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Original article

GIS–AHP-Based Assessment of the Existing Municipal Solid Waste Landfill Site in Sabratha, Libya

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Abstract
Municipal solid waste (MSW) management is a major environmental challenge in rapidly growing urban areas. This study evaluates the suitability of the existing municipal solid waste landfill site in Sabratha, Libya, using an integrated Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP) approach. Seven criteria were considered: distance from residential areas, groundwater resources, surface water bodies, road accessibility, land use, soil type, and slope. Spatial data were obtained from Sentinel-2 imagery, SRTM DEM, OpenStreetMap, field surveys, and GIS databases. AHP was applied to determine criterion weights, and a weighted overlay analysis was used to generate the landfill suitability map. The results identified distance from residential areas (27.5%) and groundwater resources (21.4%) as the most influential factors. The consistency ratio (CR = 0.017) confirmed the reliability of the weighting process. The existing landfill site was classified as having High Suitability, indicating compliance with most environmental and engineering criteria. Field investigations, however, revealed operational deficiencies, including open dumping practices, limited environmental safeguards, and drainage-related concerns. The study concludes that while the landfill location is spatially suitable, improvements in operational management and environmental protection measures are required to ensure long-term sustainability.
Keywords. GIS, AHP, Landfill Suitability, Municipal Solid Waste, Sabratha, Libya.

Introduction

Municipal solid waste (MSW) management represents a major environmental challenge, particularly in developing countries experiencing rapid population growth, urbanization, and economic expansion [1]. These factors have increased waste generation and placed significant pressure on waste collection, treatment, and disposal systems [2]. Inadequate waste management practices can lead to soil, surface water, and groundwater contamination, greenhouse gas emissions, unpleasant odors, and public health risks [3,4]. Therefore, environmentally sound waste management strategies are essential for protecting natural resources and supporting sustainable development [5].

Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) have become widely used tools for landfill suitability assessment [6] because they enable the integration of environmental, engineering, and socio-economic criteria within a spatial decision-making framework [7]. Previous studies have demonstrated the effectiveness of GIS–AHP approaches in identifying suitable landfill locations and reducing environmental risks through multi-criteria spatial analysis [9,8]. Key factors commonly considered include distance from residential areas, groundwater resources, surface water bodies, land use, slope, geology, and transportation accessibility [10]. Despite the extensive application of GIS–AHP techniques worldwide, landfill suitability studies in Libya remain limited [11]. Existing research has mainly focused on identifying potential sites for future landfill development, while little attention has been given to evaluating currently operating landfill facilities [12]. Furthermore, no comprehensive GIS–AHP assessment of the existing landfill site in Sabratha has been reported in the available literature. This gap highlights the need for a systematic evaluation of the current landfill site to determine its environmental suitability and identify potential risks associated with its operation.

Sabratha, a major coastal city in northwestern Libya, has experienced substantial urban growth and increasing waste generation. According to the Municipal Cleaning Services Department of Sabratha Municipality (2024), approximately 155 tons of MSW are generated daily, while only 125 tons are collected, resulting in a daily deficit of about 30 tons [13]. Waste generation may increase by up to 40% during peak seasonal periods, highlighting the need to evaluate the suitability of the existing landfill site. Accordingly, this study assesses the suitability of the existing landfill in Sabratha using an integrated GIS–AHP approach to support improved landfill management and sustainable waste management planning. The study area is located in Sabratha within the Jifarah Plain of northwestern Libya, between latitudes 32°45′–32°50′ N and longitudes 12°20′–12°30′ E (Figure 1). The Jifarah Plain is characterized by relatively flat topography and consists predominantly of Quaternary sandy, silty, and calcareous deposits that significantly influence local geological and hydrogeological conditions [14,15]. The existing landfill site is situated at approximately 32.596998° N and 12.367411° E within the central part of the plain.

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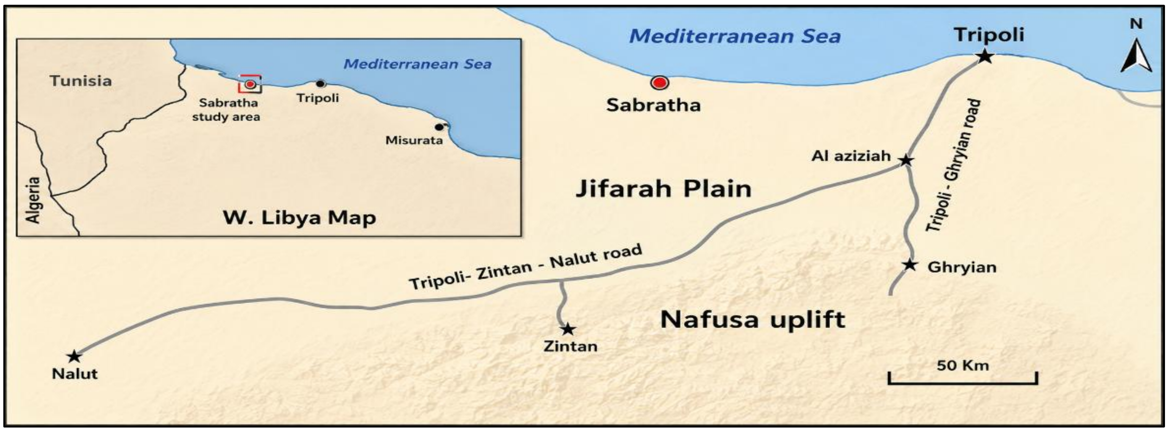

Figure 1. Location of Sabratha City and the Study Area within the Jifarah Plain.
Source: Modified from [16].

Methodology

Data Collection and Spatial Database Preparation

Spatial and attribute datasets were collected from remote sensing sources, field surveys, and existing geospatial databases to evaluate the existing landfill site in Sabratha, Libya. The datasets included satellite imagery, DEM data, road networks, residential areas, groundwater resources, surface water bodies, soil characteristics, and the landfill location. (Figure 2) presents the spatial datasets integrated into the GIS–AHP framework for assessing environmental constraints, accessibility, and site suitability.

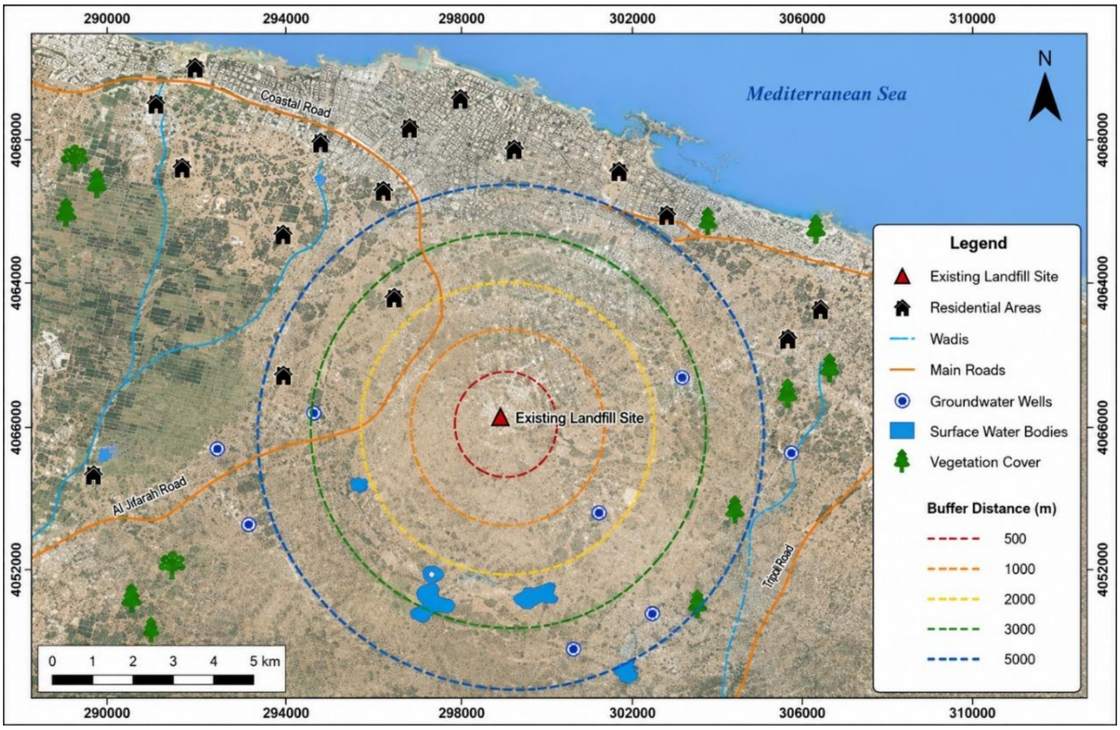

Figure 2. Spatial Database Layers Used in the GIS–AHP Analysis
Source: Authors' own elaboration based on GIS spatial analysis and AHP evaluation criteria.

Spatial datasets used in this study included Sentinel-2 imagery, SRTM DEM, road networks, residential areas, groundwater resources, surface water bodies, soil maps, and the existing landfill location. Data were obtained from ESA, USGS, OSM, field surveys, and GIS databases. (Table 1) summarizes the datasets, sources, and applications used in the GIS–AHP analysis.

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Table 1. Spatial Datasets Used in the Study

Dataset	Format	Spatial Resolution / Scale	Source	Application
Sentinel-2 Imagery	Raster	10 m	ESA	Land use classification
DEM (SRTM)	Raster	30 m	USGS	Slope analysis
Road Network	Vector	1:10,000	OpenStreetMap	Accessibility analysis
Residential Areas	Vector	1:10,000	OSM & Field Survey	Buffer generation
Groundwater Resources	Point	GPS Accuracy ±5 m	Field Survey	Environmental assessment
Surface Water Bodies	Vector	1:10,000	GIS Database	Constraint mapping
Soil Map	Vector	1:50,000	Soil Survey Data	Soil suitability analysis
Existing Landfill Site	Point	GPS Accuracy ±5 m	Field Survey	Target evaluation

Source: Authors' elaboration based on GIS spatial analysis and AHP evaluation criteria

All datasets were preprocessed, validated, and projected to the WGS 1984 / UTM Zone 32N coordinate system using ArcGIS 10.8 to ensure spatial consistency [17]. A geodatabase was then established to integrate the spatial datasets and support criterion mapping, suitability analysis, and landfill site evaluation.

Selection of Evaluation Criteria

Seven evaluation criteria were selected based on previous GIS–AHP studies, environmental guidelines, and local environmental conditions. (Table 2) presents the selected criteria, associated datasets, and their relevance to landfill suitability assessment.

Table 2. Evaluation Criteria Used in the Landfill Suitability Assessment

Code	Criterion	Data Layer	Influence on Suitability	Justification
C1	Distance from Residential Areas	Residential Areas	Positive	Reduces environmental and health impacts on nearby populations.
C2	Distance from Groundwater Resources	Groundwater Wells	Positive	Minimizes the risk of groundwater contamination by landfill leachate.
C3	Distance from Surface Water Bodies	Surface Water Bodies	Positive	Protects Surface water bodies from runoff and contaminant transport.
C4	Road Accessibility	Road Network	Negative Distance Effect*	Improves accessibility and reduces waste transportation costs and travel time.
C5	Land Use	Land Use/Land Cover Map	Variable	Avoids conflicts with environmentally sensitive and incompatible land-use types.
C6	Soil Type	Soil Map	Positive	Low-permeability soils provide greater protection against contaminant migration.
C7	Slope	DEM-Derived Slope Map	Negative Slope Effect	Gentle slopes facilitate landfill construction, operation, and long-term stability.

Source: [18].

To enable multi-criteria analysis, all criterion layers were standardized and reclassified into a common suitability scale ranging from 1 (Unsuitable) to 5 (Very High Suitability). This process converted datasets with different units and formats into comparable suitability layers for integration within the AHP-based weighted analysis (Table 3).

Table 3. Reclassification Scheme and Standardized Suitability Scores for the Selected Criteria

Criterion	Class	Suitability Score
Distance from Residential Areas (m)	< 500	1 (Unsuitable)
	500–1000	2 (Low)
	1000–2000	3 (Moderate)
	2000–3000	4 (High)

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	> 3000	5 (Very High)
Distance from Groundwater Wells (m)	< 250	1 (Unsuitable)
	250–500	2 (Low)
	500–1000	3 (Moderate)
	1000–2000	4 (High)
	> 2000	5 (Very High)
Distance from Surface Water Bodies (m)	< 250	1 (Unsuitable)
	250–500	2 (Low)
	500–1000	3 (Moderate)
	1000–2000	4 (High)
	> 2000	5 (Very High)
Distance from Roads (m)	> 2000	1 (Unsuitable)
	1000–2000	2 (Low)
	500–1000	3 (Moderate)
	< 100	4 (High)
	100–500	5 (Very High)
Land Use	Residential Areas	1 (Unsuitable)
	Agricultural Land	2 (Low)
	Mixed/Open Land	3 (Moderate)
	Bare Land	4 (High)
	Unused/Open Areas	5 (Very High)
Soil Type	Highly Permeable Sandy Soil	1 (Unsuitable)
	Sandy Loam	2 (Low)
	Silty Soil	3 (Moderate)
	Silty Clay	4 (High)
	Clay Soil	5 (Very High)
Slope (%)	> 15	1 (Unsuitable)
	10–15	2 (Low)
	5–10	3 (Moderate)
	2–5	4 (High)
	< 2	5 (Very High)

Source [19].

The selected criteria were considered sufficient to evaluate landfill suitability in the study area based on local environmental conditions, data availability, and their widespread use in previous GIS–AHP studies.

Criteria Standardization and Reclassification

The evaluation criteria were standardized and reclassified according to the suitability scheme presented in (Table 3). The resulting criterion maps served as inputs for the AHP weighting process and the subsequent weighted overlay analysis (Figure 3).

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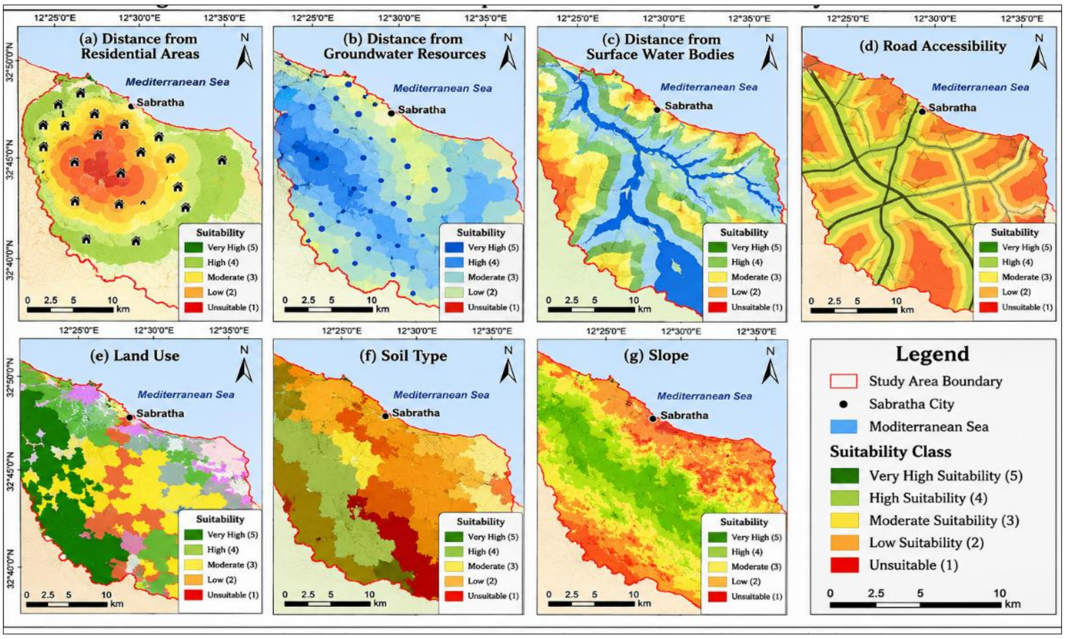

Figure 3. Standardized Criteria Maps Used in Landfill Site Suitability Assessment in Sabratha City, Libya

Source: Developed by the authors using ArcGIS 10.8 and multiple spatial datasets.

Application of the Analytic Hierarchy Process (AHP)

Criterion weights were determined using the Analytic Hierarchy Process (AHP) through pairwise comparisons based on Saaty's nine-point scale. The comparison scale used in the analysis is presented in (Table 4).

Table 4. Saaty's Pairwise Comparison Scale

Intensity of Importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values
1/3, 1/5, 1/7, 1/9	Reciprocal Values

Source [13].

Pairwise comparisons of the seven evaluation criteria were performed using Saaty's scale to derive their relative importance. The resulting comparison matrix is presented in (Table 5).

Table 5. Pairwise Comparison Matrix of Evaluation Criteria Using Saaty's Scale

Criteria	RES	GW	ROAD	LAND	SOIL	SW	SLOPE
RES	1	2	2	2	3	3	3
GW	1/2	1	2	2	2	3	3
ROAD	1/2	1/2	1	2	2	2	2
LAND	1/2	1/2	1/2	1	1	2	2
SOIL	1/3	1/2	1/2	1	1	1	1
SW	1/3	1/3	1/2	1/2	1	1	1
SLOPE	1/3	1/3	1/2	1/2	1	1	1

The pairwise comparison matrix was normalized to derive the priority vector and calculate the relative weights of the evaluation criteria. The resulting weights and priority rankings are presented in (Table 6).

Table 6. Relative Weights and Priority Ranking of Evaluation Criteria

Rank	Criterion	Weight
1	Distance from Residential Areas	0.275
2	Distance from Groundwater Resources	0.214
3	Road Accessibility	0.156
4	Land Use	0.116

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5	Soil Type	0.089
6	Distance from Surface Water Bodies	0.075
7	Slope	0.075
Total	—	1.000

Source: Calculated by the authors using the Analytic Hierarchy Process (AHP).

To evaluate the reliability of the pairwise comparison judgments, a consistency assessment was conducted using Saaty's Consistency Index (CI) and Consistency Ratio (CR). The consistency test results are presented in (Table 7).

Table 7. Consistency Assessment of the AHP Model

Parameter	Value
Number of Criteria (n)	7
Maximum Eigenvalue (λmax)	7.136
Consistency Index (CI)	0.023
Random Index (RI)	1.32
Consistency Ratio (CR)	0.017

The calculated Consistency Ratio (CR) was 0.017, which is substantially lower than the acceptable threshold of 0.10 proposed by Saaty. This result indicates a high level of consistency among the pairwise comparison judgments and confirms the reliability of the derived criterion weights for the landfill suitability assessment.

Suitability Mapping, Model Validation, and Sensitivity Analysis

The standardized criterion layers were integrated using AHP-derived weights through Weighted Overlay Analysis to generate the final landfill suitability map. Suitability scores were calculated using the weighted overlay equation and classified into five categories ranging from Unsuitable to Very High Suitability. The existing landfill site was evaluated by overlaying its location on the final suitability map. To verify the reliability of the GIS–AHP results, field observations, GPS verification, and site inspections were conducted to assess the consistency between the suitability classification and actual site conditions. In addition, model robustness was evaluated through sensitivity analysis by varying the weights of the two most influential criteria, namely distance from residential areas and groundwater resources, by ±10% and comparing the resulting suitability maps with the original model.

Results and Discussion

Relative Importance of Evaluation Criteria

Table 8 presents the AHP-derived weights of the seven evaluation criteria. Distance from residential areas (0.275) and groundwater resources (0.214) were identified as the most influential factors, together accounting for 48.9% of the total decision weight. Road accessibility (0.156) and land use (0.116) ranked next, while soil type, distance from surface water bodies, and slope received lower weights. These results indicate that environmental protection and public health considerations were the primary determinants of landfill suitability in the study area.

Table 8. Relative Weights and Priority Ranking of Evaluation Criteria

Criterion	Weight	Relative Contribution (%)	Priority Level
Distance from Residential Areas	0.275	27.5	Very High
Distance from Groundwater Resources	0.214	21.4	Very High
Road Accessibility	0.156	15.6	High
Land Use	0.116	11.6	High
Soil Type	0.089	8.9	Moderate
Distance from Surface Water Bodies	0.075	7.5	Moderate
Slope	0.075	7.5	Moderate
Total	1.000	100.0	—

Source: Results of AHP analysis performed by the authors

Consistency Analysis of the AHP Model

The consistency of the pairwise comparison judgments was evaluated using the Consistency Index (CI) and Consistency Ratio (CR). As shown in (Table 7), the calculated CR value was 0.017, which is well below the acceptable threshold of 0.10, indicating a high level of consistency and reliability in the derived criterion weights.

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Standardized Criteria Maps

(Figure 6) presents the standardized criterion maps generated for the seven evaluation factors. Higher suitability values are concentrated mainly in the central and south-central parts of the study area, whereas lower suitability classes occur near residential settlements, groundwater resources, and other environmental constraints. This pattern reflects the influence of the highest-weighted criteria, particularly distance from residential areas and groundwater resources. The resulting maps provided the basis for the weighted overlay analysis and final suitability assessment.

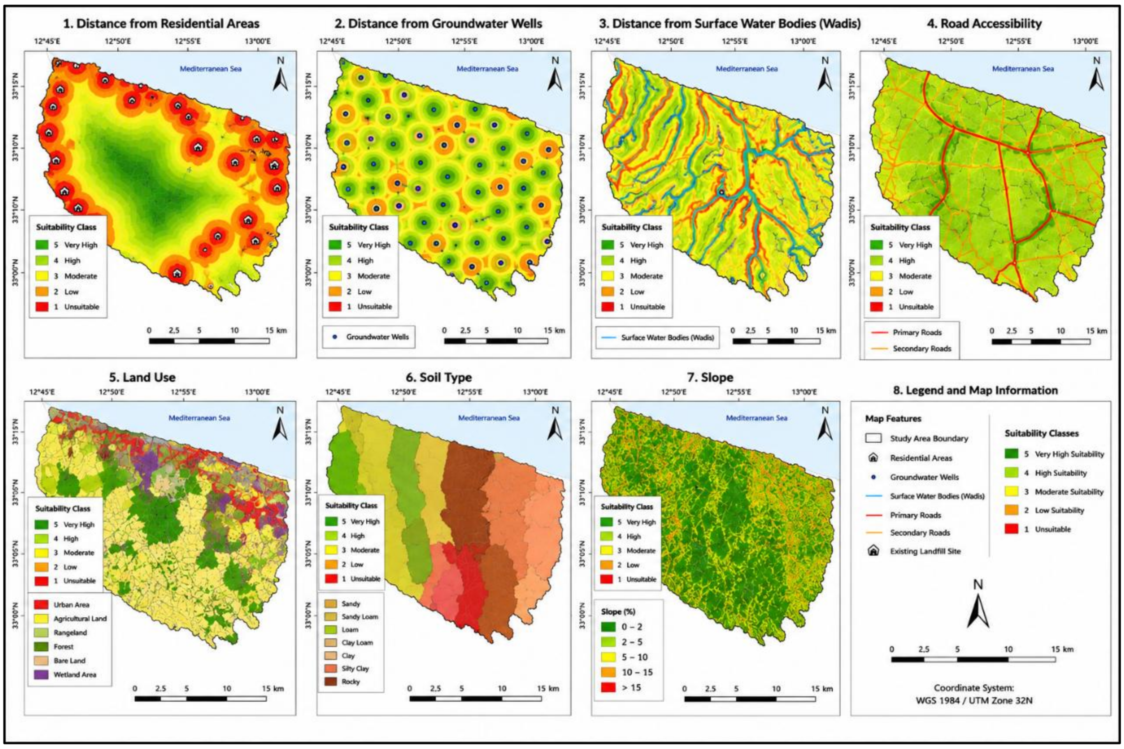

Figure4. Standardized Criteria Maps Used in Landfill Site Suitability Assessment

Source: Authors' own elaboration using ArcGIS 10.8.

Final Landfill Suitability Assessment and Evaluation of the Existing Landfill Site

(Figure 5) presents the final landfill suitability map and the GIS–AHP evaluation of the existing landfill site. The results indicate that highly suitable areas are concentrated mainly in the central portion of the study area, whereas lower suitability classes are associated with residential settlements, groundwater resources, and other environmental constraints.

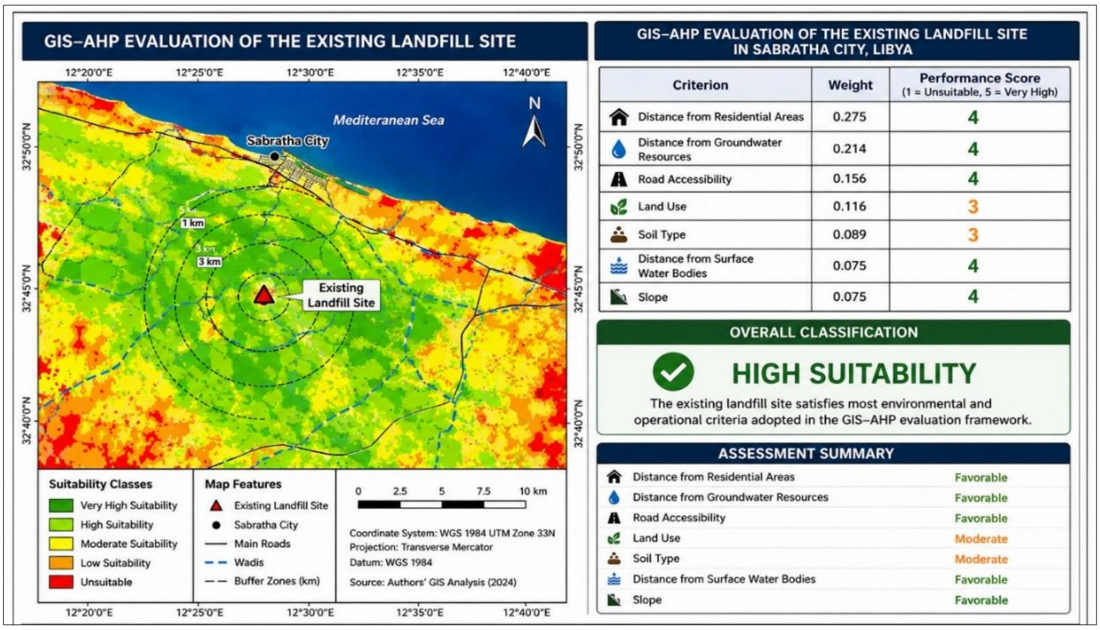

Figure 5. Final Landfill Suitability Map and Evaluation of the Existing Landfill Site

Source: Authors' own elaboration using ArcGIS 10.8 and GIS–AHP analysis.

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The existing landfill site was classified as High Suitability, primarily due to its adequate separation from residential areas and groundwater resources, the most influential criteria in the AHP analysis. These findings support the suitability of the site from a spatial planning perspective. However, field observations revealed that spatial suitability does not necessarily reflect operational performance, highlighting the need for improved environmental monitoring, waste containment, drainage management, and sanitary landfill practices to ensure long-term environmental sustainability.

Field Validation and Site Conditions

(Figure 6) illustrates the surrounding land-use characteristics and sensitive receptors identified during the field investigation. The landfill site is located within a predominantly agricultural and semi-rural area, with agricultural lands surrounding the site and scattered residential development, including Al-Nour Mosque and nearby community facilities. These observations are consistent with the GIS–AHP assessment, which classified the site within a suitable zone due to its separation from major residential concentrations. However, the proximity of agricultural activities highlights the need for continued monitoring of soil quality, surface runoff, and potential groundwater contamination.

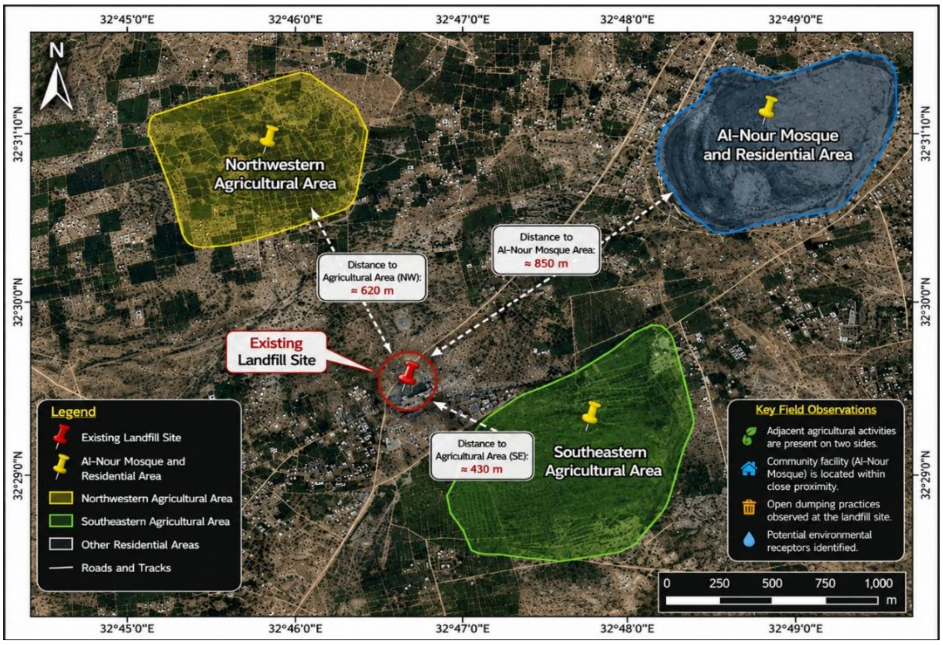

Figure 6. Surrounding Land Uses and Sensitive Receptors Identified During the Field Investigation
Source: Authors' own elaboration based on Google Earth imagery and field observations (2024).

(Figure 7) presents field photographs documenting the environmental and operational conditions of the landfill site. The observations revealed open dumping practices, exposed waste, scattered materials, limited engineering controls, and drainage features that may facilitate contaminant transport during rainfall events. Although the GIS–AHP analysis classified the site as suitable, these conditions indicate operational deficiencies and highlight the need for improved environmental monitoring, waste containment, drainage management, and a gradual transition toward sanitary landfill practices.

Figure 7. Field Survey Photographs and Environmental Characteristics of the Existing Landfill Site
Source: Authors' field photographs and observations (2024).

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Sensitivity Analysis
(Table 9) presents the results of the sensitivity analysis performed by varying the weights of the residential area and groundwater criteria by ±10%. Under all scenarios, the existing landfill site remained classified as High Suitability, indicating that the GIS–AHP model is robust and that the assessment results are not significantly affected by moderate weighting uncertainty.

Table 9. Sensitivity Analysis Scenarios

Scenario	Residential Weight	Groundwater Weight	Existing Landfill Classification
Original Model	0.275	0.214	High Suitability
Scenario 1 (+10% Residential)	0.303	0.214	High Suitability
Scenario 2 (-10% Residential)	0.248	0.214	High Suitability
Scenario 3 (+10% Groundwater)	0.275	0.235	High Suitability
Scenario 4 (-10% Groundwater)	0.275	0.193	High Suitability

Conclusion
This study assessed the suitability of the existing municipal solid waste landfill site in Sabratha, Libya, using an integrated GIS–AHP framework based on seven environmental and operational criteria. The results identified distance from residential areas and groundwater resources as the most influential factors, accounting for 48.9% of the total decision weight, while the consistency analysis confirmed the reliability of the weighting process (CR = 0.017). The weighted overlay analysis classified the existing landfill site as having High Suitability, indicating compliance with most environmental and engineering criteria. Field observations supported the spatial suitability of the site but revealed operational deficiencies, including open dumping practices, inadequate environmental safeguards, drainage-related concerns, and the absence of engineered landfill infrastructure. Sensitivity analysis further confirmed the robustness of the GIS–AHP model, as moderate variations in criterion weights did not alter the suitability classification. Overall, the landfill site is suitable from a spatial planning perspective; however, improvements in operational management, environmental monitoring, drainage control, and the adoption of sanitary landfill practices are necessary to ensure long-term environmental sustainability.

Conflict of interest. Nil

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