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GIS-Based Site Suitability Analysis for Solid Waste Disposal in Homa Bay Town, Kenya

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Abstract: *Rapid urbanization in Homa Bay Town has significantly increased municipal solid waste generation, outpacing existing disposal capacity and posing substantial environmental and public health risks. This study employed a GIS-based multi-criteria decision analysis (MCDA) framework to conduct a comprehensive site suitability analysis for solid waste disposal in Homa Bay Town, Kenya. The research integrated critical factors including population density, land use/land cover, slope derived from a Digital Elevation Model (DEM), groundwater depth, surface water buffers, settlements, and transportation access using the Analytic Hierarchy Process (AHP) for criteria weighting. The study adopted a quantitative research design utilizing spatial data from Sentinel-2 imagery, Copernicus 30m DEM, Kenya National Bureau of Statistics census data, and county records. The findings revealed that bare land, the most suitable class for waste disposal, constituted only 3.7% (47.27 hectares) of the study area, highlighting the scarcity of optimal sites. Suitable vegetation land and highly suitable areas together accounted for 983.6 hectares, while poorly suitable built-up areas and not suitable water bodies occupied 93.2 hectares combined. The analysis identified the north-eastern part of Homa Bay Town as the most suitable location for a centralized landfill, offering the best compromise between technical feasibility, environmental compliance, and cost-effectiveness. The study concluded that GIS-based MCDA provides a transparent, reproducible, and regulation-aligned approach to waste disposal siting. Recommendations include implementing the identified site with comprehensive Environmental Impact Assessment, establishing community engagement frameworks, developing waste treatment facilities, and creating a county-wide geospatial waste management database.*

Keywords: *GIS, Site Suitability Analysis, Solid Waste Disposal, Multi-Criteria Decision Analysis, Analytic Hierarchy Process, Homa Bay Town, Kenya*

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1. Introduction

Solid waste management is a critical environmental challenge confronting urban areas worldwide, particularly in rapidly developing nations where urbanization rates outpace infrastructure development. According to the United Nations Human Settlements Programme (UN-Habitat, 2020), cities in developing countries generate approximately 0.5 to 1.5 kilograms of solid waste per capita daily, with collection rates often below 50%. The improper disposal of municipal solid waste poses significant risks to environmental quality, public health and aesthetic values of urban landscapes. These challenges are particularly acute in sub-Saharan African towns where rapid population growth, limited financial resources and weak institutional frameworks constrain effective waste management.

At the regional level, East African countries face similar waste management challenges characterized by uncontrolled dumping, inadequate collection systems and limited treatment facilities. The East African Community (EAC) has recognized solid waste management as a priority area requiring coordinated regional responses. Kenya, as a member state, has enacted the Environmental Management and Coordination Act (EMCA) of 1999 (revised 2015) and the Sustainable Waste Management Act of 2022 to provide a legal framework for waste management. However, implementation at the county level remains constrained by capacity and resource limitations.

Homa Bay Town, the administrative headquarters of Homa Bay County, is located on the southern shores of Lake Victoria. The town has experienced rapid urbanization over the past two decades, with population growth from approximately 44,949 in 1999 to 65,304 in 2019 according to Kenya National Bureau of Statistics (KNBS, 2019). This growth has resulted in increased solid waste generation, currently estimated at 50-80 tonnes per day, overwhelming the existing disposal capacity. The town lacks a scientifically sited, environmentally compliant disposal facility, leading to indiscriminate dumping near settlements, roads and water bodies. This situation has created multiple interconnected problems that collectively undermine environmental sustainability and public health in the town.

Geographic Information Systems (GIS) has emerged as a powerful tool for spatial analysis and decision support in environmental management. GIS provides a spatially explicit framework for integrating multiple data layers, analysing spatial relationships, and visualizing results in the form of maps. When combined with Multi-Criteria Decision Analysis (MCDA), GIS enables systematic evaluation of competing factors and stakeholder preferences in site selection processes. The Analytic Hierarchy Process (AHP), developed by Saaty (1980), provides a structured approach for deriving criteria weights through pairwise comparisons, making it particularly suitable for complex spatial decision-making problems such as waste disposal siting.

Several studies have demonstrated the effectiveness of GIS-based MCDA approaches for waste disposal site selection. Al-Ruzouq et al. (2020) applied GIS and MCDA for site selection in the United Arab Emirates, demonstrating the method's capability for integrating environmental, social, and economic criteria. Similarly, Abdul et al. (2019) combined GIS, fuzzy logic and AHP models for solid waste disposal site selection, achieving robust results that accounted for uncertainty in criteria evaluation. These methodologies provide a transferable framework that can be adapted to the specific context of Homa Bay Town.

The present study was necessitated by the absence of a scientifically derived site suitability map for solid waste disposal in Homa Bay Town. Existing disposal practices rely on ad-hoc site selection without systematic evaluation of environmental constraints, proximity to sensitive receptors, or long-term sustainability considerations. This research addressed this gap by developing a GIS-based suitability model that integrates physical, environmental, and socio-economic factors to identify optimal disposal sites.

1.1Research Objectives

The study was to conduct a GIS-based site suitability analysis for solid waste disposal in Homa Bay Town, Kenya. The study aimed to identify optimal locations for waste disposal facilities that ensure environmental sustainability, public health protection, efficient waste management, and alignment with Kenya's environmental policies and international best practices. The specific objectives were:

1. To identify the most suitable locations for solid waste disposal in Homa Bay Town by analysing environmental socio-economic factors using GIS-based multi-criteria evaluation.
2. To minimize the negative environmental impacts of solid waste disposal by identifying areas sensitive to water pollution, soil contamination, and air quality degradation.
3. To ensure compatibility of proposed waste disposal sites with existing land use patterns, minimizing conflicts with residential, agricultural, and commercial areas.

1.2 Research Questions

The study sought to answer the following research questions:

1. What are the most suitable locations for solid waste disposal in Homa Bay Town based on GIS-based multi-criteria analysis?
2. How can GIS-based site suitability analysis inform waste management planning and policy making in Homa Bay Town?
3. What are the environmental and health impacts of improper solid waste disposal in Homa Bay Town?

2. Literature Review

Studies on identifying suitable locations for solid waste disposal emphasize the importance of integrating multiple environmental socio-economic factors. Sener et al. (2011) demonstrated that distance to settlements, surface water, roads, and slope are among the most critical criteria for landfill site selection. The authors found that these factors collectively account for approximately 70% of the total weight in expert-derived criteria hierarchies. Moeinaddini et al. (2010) developed a GIS-based model for landfill site selection that integrated 14 criteria including environmental, socio-economic and technical factors. The study found that proximity to residential areas and water bodies were consistently ranked as the most important criteria across different expert groups. This finding supports the emphasis on these criteria in the present study.

There is a critical role of buffer distances from sensitive environmental features. Delgado et al. (2008) found that maintaining minimum distances from water bodies, wetlands, and protected areas significantly reduces the risk of environmental contamination from waste disposal facilities. The study recommended buffer distances of 500-1000 meters from surface water bodies. Groundwater vulnerability assessment has received significant attention in the literature. Aller et al. (1987) developed the DRASTIC model for groundwater vulnerability assessment, which has been widely applied in landfill siting studies. The model considers depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone, and hydraulic conductivity. More recent studies have integrated DRASTIC with GIS for spatial vulnerability mapping.

Studies emphasizes that proximity to residential areas is the primary factor influencing community exposure to waste-related health risks. Vrijheid (2000) conducted an epidemiological review of health effects associated with residence near landfill sites, finding elevated risks of certain health outcomes within 2 kilometres of active sites. This evidence supports the application of substantial buffer distances from settlements. The World Health Organization (WHO, 2018) guidelines on waste management emphasize the importance of integrating health impact assessment in site selection processes. The guidelines recommend community consultation and health risk assessment as integral components of waste disposal planning. These recommendations informed the stakeholder engagement component of the present study.

Literature on land use compatibility demonstrates that land use / land cover classification provides essential information for identifying areas suitable for waste disposal. Built-up areas, agricultural land, and protected areas are typically excluded from consideration, while degraded or barren lands may be suitable (Sener et al., 2010). Remote sensing data, particularly from Landsat and Sentinel satellites, has been widely used for land use/land cover mapping in suitability studies. Slope is another important factor influencing land use compatibility for waste disposal. Gentle slopes (2-12%) are preferred for construction and operation of landfill facilities, while steep slopes increase costs and environmental risks (Gbanie et al., 2013). Digital Elevation Models from SRTM and Copernicus have become standard data sources for slope analysis in GIS-based suitability studies.

2.1 Theoretical Framework

This study was grounded on Multi-Criteria Decision Analysis (MCDA) theory, specifically the Analytic Hierarchy Process (AHP) developed by Saaty (1980). MCDA provides a structured framework for evaluating alternatives against multiple, often conflicting criteria. The theoretical foundation rests on the premise that complex decision problems can be decomposed into hierarchical structures comprising goals, criteria, sub-criteria, and alternatives.

The AHP methodology employs pairwise comparisons to derive criteria weights and alternative priorities. The fundamental scale of absolute numbers (1-9) enables decision-makers to express preferences between criteria in a structured manner. The consistency ratio (CR) provides a measure of the logical coherence of the pairwise comparisons, with values below 0.10 indicating acceptable consistency (Saaty, 1980).

GIS complements MCDA by providing spatial analysis capabilities that enable the evaluation of geographic criteria. The integration of GIS and MCDA, often referred to as spatial multi-criteria analysis, combines the analytical power of GIS for processing spatial data with the structured decision-making framework of MCDA. This theoretical integration has been widely applied in land use planning, environmental management, and facility siting problems (Malczewski, 2006).

3. Methodology

The Study Setting: The study was conducted in Homa Bay Town, the administrative headquarters of Homa Bay County, Kenya. Homa Bay Town is located on the southern shores of Lake Victoria, approximately 420 kilometres west of Nairobi. The town lies between latitudes 0°20′ South to 0°32′ South, and longitudes 34°20′ East to 34°35′ East (Figure 1). It covers an area of approximately 1,219 hectares.

Homa Bay Town was selected for this study because it exemplifies the waste management challenges facing rapidly urbanizing Kenyan towns. The town's proximity to

Lake Victoria creates unique environmental sensitivity, as improper waste disposal poses direct risks to the lake ecosystem. The population of Homa Bay Town was 65,304 according to the 2019 Kenya Population and Housing Census, representing a 45.4% increase from 1999. The town serves as a commercial and administrative hub for Homa Bay County, with economic activities including fishing, trade, agriculture and government services. This population concentration generates significant quantities of municipal solid waste that require proper management. The availability of spatial data and the cooperation of county government officials further supported the selection of Homa Bay Town as the study location.

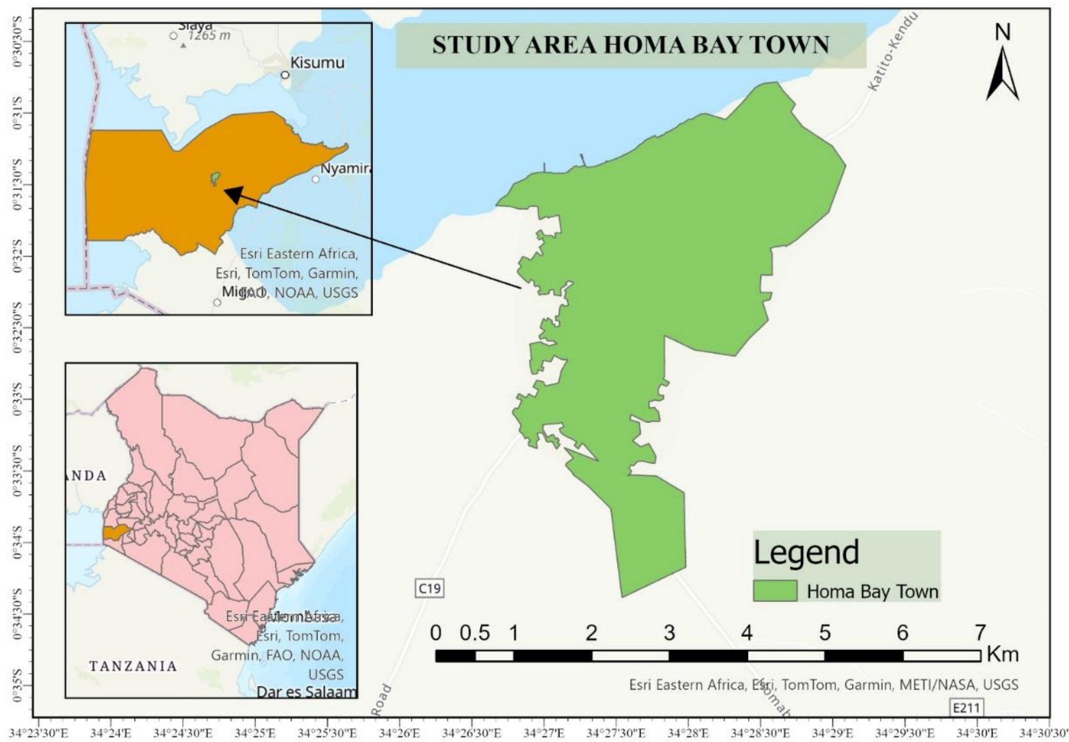

Figure 1. Map of Homa Bay Town in the Kenyan Context

Source: ***Homa Bay County Integrated Development Plan (2018-2022)***

Research Design, Sample Size and Data Collection

The study adopted a quantitative research design utilizing Geographic Information Systems and Multi-Criteria Decision Analysis. The design was chosen because it enabled the integration of multiple spatial criteria in a systematic and reproducible framework. The research design consisted of several sequential phases. The first phase involved problem definition and criteria selection based on literature review and regulatory requirements. The second phase involved data acquisition from multiple sources including satellite imagery, topographic data, and socioeconomic records. The third phase involved data pre-processing, including re-projection, resampling, and classification. The fourth phase involved AHP-based weight derivation and weighted overlay analysis. The final phase involved result interpretation, field verification, and recommendation formulation.

The study variables included six independent variables (distance to settlements, distance to surface water, groundwater depth/vulnerability, slope, land use/land cover, and distance to roads) and one dependent variable (site suitability). Each independent variable was operationalized as a raster data layer, standardized to a common scale, and weighted according to its relative importance derived through AHP.

Analytical approach: Data analysis involved technical steps implemented using QGIS geographic information system software and Microsoft Excel for AHP calculations. Step 1 involved Data Pre-processing; Step 2: Land

Use/Land Cover Classification; Step 3: Criteria Layer Preparation; Step 4: AHP Weighting. The final criteria weights are presented in Table 1 below.

Table 1: Final Criteria Weights Derived from AHP

Criterion	Weight	Rank
Distance to Settlements	0.30	1
Distance to Surface Water	0.25	2
Groundwater Depth/Vulnerability	0.15	3
Slope	0.10	5
Land Use/Land Cover	0.10	5
Distance to Roads	0.10	5

The consistency ratio of 0.06 indicated acceptable consistency in the pairwise comparisons. Distance to settlements received the highest weight (0.30), reflecting the priority placed on community health protection. Distance to surface water was the second most important criterion (0.25), consistent with the environmental sensitivity of the Lake Victoria basin. Step 5 involved Weighted Overlay Analysis. The final step, Step 6 involved Suitability Classification. The continuous suitability scores were classified into five categories using natural breaks (Jenks) classification: highly suitable (0.70-1.00), suitable (0.50-0.69), moderately suitable (0.30-0.49), poorly suitable (0.10-0.29), and not suitable (0.00-0.09).

General and Demographic Information

The study area covered approximately 1,219 hectares within Homa Bay Town boundaries. The GIS analysis utilized eight spatial datasets that were successfully acquired, pre-processed and integrated. The land use/land cover classification achieved an overall accuracy of 87.3% with a Kappa coefficient of 0.84, indicating reliable classification results.

The AHP weighting process involved eight experts from county government departments and community representatives. All pairwise comparison matrices achieved consistency ratios below 0.10, with an average CR of 0.06, indicating acceptable consistency in the expert judgments (Saaty, 1980). The final criteria weights placed highest importance on distance to settlements (0.30), followed by distance to surface water (0.25).

4. Results and Discussion

4.1 Land Use Land Cover Analysis

The land use/land cover classification identified five major classes in Homa Bay Town as presented in Table 2 and Figure 2.

Table 2: Land Use Land Cover Classification Areas

LULC Class	**Area (Hectares)**	**Percentage (%)**
Water Bodies	773.59	63.5
Built-up Areas	236.73	19.4
Agriculture	103.90	8.5
Vegetation	66.60	5.5
Bare Land	47.27	3.9
Built-up	26.60	2.2
Total	1,255.69	100.0

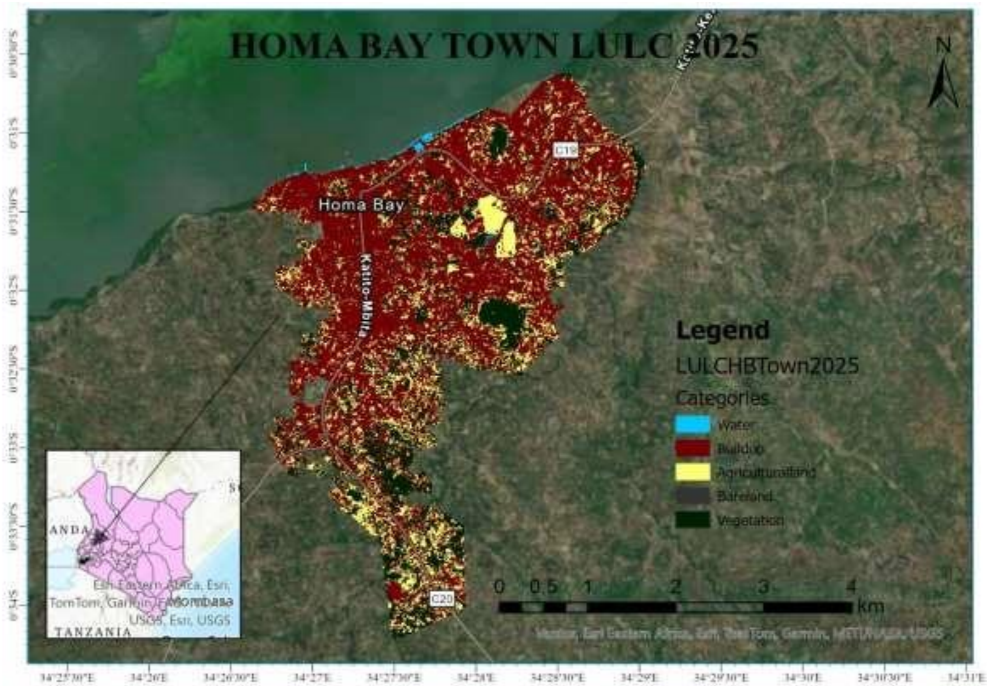

Figure 2: Land Use Land Cover Classification of Homa Bay Town

The classification revealed that water bodies (Lake Victoria and associated wetlands) constituted the largest land cover class at 63.5% of the study area. Built-up areas covered 19.4%, while bare land, the most suitable class for waste disposal planning, constituted only 3.9% (47.27 hectares) of the total area. The finding that bare land constituted only 3.7% of the study area is consistent with observations by Wangongo and Ngetich (2020) in Kericho Town, who similarly reported limited availability of optimal sites. This finding supports the recommendation by Sener et al. (2011) that land use planning should integrate waste management considerations to reserve suitable areas for future disposal facilities. The predominance of water bodies (63.5%) reflects Homa Bay Town's unique lakeshore geography and reinforces the environmental sensitivity of the area that must be considered in disposal planning.

4.2 Slope Suitability Analysis

The slope analysis derived from the 30m DEM categorized the terrain into four suitability classes. The slope suitability map is illustrated in Figure 3.

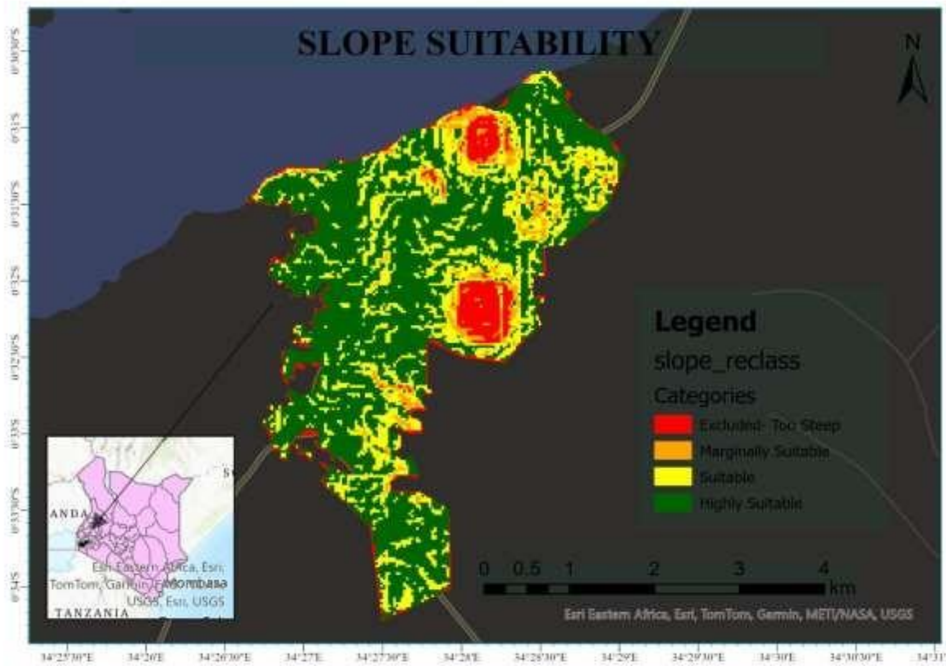

Figure 3: Slope Suitability Map of Homa Bay Town

Areas near the lakeshore and central business district showed steep slopes categorized as too steep for waste disposal. This conflicted with the built-up and water body constraints identified in the LULC analysis. Marginally suitable areas formed a transitional zone around the town centre. Suitable and highly suitable gentle slopes were found in the eastern parts of the town, away from the Lake. This pattern is consistent with the geological characteristics of the Lake Victoria basin, where terrain becomes gentler with increasing distance from the shoreline. The slope suitability results are summarized in Table 3.

Table 3: Slope Suitability Classes

Slope Class	Range (%)	Suitability	Characteristics
Too Steep	> 15%	Not Suitable	Lakeshore and CBD areas, drainage challenges
Marginally Suitable	8-15%	Low	Transitional areas around town centre
Suitable	4-8%	Moderate	Gentle terrain, moderate drainage
Highly Suitable	2-4%	High	Eastern parts, gentlest terrain

4.3 Topographic Wetness Index (TWI) Suitability Analysis

The TWI analysis identified areas with high moisture accumulation potential (Figure 4). High TWI values indicate areas prone to waterlogging and surface water accumulation, which are unsuitable for waste disposal due to increased leachate generation risk.

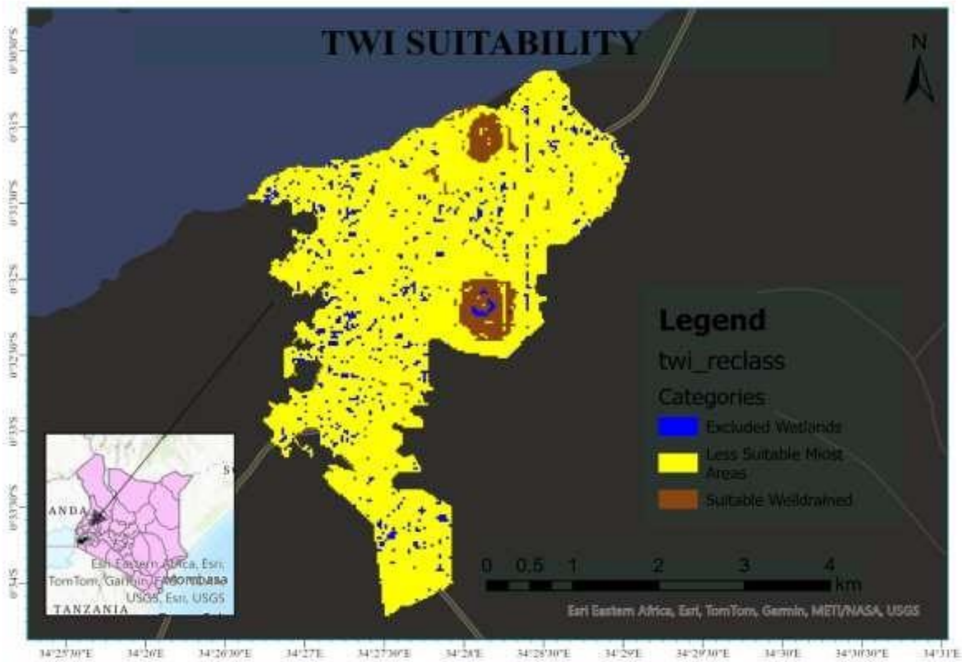

Figure 4: TWI Suitability Map of Homa Bay Town

Low-lying areas near Lake Victoria and along stream channels showed high TWI values, indicating poor drainage and high moisture accumulation. The 500-meter buffer from Lake Victoria and associated wetlands was the most significant exclusion constraint. This finding supports the recommendations of Delgado et al. (2008) regarding buffer distances from surface water bodies. Areas with lower TWI values, indicating better drainage conditions, were found in the higher elevation eastern parts of the town. The TWI analysis complemented the slope and LULC analyses by identifying areas where topographic conditions create unfavourable moisture regimes for waste disposal. Areas with high TWI values were classified as less suitable even where other criteria were favourable. This finding emphasizes the importance of considering multiple environmental factors in site suitability assessment.

4.4 LULC Suitability Classification

The LULC-based suitability classification integrated the land cover data with criteria weights to produce a composite suitability layer. This analysis identified which land cover types were most compatible with waste disposal based on environmental sensitivity and land use conflicts (Figure 5).

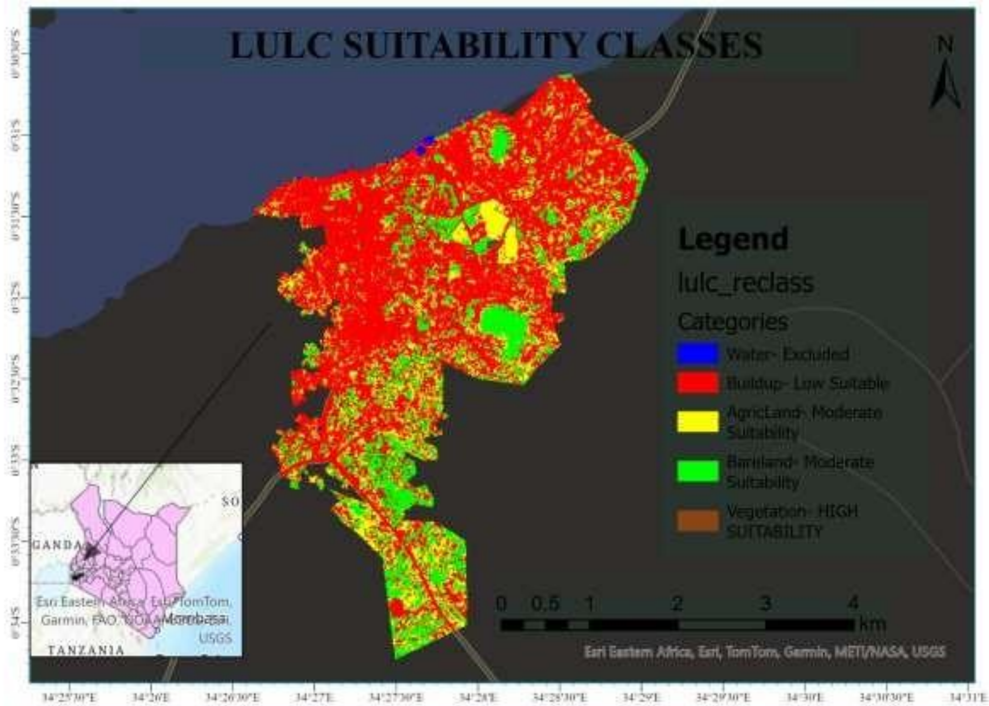

Figure 5: LULC Suitability Classification Map

Bare land areas were classified as most suitable due to minimal ecological value and absence of conflicting land uses (Figure 5). Agricultural areas received moderate suitability ratings due to food security considerations. Built-up areas (residential areas, schools, and health facilities) and water bodies were classified as unsuitable. This finding is consistent with the epidemiological evidence reviewed by Vrijheid (2000), which demonstrated elevated health risks near landfill sites. The 1-kilometer minimum buffer from settlements applied in this study exceeds the minimum requirement in some contexts but provides an additional safety margin for community protection.

The LULC suitability classification confirmed that bare land areas offered the highest suitability for waste disposal. However, the limited extent of bare land (47.27 hectares) necessitated consideration of other land cover types. Agricultural areas, while productive, may be considered with appropriate mitigation measures if no bare land options are available within the suitable zone.

4.5 Overall Site Suitability Distribution

The weighted overlay analysis produced the final site suitability map by integrating all six criteria with their AHP-derived weights. The overall suitability distribution is presented in Figure 6 and Table 4.

Table 4: Overall Suitability Distribution

Suitability Class	Area (Hectares)	Percentage (%)
Highly Suitable	345.1	28.3
Suitable	638.5	52.4
Moderately Suitable	103.9	8.5
Poorly Suitable	66.6	5.5
Not Suitable	26.6	2.2

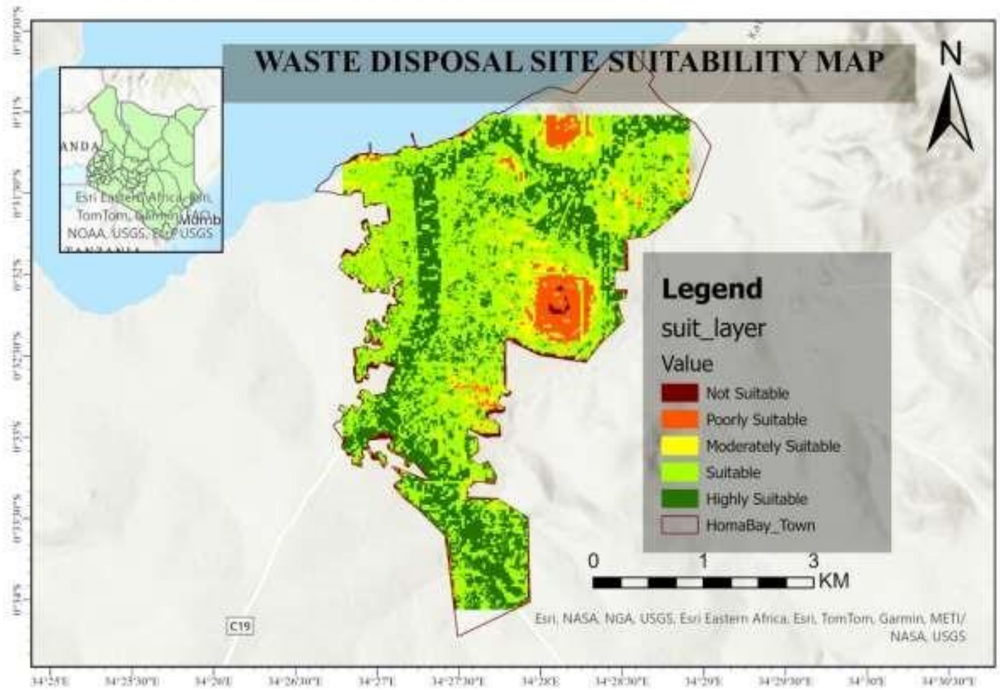

Figure 6: Overall Suitability Distribution Map of Homa Bay Town

Figure 6 indicates that the north-eastern part of Homa Bay Town showed the highest suitability scores for a centralized landfill. This finding aligns with the recommendation of Al-Ruzouq et al. (2020) that GIS-MCDA approaches effectively identify optimal sites by balancing multiple competing factors. The identified site offers the best compromise between technical feasibility, cost-effectiveness, and environmental compliance. The lakeshore areas were classified as not suitable due to water body proximity constraints.

The suitability analysis revealed that highly suitable vegetation lands and suitable areas together comprised the largest portions of the study area, covering 345.1 hectares and 638.5 hectares respectively, together accounting for approximately 80.7% of Homa Bay Town's land area. Moderately suitable agricultural areas totalled 103.9 hectares, representing a transitional zone where development may be possible with appropriate mitigation measures. Poorly suitable built-up areas and not suitable water lands occupied considerably smaller areas at 66.6 hectares and 26.6 hectares respectively. Table 5 presents the summary of suitability by land cover type.

Table 5: Suitability Summary by Land Cover Type

Land Cover Type	Suitability	Area (Ha)	Planning Implication
Bare Land	Most Suitable	47.27	Priority for site selection
Vegetation	Highly Suitable	345.1	Suitable with minimal mitigation
Agriculture	Moderately Suitable	103.9	Requires mitigation measures
Built-up	Poorly Suitable	66.6	Avoid due to health risks
Water	Not Suitable	26.6	Absolute exclusion zone

5. Conclusion and Recommendations

5.1 Conclusion

The GIS-based multi-criteria decision analysis approach proved effective for identifying suitable solid waste disposal sites in Homa Bay Town. The integration of GIS spatial analysis capabilities with AHP-based weighting provided a transparent, reproducible, and defensible methodology for site selection. The suitability model successfully balanced environmental protection, public health, and operational considerations to identify the north-eastern part of the town as the optimal location for a centralized landfill facility.

Homa Bay Town faces a significant challenge in finding suitable land for waste disposal due to its unique geographic characteristics. The high proportion of water bodies (63.5%) and built-up areas (19.4%) severely constrains the available options. The finding that bare land constitutes only 3.7% of the study area underscores the urgent need for systematic land use planning that reserves suitable areas for waste management infrastructure.

5.2 Recommendations

Based on the conclusions drawn from this study, the following recommendations are made:

1. The Homa Bay County Government should adopt the GIS-based suitability map as a planning tool for waste management infrastructure development. The identified suitable sites in the north-eastern part of the town should be prioritized for detailed geological and environmental investigations to confirm their suitability for landfill development.
2. The County Government should establish land reserves for future waste management infrastructure based on the suitability analysis. Suitable areas identified in this study should be protected from alternative development to preserve options for future waste management needs.
3. The County Government should conduct community engagement before site development to address concerns and build support for the proposed facility. Transparent communication of the suitability analysis methodology and findings will help demonstrate that the site selection was based on scientific evidence rather than arbitrary decisions.
4. A monitoring program by the County Government should be established to track environmental conditions at the selected site before, during, and after landfill operation. Groundwater monitoring wells should be installed up gradient and down gradient of the facility to detect any leachate contamination.

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