Research Article
Open Access CrossMark

Suitability analysis for landfill site selection: A case study on Kamuli district

Abstract

A landfill is one of the most cost-effective methods for solid waste management; however, its improper siting and management can lead to environmental and health risks. This study aimed to identify sites with low pollution risk, easy accessibility, affordable land acquisition, and effective operation that can serve as landfill locations in Kamuli District. Ten factors—including soil type, water bodies, wetlands, gazetted areas, lineaments, roads, slope, built-up areas, land price, and land use were used to select suitable landfill areas. A Geographical Information System (GIS)-based multicriteria decision-making method was employed to perform the spatial decision-making process by grouping factors into environmental, socio-economic, and geographical criteria. The Analytical Hierarchy Process (AHP) of pairwise comparisons estimated percentage weights to indicate the relevance of each factor to overall suitability. Input layers for the factors were processed and combined in ArcGIS 10.8 software using Weighted Linear Combination to obtain an overall landfill suitability map. Results indicate that 474 km² (30.42%), 6.7 km² (0.43%), 0.6 km² (0.04%), 249.2 km² (15.99%), 778.9 km² (49.99%), and 48.7 km² (3.13%) of the total district area are categorized as unavailable, unsuitable, slightly suitable, moderately suitable, suitable, and highly suitable, respectively. Additionally, highly suitable areas had to be more than 20 hectares in size and usable for at least 25 years. Candidate landfill sites with the shortest haul distances of 4.2 km, 6.0 km, and 8.0 km from the largest waste-generating town in Kamuli District were selected. While environmental factors are crucial, haul distances significantly influence landfill siting decisions.

Keywords: landfill siting, solid waste management, multicriteria decision analysis, environmental impact

Volume 9 Issue 1 - 2025

Bruce Ayesigye, Nicholas Kiggundu, Prossie Nakawuka

Department of Agricultural and Biosystems Engineering, College of Agricultural and Environmental Sciences, Makerere University, Uganda

Correspondence: Nicholas Kiggundu, Department of Agricultural and Biosystems Engineering, College of Agricultural and Environmental Sciences, Makerere University, Uganda, Tel: +256772443552, Email: nicholas.kiggundu@mak.ac.ug

Received: March 01, 2025 | **Published:** March 13, 2025

Introduction

The global population and economic growth have caused an exponential increase in solid waste production.[1-3] By mid-November 2022, the global human population had grown to 8.0 billion from the estimated 2.5 billion in 1950.[4] It's expected to reach 9.8 billion in 2050 and 11.2 billion in 2100.[5] Also, global municipal solid waste (MSW) production experienced a significant increase, from 635 Metric tons in 1965 to about 2,000 Metric tons in 2015, and is expected to reach 3,539 Metric tons by 2050.[6,7] Aryampa et al.[8] stated that solid waste generation in Kampala only increased from 0.26 to 0.47 kg/person/day for a period of seven years starting in 2011. Also, of about 2,500 tonnes generated in Kampala per day, an average of 1,300 to 1,500 tonnes (approximately 50%) is collected and disposed of.[9] Therefore, managing this ever-increasing volume of waste is one of the most serious challenges all over the world.[10] However, proper waste management is essential for environmental sustainability, safeguarding public health and well-being.[11]

Nzalalemba & Simatele[12] stated that poor solid waste management threatens the health of the environment and human beings in urban areas. In rural locations where there are few scientific waste management solutions, the problem is even more concerning.[13] Environmental contamination is one of the major global results of poor waste disposal.[14] Also, uncontrolled disposal results in significant pollution of water, soil, and vegetation with heavy metals due to leachate migration. Heavy metals enter the human food chain via the consumption of contaminated vegetation or animals, including fish, thereby posing risks to human health.[15] Open burning contributes to the atmosphere's pollution emissions of CO, CO_2, SO, NO, PM_{10}, and other substances. Ghorani-Azam et al.[16] stated that humans exposed to air-suspended toxicants may have a variety of toxicological effects, including eye irritation, neuropsychiatric problems, respiratory and cardiovascular disorders, skin disorders, and long-term chronic diseases like cancer. These impacts not only affect the local community but also the nation's economic growth.[17]

Kamuli district, among other developing areas in Uganda, faces the same challenge of poor solid waste management. The district has a population growth rate of 2.5% per year and a per capita waste generation of 0.55 kg/person/day.[18,19] Compared to rural areas, urban and rural growth centers produce greater waste. In most growth centers, open dumping is common, and in the few places where waste bunkers exist, they are poorly maintained, with garbage all over the place. Also, waste is disposed of in vacant borrow pits since the district lacks gazette disposal locations for waste. This poorly disposed waste is washed away by runoff before or after they are burnt, and it discharges into water bodies (River Nile), wetlands, and open land. This leads to contamination of water bodies, and agricultural land, causing environmental, health, social, and economic threats to the community.

In this waste management ecosystem, a landfill is a frequently used method for disposing of waste materials, serving as a final step in disposing of municipal solid waste.[20] However, for proper management of solid waste, the identification and selection of a suitable landfill site are key steps. It is an essential planning procedure that helps to avoid environmental concerns such as water contamination, and public health degradation caused by unsanitary landfills.[21] In a study carried out by Njoku et al.,[22] 78% of participants who lived closer to the landfill site reported substantial pollution of air quality due to strong odors associated with the garbage site. Landfills are also typically associated with contamination of surface and groundwater by landfill leachate, loud unsettling noise from landfill bulldozers, bioaerosol emissions, and volatile organic compounds.[22-24] Therefore environmental, socio-economic, socio-cultural, engineering, and geological factors should be taken into account when deciding on a landfill location.[25-27] Since the site selection procedure is dependent on a variety of criteria and laws, using a robust and inventive approach is necessary to increase the effectiveness of managing solid waste. Some of such innovative approaches are Geographic Information Systems (GIS) and Remote Sensing (RS).

GIS is a tool for gathering, storing, verifying, modifying, evaluating, and presenting data that is geographically related to the Earth.[28,29] Remote sensing is the art, science, and technology that involves the capturing, measurement, and interpretation of photographic pictures, patterns of electromagnetic radiation, and other phenomena to gather reliable data about physical objects and the surrounding environment.[30] In this study, GIS and RS were used to identify a suitable area for the location of a landfill site for the disposal of solid waste in Kamili District.

Methodology

Description of the study area

The study was carried out in the Kamuli district. Kamuli district is located in the Eastern region of Uganda, approximately 72 Km, by road, North of Jinja town between N 1^{0}15', N 0^0 36', E 32^0 54', and E33^0 24' grids. It boards Kayunga district in The West, Iganga in the East, Jinja in the South, Pallisa in the North East, and Soroti in the North. It covers an area of about 1055.15 km^2. The district area covers thirteen sub-counties (Figure 1).

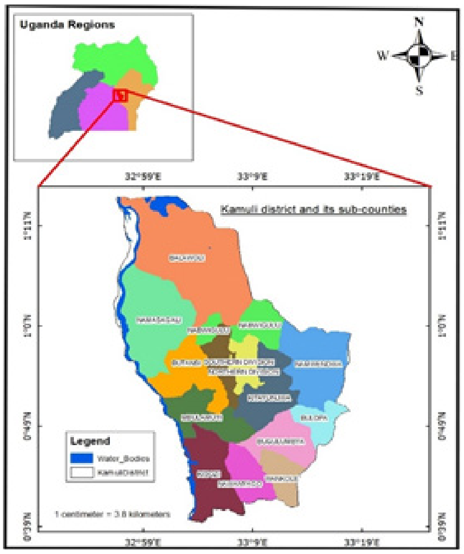


Figure 1 A map of Uganda showing Kamuli district.

Rainfall is a climatic factor of the greatest economic significance for the district. The district experiences a bimodal type of rainfall with peaks in March – June as well as August – November; with the March to June peak as the major one. Except for the heavy rains experienced at the end of 1997, the year of "El Nino", the annual average rainfall is 1350 mm, while the monthly mean is 75 mm to 100 mm.

Geologically, Kamuli District like most of Uganda has "wholly changed rocks", a kind of "Precambrian rocks". Only on the lakesides of Lake Kyoga one finds "quaternary sedimentary rocks". The soils are predominantly dark brown clays (grumosolic soils), underlain by gneiss. They are mainly derived from the alluvium and volcanic ash in low-lying bottomlands.

Data collection

The data collection process was achieved by gathering relevant spatial data layers of the considered factors that affect landfill suitability in the study area. These datasets were obtained by downloading vector, raster, or multitemporal geodata from different open-source data sources. The data layers were geo-referenced map layers that give a spatial representation of soil characteristics, built-up areas, land cover, surface water bodies, wetlands, slopes, protected areas, lineament, population density/ price of land, and roads (Table 1). These were used as the variables or constraint criteria, to determine highly suitable areas in a mapping software (ArcGIS).

Table 1 Data types and their sources

Data type	Source	Description
Soil data (Soil map)	Food and Agriculture Organization (FAO)/ UNESCO Soil Map of the World/ FAO Soils Portal (at 1:5 000 000 scale). https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/	A soil map is a depiction of the different types of soil in a given geographic area, together with some of their characteristics (such as soil horizons, layers, pH, texture, organic matter concentration, and color).
Digital Elevation Model (DEM)	United States Geological Survey (USGS) Earth Explorer (30m) https://earthexplorer.usgs.gov/	This is a map where every point in one or the same grid cell represents a single height above sea level.
Population density	Uganda Bureau of Statistics	A map where the pixels represent the demographic population data of a particular areas
Built-up area	OpenStreetMap https://www.openstreetmap.org/	A map where each polygon represents a building, home, store, shop, or church.
Land use/ Land cover	Sentinal-2 10 m Land Use/ Land Cover Time series (Mature Support) https://livingatlas.arcgis.com/landcover/	A mapping system in which every pixel is assigned to one of nine classes water, trees, flooded vegetation, crops, built-up area, bare ground, snow, clouds, or rangeland.
Roads, Administrative boundaries, gazettes, Water bodies (Lakes, Rivers, and Wetlands	Distributed Information and Versioned Archive Geographic Information System (DIVA-GIS). https://www.diva-gis.org/gdata	

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection:A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

Data processing

The collected data was processed in ArcGIS software Version 10.8, a Geographical Information System environment. The layers were all first reprojected to the WGS 1984 coordinate system to avoid performing analysis on mismatching data. Other dataset pre-processing activities included extraction, and overlaying in the Google Earth Pro to correct the overlay images that do not correspond to map images. This was done for roads, wetlands, built-up areas, and surface water bodies.

Criteria Selection Model: To present a suitable site for a landfill, each criteria map was manipulated by using exclusionary regions to create mapping limits. For example, multiple ring buffer zones were created around important areas to fit the criteria map. The vector layers were rasterized using the polygon to raster conversion tool in the arc toolbox. This is because weighted overlay services are based on raster layers.[31] Each criterion's respective cells were reclassified to a uniform preference scale ranging from 1 to 5, where a rating of 5 indicates the highest suitability as shown in Table 2.

Table 2 Suitability of classes and grades

Grade	1	2	3	4	5
Suitability class	Unsuitable	Slightly suitable	Moderately suitable	Suitable	Highly suitable

Criteria evaluation for identifying the most suitable areas: In this study, ten data sets, including population density/ price of land, soil type, roads, surface water bodies (rivers and lakes), wetlands, lineaments, built-up area, Gazzeted/ protected areas, slope, and land cover, were used to perform the suitability modeling. The datasets and criteria were selected according to the Guidelines for the management of landfills in Uganda.[32,33] Each dataset was divided into five groups and each group was graded from 1 to 5, with 5 being the most suitable as shown in Table 3.

Table 3 Landfill suitability ratings and classes for the considered factors

Factor	Criteria	Class	Grade	Suitability class
Soil type	Soil texture	Clay, Clay loam	5	Highly suitable
		Sand	1	Unsuitable
Slope	Angular slope (⁰)	0 – 5	5	Highly suitable
		5 – 10	4	Suitable
		10 – 15	3	Moderately suitable
		15 – 20	2	Slightly Suitable
		20	1	Unsuitable
Land use	Land cover	Bare ground	2	Slightly suitable
		Built-up area, flooded vegetation, & water.	1	Unsuitable
		Crops	4	Suitable
		Rangeland	5	Highly suitable
Surface Water bodies	Proximity to the river bank or lake shore (m)	0 – 500	1	Unsuitable
		500 – 600	2	Slightly suitable
		600 – 700	3	Moderately suitable
		700 – 800	4	Suitable
		>800	5	Highly suitable
Wetlands	Proximity to a wetland (m)	0 - 500	1	Unsuitable
		500 - 600	2	Slightly suitable
		600 - 700	3	Moderately suitable
		700 - 800	4	Suitable
		> 800	5	Highly suitable
Built up area	Proximity to a built-up area (m)	0 – 500	1	Unsuitable
		500 – 600	2	Slightly suitable
		600 – 700	3	Moderately suitable
		700 – 800	4	Suitable
		>800	5	Highly suitable
Lineament	Proximity to an earth fracture (m)	0 – 500	1	Unsuitable
		500 – 550	2	Slightly suitable
		550 – 600	3	Moderately suitable
		600 – 650	4	Suitable
		>650	5	Highly suitable
Roads	Proximity to roads (m) Other roads	0 – 50	1	Unsuitable
		50 – 100	5	Highly suitable
		100 - 150	4	Suitable
		150 – 200	3	Moderately Suitable
		>200	2	Slightly suitable
	High ways	0 – 100	1	Unsuitable
		100 - 200	2	Slightly suitable
		200 – 300	3	Moderately suitable
		300 – 400	4	Suitable
		>400	5	Highly suitable
Price of land	Population density (people/Km²)	0 – 160	5	Highly suitable
		160 – 250	4	Suitable
		250 - 350	3	Moderately suitable
		350 - 500	2	Slightly suitable
		>500	1	Unsuitable
Gazzeted areas	Proximity to a protected area (m)	0 - 200	1	Unsuitable
		200 - 300	2	Slightly suitable
		300 - 400	3	Moderately
		400 - 500	4	Suitable
		>500	5	Highly suitable

Population density/ price of land: To facilitate cheaper acquisition of land, the ultimate site's price should be as low as feasible. Patterns of land prices and gross population densities are closely associated. The price of land in Kamuli is increasing due to the rapid economic and population growth. Therefore, in this study, the price of land was selected according to the population densities of the district sub-counties for the 2024 projected population based on a 2.5% annual population growth rate. The sub-counties with the highest population density/ price of land were scored as 1 (Unsuitable) while the ones with low population densities were scored 5 (highly suitable). Kamuli town council and Balawoli sub-county had the highest and lowest population densities of 740 People/km^2 and 149 people/ km^2 respectively.

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection: A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

Geology and soils: Geologically, Kamuli District, like most of Uganda has "wholly changed rocks", a kind of "Precambrian rocks". Only on the lakesides of Lake Kyoga one finds "quaternary sedimentary rocks". According to the FAO classification system, the soils in Kamuli are Humic andosols with black or dark brown color, plinthic ferralsols that exhibit red and yellow hues, and rhodic ferralsols with a distinctive red color.

According to Al-Fares[34] & Asefi et al.,[35] soils with a low permeability, and high clay content should be considered for landfill site selection. Soils with high clay content have a low permeability and prevent leachate contamination of groundwater. In this study, the soil suitability was based on the soil's physical texture. Soils with a high clay content (clay content > 25%) were classified as highly suitable (scored a 5) while those with low clay content were classified as unsuitable (scored a 1).

Slope: The elevations within the Kamuli district range between 1,025 m and 1,144 m above sea level. The district has slopes that range from 0 and 28.7º.

The slope of the area should be put into consideration to reduce earth formation and excavation expenses associated with steep slopes while guarding against the possibility of landfill by-product leakage. A moderate slope is appropriate for a landfill site since it facilitates stormwater and leachate control activities, as well as vehicle mobility to and from the site.[36] Using the Digital Elevation Model map, the slope of the area was generated in degrees. NEMA[32] stated that landfills should not be located in areas with slopes greater than 60º. In this study, areas with slopes ranging from 0 to 5º were classified as highly suitable (graded as 5), 5º to 10º were graded as 4, 10º to 15º were graded as 3, 15º to 20º graded as 4 whole those with slopes greater than 20º were graded as 1 (classified as unsuitable).

Water bodies: Kamuli District has both surface and underground water resources, which provide water to residents for various purposes. Kamuli District heavily relies on groundwater with deep boreholes and shallow wells as the most technology used. The surface water bodies in Kamuli district are the river Nile which acts as its boundary with Kayunga district on the West and some parts of Lake Kyoga.

Landfills should be located in an area that is 500 m away from the river bank, lake shore, or wetland and a 200 m buffer should be maintained since they are sensitive features.[33] This is to protect surface water from microbiological, inorganic, and organic pollutants as well as leachate leakage from solid waste landfills.[37] The nature of the components in the stack allows for a very broad spectrum of potential contaminants. These include nitrogen and other nutrients, volatile organic chemicals, and heavy metals.[38] However, constructed wetlands are an option for leachate treatment.[39] In this study, a buffer area of 500 m was created around surface water bodies as graded as 1 (Unsuitable). Buffers of 600 m, 700 m, 800 m, and greater than 800 m were graded as 2 (Slightly suitable), 3 (Moderately suitable), 4 (Suitable), and 5 (Highly suitable) respectively.

Settlements/ built-up: Including a 200 m buffer zone, landfills should be 500 m away from human settlement.

This is to maintain the air quality within settlement areas and prevent health risks. A buffer zone of 500 m was created around the settlement and graded as 1. Areas within 500 – 600 m, 600 – 700 m, 700 – 800 m, and greater than 800 m were classified as slightly suitable, moderately suitable, suitable and highly suitable.

Gazzeted areas: Gazzeted areas in Kamuli district were the four central forest reserves of Ngereka, Buwaiswa, Bulogo, and Namasagali, five local forest reserves of Makoka, Kamuli, Kidiki, Mbulamuti and Mafudu and one Kasolwe farm. Protected areas should be avoided to keep valuable and endangered species free from exploitation due to pollution. A buffer of areas within 200 m around protected areas was classified as unsuitable and therefore scored a 1. Those in 300, 350, 400, and greater than 400 m were graded as 2, 3, 4 and 5 respectively.

Wetlands: NEWMR[33] state any waste management facility should not be located within a wetland or 500 m from a fragile ecosystem. This is due to the high potential of waste dump leachate contamination into the ecosystem and wetlands. In this study, a buffer zone of 500 m was scored a 1, 600 m buffer was scored a 2, 700 m scored a 3, 800 m scored a 4, and buffer areas greater than 800 m were scored a 5.

Lineament: A landfill or waste management facility should not be located in a fractured zone.[21,40] The fissures influence the movement of pollutants, making it easier for groundwater supplies to become contaminated.[1] The lineament map was generated from the hill shade maps created from the DEM layer. Areas within 500 m away from the fractured zone were given a score of 1, those win in 550 m were given a score of 2, while scores of 3, 4, and 5 were given to those in 600 m, 650 m, and greater than 650 m respectively.

Landcover: Landcover features in Kamuli district included water, built-up (residential, urban, and rural setups), forests (dense, moderate, and sparse), waterbodies (River Nile on its West), Farmlands, cropland (subsistence and commercial), and flooded vegetation (Wetlands).

Hailu[36] stated that land that has less socioeconomic, environmental, or political importance should typically be considered for disposal while areas with a high potential for development and expansion, and public health concerns should be left out. Therefore, bare land, closed shrubland, open shrubland, and grassland should have a high suitability. Forests, water, and built-up areas were classified as unsuitable (a score of 1), rangeland scored a 5, while crops, bare ground, and crops were scored between 2 and 4.

Roads: Kamuli district has a wide range of road types, including tertiary, secondary, service, residential, and paths. A buffer of 200 m was created on both sides of highways or major and secondary roads and scored a 1. The area's suitability increased as the distance from the highway roads increased. However, areas 50 m closer to the landfill are used for access roads. To minimize construction costs for the new roads, a 50 m buffer was created on both sides of the secondary roads and tracks and scored a 1. Other buffer rings of 150, 250, 300 m, and > 300 m were created and graded as 5, 4, 3, and 2 respectively.

Multicriteria evaluation

Multiple criteria evaluation (MCE) is an important method for screening and choosing spatially diverse decision variants.[41] SMCE is a procedure that combines and transforms a variety of geographic data (input) into a resulting judgment (output) is known as spatial multi-criteria evaluation.[42] The notion that the research area is not uniform since the standards for evaluation frequently differ from place to place. The inclusion of the geographic component distinguishes spatial multi-criteria decision analysis (MCDA) from conventional methods. Data about the locations of the choices or criterion values are required for spatial MCDA. Both MCDA and GIS approaches are used to process the data to gather information for the decision-making process.

In this study, the criteria were arranged in two hierarchies. In the first hierarchy, the parameters were grouped as key multifactor groups of environmental, geological/geographical, and socio-economic

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection: A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

parameters. In the second hierarchy, the groups in the first hierarchy were subdivided into ten individual key parameters, which are effective factors in sanitary landfill site selection as shown in Figure 2.

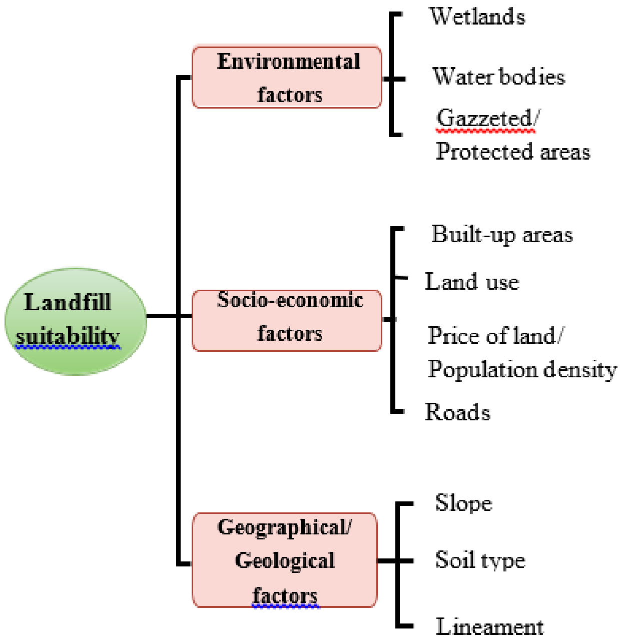


Figure 2 Hierarchy model for landfill suitability.

The weights or relative importance of the factors that determine suitability were adopted according to Okot et al.[43] These were established using pairwise comparison by the Analytical Hierarchy Process (AHP). The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making technique in which the relative weights of each criterion are determined by pairwise comparison in the matrix, with each criterion being assigned to a distinct level.[44] It produces the judgment matrix by comparing the relative element's degree of relevance.[44,45]

The analytical hierarchy process (AHP): The analytical hierarchy processing (AHP), created by Saaty in 1980, is a method for examining and supporting choices where there are numerous alternatives and different, conflicting objectives. The three guiding concepts of the technique are decomposition, comparative evaluation, and priority synthesis. A complex choice problem is first broken down into simpler ones to create a decision hierarchy in the AHP.[46] Pairwise comparisons are evaluated using a nine-degree numerical scale that ranks the relative importance of each pair based on its sequence of values, ranging from 1 (equal importance) to 9 (extreme importance) as shown in Table 4.

Table 4 Scale of relative importance for pairwise comparison[47,48]

Numerical value	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extremely strong importance
9	Extreme importance

So, to do a paired comparison in the matrix (relative scale of importance), each alternative was assessed in terms of the choice criteria, and each criterion was estimated by its weight.[37] The values of (a_{ij}) when (ii= 1, 2, 3, . . ., m) and (j = 1, 2, 3, . . ., n) represent the performance values that are displayed in the matrix's rows and columns (Figure 3). The values of the comparison criterion were filled into the top diagonal triangle of the matrix, while the reciprocal values of the upper diagonal were represented in the lower triangle.[49,50] using Equation 1.

$$a_{ij} = \frac{1}{a_{ij}} \qquad \textbf{Equation (1)}$$

$$\begin{bmatrix} a_{11} & a_{11} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ a_{m1} & a_{m2} & \cdots & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ \cdot \\ W_n \end{bmatrix}$$

Figure 3 A standard matrix for comparing the relative relevance of the criteria.[37]

Where (a_{ij}) is the element of the row (i) and column (j) of the matrix.

Using geometric principles, the eigenvectors for each row were computed by multiplying the values of each criterion in each column in the same row of the initial pair-wise comparison matrix, and then applying this to each row as shown in Equation 2.[48]

$$\text{Eg}_i = (a_{11} \times a_{12} \times a_{13} \ldots \times a_n)^{\frac{1}{n}} \qquad \textbf{Equation (2)}$$

where, Egi = eigenvalue for the row (i); n = number of elements in row (i)

When the eigenvalue is normalized to 1 (divided by their sum), the priority vector, or AHP weight, is obtained as shown in Equation (3).[48]

$$\text{Pr}_i = \frac{\text{Eg}_i}{(\sum_{i=1}^{n} \text{Eg}_i)} \qquad \textbf{Equation (3)}$$

The maximum eigenvalue, also known as the maximum lambda (λ_{max}), was derived by adding the products of each priority vector element and the reciprocal matrix's total column sum Saaty[48] as indicated in Equation (4).

$$\lambda_{\max} = \sum_{j=1}^{n} \left[W_j \sum_{i=1}^{n} a_{ij} \right] \qquad \textbf{Equation (4)}$$

Where a_{ij} represents the criterion in each column of the matrix, and W_j is the weight assigned to each criterion, corresponding to the priority vector in the decision matrix.

The consistency index (Equation 5) measures the mean deviation of each comparative element and the standard deviation of the evaluation error from the true values. This index is usually larger than that of a fully consistent matrix, indicating the severity of the deviation.[48,51]

$$\text{CI} = \frac{\lambda_{\max} - n}{n - i} \qquad \textbf{Equation (5)}$$

where CI is the consistency index, n is the size or order of the matrix

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection:A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44.
DOI: 10.15406/hij.2025.09.00321

The consistency ratio (CR) was calculated by dividing the consistency index (CI) by the random index (RI) (Equation 6), where n is the matrix size. (Table 4)

$$CR=\frac{CI}{RI} \qquad \textbf{Equation (6)}$$

Weighted overlay analysis: Using the reclassify tool from spatial analyst stools, all the layers were reclassified. They were then resampled to the same cell size of 30 m and the same extent. The reclassified raster layers for the criteria were then added to the weighted overlay table in the Arc toolbox to specify the criteria rasters and their properties for the Weighted Overlay tool. The map layer for constrained areas that include built-up areas, lakes, rivers, wetlands, and protected areas was created and overlayed with the result of overlay analysis (Figure 4).

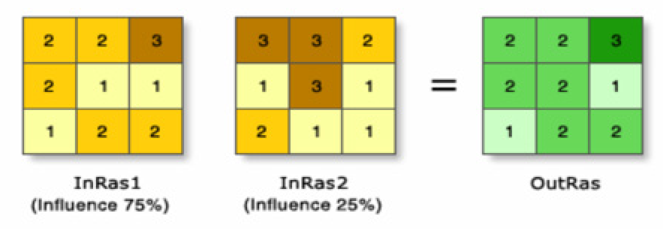


Figure 4 Weighted overlay illustration.[52]

The formula for calculating the scores is as follows:

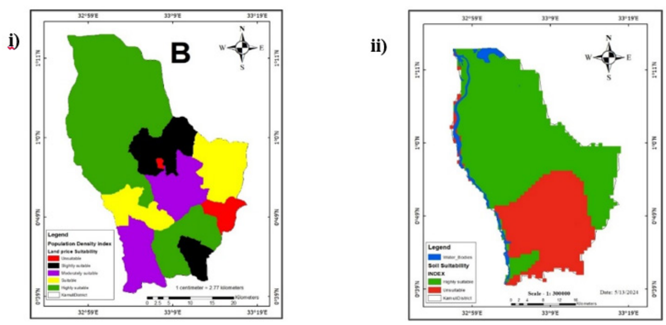
The suitable area = Soil type/ permeability*0.09 + Slope*0.09 + Land use*0.07 + Rivers*0.15 + Lakes*0.15 + Swamps*0.15 + Population*0.10 + Railway/roads*0.09 + Built up*0.11

The weighted overlay resulted in a single-layer map with 6 mapping units with each representing a suitability class. The area corresponding to the different suitability classes was generated using the "Calculate Geometry tool" in the attribute tables. The attribute table containing the suitability contents was exported as a dBase file and percentage cover was calculated from Microsoft Excel 2019.

Results and discussions

Reclassified factor maps

The reclassification resulted in a uniform preference scale of numeric values from 1 to 5, with 1 being unsuitable and 5 being highly suitable. The numerical values therefore increased with an increase in suitability. The reclassified land suitability maps for landfill location for price of land, soil type, slope, distance from waterbodies, settlements, protected areas, lineament, wetlands, roads, and land use/ landcover are shown in Figure 5.



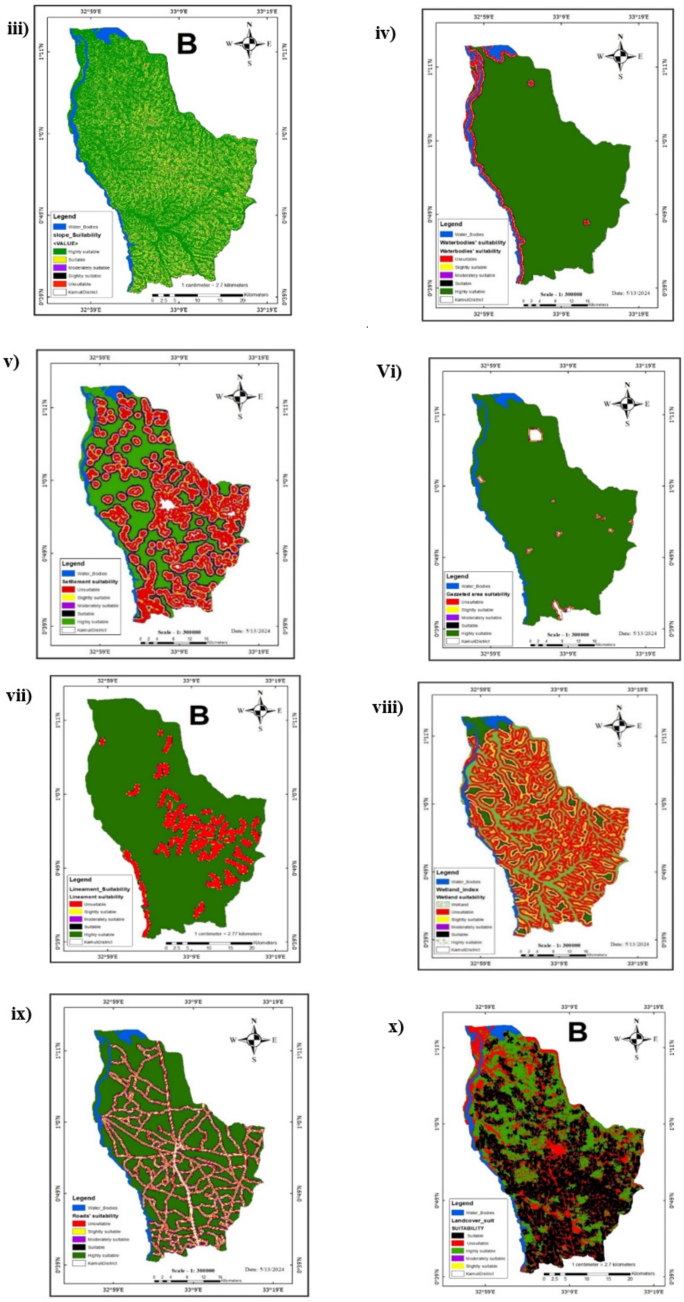


Figure 5 Factor suitability maps for landfill. i) Land price suitability, ii) Suitability for soils, iii) Slope suitability, iv) Waterbodies' suitability, v) Settlements' suitability, vi) Gazzeted areas' suitability, vii) Lineament suitability, viii) Wetlands' suitability, ix) Roads' suitability, and x) Landcover suitability.

The relative importance of factors in determining suitability for landfill location

The analytical Hierarchy Process produced the judgment matrix by comparing the relative element's degree of relevance. The relevance is indicated by the weights that were assigned to each factor, which indicate their relative importance in determining land suitability for a landfill location. Environmental factors (Distance from wetlands, gazetted/protected areas, and water bodies) were the key characteristics in reducing land suitability. Areas closer to those features were considered unsuitable while those at a distance of 800 m away were considered highly suitable. The highest weights (15%) that

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection: A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

were assigned to all environmental factors indicate that they have the biggest influence. However, their influence is negative in that, where there are those features, the land is unsuitable. This is due to the high potential of waste dump leachate contamination into the ecosystem.

The price of land is influenced by the current land use/land cover, population density, or plan for future use. The weight of 10% indicates its influence on the land suitability. Land with very low economic feasibility and in a sparsely populated represented by a higher weight of 10% was considered suitable.

Proximity to the road receives a moderate weight of 10% meaning that land closer to the road has a higher suitability due to easy accessibility and elimination of road construction expenses.

The moderately higher weight of 10% for slopes indicates its influence on land suitability. Land with flat and gentle slopes is considered highly suitable compared to steep slopes. Flat and gentle slopes influence low excavation costs, reduce lateral movement of leachate to the water, and possibility of landslides.

The landfill's proximity to settlements causes air contamination and the potential for the outbreak of diseases. However, areas far away from settlements or waste generators increase haul distances for dump trucks and hence a big financial burden. The weight of 8% indicates that the land should not be too near to settlements to cause odor nuisance disease outbreaks and not too far to create a financial burden for transportation.

The land use/land cover comprises of existing land practices and the natural features or vegetation covering the land. It intends to eliminate sensitive ecosystems and environments, land high economic prospects, and reduce encroachment on protected or gazetted areas. This factor therefore has both environmental and socio-economic consequences. The moderate weight of 7% indicates the significance of land use or cover on land suitability for a landfill.

Soils with a low clay content, indicated by a lower weight of 5% have a higher permeability. High clay content and lower permeability prevent leachate movement to the ground water reducing land and water contamination.

The land closer to earth fractures, indicated by a low weight of 5% indicates a low significance in determining land suitability. Proximity to fractures facilitates leachate movement to the groundwater leading to the accumulation of toxic and harmful components in it.

The respective weights for the factors are shown in Table 5.

Table 5 The mean random index value RI for a matrix with different sizes.[53,54]

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56

A CR of less than 0.1 suggests a reasonable level of consistency in pairwise comparisons.

Land suitability for landfill location (Figure 6)

Out of the 155,925 ha occupied by the Kamuli district, 671 ha (0.4%) was obtained as unsuitable for landfill location. On the other hand, 47,403 ha (30.4%) is currently restricted from landfill location, that is, this land is covered by wetlands, built-up areas, protected sites (forests), and surface water bodies. Also, 62 ha (0.04%) was obtained as slightly suitable, 24,920 ha (16%) as moderately suitable, 77,893 ha (50%) as suitable, and finally, 4,977 ha (3.1%) of the total area was obtained as highly suitable for landfill location.

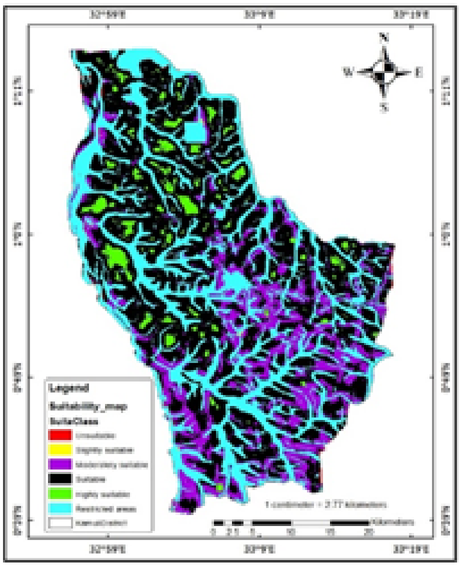


Figure 6 Landfill suitability classes.

Most of the highly suitable areas (82.5% of the total highly suitable areas) were found in the Northern and Northwestern sparsely populated areas sub-counties of the district as shown in Figure 5. Balawoli, located in the North West, had the highest number of highly suitable sites at 87, while Namasagali in the North ranked second with 44 such sites. They contributed to 43% and 34% of the highly suitable areas. The western, Eastern, and central sub-counties contributed to the second most suitable land while the southern had the least. And, some sub-counties in the central and southern, that is, Butansi, Kamuli town council, and Wankole had no highly suitable land. For suitable land, the biggest portions lie in the central sub-counties of Butansi (19%) and Nabwigulu (21.2%) and sparsely populated Namasagali (19.4%) and Balawoli (14.8%). The southern sub-counties of Kisozi (1.9%), Wankole (1.5%), Nawanyago (1.6%), and Bulopa (1.3%) have small portions of suitable land while Kamuli town council, the urban area has no suitable area. The largest portion of the moderately suitable land is found in Kitayunjwa (18.3%) followed by the Kisozi sub-county (13.7%) that borders River Nile on the West, and then Namwendwa subcounty (12.5%). Most of the unsuitable land is located between River Nile and Lake Kyoga on the Western and Northern borders of the district respectively (Table 6).

Size suitability

For this study, the optimum size of a landfill area was determined depending on the population growth rate, per capita waste generation, and required operational period of 20 years, starting in 2025. According to UBOS,[55] the population of Kamuli municipality in the National Population and Housing Census 2014 was 58,984 people. The per capita waste generation of 0.55 kg/person/day was used.[32]

Population growth rate

The Ministry of Finance Planning and Economic Development[56] stated that Kamuli municipality had reached a population of 95,200

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection:A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

people in 2021, from 58,984 in 2014. Therefore, the population growth rate was calculated using the geometric progression relationship shown in Equation 7

$$P_{2021} = P_{2014}(1 + \frac{r}{100})^n \quad \textbf{Equation 7}$$

Table 6 A table showing criteria weights for the factors that affect site selection

Aim	Hierarchy 1	Hierarchy 2	Weight (%)
Highly suitable area for a landfill	Environmental factors	Wetlands	15
		Water bodies	15
		Gazzeted or protected areas	15
	Socio-economic factors	Built up areas	8
		Land use	7
		Price of land	10
		Roads	10
	Geographical and geological factors	Slope	10
		Soil type	5
		Lineament	5

Where P_{2021} and P_{2014} are the population of Population of Kamuli municipality in 2021 and 2014 respectively, r is the population growth rate and n is the number of years between 2014 and 2021.

$$95{,}200 = 58{,}984(1 + \frac{r}{100})^2$$

$$1.614 = (1 + \frac{r}{100})^2$$

$$r = 7\%$$

The projected population of Kamuli municipality in 2025

$$(P_{2025}) = P_{2014}\ (1 + \frac{7}{100})^{11}$$

$$= 58{,}984(1 + \frac{7}{100})^{11}$$

$$= 124{,}153 \text{ people}$$

Solid waste generation

Amount of waste generated per year = Per capita waste generation (0.55 kg/person/day) * Number of people * 365 days, assuming a constant rate of waste generation throughout the operation period (Table 7&8).

Table 7 A table showing the number of highly suitable areas in each sub-county

Sub-county	Number of highly suitable areas	Area (ha) of Highly suitable land	Percentage (%) of area per sub-county
Balawoli	87	2,121	43
Butansi	17	333	7
Bulopa, Wankole, and Kamuli Tc	0	0	0
Kitayunjwa	5	72	1
Nabwigulu	3	25	0
Namasagali	44	1,685	34
Namwendwa	25	356	7
Bugulumbya	1	27	1
Kisozi	3	153	3
Mbulamuti	9	199	4
Nawanyago	2	7	0
Total	196	4,978	100

Table 8 A table showing the annual waste production throughout the operation period

Year	Number of years	Population	Amount of waste generated (kg)
2025	0	124152	24,923,514
2026	1	132843	26,668,160
2027	2	142142	28,534,931
2028	3	152092	30,532,376
2029	4	162738	32,669,643
2030	5	174130	34,956,518
2031	6	186319	37,403,474
2032	7	199361	40,021,717
2033	8	213316	42,823,237
2034	9	228248	45,820,864
2035	10	244226	49,028,324
2036	11	261322	52,460,307
2037	12	279614	56,132,529
2038	13	299187	60,061,806
2039	14	320130	64,266,132
2040	15	342539	68,764,761
2041	16	366517	73,578,295
2042	17	392173	78,728,775
2043	18	419625	84,239,789
2044	19	448999	90,136,575
The total amount of waste			1,021,751,727

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection: A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

The volume of the landfill required = Weight of the waste generated/Density of the compacted waste. The weight densities of waste in low-income level countries range between 300 – 600 kg/m^3.[57] According to Yusuf et al.,[19] a value of 500 kg/m^3 was used. However, about 85% of the waste remains at the landfill after extraction of the recyclables.

$$\text{The volume of landfill required} = \frac{1{,}021{,}751{,}727 \times 0.85}{500} = 1{,}736{,}978\ m^3$$

Required area = Volume of a landfill/depth of a landfill

As stated by Cointreau[58] and Yusuf et al.,[19] the height of a landfill should be restricted to 10 m.

$$\text{Required area} = \frac{1{,}736{,}978}{10 \times 10{,}000}$$

$$= 17.4\ \text{ha}$$

Therefore, the minimum required area for the landfill excavation should be 17.4 ha. However, the identified area for a landfill must not only cover the area required for a landfill but also a buffer zone around it. The buffer area should be reserved for natural and landscape screening, access roads, surface water management works, leachate management, landfill gas management and monitoring works, firebreaks, and other ancillary works. According to NEMA,[32] the total landfill area should be at least 20 ha. Therefore, candidate landfill sites with areas greater than 20 ha were considered (Figure 6).

Highly suitable land with an area less than 20 ha was left out, while those with an area greater than 20 ha were considered. A total of 52 highly suitable candidate sites (portions with area ≥ 20 ha) were obtained which reduced the highly suitable sites from 3.13% (4,978 ha) to 2.8% (4,340 ha) of the total district area. The number of suitable sites reduced significantly from 194 to 47 sites (75.8% reduction), however, the size of the area reduced slightly by 15.7% as in Figure 7. Most of the candidate landfill sites are found in the sparsely populated Balawoli sub-county (45%) followed by Namasagali (38%). The biggest candidate land in size is located in the Namasagali sub-county with an area of 589.56 ha, and the second (358.36 ha) is in the Balawoli sub-county.

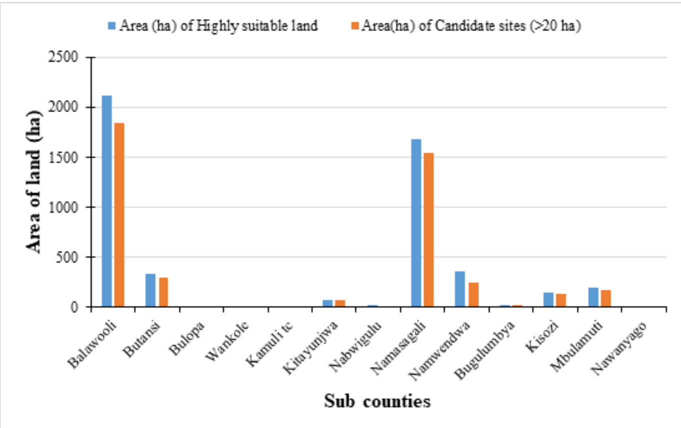


Figure 7 A graph showing the areas covered by highly suitable areas and candidate suitable areas after the sizing procedure.

Discussions

In this study, it was found that Kamuli district has a total area of 4,977 ha in size, that are highly suitable for landfill location. This includes the portions with an area of less than 20 ha, otherwise, it has 4,339.6 ha. Areas that are currently occupied by wetlands, settlements, water supply and water treatment plants, aquatic areas, basins, Gazzeted/protected areas, and roads were excluded. Also, areas whose characteristics do not favor landfill location like steep slopes, faults, sandy soils, and remote areas were excluded due to guidelines to protect the environment.[32]

The suitability varied across the sub-counties due to the landcover/land use activities in the area. For example, the Northern and northwestern sub-counties (Balawoli (43%) and Namasagali (35%) had the highest number of suitable lands. This is due to the highest percentage of rangelands, and soils with high clay content (47% and 32%), less built-up areas, a moderate road network, and favorable slopes (< 20°) which all favor landfill suitability.

Dense wetlands and the high density of residential areas are the most critical factors that restrict the suitability of land in the district. The soil characteristics and faults had a low effect on the lands' suitability for landfill. Also, some factors like proximity to airports, train stations, functional railway networks, tourist attractions, and mines aren't present in the study area, hence didn't affect suitability. However, they are classified as restricted in case they are present.[59,60] Although sub-counties in the south and central Kamuli (Kitayunjwa, Northern and Southern Division, Namwendwa, Bugulumbya, and others) had a smaller number of suitable areas, they have the best road network, short-haul distances, and highest waste-generating population. Site visits were made in some of the areas with the lowest haul distances from the highest waste-generating areas.

LF1, LF2, AND LF3 are candidate landfill sites as shown in Figure 8.

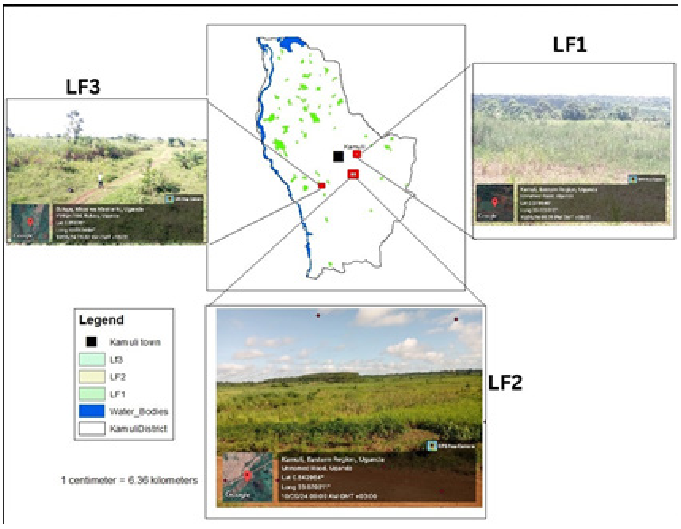


Figure 8 Referenced images of some candidate landfill sites.

LF1 is located in the Northern division with a haul distance of 4.2 km, LF2 in the Kitayunjwa sub-county with a haul distance of about 6 km, and LF3 in the Mbulamuti sub-county with a haul distance of about 8 km from Kamuli town.

Conclusion and Recommendations

Conclusion

In this study, GIS, Remote Sensing techniques, and Multi-Criteria Decision Analysis using AHP were used to identify suitability analysis for a landfill location in Kamuli District. MCDA was used from a structure of three hierarchy levels, that is, environmental, geoscience (geological and geographical), and socio-economic factors. Then,

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection:A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

the weighted values that show the relative importance of each factor were determined using AHP. ArcGIS 10.8 software was finally used to create suitability layers by ranking and scoring locations based on the criteria and weight or influence. The quantity of solid waste to be generated during the 25-year operation period (237,484,841 kg) and the required dumping area (≥ 20 ha) were also determined. The study showed that Kamuli district has 2.8% of the total area that is suitable for landfill location. The environmental and geological factors were considered due to leachate and methane release to the environment that causes environmental pollution. The socio-economic factors affect the acquisition of land, excavation, accessibility, and haul distance expenses. The environmental factors had the highest influence (15% each) in restricting land suitability for a landfill. Regardless of the influence of environmental and geological factors, economic status will always play a significant role in influencing the location of landfill sites. Finally, the integration of Multi-Criteria Decision Analysis (MCDA) and Geographic Information Systems (GIS) proved to be highly effective in enhancing solid waste management. MCDA allowed for the systematic evaluation of various factors and criteria, facilitating informed and balanced decision-making processes.

Recommendation

Future studies should include environmental and climate change projections to assess the future suitability (within the operational period) of landfill sites. Factors like changes in rainfall amounts, temperature changes, extreme weather events, and other climatical factors that affect operational efficiency should be considered in future studies. A standardized set of criteria and weightings that can be applied worldwide, while allowing for regional adjustments based on local conditions should be developed. This is because different areas or regions have different features.

Acknowledgments

None.

Conflicts of interest

The authors declare that there is no conflicts of interest.

References

1. Ajibade FO, Olajire OO, Ajibade TF, et al. Combining multicriteria decision analysis with GIS for suitably siting landfills in a Nigerian state. Environ Sustain Indicators. 2019;3–4:100010.
2. Cheng J, Shi F, Yi J, Fu H. Analysis of the factors that affect the production of municipal solid waste in China. *J Clean Prod.* 2020;259:120808.
3. Khorsandi H, Faramarzi A, Aghapour AA, et al. Landfill site selection via integrating multi-criteria decision techniques with geographic information systems: a case study in Naqadeh, Iran. *Environ Monit Assess.* 2019;191(12).
4. United Nations. Population. Our growing population. 2023.
5. United Nations. Population division of the United Nations department of economic and social affairs. UN population estimates and projections. 2022.
6. Chen D, Meng-Chuen, Bodirsky BL, et al. The world's growing municipal solid waste: trends and impacts. *Environ Res Lett.* 2020;15:13.
7. Sanyal AP, Mohanty S, Sarkar A. Application of recycled aggregates generated from waste materials towards improvement in acoustical and thermal conductivity of concrete. *Mater Today Proc.* 2023.
8. Aryampa S, Maheshwari B, Sabiiti E, et al. Status of waste management in the East African cities: Understanding the drivers of waste generation, collection and disposal and their impacts on Kampala City's sustainability. Sustainability (Switzerland). 2019;11(19):1–16.
9. Gross R. Waste and recycling. Business scouts for development. 2023.
10. Masud MH, Mourshed M, Hossain MS, et al. Generation of waste: problem to possible solution in developing and underdeveloped nations. In: *Waste Management and Resource Recycling in the Developing World.* 2023:21–59.
11. Roy S, Rautela R, Kumar S. Towards a sustainable future: Nexus between the sustainable development goals and waste management in the built environment. *J Clean Prod.* 2023;415:137865.
12. Nzalalemba SK, Simatele MD. Sustainable solid waste management in developing countries: a study of institutional strengthening for solid waste management in Johannesburg, South Africa. *J Environ Plan Manag.* 2020;63(2):175–188.
13. Das S, Lee SH, Kumar P, et al. Solid waste management: Scope and the challenge of sustainability. *J Clean Prod.* 2019;228:658–678.
14. Ferronato N, Torretta V. Waste mismanagement in developing countries: A review of global issues. *Int J Environ Res Public Health.* 2019;16(6).
15. Vongdala N, Tran HD, Xuan TD, et al. Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. *Int J Environ Res Public Health.* 2019;16(1):22.
16. Ghorani-Azam A, Riahi-Zanjani B, Balali-Mood M. Effects of air pollution on human health and practical measures for prevention in Iran. *J Res Med Sci.* 2016;21(5).
17. Dinesh. No negative impacts of poor waste management. Quickwasters. 2021.
18. Kamuli District Local Government. A district where people live a quality life through access of basic social services with sustainable household income by 2040. Sustainable Industrialization for inclusive growth, employment and wealth creation. 2021.
19. Yusuf AA, Peter O, Hassan AS, et al. Municipality solid waste management system for Mukono District, Uganda. *Procedia Manuf.* 2019;35:613–622.
20. Yaashikaa PR, Kumar PS, Nhung TC, et al. A review on landfill system for municipal solid wastes: Insight into leachate, gas emissions, environmental and economic analysis. *Chemosphere.* 2022;309(Pt 1):136627.
21. Debasish R, Das S, Paul S, Paul S. An assessment of suitable landfill site selection for municipal solid waste management by GIS-based MCDA technique in Siliguri municipal corporation planning area, West Bengal, India. *Comput Urban Sci*. 2022;2(1).
22. Njoku PO, Edokpayi JN, Odiyo JO. Health and environmental risks of residents living close to a landfill: A case study of Thohoyandou landfill, Limpopo province, South Africa. *Int J Environ Res Public Health.* 2019;16(12):10–12.
23. De Feo G, De Gisi S, Williams ID. Public perception of odour and environmental pollution attributed to MSW treatment and disposal facilities: A case study. *Waste Manag*. 2013;33(4):974–987.
24. Ibtisam B, Ghaffar A. Ground water quality assessment near Mehmood Boti landfill, Lahore, Pakistan. *Asian J Soc Sci Hum.* 2012;1(2):13–24.
25. Asefa EM, Damtew YT, Barasa KB. Landfill site selection using GIS-based multicriteria evaluation technique in Harar city, eastern Ethiopia. Environ Health Insights. 2021;15.
26. Rezaeisabzevar Y, Bazargan A, Zohourian B. Landfill site selection using multi-criteria decision making: Influential factors for comparing locations. *J Environ Sci.* 2020;93:170–184.
27. Sambiani K, Lare Y, Zanguina A, et al. Location-allocation combining fuzzy analytical hierarchy process for waste to energy facilities siting in developing urban areas: The case study of Lomé, Togo. *Heliyon.* 2023;9(9):e19767.

Citation: Ayesigye B, Kiggundu N, Nakawuka P. Suitability analysis for landfill site selection: A case study on Kamuli district. *Horticult Int J.* 2025;9(1):34‒44. DOI: 10.15406/hij.2025.09.00321

28. Aronof S. Geographic information systems. A management perspective. Ottawa: WDL pub; 1989.
29. Maguire DJ. An overview and definition of GIS. In: Geographical Information Systems. Vol 1: Principles. 1991;9–20.
30. Lillesand & Kiefer. Advanced methodologies and technologies in engineering and environmental science. 2004.
31. ESRI. Prepare your data for weighted overlay. 2022.
32. NEMA. Guidelines for the management of landfills in Uganda. December 2020.
33. NEWMR. The national environment (waste management) regulations, 2020. The Uganda Gazette. 2020;CXIII(10):4165–4380.
34. Al-Fares RA. Optimal landfill site selection through the application of GIS analysis & geotechnical investigation. *Ann GIS.* 2024;30(3):383–409.
35. Asefi H, Zhang Y, Lim S, et al. A multi-criteria decision support framework for municipal solid waste landfill siting: a case study of New South Wales (Australia). *Environ Monit Assess.* 2020;192(11).
36. Hailu Y. Municipal solid waste suitable disposal site selection, case study, Wolkite Town, Ethiopia. *Int J Environ Sci Nat Res.* 2019;20(4).
37. Alkaradaghi K, Ali SS, Al-Ansari N, et al. Landfill site selection using MCDM methods and GIS in the Sulaimaniyah Governorate, Iraq. *Sustainability (Switzerland)*. 2019;11(17).
38. Kadlec RH. *Constructed wetlands for treating landfill leachate.* 1st ed. CRC Press; 2019.
39. Kumar P, Choudhary AK. Constructed Wetlands-A Sustainable Solution for Landfill Leachate Treatment. *Int J Latest Technol Eng.* 2018;VII(June).
40. Balew A, Alemu M, Leul Y, et al. Suitable landfill site selection using GIS-based multi-criteria decision analysis and evaluation in Robe town, Ethiopia. *Geo Journal.* 2022;87(2):895–920.
41. Beinat E, Nijkamp P. *Multicriteria analysis for land-use management.* 2nd ed. Environment & Management (EMAN, volume 9).
42. Malczewski J. *GIS and multicriteria decision analysis.* 1st ed. John Wiley & Sons; 1999.
43. Okot P, Ogao PJ, Abandu J. Site selection model for urban solid waste disposal management using GIS and remote sensing: A case of Gulu Municipality. *Int J Environ Waste Manag.* 2019;24(4):405–436.
44. Saaty TL. The analytic hierarchy process: planning, priority setting, resource allocation. 2nd ed. McGraw-Hill International Book Company; 1980.
45. Rezaei-Moghaddam K, Karami E. A multiple criteria evaluation of sustainable agricultural development models using AHP. *Environ Dev Sustain.* 2008;10(4):407–426.
46. Saranya T, Saravanan S, Jennifer JJ, et al. Assessment of groundwater vulnerability in highly industrialized Noyyal basin using AHP-DRASTIC and Geographic Information System. *Disaster Resilience and Sustainability: Adaptation for Sustainable Development*. 2021:151–170.
47. Saaty TL. The analytic hierarchy process: Planning, priority setting. 2nd ed. RWS Publications; 1990.
48. Saaty TL. A scaling method for priorities in hierarchical structures. *J Math Psychol*. 1977;15(3):234–281.
49. Şener Ş, Sener E, Karagüzel R. Solid waste disposal site selection with GIS and AHP methodology: A case study in Senirkent-Uluborlu (Isparta) Basin, Turkey. Environ Monit Assess. 2011;173(1–4):533–554.
50. Uyan M. MSW landfill site selection by combining AHP with GIS for Konya, Turkey. Environ Earth Sci. 2014;71(4):1629–1639.
51. Sólnes J. Environmental quality indexing of large industrial development alternatives using AHP. *Environ Impact Assess Rev.* 2003;23(3):283–303.
52. ESRI. Weighted overlay. 2023.
53. Chang CW, Wu CR, Lin CT, et al. Evaluating digital video recorder systems using analytic hierarchy and analytic network processes. *Inform Sci.* 2007;177(16):3383–3396.
54. Isalou AA, Zamani V, Shahmoradi B, et al. Landfill site selection using integrated fuzzy logic and analytic network process (F-ANP). *Environ Earth Sci.* 2013;68(6):1745–1755.
55. UBOS. Area specific profiles kamuli district. The national population and housing census 2014. April 2017.
56. Ministry of Finance, P. and E. D. Development policy and performance portal. KAMULI MUNICIPALITY, 2020/21; 2021.
57. Abilmagzhanov A. Studying of energy and environmental characteristics of municipal solid waste from shymkent city polygon. 2022;1–18.
58. Cointreau S. Sanitary landfill design and siting criteria-Guidance Published in May 1996 by the World Bank as an Urban Infrastructure Note. World Bank. November 2004:1–6.
59. Majid M, Mir BA. Landfill site selection using GIS based multi-criteria evaluation technique. A case study of Srinagar city, India. *Environ Challenges.* 2021;3(December 2020).
60. Mvula RLS, Mundike J, Nguvulu A. Spatial suitability analysis for site selection of municipal solid waste landfill using hybrid GIS and MCDA approach: The case of Kitwe, Zambia. *Sci African.* 2023;21(March):e01885.