxide, methane (CH_4), ammonia (NH_3), nitrous oxide (N_2O), and particulate matter (PM) that are usually released during the decomposition of animal faeces such as cow dung under poor AWM conditions. Other pollutants and leachates generated as a result of the decomposition of waste may contaminate air, surface, and groundwater sources; cause fire hazards; and pose public health risks (Mrozik et al., 2021).

However, the change in land-use and the continuous increase in residential developments and the lack of spatially informed development planning for AWM highlight the importance of a comprehensive LSA in Ilorin. The use of GIS, RS, AHP, and MCDA to identity areas that are environmentally suitable and sustainable based on rapid land-use changes, expanding residential developments, and the absence of spatially informed planning for AWM highlight the need for a comprehensive LSA in Ilorin. Identifying environmentally suitable locations using GIS, RS, AHP, and MCDA will provide scientific evidence to support sustainable land-use planning, improve AWM, and assist policymakers in developing climate-resilient waste management strategies for Ilorin.

The use of GIS and remote sensing (RS) technologies provides a rigorous decision-support framework for addressing the challenges of AWM by the identification of environmentally suitable landfill locations. The combination of various spatial data sets and MCDA enabled a systematic evaluation of factors such as proximity to residential areas, water bodies, and geology to identify optimal locations for AWM to enhance CSA. Despite the advancement and increasing application of GIS techniques in waste management and planning, research attention has been focused largely on municipal solid waste disposal, with limited attention on agricultural waste landfill suitability. Therefore, this study applies GIS and RS integrated with MCDA to identify suitable AW landfill sites in Ilorin, Kwara State, Nigeria, providing a scientific basis for sustainable waste management planning and CSA development. Previous studies have focused mainly on municipal solid waste, whereas little attention has been given to agricultural waste landfill suitability in Ilorin using GIS-MCDA.

MATERIAL AND METHODS

Study Area

For the study, three (3) local government areas, viz., Ilorin East, Ilorin West, and Ilorin South in Kwara State, consisting of 35 wards, were chosen (Figure 1). It is located geographically on latitudes 8° 24´ N and 8° 36´ N and along longitudes 4° 10´ and 4° 36´ E of the Greenwich Meridian, with an estimated land area of 765 km² and an average altitude of 300 m (Ibikunle et al., 2021; Alimi et al., 2023). It has an annual mean rainfall value of 1200 mm and an average monthly temperature that fluctuates between 25 and 29.5°C, with March having the maximum of 30°C (NiMET, 2021). According to the World Population Review (2024) estimation, Ilorin has a population of 1,063,713 inhabitants. The Kwara State Environmental Protection Agency (KWASEPA) is saddled with the responsibility of managing waste generated in the state.

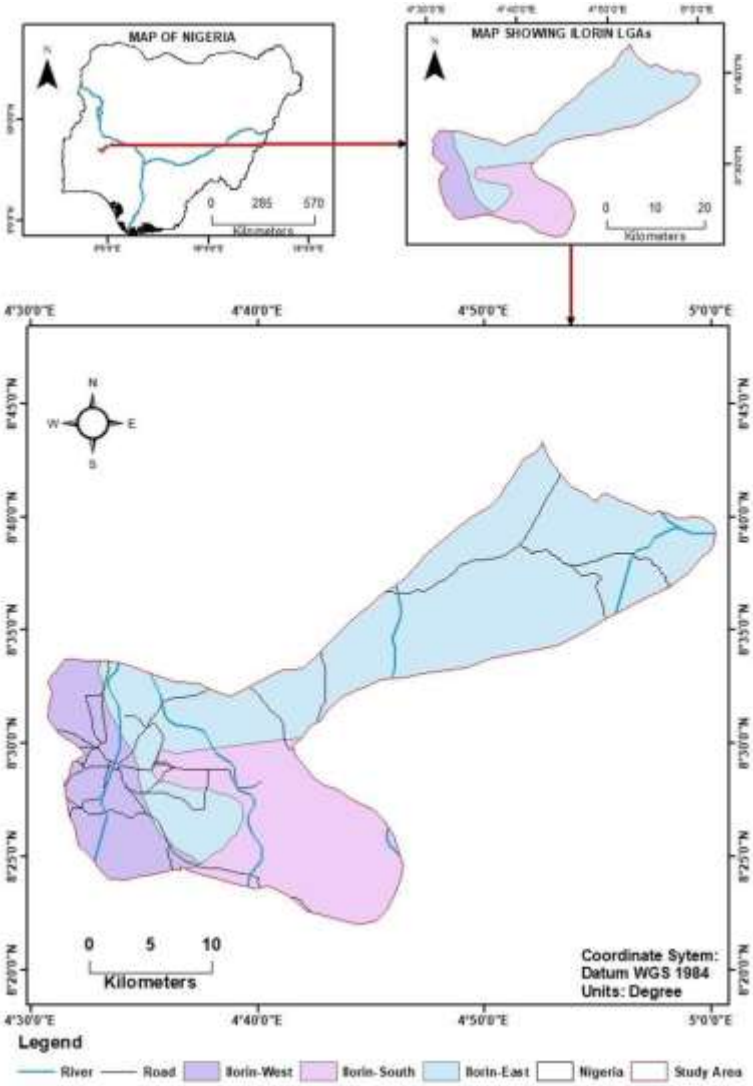

Figure 1: Study Area

Modelling Approach

The data and material used for this research are LANDSAT 9 Operational Land Imager (OLI) imagery acquired in the year 2022 at a spatial resolution of 30 m, from which a land cover map of the study area was produced. Elevation and slope of the study area were generated using Shuttle Radar Topography Mission (SRTM) imagery at 30 m resolution covering the study area, which was also used in the research to generate the elevation and slope of the study area. The geological map was obtained from the Nigeria Geological Survey, from which the geology of the study area was extracted. The FAO/UNESCO soil map was used to extract the soil types in the study area. GeoEye satellite imagery of the study area obtained from Google Earth was used to map out the railroad and the existing government-approved open dumpsites. Land cover types were extracted from LANDSAT, and the road network was extracted from Google Earth. The geometric data (coordinates) of the existing dumpsites within the study area were acquired through a field survey using a Global Positioning System (GPS).

Identification and Reclassification of Potential Agricultural Waste Landfill Using Multi-Criteria Decision Analysis (MCDA)

The process of determining the most suitable location for the AW landfill in the study area was multifaceted, drawing upon different datasets and criteria in accordance with the guidelines outlined in the Environmental Protection Agency (EPA) Landfill Manual of 2006 (Table 1). GIS technology was used to create constraint maps based on EPA guidelines. Suitability criteria created include road networks, waterbodies, built-up areas, soil quality, slope, and geological characteristics, with a consistency index of $0.016 < 0.1$. The Analytical Hierarchy Process (AHP) was employed within the multi-criteria decision analysis (MCDA) to prioritise decisions. A square matrix referred to as a pairwise comparison matrix used in AHP to compare the relative importance of two alternative criteria at a time was employed. Maps are created for each criterion, and specific values are assigned through reclassification (Table 2). The weighted linear combination (WLC) approach is used to overlay these maps to determine the most suitable landfill site. This endeavour involved several key steps, including the integration of both acquired datasets and an analogue map (geological map) into a digital format compatible with ArcGIS 10.3 software.

Buffer Analysis of Suitability Criteria

The application of buffer analysis resulted in the creation of maps that define areas judged suitable and unsuitable for the establishment of a landfill in the study area for AWM.

Water Body

According to Alao et al (2023) and Tesseme et al (2022), the potential environmental hazards associated with landfill sites are indeed a matter of great concern, particularly in their proximity to surface water sources. These sites could release noxious gases and, more critically, pose a risk of waste- related chemical leakage, which can lead to contamination of surrounding water bodies (Dasila et al., 2023). The EPA (2006) landfill manual was consulted to create constraint map of water bodies. The water bodies' buffer and ranking maps depicted in Figures 2 and 3 delineates various zones. Areas highly suitable for landfill is ranked 4 and 1 representing not suitable. Areas

least suitable and moderately suitable for landfill are represented by 2 and 3 respectively. The zones ranked 1, are greater than 960 m from water bodies and are the most appropriate, while zones within 0-160 m are ranked as 1 and are unsuitable. Distances at 480–960 m and 160–480 m are ranked 3 and 2 to depict moderately and least suitable areas, respectively.

In alignment with the findings, areas greater than 960 metres from water bodies are considered safe for landfill placement in the study area to prevent water body pollution. This inference resonates with the perspectives of Deniz and Topuz (2018), regarding areas within or equal to 100 metres as unsuitable for landfills. Additionally, studies by Khan and Samadder (2015), Torabi-Kaveh et al. (2016), and Makonyo and Msabi (2022) differ, and declared any site within 500 m to water body as unsuitable for landfill irrespective of criteria selection or ranking. Ajibade et al. (2022) support the study's outcome, emphasising that landfill sites should be more than 960 m away from water bodies to safeguard against pollution. This finding aligns with the assertions of Khan and Samadder (2015) and Yousefi et al. (2017) regarding the appropriate siting of Solid Waste landfills.



Figure 2: Water body buffer

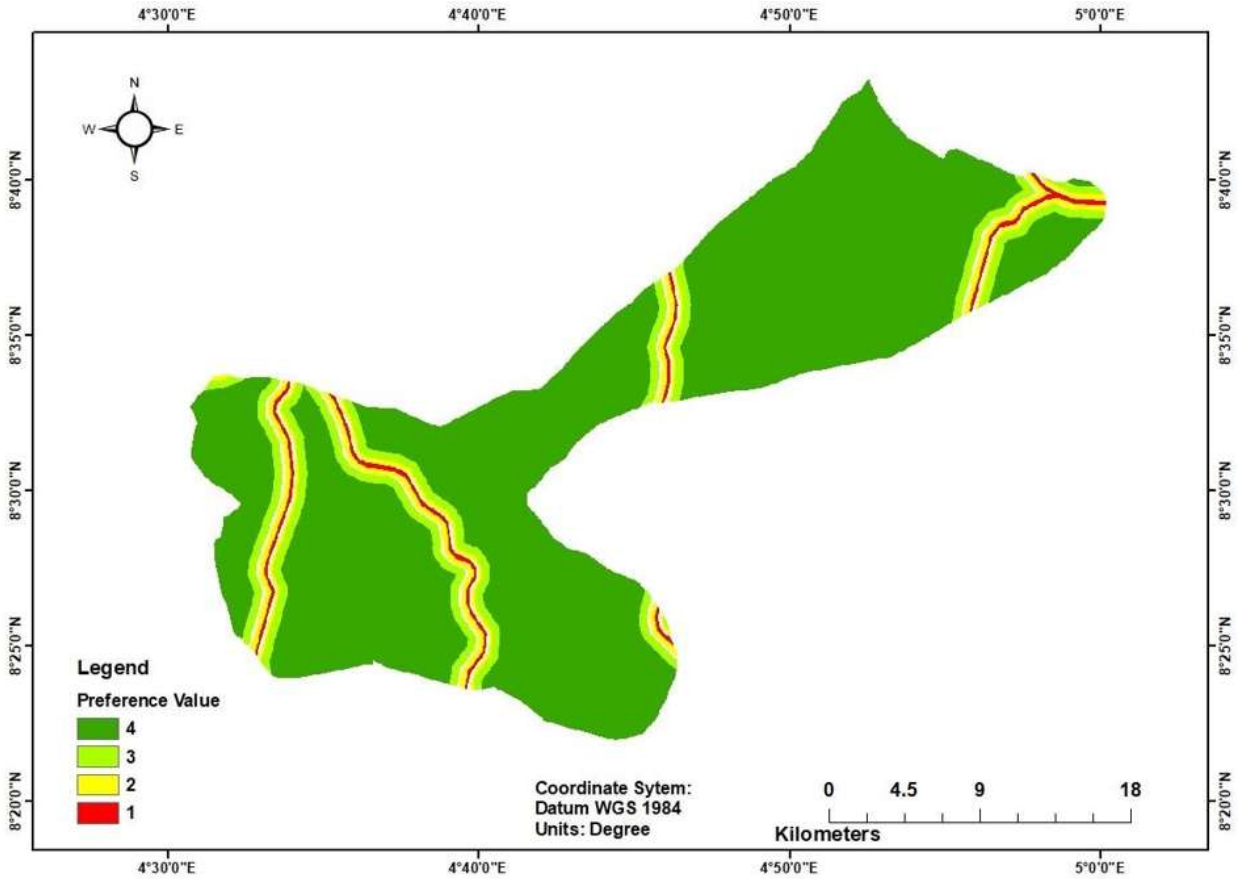

Figure 3: Reclassified water body map

Road Network

The optimal siting of landfills involves striking a balance between proximity to roads and collection points (Balew et al. 2022). The proximity of landfill to road at a reasonable distance is significant in site selection process, with several compelling advantages (Liu et al., 2021; Roy et al., 2022). The concern is to prevent delays in the collection and conveyance of AW to the disposal sites. Locations far from roads pose challenges, as constructing new minor roads becomes economically burdensome and contributes to environmental pollution through increased fossil fuel consumption for long-distance travel (Oguntoke and Adeyemi, 2017; Balew et al., 2022; Sisay et al., 2021). While areas too close landfills are under the possible threat of leachate, odours and socio-economic effect of its proximity. The road buffer maps are illustrated in Figures 4 and 5. Areas ranked 1 (0 – 100 m) are unsuitable for landfill while areas ranked 4 (100 – 1000 m) are highly suitable based ranking formulated from EPA (2006) standard. Areas ranked 3 1(000 – 2000 m) while those ranked 2 (> 2000 m) are least suitable for landfill placement. These findings align with the stand of Ajibade et al. (2022) and Khan and Samadder (2015) for avoiding distances greater than 1000 m from main roads and highways, emphasising the cost implications of constructing new roads and the increased transportation and collection costs of

solid waste. The consensus among Mitab et al. (2023) and Karimi et al. (2019) further supports a distance between 200 and 500 metres from the main road as the most suitable, ensuring that potential landfill sites are strategically located for efficient and cost-effective transportation of solid waste.

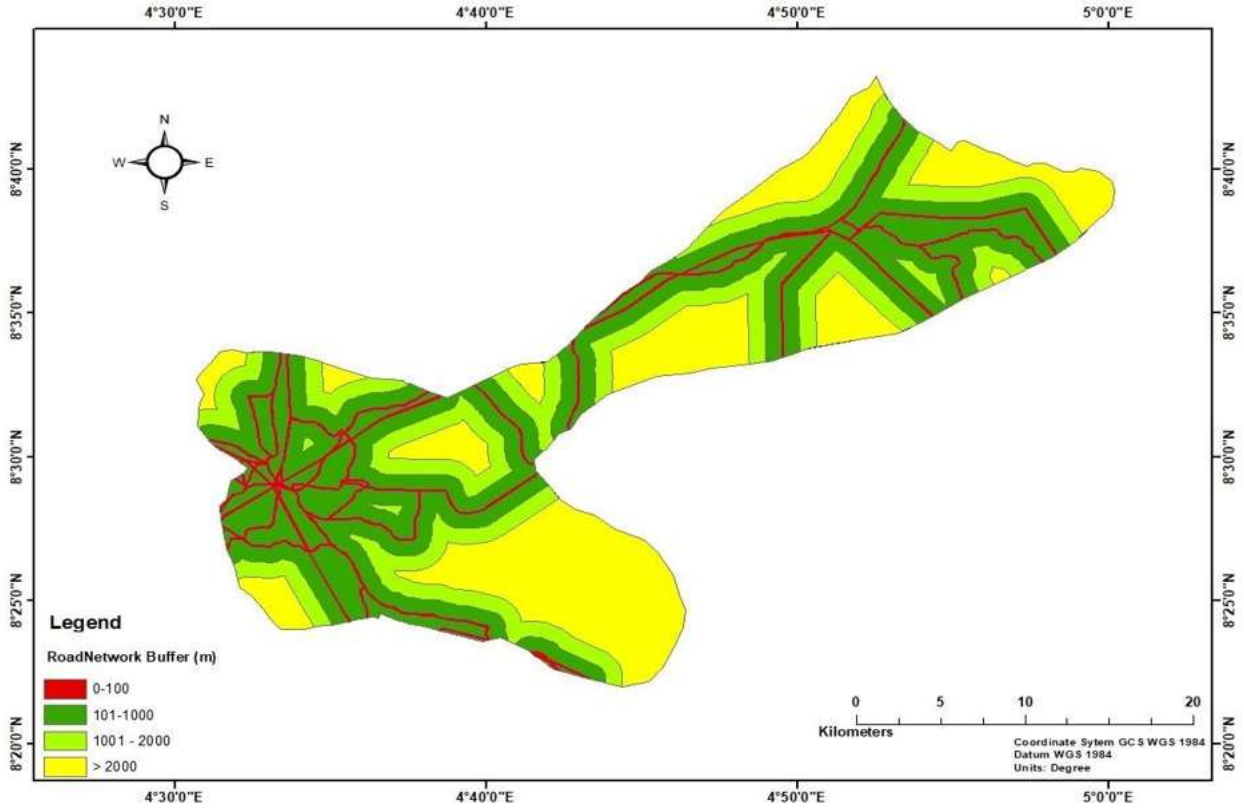

Figure 4: Road Network buffer

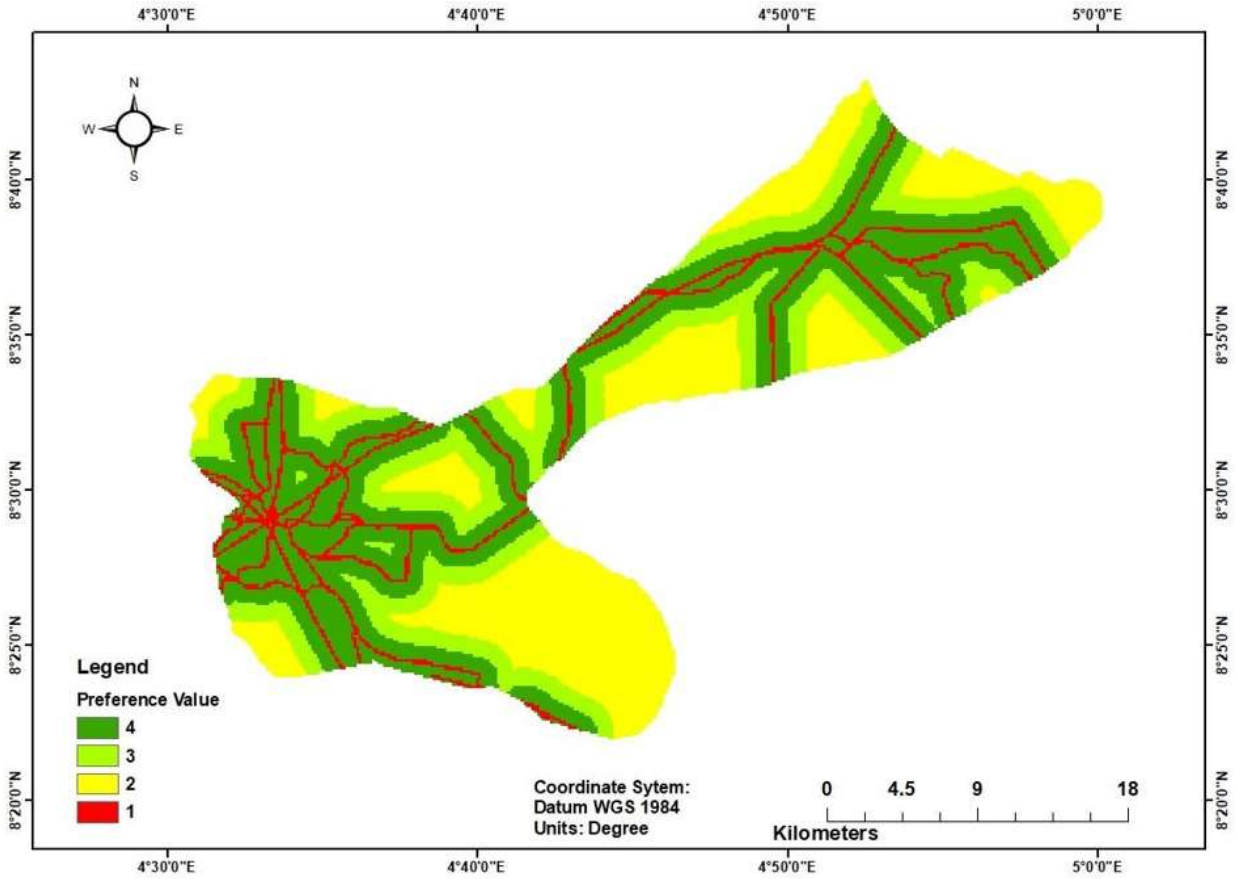

Figure 5: Reclassified Road network map

Built-up Area

Maintaining a safe distance between landfills and built-areas and or human settlement is paramount to reducing exposure to unpleasant odours and avoiding associated health risks (Cannon, 2020; Pereira et al., 2021). The guidelines established by the Environmental Protection Agency (EPA, 2006) serve as a valuable reference in ensuring that landfills are situated at a safe distance from built-up areas. The strategic consideration of human settlement (built-up area) emerges as a crucial factor in public acceptance of landfill locations in a specific location (Banjoko and Shuaib, 2023; Popoola et al., 2023). In order to mitigate issues such as odours and the proliferation of vector organisms such as flies that may arise from the establishment of AW landfills in the study area, built-area buffer map was created. From the buffer map, areas ranked 1 (0–300 m) are unsuitable for landfill, while areas ranked 4 (300–500 m) are highly suitable (Figures 6 and 7). It is a well-established principle that landfill sites should steer clear of residential or urban areas to prevent adverse impacts on human and animal health and land value and to avoid impeding future development (Balew et al., 2022; Girma and Teshome, 2023; Mitab et al., 2023). This approach safeguards communities from potential environmental hazards associated with landfill sites. However, it's worth noting that this stance deviates from Demesouka et al. (2014) and Makonyo and Msabi (2022) perspectives for landfills to be situated

within 10000 m but not within 500 and of 2500 m from built-up areas respectively. For this study, a distance within the range of 300–500 m from built-up areas was categorised as highly suitable for landfill siting, reflecting a complex consideration of both environmental and developmental concerns in the quest for a balanced and sustainable waste management strategy for landfill site selection.

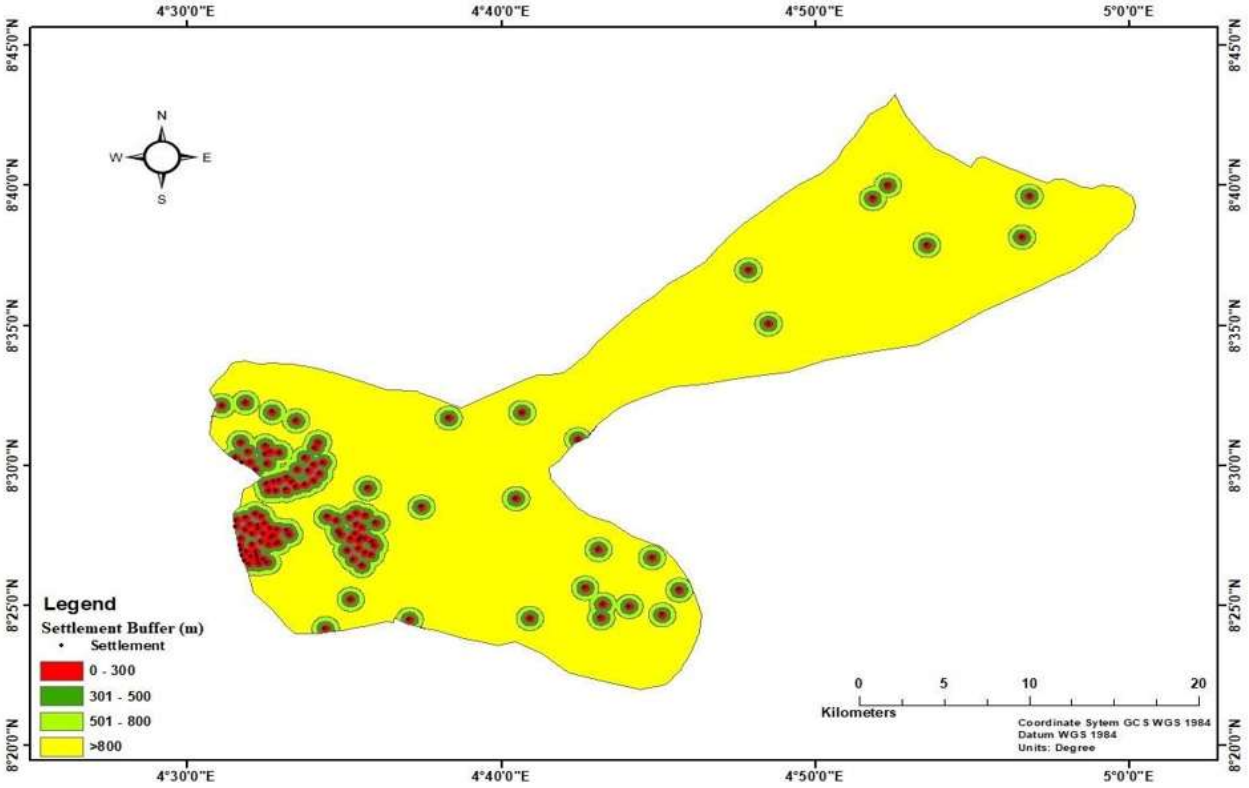

Figure. 6: Built area buffer

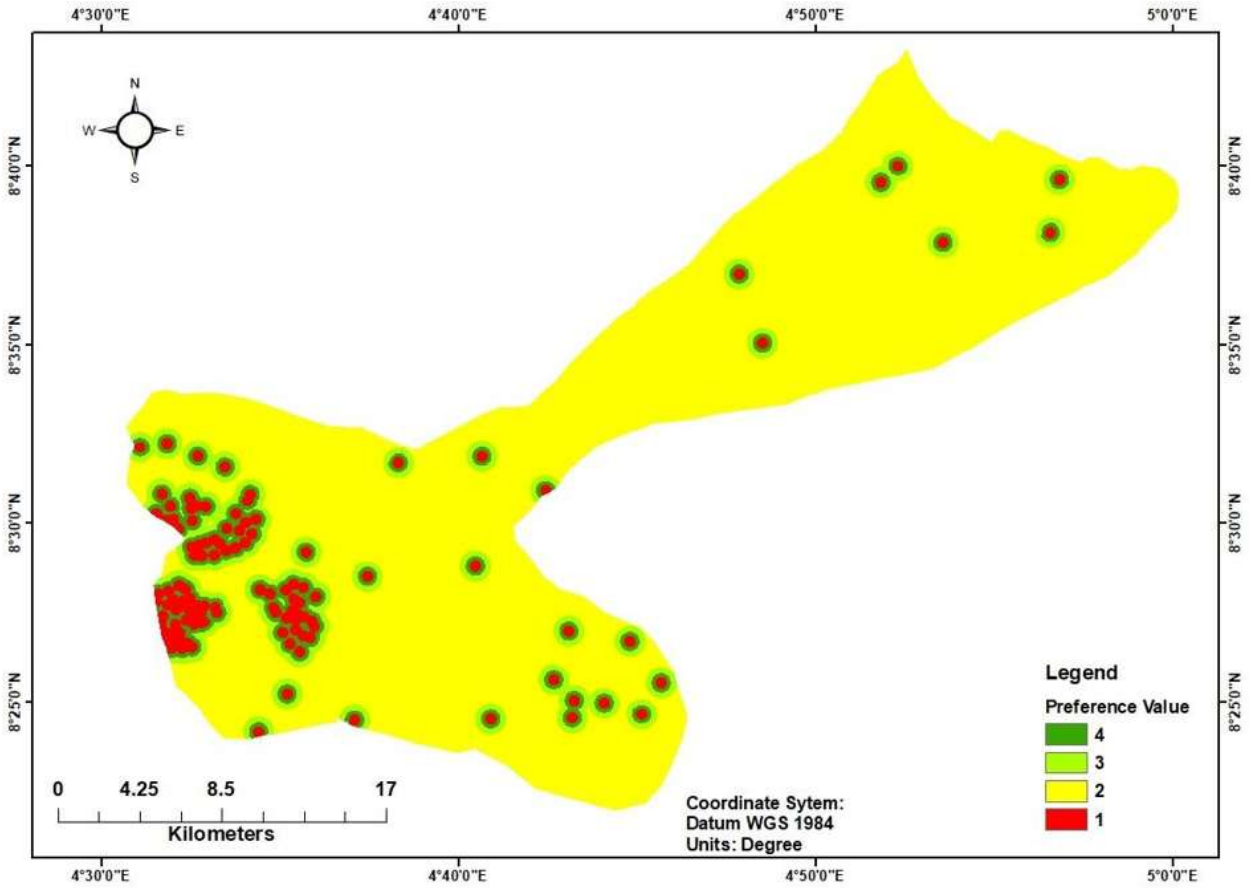

Fig 7: Reclassified Built area map

Soil

The selection of suitable soil for AW landfill sites is a critical factor in waste management to prevent the leaching of harmful substances into groundwater and minimise environmental contamination. The primary concern with soil suitability is its permeability, which determines the ability of the soil to allow the passage of liquids, potentially dissolving hazardous chemicals that could contaminate groundwater and lead to widespread pollution. Soil suitability was determined based on their permeability and coarseness (Makonyo and Msabi, 2022). Soil with high unconsolidated materials is considered highly suitable for analysis. The study area consists of two major types: small particles hence low transmissions and permeability rate; considered as the highly suitable and moderate transmissions and permeability rate as moderately suitable (Figures 8 and 9). The findings of the study agree with the opinions of Sisay et al. (2021) and Mohamed et al. (2023) that soil with low permeability are highly suitable for landfill.

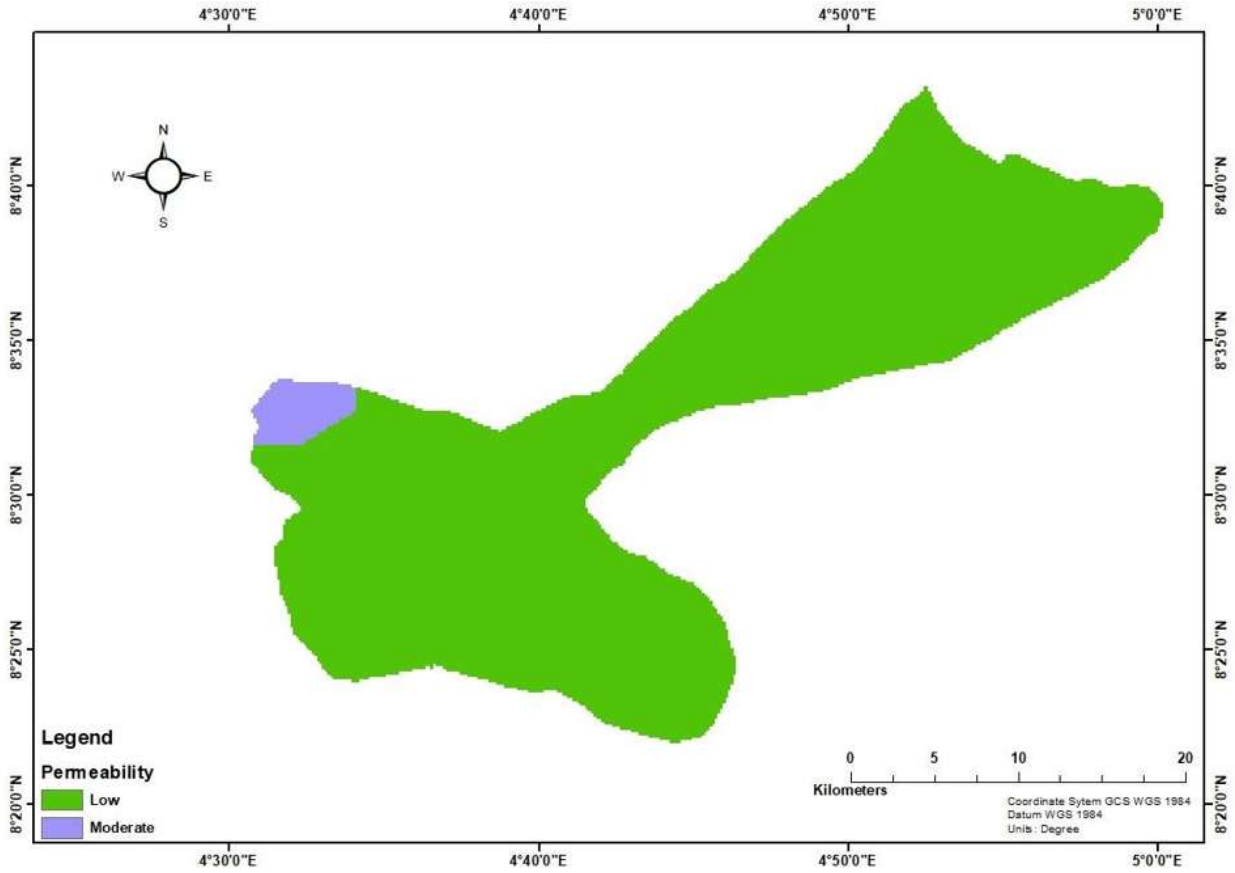

Fig. 8: Soil permeability of the study area

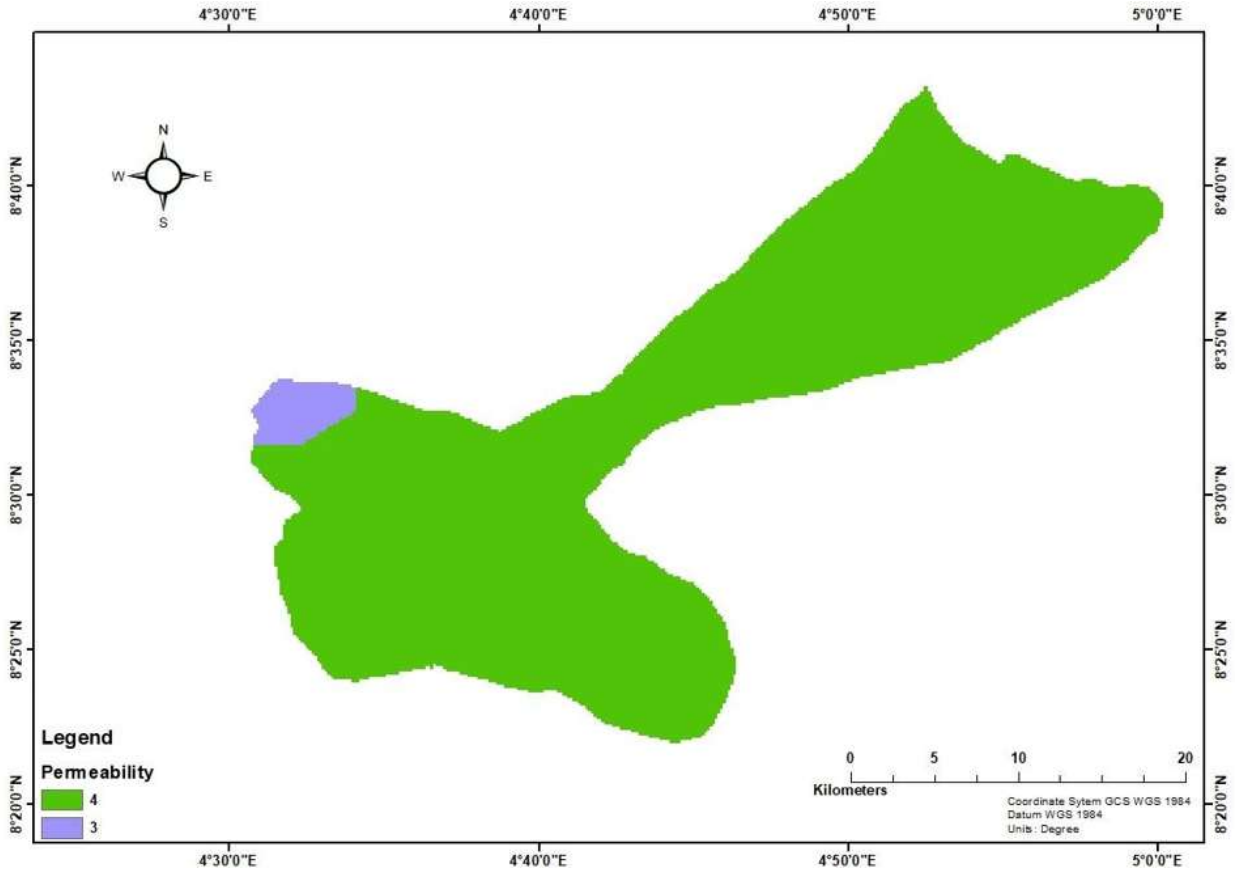

Figure 9: Reclassified soil permeability

Geology

In the geological formation of Ilorin, the predominant rock types are migmatite gneiss and granite gneiss, both known for their resistance to weathering, as noted by Konwea et al. (2023). Migmatite exhibits a higher resistance to weathering compared to granite gneiss. This can be attributed to the composition of migmatite, which combines metamorphic and igneous rocks, whereas granite gneiss is derived solely from igneous rock. The dual nature of metamorphic rocks, based on their precursor, contributes to their suitability for landfill (Barakat et al. 2016). The geological map of Ilorin, represented in Figures 10 and 11, identifies and ranked geology formation in accordance with the Environmental Protection Agency (EPA 2006) standard for landfill siting in 2006. The Migmatite-Gneiss Complex is ranked 3 and categorised as moderately suitable for landfill siting. Granite Gneiss is ranked 4 and highly suitable for landfill placement. This aligns with the findings of Ajibade et al. (2019) regarding the geological qualities favourable for landfill siting, emphasising the importance of geological considerations in making informed decisions about landfill placement.

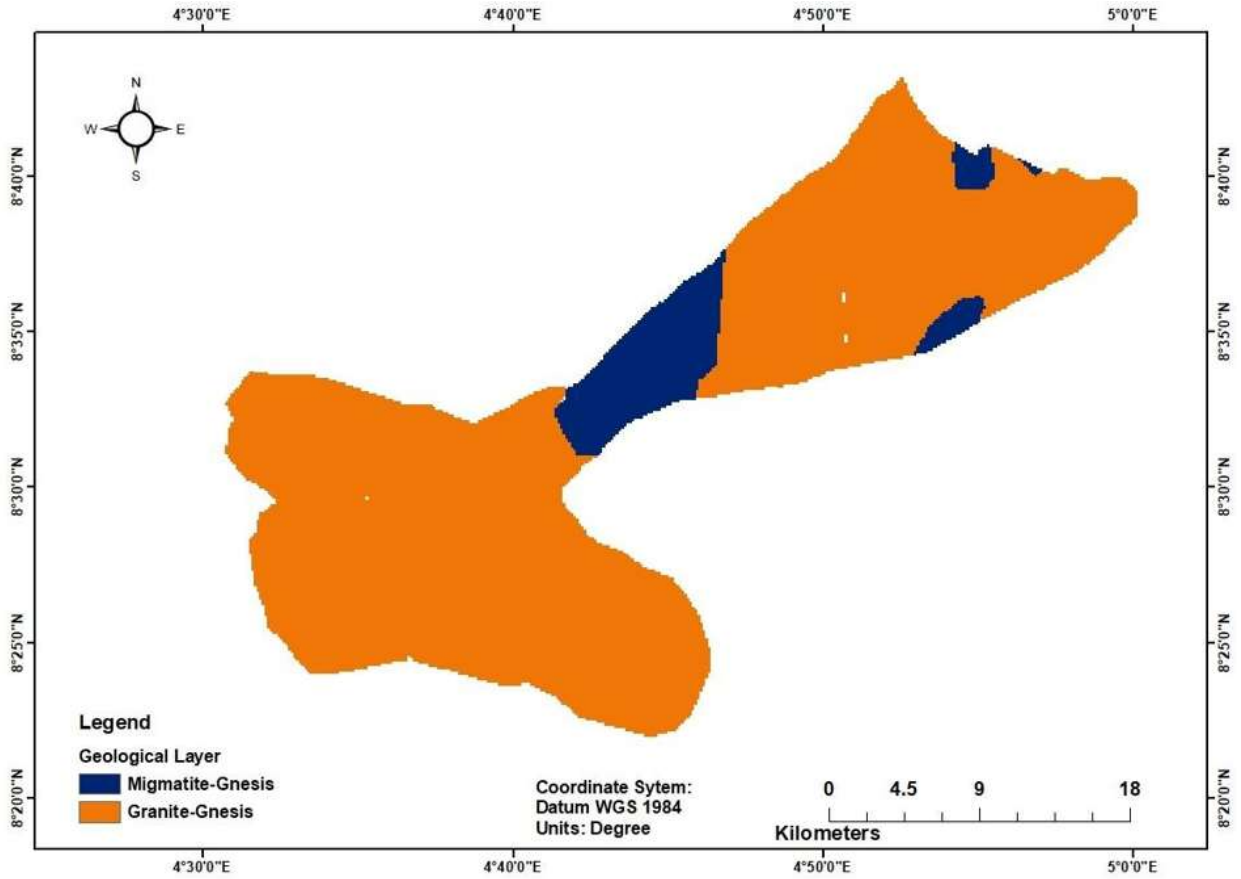

Figure. 10: Geological map of the study area

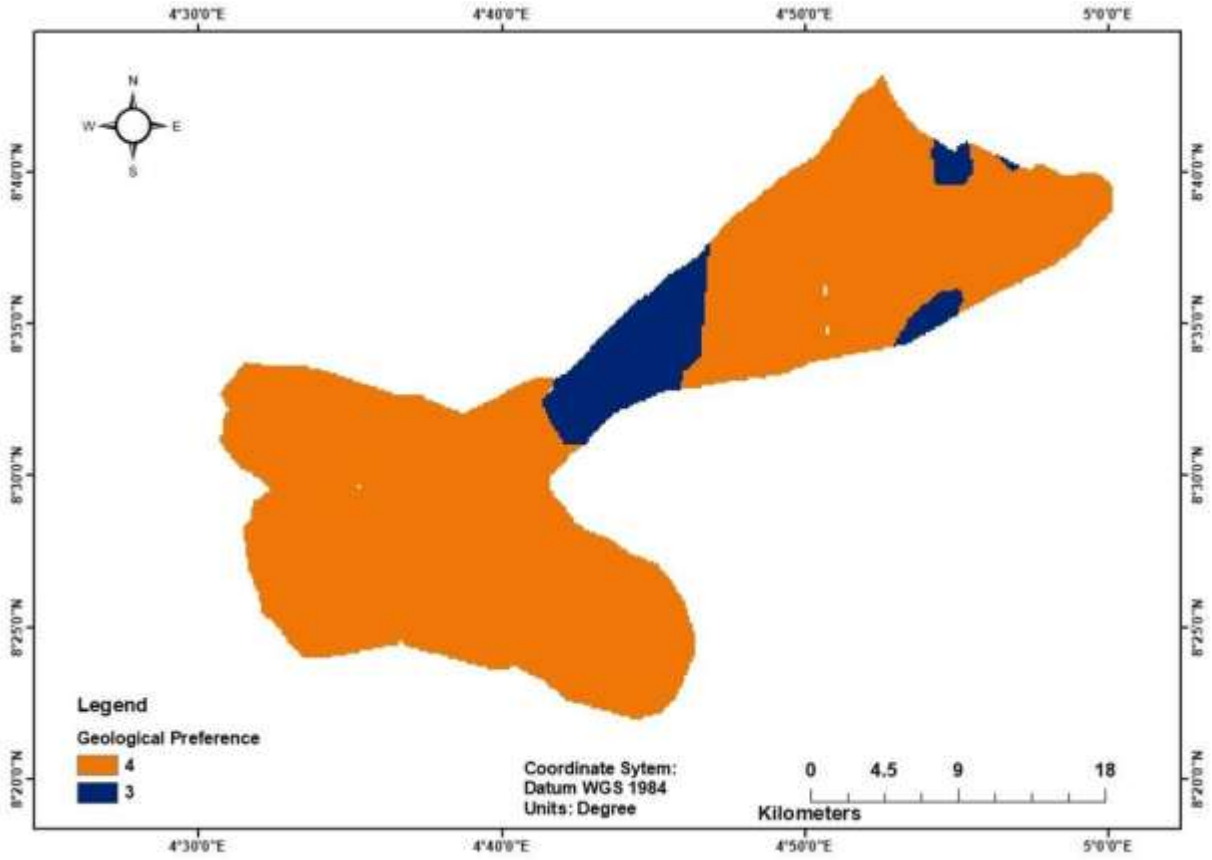

Figure. 11: Reclassified geological map of the study area

Slope

The process of selecting a landfill site is influenced by varying degrees of slope (Wamyil et al., 2026). Areas characterised by high slopes pose the risk of erosion, necessitating substantial financial investments for both construction and management (Jahanfar et al. 2017). In the study area, the slope distribution spans from 0 to 17.5 degrees. Considering economic considerations and the desire to minimise shaping and grading costs, the Environmental Protection Agency's (EPA, 2006) guidelines for landfill site selection in relation to slope is crucial. The slope map of the study area is depicted in Figs. 12 and 13. Areas with slopes exceeding 15 degrees are ranked 1 (unsuitable), 10 to 15 degrees are ranked 2 (least suitable). Areas with slopes ranging 5 to 10 degrees are ranked 3 (moderately suitable) and areas with slopes ranging from 0 to 5 degrees are ranked 4 (highly suitable).

This aligns with the findings of Ajibade et al. (2019) and Kareem et al. (2021), corroborating the assertion in this study that areas with slopes ranging from 0 to 5 degrees are the most suitable for landfill siting, while steep slopes exceeding 15 degrees are unsuitable. Additionally, Karimi et al. (2019) underscore the economic impracticality of constructing landfills in areas with highly steep slopes, further emphasising the suitability of almost flat or flat areas for landfill siting. This

holistic consideration ensures that landfill sites are strategically chosen not only for environmental sustainability but also for economic feasibility.

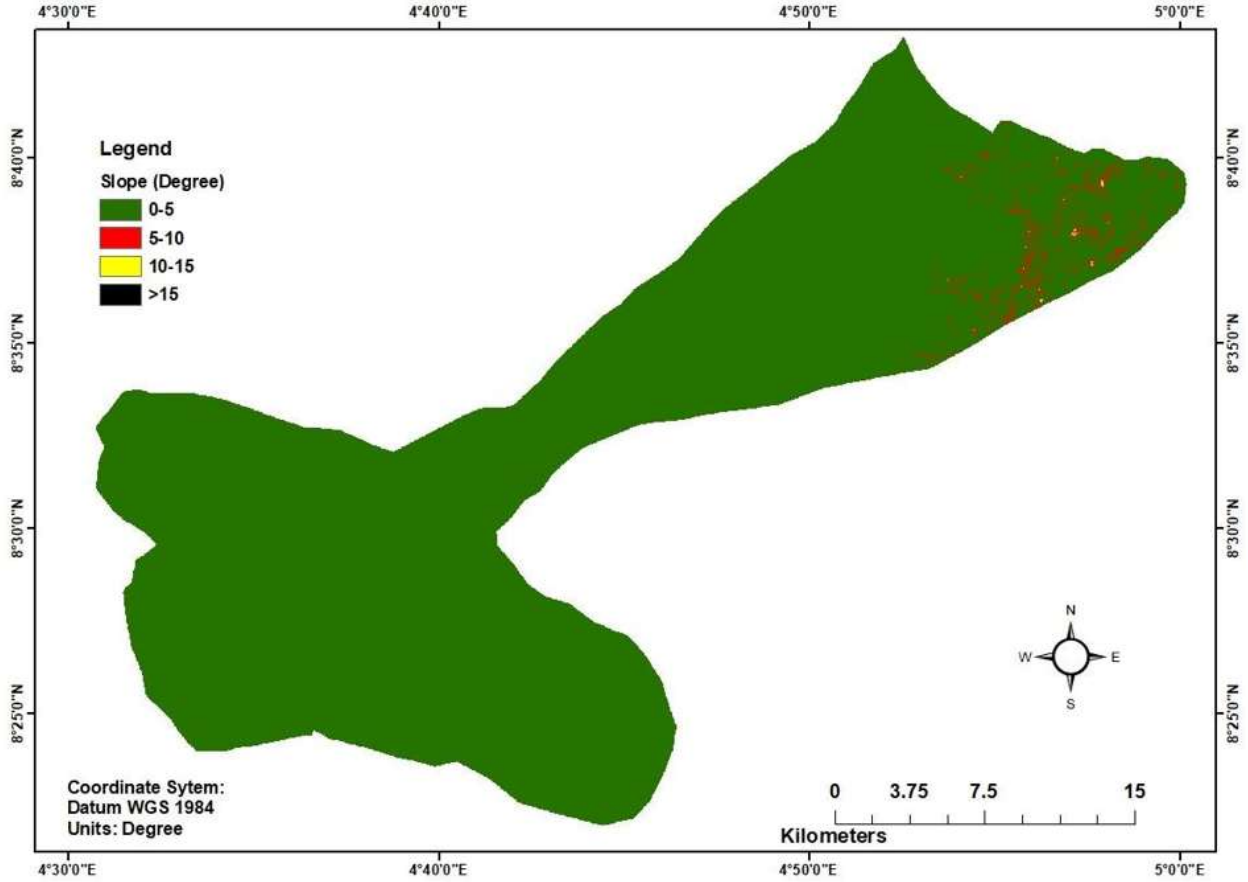

Figure 12: Slope map of the study area

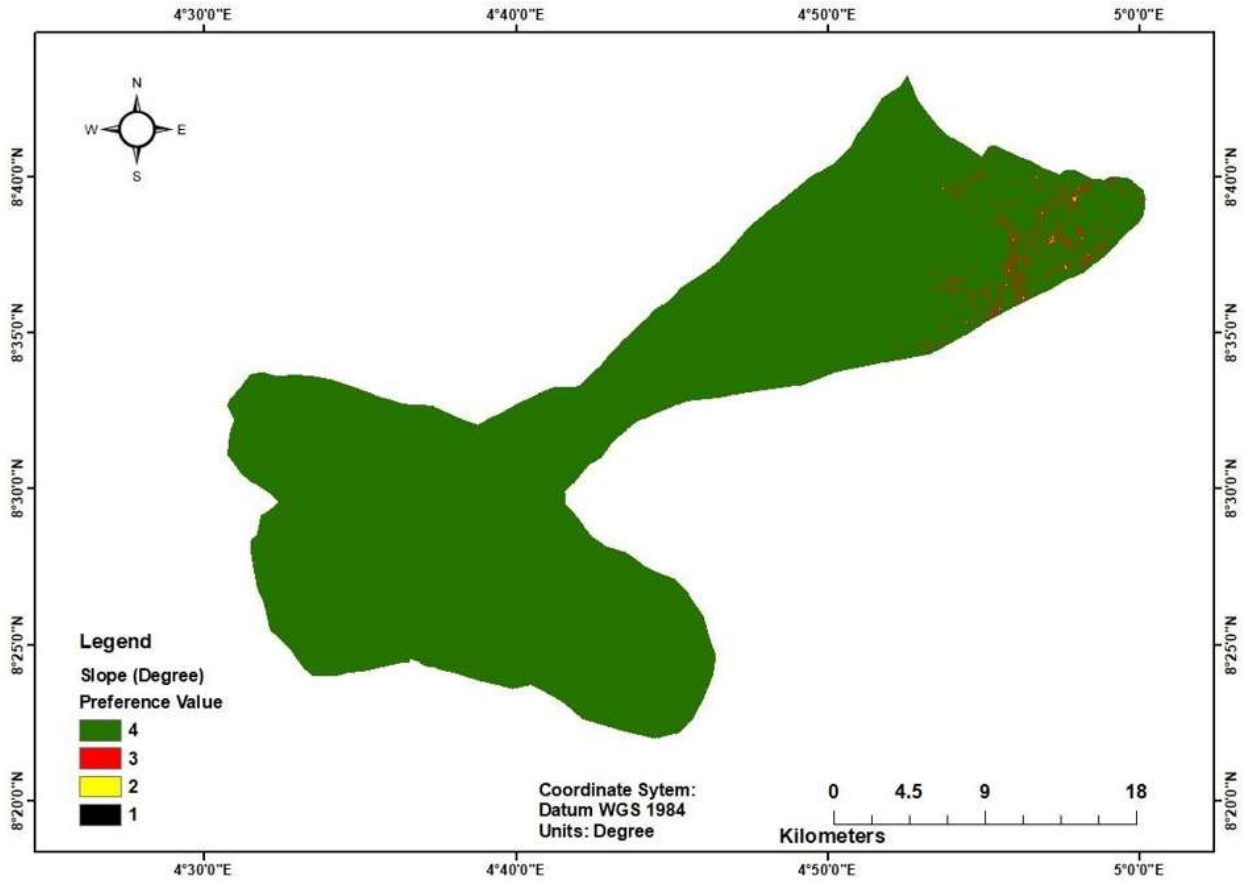

Figure 13: Reclassified Slope map

Weighted overlay result

Six criteria were created for the study based on EPA (2006) guideline as shown in Table These criteria were classed and multiplied by their respective weights before being overlaid to create the Landfill suitability layer depicted in Fig.15.

Landfill Suitability Map

The created maps for each criterion (waterbody, road network, built area, permeability, geology, and slope) were overlaid and reclassified. The overlaying of individual criterion maps resulted in the creation of an AW landfill suitability map, as depicted in Fig. 14. The map is categorised into unsuitable, least suitable, moderately suitable, and highly suitable. The Ilorin region covers 8632.42 sqkm of land area. The result shows the spatial distribution of AW landfill suitability in Ilorin is controlled by the combined effects of environmental, geological, infrastructural, and socio-economic factors, with western areas of the study area showing higher suitability of 2017.7 sqkm (23.42%) due to lower settlement pressure and greater land availability. The findings further indicate that 507.23 sq km (5.88%) is unsuitable because highly populated areas increase land-use and environmental concerns. 1204.21 sq km (13.95%) is categorised as least suitable, and 4899.28 sq km (56.75%) falls under the classification of moderately suitable. Four locations

at Iporin, Apata Yakuba, Marafa Nda, and Ga Tata from the extremely suitable areas were identified as optimal sites for the proposed development of AW Landfill. These locations provide a balance between CE principles, environmental safety, technical feasibility, accessibility, and socio-economic acceptability for sustainable AW landfill development.

A comparative perspective can be drawn from a similar study conducted by Fagbohun and Aladejana (2016) in Ekiti City for landfill site selection. In that study, 39.23 sq km were identified as suitable for AW landfills, with high suitability covering 6.47 sq km (16.49%), moderate suitability spanning 25.48 sq km (64.95%), and low suitability accounting for 7.28 sq km (18.56%). Similarly, in a study conducted in Akure, Ondo State, by Ajibade et al. (2019), 34% (180.9 sq km) was unsuitable, and 14.5% (81.1 sq km) was identified as highly suitable for landfill sites. However, it's noteworthy that the outcomes of this study differ from Cüre et al.'s (2021) research in Denizili, Turkey. In that study, 0.07% and 1.76% of the studied area were identified as unsuitable and highly suitable, respectively, for the placement of landfills. These variations illustrate the socioeconomic and environmental complexities that influence landfill site suitability in various regions.



Figure 14: Agricultural Waste Landfill Suitability Map.

The result of the overlay of the current government-approved designated dumpsite on the AW landfill map falls outside the study area (Fig. 15), suggesting it may not be the most appropriate location for AW disposal. This finding indicates negative environmental and economic impacts associated with the current dumpsite location because it is situated in another LGA. The evaluation of existing government-approved dumpsites reveals critical implications for climate-smart agriculture, environmental sustainability, economic efficiency, and public health. Poorly located dumpsites contribute to environmental pollution, increased financial burdens on farmers, and health risks arising from improper AW disposal and disease vectors. Furthermore, the excessive use of resources, particularly fuel, intensifies environmental degradation.

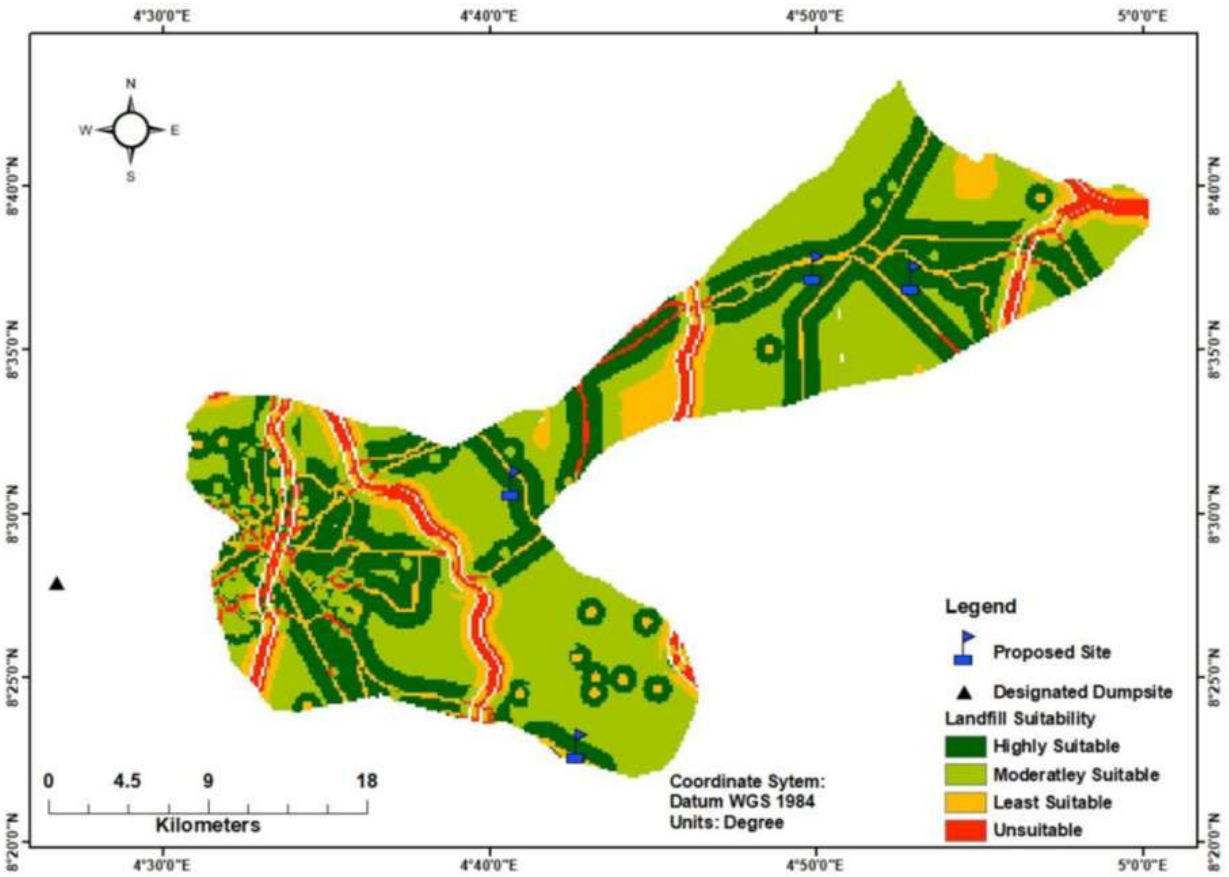

Figure 15: Overlayed of existing government designated dumpsite on suitability map of the study area

Conclusion

The results of this study demonstrate a spatially explicit framework for agricultural waste landfill siting that supports climate-smart agriculture in the study area. The classification of land into varying suitability categories provides a robust basis for informed decision-making. Specifically, 5.88% of the land area identified as unsuitable underscores the necessity of excluding environmentally and socially sensitive zones from landfill development. The 13.95% classified as least suitable may serve only as contingency options where alternatives are unavailable. The 56.75% designated as moderately suitable presents viable opportunities for controlled landfill development, subject to the adoption of best management practices that minimise greenhouse gas emissions and environmental degradation. Therefore, the identification of optimal AW landfill locations within 23.42% of the study area, particularly at Iporin, Apata Yakuba, Marafa Nda, and Ga Tata in Ilorin, highlights priority zones for sustainable agricultural waste disposal. These sites offer strategic advantages for reducing transport-related emissions, enhancing waste-to-resource potential, and supporting climate-resilient waste management systems for urban agriculture. The proposed landfill sites should incorporate methane recovery, composting, circular bioeconomy practices, and a comprehensive environmental monitoring programme to promote sustainable, low-carbon agricultural waste management. Overall, the findings provide a scientifically grounded basis for policymakers and environmental managers to optimise AW landfill siting, mitigate environmental and health risks, and promote sustainable, low-carbon agricultural waste management practices in line with climate-smart agriculture initiatives.

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