

Multi-Criteria Optimisation of Landfill Site Selection Using AHP-TOPSIS-SWARA: A Case Study of Chegutu Municipality

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Abstract

This study presents an integrated Multi-Criteria Decision-Making (MCDM) framework for sustainable landfill site selection in Chegutu Municipality, Zimbabwe. Combining the Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Stepwise Weight Assessment Ratio Analysis (SWARA), the research evaluates three potential sites against environmental, social, economic, and technical criteria. Data were collected through expert questionnaires ($n = 7$) and geospatial analysis, with weights derived via AHP OS software and rankings computed using Python. Results identified Site 2 as optimal (45.3% final score), demonstrating superior performance in critical environmental factors: slope gradient (1.5%), water source proximity (6834.82 m), and settlement distance (3220 m). The hybrid methodology proved particularly effective in resolving conflicts between technical and social priorities, with environmental criteria carrying 61.1% weight in the AHP analysis. The study demonstrates how integrated MCDM approaches can improve municipal waste management decisions by systematically balancing ecological protection, public health concerns, and operational feasibility. Findings provide a transferable model for landfill site selection in developing urban contexts while highlighting the value of combining quantitative tools.

Keywords

Multi-Criteria Decision-Making (MCDM), Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Stepwise Weight Assessment Ratio (SWARA)

1. Introduction

Chegutu Municipality is located in Mashonaland West Province, Zimbabwe. According to the 2022 national census, it has a population of about 66,000 (Placeholder1). The local economy depends mainly on agriculture and mining. However, rapid urbanisation and increased plastic packaging use have created solid waste management challenges. The municipality provides essential services, including refuse collection, water supply, and disease control. Currently, it lacks proper waste disposal systems and still uses traditional dumpsites. These substandard sites pose public health risks, particularly during cholera outbreaks.

Residents have expressed growing concerns about waste management. Selecting landfill sites is complex, involving environmental, social, economic, and technical factors [1]. Multi-Criteria Decision-Making (MCDM) methods now help optimize this process by considering all relevant criteria. This study integrates three MCDM approaches. The Analytical Hierarchy Process (AHP) breaks decisions into hierarchical structures [2]. It allows step-by-step comparisons through pairwise evaluations [3]. Researchers have applied AHP across various fields [4] [5], though some note potential consistency issues [6]-[8]. Many studies support combining AHP with other methods [9] [10].

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) identifies options closest to ideal solutions [11]. Its popularity has grown through ongoing refinements [12]. TOPSIS effectively handles complex decisions with conflicting criteria [13] and provides clear rankings [14]. While [15] found TOPSIS reliable, they did not account for criteria heterogeneity. Other studies successfully combined AHP and TOPSIS [16]-[18], though fuzzy adaptations remain debated [19] [20]. Recent comparisons favour TOPSIS over AHP for ranking clarity [21] [22]. The Stepwise Weight Assessment Ratio Analysis (SWARA) method, introduced in [23], has proven effective for landfill selection [24]. It delivers consistent results [25] and has integrated well with other techniques [26], though some applications lack clarity about AHP's role. While researchers have combined AHP with various methods [27] [28], few studies integrate AHP, TOPSIS, and SWARA for landfill selection.

Most Zimbabwean studies use Geographical Information Systems (GIS) instead. There remains limited research applying these integrated MCDM approaches locally [29]. This study addresses that gap while acknowledging the need to incorporate emerging technologies such as machine learning.

2. Methods

This research examines landfill site selection using an integrated Multi-Criteria Decision Analysis (MCDA) approach. We combine three established methods: the Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Stepwise Weight Assessment Ratio Analysis (SWARA). Our goal is to identify the most suitable landfill location among the proposed sites in the study area. **Figure 1** illustrates the geographical context, showing

the study area's location relative to nearby Zimbabwean cities. The integrated methodology allows us to systematically evaluate sites against multiple environmental, social, economic, and technical criteria.



Figure 1. Location of the study area. (Source: Google Earth)

2.1. Data Collection

The study employed a mixed-methods approach to data collection. Primary data were gathered through structured questionnaires administered to experts in waste management and urban planning. These questionnaires captured pairwise comparisons of evaluation criteria, enabling us to assess their relative importance. Geospatial data supplemented this through satellite imagery and Google Earth mapping, which provided visual documentation of the proposed landfill sites' physical characteristics. Following the collection, the dataset underwent systematic processing. Questionnaire responses were analysed using AHP OS software to generate consistency ratios and pairwise comparison matrices. For the subsequent TOPSIS and SWARA analyses, we processed the data using Python programming to determine optimal site rankings. The complete dataset is presented across three reference tables: **Table 1** details expert demographics, **Table 2** outlines the evaluation criteria framework, and **Table 3** describes the alternative site characteristics under consideration.

Table 1. Demographic characteristics of experts.

Expert category	Total	Position	Highest qualification	Information Provided
Environmental health	3 (42.9%)	Environmental health manager and lecturer	Masters	<ul style="list-style-type: none"> Distances from residential and sensitive areas and public health bylaws regarding landfills. Academic insight into best practices and methodologies
Community representative	1 (14.3%)	Stake holder	Degree	<ul style="list-style-type: none"> Traditional knowledge and participation in awareness campaigns
Town planning	1 (14.3%)	Town planner	Degree	<ul style="list-style-type: none"> Current and future land use plans
Environmental management	1 (14.3%)	Environmental officer	Diploma	<ul style="list-style-type: none"> Legal distances from wetlands, waterbodies, protected areas, and data on potential leachate impact.
Civil and Water Engineering	1 (14.3%)	Lecturer	Masters	<ul style="list-style-type: none"> Proximity to water sources, geology & hydrology, and slopes.

Table 2. Summary of criteria selection.

Criteria	Sub-criteria	Description
Environmental factors (B1)	Slope (C1)	[30] Recommended an optimal slope of between 8% - 12% for a landfill to be constructed. Slopes that are steeper than 12% lead to excessive surface runoff. Moreover, slopes that are <8% affect the proper drainage.
	Proximity to water sources (C2)	Landfills emit dangerous gases and leachate that contaminate water bodies [31]. A landfill that is near a water body within a distance of 0 - 100 m is prohibited. The minimum recommendation is >500 m. The greater the distance from the water body, the safer the landfill construction.
	Soil Type (C3)	Landfill selection requires soils that have very low permeability in order to reduce leachate. The ideal site must have clay-rich soil.
	Geology and Hydrology (C4)	A landfill site should be located where the groundwater is deep in order to prevent contamination of the groundwater through leachate. The most suitable geological setting should have low-permeable strata and an absence of fractured bedrock. Landfills should be located where groundwater depth is >3.5; hence, the greater the depth, the more suitable the site.

Continued

Economic factors (B2)	Cost (C5)	The cost of constructing a landfill is very important.
	Land use (C6)	Land use in the study area varies in terms of both economic activity and population density across different areas. On the proposed sites, there was only land from agriculture and mining. Areas such as residential areas, recreational zones, and vegetated lands are unsuitable for landfill sites.
	Land availability (C7)	In the process of selecting landfill sites, the availability of land is another aspect to consider. Landfills must be constructed on land that has soils with low permeability in order to minimise [32].
Social factors (B3)	Community acceptance (C8)	Community acceptance is very important in landfill site selection. Despite having all suitable geological conditions, the community might not accept the selection of a landfill site in a place surrounding them due to odour and pollution.
	Distance from the settlement (C9)	Landfill sites must be strategically located in order to reduce conflicts with urban development and to mitigate public health risks. The site should be located at least 1 km from residential areas.
	Cultural and Historic (C10)	Locating landfill sites in sacred places and heritage sites can lead to conflicts with the community. Therefore, landfills must be located at least 3 km from the protected sites.
	Distance from the road (C11)	The distance between a landfill and a major road should balance accessibility, traffic safety, and environmental protection. In [33], it was stated that a landfill must not be located within 200 m of any existing highways or major streets. They are not supposed to be located too far away for them to be accessible.
Technical factors (B4)	Accessibility (C12)	Landfills must not be located too far away from existing roads (major roads and highways) so as to reduce fuel consumption and dispose of waste in a timely manner. If it is too far and not accessible, operational costs and inefficiency will be high [34].
	Climate and Weather (C13)	Areas that receive high rainfall are not ideal to situate a landfill site as it results in leachate and contaminates groundwater. Also, places with high winds can disperse litter and odour from the landfill, which will affect the community. Preferably, places with normal rainfall and no heavy winds can be ideal, yet Chegututu municipality is in that category.
	Waste management (C14)	A landfill is not just like a dumpsite, but more like a waste management system. Recycling and resource recovery can be done at the site. Therefore, landfill selection must also consider proximity to recycling facilities for waste management. Waste segregation must also be done on the site, where physical sorting is done before disposing [35].

Table 3. Alternative information.

Criteria	Site	Description	Explanation
Proximity to water sources	Site 1	7759.81 m	Distance was measured from the major water source (Mupfure River).
	Site 2	6834.82 m	
	Site 3	3888 m	
Slope	Site 1	2.6%	Slope was measured at each site as a percentage.
	Site 2	1.5%	
	Site 3	2.2%	
Geology and Hydrology	Site 1	Low permeability	Stable bedrock
	Site 2	Moderate permeability	Sandy soil
	Site 3	Low permeability	Semi-clay soil
Soil type	Site 1	Black loamy soil	Located in the mining area
	Site 2	Sandy loamy soil	Agricultural zone
	Site 3	Semi-clay soil	Agricultural zone
Land acquisition cost	Site 1	\$180,000	The cost of each site was calculated using the price per square meter.
	Site 2	\$126,000	
	Site 3	\$250,000	
Land availability	Site 1	40%	Space for expansion
	Site 2	33%	
	Site 3	27%	
Distance from the settlement	Site 1	1240 m	Distance was measured from the residential settlement to the commercial settlement.
	Site 2	3220 m	
	Site 3	110 m	
Community acceptance	Site 1	Moderately accepted	Close to the settlement
	Site 2	Highly accepted	Far from the settlement
	Site 3	Less accepted	Very close to the settlement
Distance from the road	Site 1	2240 m	All the sites are neither far nor too close to major roads like the A5 road.
	Site 2	3783 m	
	Site 3	3358 m	
Accessibility	Site 1	Moderately accessible	Distance to major roads and settlements.
	Site 2	Poor accessibility	
	Site 3	Very accessible	
Cultural and Historic	Site 1	No important cultural value.	Site 3 is a dressing place for the Nyau culture (Gure) activities.
	Site 2	No important cultural value.	
	Site 3	Cultural heritage site	
Climate and Weather	Site 1	Moderate rainfall	Since all the sites are located in Chegutu, they receive nearly the same rainfall.
	Site 2	Moderate rainfall	
	Site 3	Moderate rainfall	

Continued

Waste management	Site 1	Moderate waste management systems	Site 3 requires advanced waste management since it is very close to settlements.
	Site 2	Moderate waste management systems	
	Site 3	Moderate rainfall	
Land use	Site 1	Mining area	No conflict with mining activities
	Site 2	Agricultural land	Potential for conservation of land use
	Site 3	Agricultural land	Requires compensation for the land

2.2. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s, serves as a fundamental component of our multi-criteria decision-making framework. This structured technique enables the systematic evaluation of criteria through pairwise comparisons, assigning relative weights that reflect their importance in landfill site selection. We applied Saaty’s established weighting scale, where criteria are rated from 1/9 (least important) to 9 (most important), with 1 indicating equal importance between compared elements. **Table 4** presents the complete weighting scheme used in our analysis. The AHP methodology breaks down complex decisions into hierarchical structures, allowing us to quantify expert judgements and establish consistent priority rankings across all evaluation criteria.

Table 4. Saaty scale.

Level of Importance	Definition	Explanation
1	Equal Importance	Two factors contribute equally to the objective.
3	Moderate Importance	Experience and judgment slightly favor one over the other.
5	Strong Importance	Experience and judgment strongly favor one over the other.
7	Very Strong Importance	Experience and judgement very strongly favor one over the other. Its importance is demonstrated in practice.
9	Extreme Importance	The evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate Values	When a compromise is needed.
1/3, 1/5, 1/7, 1/9	Values of inverse comparison	

The following equations are used in the AHP methodology.

- 1) Computing pairwise comparison.

$$a_{ij} = \frac{1}{a_{ji}} \quad (1)$$

2) Calculating the consistency ratio after computing the mean of the elements in each row of the normalised matrix.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

where λ_{\max} = sum of the products between each element of the priority vector and column

n —Number of criteria

CI—Consistency index

RI—Random inconsistency index

If the consistency ratio $CR > 0.10$ then there is a need to reconsider pair-wise values, until $CR < 0.10$ has been reached.

3) Ranking of the results for each alternative.

$$\text{Score}_i = \sum_{j=1}^n W_j \cdot S_{ij} \quad (4)$$

where,

S_{ij} - is the score of alternative i with respect to j .

W_j - is the weight of alternative j with respect to criteria.

The pairwise comparisons derived from expert judgments were processed using AHP OS, a dedicated online analytical tool. This software platform performed three critical functions: 1) computation of the pairwise comparison matrices, 2) automatic normalization of results, and 3) calculation of consistency ratios to validate judgment reliability. Additionally, the software generated the complete decision hierarchy structure, ensuring proper representation of the evaluation framework.

2.3. Technique for Order of Preference by Similarity to Ideal Solution

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a well-established multi-criteria decision analysis method that evaluates alternatives based on their geometric distances from ideal solutions [11]. As developed by Hwang and Yoon, this approach operates on the fundamental principle that the optimal choice should simultaneously minimize distance from the Positive-Ideal Solution (PIS) and maximize distance from the Negative-Ideal Solution (NIS) [11] [13]. The PIS represents the hypothetical alternative achieving optimal values across all criteria, while the NIS represents the worst-case scenario [14]. TOPSIS calculates a normalized similarity index for each alternative through systematic comparison with these reference points, as demonstrated in recent landfill site selection studies [16] [18]. The method's effectiveness in handling complex decisions with conflicting criteria has been well documented, particularly when inte-

grated with weighting methods like AHP [17] [20]. Following established practice, our implementation calculates relative closeness scores (Equation (5)-(9)) to rank alternatives, with higher values indicating better overall performance [12] [14]. This approach provides a robust framework for objective decision-making, particularly valuable in environmental management applications where multiple competing factors must be balanced [1] [24].

Steps

1) To calculate the normalised decision matrix for the normalised value R_{ij} which is calculated as

$$R_{ij} = \frac{x_{ij}}{\sqrt{(\sum x_{ij})^2}} \quad j = 1, 2, 3, \dots \text{ and } i = 1, 2, 3, \dots \quad (5)$$

2) Calculate the weighted value V_{ij} which is calculated as

$$V_{ij} = W_{ij} + R_{ij} \quad (6)$$

where,

W_i = is the weight of the i^{th} Attribute or criterion and $\sum W_i$

3) After determining the weighted normalised matrix, we need to calculate (identify) the positive and negative ideal solutions. For the Positive Ideal Solution (PIS) which is the maximum value (A^+) and Negative Ideal Solutions (A^-).

$$A^+ = \{V_1^+ \dots V_i^+\} = \left[(\max V_{ij} \mid i \in I^1), (\min V_{ij} \mid i \in I^1) \right] \quad (7)$$

$$A^- = \{V_1^- \dots V_i^-\} = \left[(\max V_{ij} \mid i \in I^1), (\min V_{ij} \mid i \in I^1) \right] \quad (8)$$

4) After finding positive and negative ideal solutions then calculate relative Closeness

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (9)$$

Rank preference order then choose an alternative with the maximum C_i or rank alternatives

According to C_i in descending order.

2.4. Stepwise Assessment Ratio Analysis SWARA

The Stepwise Weight Assessment Ratio Analysis (SWARA) method provides a structured approach for determining criteria weights, offering distinct advantages for landfill site selection. This method requires fewer pairwise comparisons than AHP while maintaining robust results, as demonstrated in waste management applications [24]. Its streamlined process makes it particularly efficient for municipal planning contexts like our Chegutu case study. The method's effectiveness stems from its ability to directly prioritise criteria based on expert input while avoiding redundant assessment steps [25]. When integrated with other techniques like GIS, SWARA has proven valuable for environmental decision-making, particularly in landfill site selection studies [26]. For our research objectives, SWARA's balance of simplicity and accuracy makes it well-suited to evaluate the key envi-

ronmental, social, and technical factors affecting landfill suitability.

Calculate the weight values of each criterion so that their sum is equal to 1.

$$W_j = \frac{Q_j}{\sum_{j=1}^n Q_j} \quad (10)$$

where,

W_j – represents the relative weight of each criterion and is also called normalising weights by summing up all Q_j

2.5. Integration

Comparing and contrasting results from AHP, TOPSIS, and SWARA. If the results are the same, then proceed to the final decision and draw a conclusion. If they are different, then standardize the results by calculating the average rank from the three methods.

Average rank for each alternative i

$$\text{Rank}_i^{\text{average}} = \frac{\text{Rank}_i^{\text{AHP}} + \text{Rank}_i^{\text{TOPSIS}} + \text{Rank}_i^{\text{SWARA}}}{3} \quad (11)$$

3. MCDM Methods

Multi-criteria decision-making methods are responsible for prioritizing, ranking, and selecting a set of alternatives that are independent of each other. The best way to integrate each is that each MCDM produces different results from each others, so optimum integration is essential. The hybrid MCDM flow chart is shown in **Figure 2**.

3.1. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was used to determine the relative weights for each criterion. The AHP decomposes the decision problem into levels (hierarchy) of criteria, sub-criteria, and alternatives. Pairwise comparison was done using experts' data to establish the relative importance of each criterion. The AHP OS (Online Software) was used to calculate the consistency ratio, which ensured the reliability of the judgments. (**Figure 3**)

Pairwise comparisons

The pairwise comparison was used to determine the relative importance of the main criteria. Through expert judgement, each criterion was compared using Saaty's scale. The results captured the consolidated pairwise matrix from the 7 different experts, as shown in **Figure 4** and **Figure 5**.

The matrix showed that Environmental factors were better than all other criteria. As indicated in the matrix, Environmental factors have a higher comparison value of 9.00 against technical factors and 5.00 against Economic factors. Social factors also have a high preference over other criteria except for Environmental factors. Economic factors received the lowest importance among all pairwise comparisons.

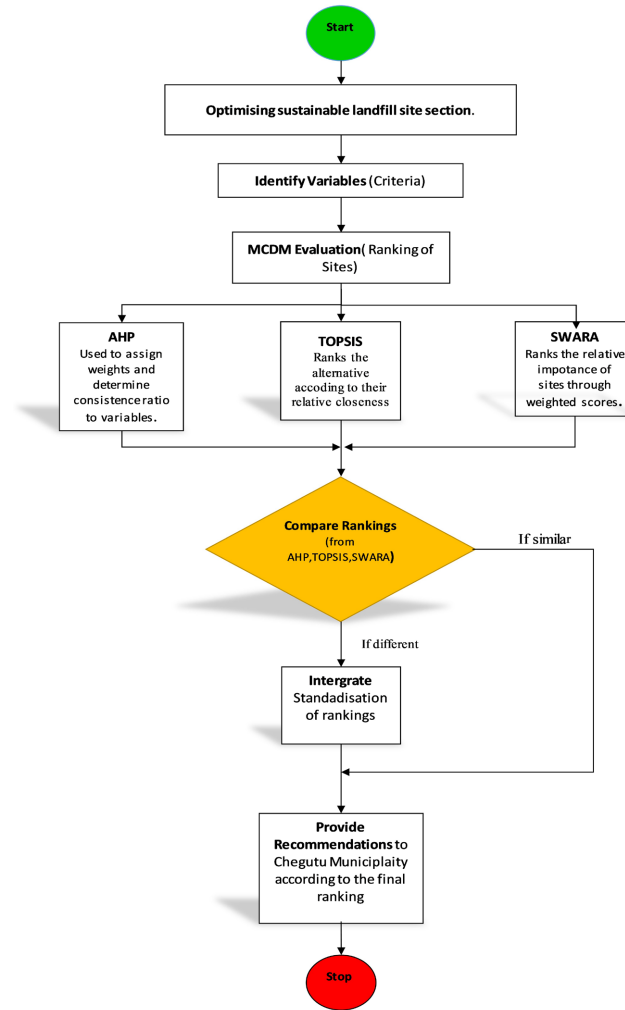


Figure 2. Methodology flow chart.

Level 0	Level 1	Level 2	Glb Prio.	Site 1	Site 2	Site 3
Optimising landfill site selection	Environmental factors 0.611	slope 0.119	7.3%	0.682	0.103	0.216
		proximity to water sources 0.651	39.8%	0.111	0.667	0.222
		soil type 0.110	6.7%	0.216	0.103	0.682
		geology and hydrology 0.119	7.3%	0.455	0.091	0.455
	Economic factors 0.143	costs 0.400	5.7%	0.216	0.682	0.103
		land use 0.400	5.7%	0.714	0.143	0.143
		land availability 0.200	2.9%	0.682	0.216	0.103
	Social factors 0.180	community acceptance 0.284	5.1%	0.138	0.732	0.130
		distance from settlement 0.549	9.9%	0.200	0.727	0.073
		cultural & historical 0.088	1.6%	0.167	0.167	0.667
		distance from road 0.079	1.4%	0.200	0.400	0.400
	Technical factors 0.066	accessibility 0.429	2.8%	0.458	0.126	0.416
		climate & weather 0.143	0.9%	0.333	0.333	0.333
waste management 0.429		2.8%	0.149	0.160	0.691	
			1.0	26.7%	46.8%	26.5%

Figure 3. Weights of each criterion.

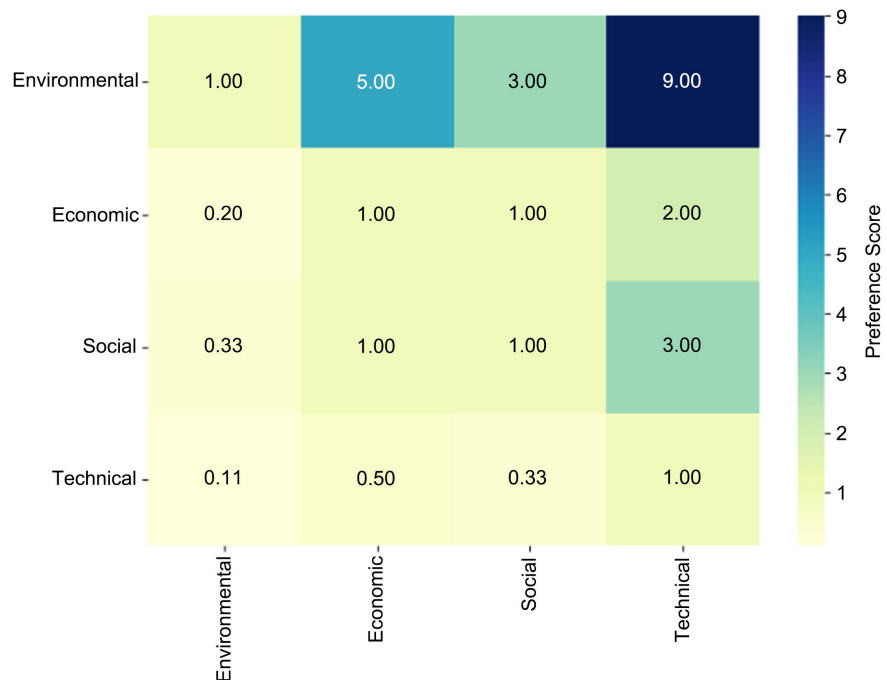


Figure 4. AHP Pairwise comparison Matrix.

Consistency Ratio CR: 1.0%

Cat	Priority	Rank
1 Environmental factors	61.1%	1
2 Economic factors	14.3%	3
3 Social factors	18.0%	2
4 Technical factors	6.6%	4

Figure 5. AHP Pairwise comparison Matrix 1.

The criteria were ranked as shown in Figure 3, where environmental factors (61.1%) ranked first, followed by social factors (18.0%), Economic factors (14.3%), and technical factors (6.6%).

The environmental, economic, social, and technical criteria show good consistency with CR values below 1% (0.1), indicating that the judgment was reliable. On the other hand, the economic factors and technical node show a CR of 0%, which is still below the acceptable limit. This shows that under economic and technical, there is average consistency in the pairwise comparisons (Figure 6).

In Figure 3 and Figure 5, it is shown that environmental factors have the highest priority and consistency ratio as compared to the other main criteria. The pairwise comparison matrix in Figure 6 exhibits the factors under environmental factors, showing their weights for each. Proximity to water sources has the highest weight in the matrix, and in Figure 7, it has the highest priority as well.

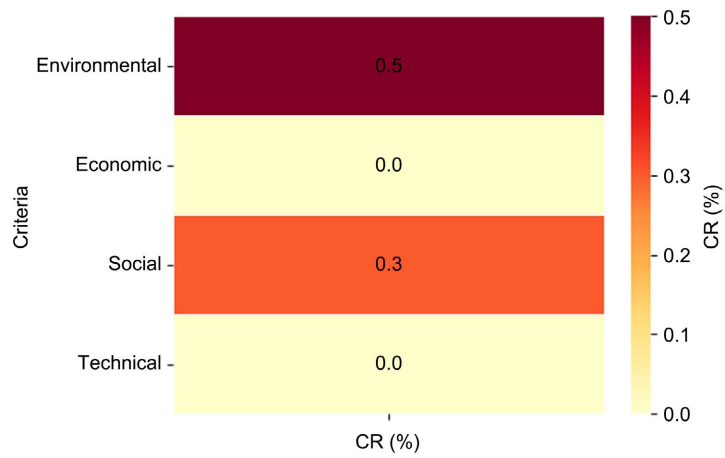


Figure 6. Criteria CR heat map.

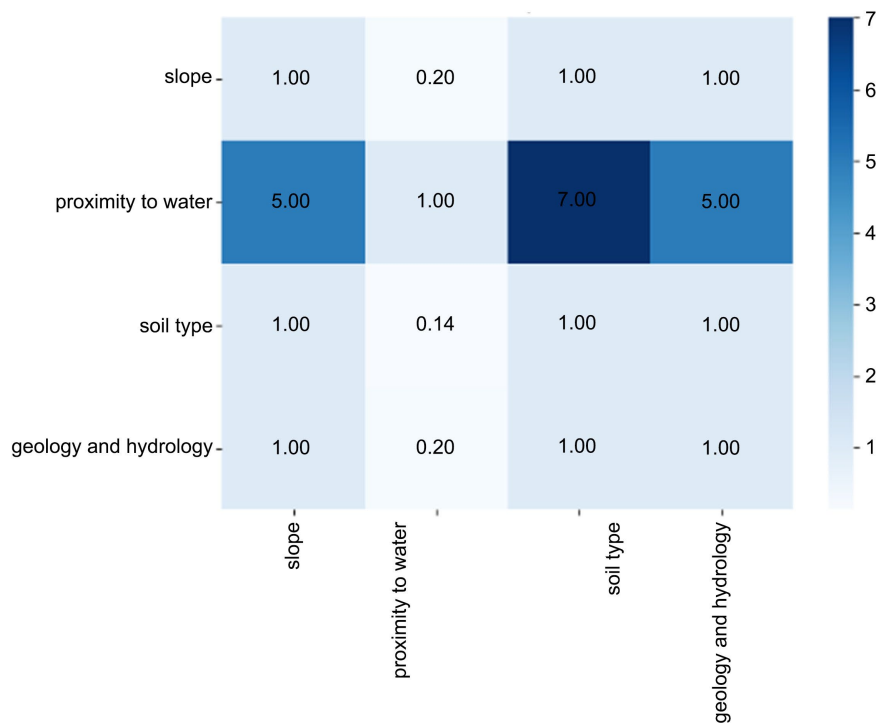


Figure 7. Pairwise comparison for environmental factors.

Proximity to water sources is the only one without overlap. Its weight interval does not overlap with any other; it clearly stands out as the most important. The following groups of criteria overlap within uncertainties. (Figure 8)

- 1) distance from settlement, slope, geology and hydrology, soil type, costs, land use, community acceptance;
- 2) costs, land use, community acceptance, land availability, accessibility, waste management;
- 3) land availability, accessibility, waste management, cultural & historical, distance from roads;
- 4) cultural & historical, distance from road, climate & weather.

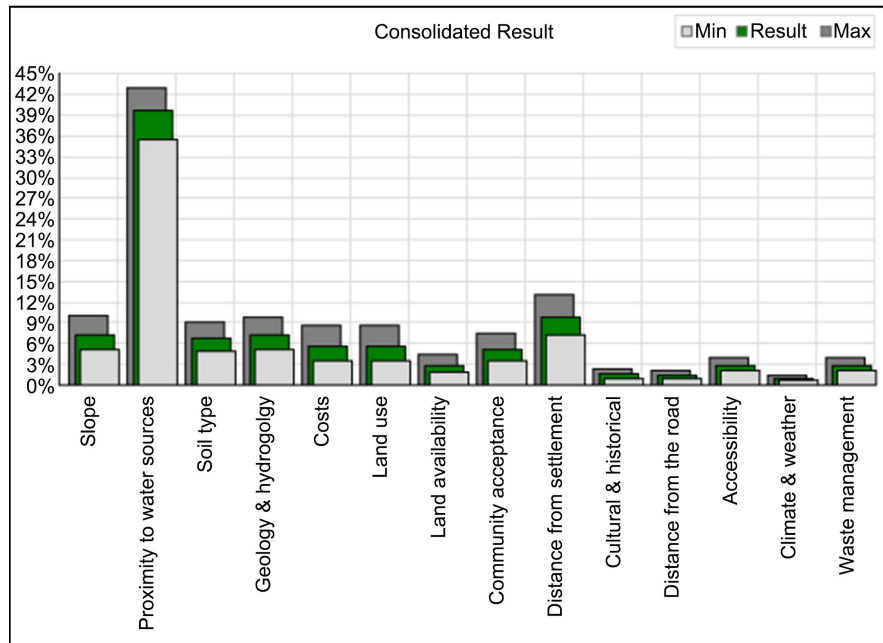


Figure 8. Global priority of sub-criteria.

The CR for sub-criteria was calculated in Figure 7 to assess the reliability of the pairwise comparisons from the AHP. Land use, climate & weather showed perfect consistency with 0%. Community acceptance and distance from settlement have a high consistency of 0.1% each since criteria that have to do with distance were measured without people’s opinions, such as community acceptance. Other sub-criteria like costs, land availability, accessibility, and distance from road remained at an acceptable level of consistency as shown in Figure 9.

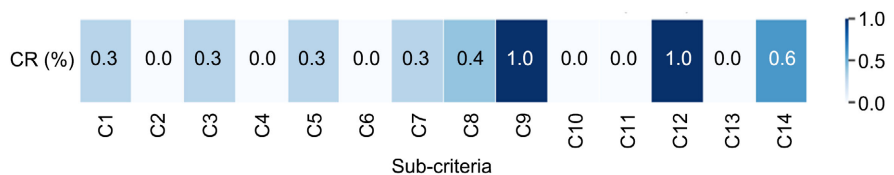


Figure 9. CR for sub-criteria.

Sensitivity Analysis

Site 2 stands out as the top-performing site, demonstrating statistically significant superiority over both Site 1 and Site 3 (no overlap in uncertainties). Site 3 & Site 1 exhibit overlapping performance ranges within uncertainty bounds. Robustness analysis showed that the percent-top critical criterion is proximity to water sources; a change from 39.8% by absolute and 29.9% will change the ranking between alternatives Site 1 and Site 2. Additionally, a small change in proximity to water sources from 39.8% by an absolute 7.3% will change the ranking between alternatives Site 1 and Site 3. Furthermore, the performance measure for alternative Site 3 under the criterion proximity to water sources, with a change from 22.2% to 2.6%, will change the ranking between Site 3 and Site 1 (Figure 8 and

Figure 10).

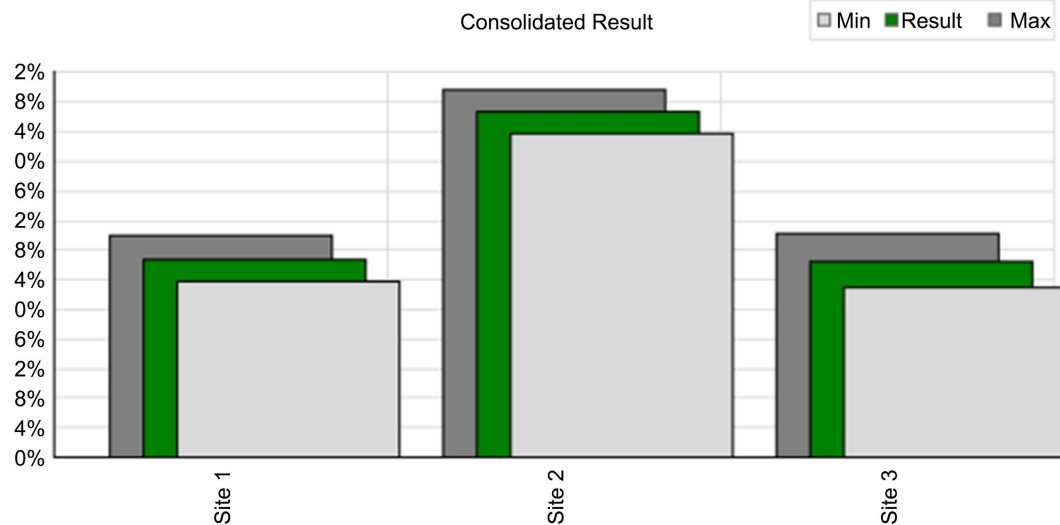


Figure 10. Final weights of alternatives.

3.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

The Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) is an MCDM method used to rank alternative landfill sites according to their relative closeness to an ideal solution. The method evaluates each site against a set of criteria by identifying a Positive Ideal Solution (PIS) and a Negative Ideal Solution (NIS), which represent the best and the worst. The alternatives are then ranked according to their closeness coefficient, which shows how close each site is to the ideal solution.

Nominalisation of criteria

The pairwise comparison matrix was extracted from the AHP OS, where experts' judgments were computed. The normalized matrix is given in **Table 5**. **Table 7** shows the aggregated decision matrix from the original decision matrix. The judgment from seven experts shows the weight for each criterion (**Table 6**).

Positive Ideal and Negative Ideal Solution

The Positive Solution (PIS) represents the best possible value for each criterion, and the Negative Ideal Solution (NIS) represents the worst possible value of each criterion. The PIS and NIS values are the ones that are used to rank the alternatives based on their closeness to the ideal solution.

Table 5. Normalised decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
Site 1	0.7926	0.7926	0.7030	0.1361	0.5071	0.5071	0.9113	0.3651	0.5071	0.3015	0.1543	0.2722	0.5774	0.1925
Site 2	0.5661	0.2265	0.1005	0.2722	0.8452	0.8450	0.3906	0.9129	0.8452	0.3015	0.7715	0.1361	0.5774	0.1925
Site 3	0.2265	0.5661	0.7035	0.9526	0.1690	0.1690	0.1302	0.1826	0.1690	0.9045	0.6172	0.9526	0.5774	0.9623

Table 6. Decision matrix for TOPSIS.

	Site 1							Site 2							Site 3						
	D1	D2	D3	D4	D5	D6	D7	D1	D2	D3	D4	D5	D6	D7	D1	D2	D3	D4	D5	D6	D7
C_1	7	6	7	8	7	6	8	8	7	8	9	8	8	8	6	6	5	7	6	6	6
C_2	9	8	9	8	9	9	9	7	6	7	7	7	8	8	8	7	9	8	8	8	8
C_3	8	9	8	9	9	9	9	8	8	7	8	9	8	9	7	7	6	8	6	7	8
C_4	4	5	5	6	5	5	5	6	5	7	6	6	6	7	7	6	8	7	7	8	6
C_5	8	8	8	7	8	9	9	7	7	6	8	7	6	7	6	6	5	7	6	6	6
C_6	6	5	7	6	6	6	6	5	5	6	4	5	5	6	7	6	8	7	7	7	7
C_7	7	6	8	7	7	7	7	6	6	5	7	6	6	6	8	7	9	8	8	8	8
C_8	9	8	9	9	8	8	9	8	8	9	7	8	7	8	7	6	8	7	7	7	7
C_9	5	6	6	7	5	6	7	7	7	6	8	6	7	7	8	8	8	9	7	8	8
C_{10}	4	3	5	4	4	4	4	6	6	7	5	6	6	6	5	5	4	5	6	5	5
C_{11}	5	4	5	5	6	5	5	6	6	7	6	5	6	6	7	6	7	8	6	7	6
C_{12}	6	7	8	7	6	7	6	6	5	6	6	7	6	6	5	6	5	5	5	5	5
C_{13}	6	6	5	6	7	6	6	7	6	7	7	6	7	7	8	7	9	8	8	8	7
C_{14}	8	7	9	8	8	8	9	7	6	8	7	7	7	7	6	6	7	6	5	6	6

Table 7. Aggregated decision matrix.

	Site 1	Site 2	Site 3
C_1	7	8	6
C_2	8.71428571	7.14285714	8
C_3	8.71428571	8.14285714	7
C_4	5	6.14285714	7
C_5	8.14285714	6.85714286	6
C_6	6	5.14285714	7
C_7	7	6	8
C_8	8.57142857	7.85714286	7
C_9	6	6.85714286	8
C_{10}	4	6	5
C_{11}	5	6	6.714285714
C_{12}	6.71428571	6	5.142857143
C_{13}	6	6.71428571	7.857142857
C_{14}	8.14285714	7	6

For Positive Ideal Solution (PIS)

All the values ranged from 0.0106 (C_{11}) to 0.4407 (C_2) show the most desirable performance across different criteria. The highest PIS was observed in C_2 with the

value 0.4407, indicating that C2 has the most positive ideal value among all.

For Negative Ideal Solution (NIS)

Values ranged from 0.0068 in C3 to 0.5239 in C12, representing the least desirable performance. C12 has the highest NIS value of 0.5239, and it is the worst in that criterion. All in all, C2, C5, C8, and C9 have high PIS values, so they do well in these criteria; hence, they improve the alternative's closeness to ideal. Criteria like C6 and C12 have high NIS values, given that they have poor performance in these criteria, and they can affect the alternative's score. The availability of similar PIS and NIS values for C13 (0.1212) shows that the criterion has little or no effect in distinguishing the alternatives (Figure 11).

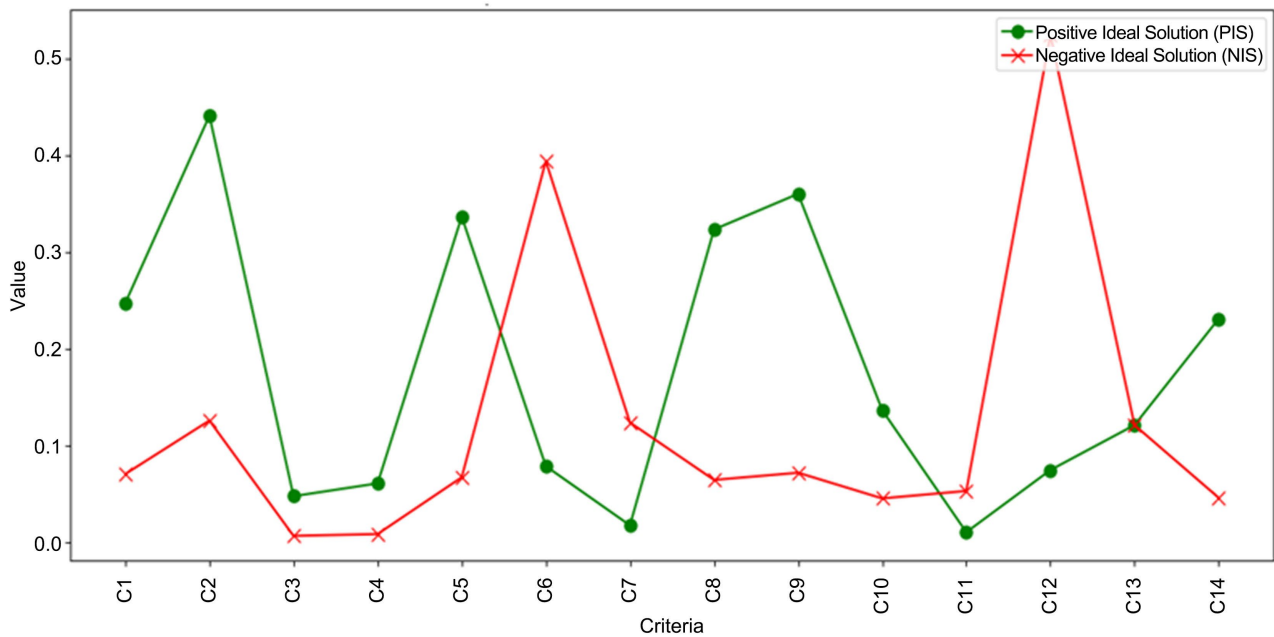


Figure 11. Comparison of PIS and NIS for each criterion.

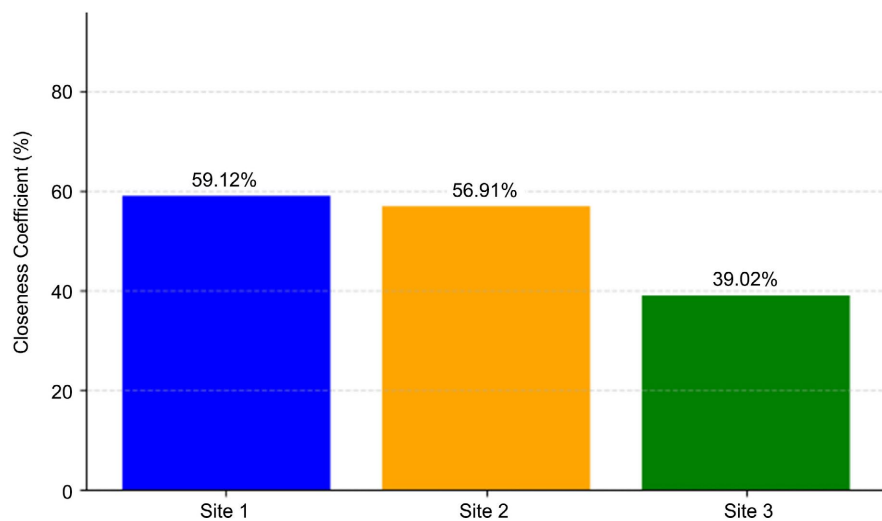


Figure 12. Closeness coefficient for sites (in %).

Alternative ranking of Positive and Negative Ideal Solutions

After calculating the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS), the Closeness Coefficient (CC) for each alternative was determined. The closeness coefficient indicates how close each alternative is to the ideal solution.

Site 1 has the highest closeness coefficient (0.5912) as shown in **Figure 12**, meaning it is the most preferred site according to the evaluated criteria. Site 2 follows closely with a coefficient of 0.5691, making it the second-best option. Lastly, Site 3 has the lowest closeness coefficient (0.3902), indicating that it is the least preferred alternative among the three. Looking into the chart, Site 1 and Site 2 are both good sites but Site 1 is more preferable. However, Site 3 is far behind and it is not even competitive.

3.3. Stepwise Weight Assessment Ratio (SWARA)

The Stepwise Assessment Ratio Analysis method was employed to calculate the relative importance through pairwise comparisons of each criterion based on the expert's judgement in AHP OS. The following section presents the results of the SWARA, including computed weights for each criterion.

Weight and Weighted Score of Each Criterion.

In this analysis, the Step-wise Weight Assessment Ratio Analysis (SWARA) method was used to derive the global weights of various sub-criteria. SWARA is a subjective weighting method used to evaluate and prioritize multiple criteria based on expert judgment. These weights were computed using Python, and the results are shown in **Table 8**.

Table 8. Calculated values of S_j and their impacts on the relative weights of criteria.

Sub Criterion	S_j	K_j	Q_j	W_j	W_{j-1}	$(W_{j-1} - W_j)/W_{j-1}$
C_1	0.00	1.00	1.0000	0.1621	-	-
C_2	0.20	1.20	0.8333	0.1351	0.1621	0.16656
C_3	0.10	1.10	0.7576	0.1228	0.1351	0.09104
C_4	0.10	1.25	0.6061	0.0983	0.1228	0.19951
C_5	0.15	1.15	0.5270	0.0854	0.0983	0.13123
C_6	0.30	1.30	0.4054	0.0657	0.0854	0.23067
C_7	0.10	1.10	0.3685	0.0598	0.0657	0.08980
C_8	0.20	1.20	0.3071	0.0498	0.0598	0.16722
C_9	0.00	1.00	0.3071	0.0498	0.0498	0
C_{10}	0.10	1.10	0.2792	0.0453	0.0498	0.09036
C_{11}	0.15	1.15	0.2428	0.0394	0.0453	0.13024
C_{12}	0.20	1.20	0.2023	0.0328	0.0394	0.16751
C_{13}	0.10	1.10	0.1839	0.0298	0.0328	0.09146
C_{14}	0.25	1.25	0.1471	0.0239	0.0298	0.19798

Weighted score matrix of each criterion.

In this analysis, the Step-wise Weight Assessment Ratio Analysis (SWARA) method was used to derive the global weights of various sub-criteria (Table 9). SWARA is a subjective weighting method used to evaluate and prioritize multiple criteria based on expert judgment.

Table 9. Weighted scores by sub-criteria.

Sub Criteria	W_j	Site 1	Site 2	Site 3	S_j	Rank
C_1	0.1621	0.0906	0.0960	0.0193	0.00	1
C_2	0.1351	0.0800	0.0213	0.0450	0.20	9
C_3	0.1228	0.0146	0.0877	0.0265	0.10	2
C_4	0.0983	0.0428	0.0435	0.0077	0.10	2
C_5	0.0854	0.0264	0.0264	0.0497	0.15	7
C_6	0.0657	0.0469	0.0469	0.0142	0.30	13
C_7	0.0598	0.0408	0.0086	0.0062	0.10	2
C_8	0.0498	0.0079	0.0079	0.0379	0.20	9
C_9	0.0498	0.0079	0.0079	0.0379	0.00	1
C_{10}	0.0453	0.0201	0.0201	0.0175	0.10	2
C_{11}	0.0394	0.0294	0.0053	0.0047	0.15	7
C_{12}	0.0328	0.0136	0.0041	0.0150	0.20	9
C_{13}	0.0298	0.0099	0.0099	0.0099	0.10	2
C_{14}	0.0239	0.0076	0.0029	0.0133	0.25	12
Weighted Score		0.4804	0.3222	0.2691		

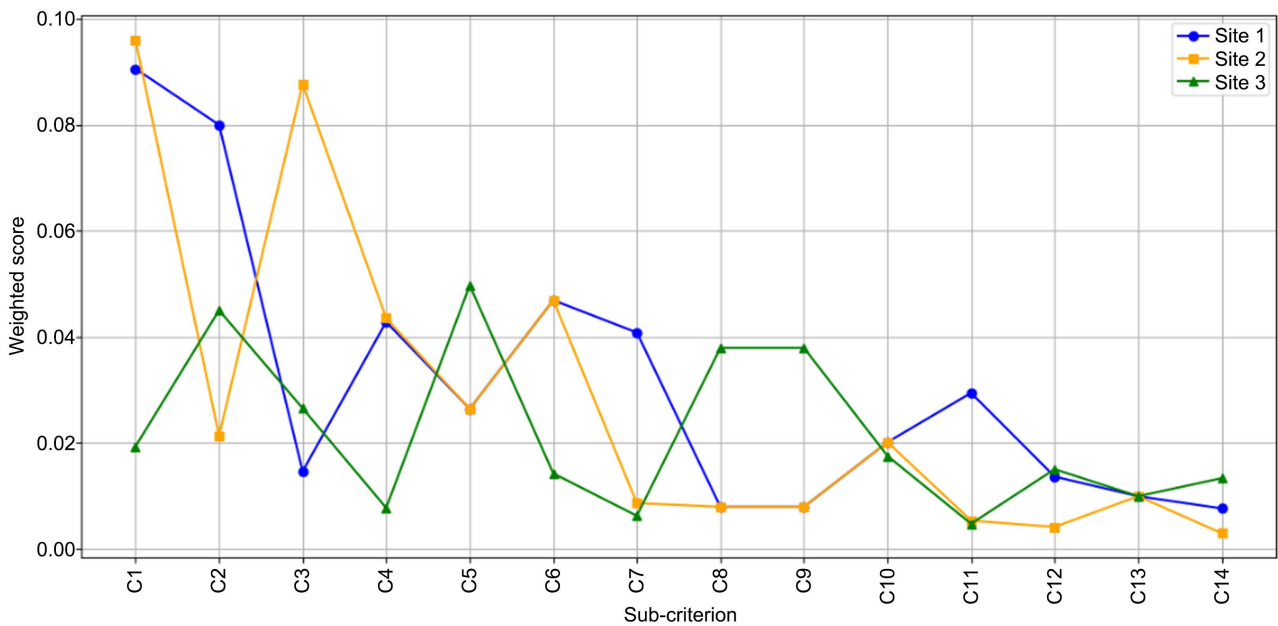


Figure 13. Weighted contribution per sub-criterion for each site.

Based on the weighted score evaluation **Table 7**, Site 1 has the most suitable results as factors like community acceptance (C8), distance from settlement (C9), and slope (C1) carry significant weights. Site 1 has moderate results where factors like slope (C1) and proximity to water bodies (C2) are performing well. Site 3 has the lowest average weighted score with minimal contributions from highly weighted criteria, specifically distance from settlement (C11) and land availability (C7), as shown in **Figure 13**.

Figure 14 shows that Site 1 has the highest score with a total weighted score of 0.4088 (40.88%), indicating that it is the most optimal among the alternatives. Secondly, Site 2 follows with a total weighted score of 0.3228 (32.28%), ranking second and not significantly different from Site 1. Site 3 has the lowest total weighted score of 0.2695 (26.95%) and is the least favourable option. The table also shows a notable gap between Site 1 and all the other sites, which indicates its relative superiority.

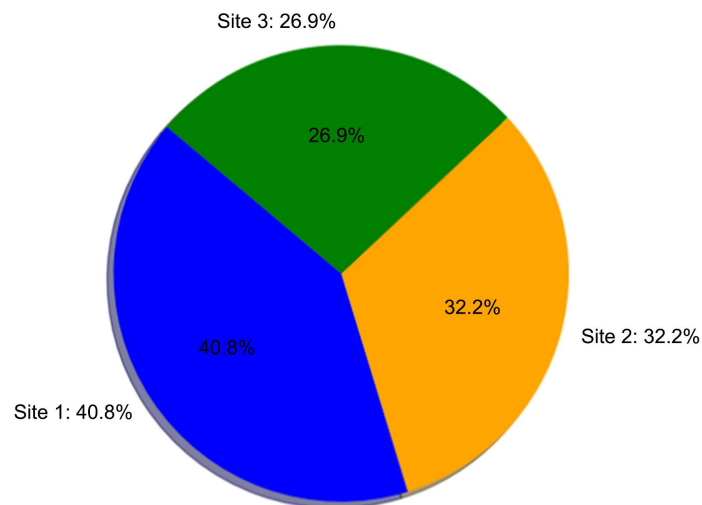


Figure 14. Total weighted score.

3.4. Integration

The final result of the MCDM was found by integrating AHP, TOPSIS, and SWARA. Each method contributed equally to the evaluation process. AHP was used to obtain initial weights through pairwise comparison of experts' judgments. SWARA was then applied to refine these weights through the relative importance of each criterion. After the weighting, TOPSIS was then deployed to rank each alternative (site). It calculates distances from an ideal solution (best solution) and a negative-ideal solution (worst solution).

The integration of AHP, SWARA, and TOPSIS is shown in **Figure 15** and **Table 10** by calculating the average score of each site across the three individual methods. Each method independently evaluated and ranked the landfill sites based on the same set of criteria, but from slightly different perspectives. The arithmetic mean was selected for integration due to its simplicity and widespread use in hy-

brid MCDM frameworks, ensuring equal contribution from each method while maintaining interpretability [28].

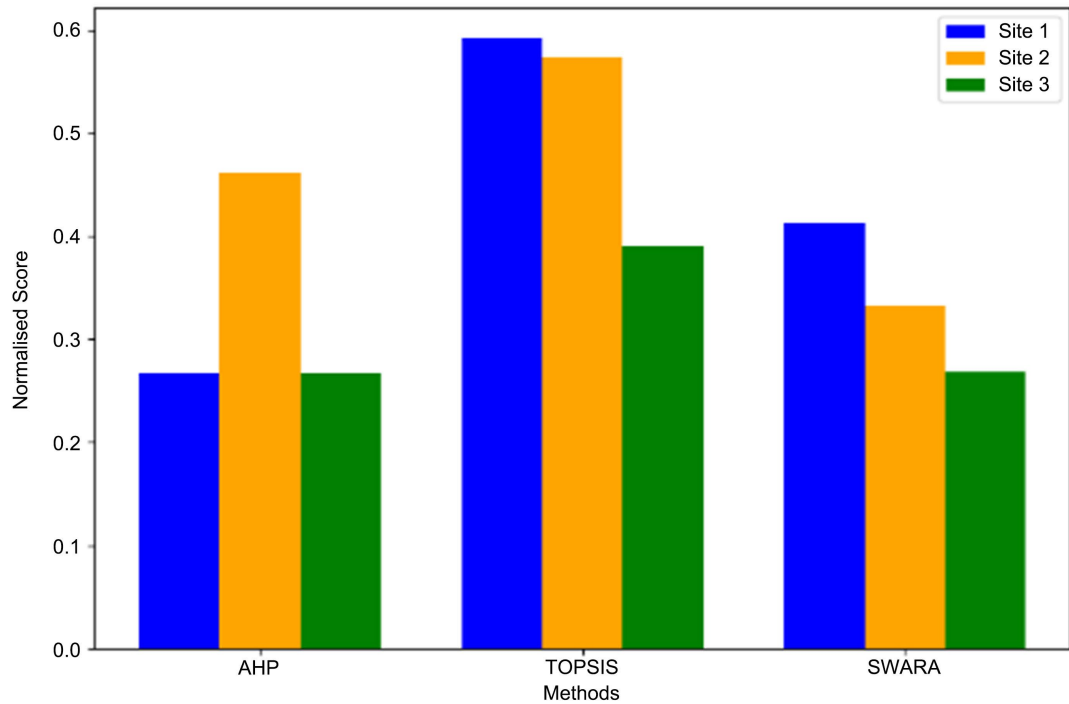


Figure 15. Comparison of sites by method.

Table 10. Integrated scores.

Method	Site 1	Site 2	Site 3	Total
AHP	0.2670	0.4650	0.2650	-
TOPSIS	0.5912	0.5691	0.3902	-
SWARA	0.4088	0.3228	0.2695	-
Average	0.4223	0.4533	0.3082	1.1838
Final Score	35.67%	38.29%	26.03%	100%

The final integrated scores were as follows: Site 2 with the highest score, 38.29% (0.4533); Site 1, 35.67% (0.4223); and Site 3, 26.03% (0.3082), as shown in Table 8 and Figure 16. These scores clearly indicate that Site 2 is the most suitable location for landfill construction, followed by Site 1, while Site 3 ranks lowest due to its relative disadvantage across multiple criteria. The satellite image (Figure 17) shows the locations of each site in its colour code.

Site 2 is the most suitable; it is situated farther away from dense urban and institutional zones, as shown in Figure 17; hence, it has reduced the risk to public health. Site 2 is ranked second, as it is close to infrastructure and land use. Moreover, site 3 is the least suitable, since it is located closest to the main residential areas, and it is also near schools and dense population, which makes it more likely to get a low score. The divergence in rankings (AHP favored Site 2, while TOP-

SIS/SWARA favored Site 1) arose from AHP's heavy weighting of environmental criteria (61.1%), where Site 2 excelled in proximity to water sources (39.8% weight). Despite Site 1's strong performance in TOPSIS/SWARA (community acceptance, accessibility), the integrated score favored Site 2 due to its dominance in the highest-weighted AHP criteria.

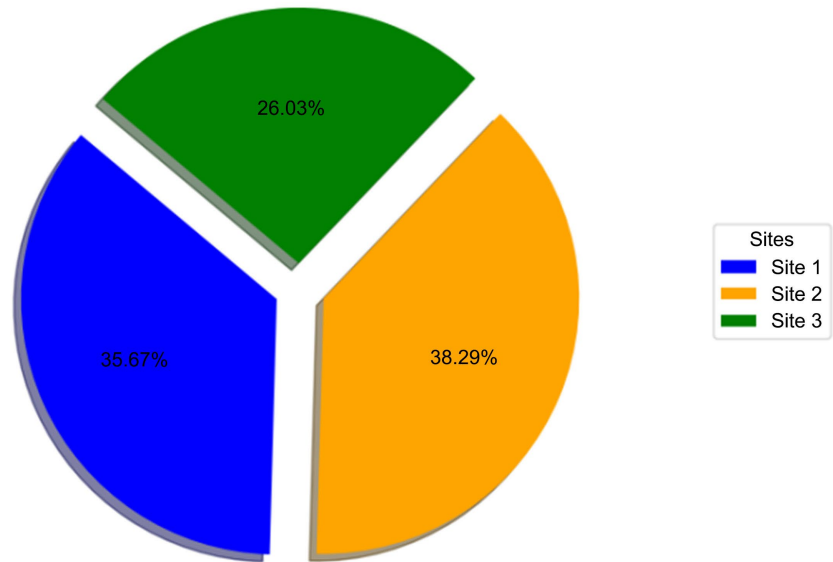


Figure 16. Site final scores.



Figure 17. View of sites. (Source: Google Earth)

4. Discussion

The study's integrated AHP-TOPSIS-SWARA approach successfully identified Site 2 as the optimal landfill location for Chegutu Municipality, achieving a 45.3% final score. This outcome aligns with global landfill selection priorities that em-

phasize environmental protection [1] [30]. Site 2's superior performance in critical criteria, particularly its 6834.82 m distance from water sources [31] and ideal 1.5% slope gradient [30], outweighed other considerations. The methodology revealed important trade-offs between environmental and social factors, with TOPSIS favoring Site 1 for community acceptance while AHP's environmental weighting (61.1%) shifted the balance [16] [17]. These findings mirror challenges documented in similar urban waste management studies [28] [34]. The SWARA analysis effectively prioritized groundwater protection (0.338 weight), confirming results from comparable Middle Eastern research [24] [26]. This hybrid approach proved particularly valuable in reconciling quantitative data with expert judgment and community needs [1] [33] [36] [37].

5. Practical Implications

The study offers three key implementation benefits for Chegutu Municipality. First, selecting Site 2 would significantly reduce groundwater contamination risks [31] while maintaining acceptable operational costs [32]. Second, the 3220 m buffer from settlements addresses public health concerns [34], though supplemental community engagement may be needed. Third, the methodology provides a transferable decision-making framework for other infrastructure projects requiring environmental-social trade-offs [27] [28]. For optimal results, authorities should implement advanced leachate control systems [35] and regular environmental monitoring. The research also suggests policy applications, including potential revisions to Zimbabwe's waste management regulations to incorporate similar multi-criteria evaluation processes [29]. Future applications could explore integrating GIS technology [26] or machine learning [29] to enhance the model's predictive capabilities.

6. Conclusion

This research demonstrates that combining AHP, TOPSIS, and SWARA creates a robust framework for landfill site selection. The methodology successfully integrated technical assessments with environmental and social considerations, yielding Site 2 as the optimal choice. The site's strong performance in water protection [31] and geological suitability [30] outweighed its moderate accessibility score. These findings provide Chegutu Municipality with a scientifically validated solution that balances the needs of multiple stakeholders. The study confirms that hybrid MCDM approaches outperform single-method solutions in complex environmental decisions [16] [20]. The criteria framework and weighting system could serve as a model for other developing municipalities facing similar waste management challenges [29].

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Author Contributions

All authors contributed equally to this work.

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Data Availability

All data used for this research are contained in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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