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Research Article

Applying f-CIMAS for Expert-Based Criteria Weighting in Sustainable Landfill Site Selection

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ABSTRACT

In developing countries like Libya, where unplanned waste disposal jeopardizes ecological integrity and impedes the advancement of cleaner industry, choosing sustainable landfill sites is a crucial concern. In order to choose landfill sites in Misurata, Libya, this study suggests an integrated multi-stage methodological framework for expert-based criteria weighting. Eleven geographical and environmental criteria were identified via a thorough examination of the literature. A standardized Likert-scale questionnaire was used by a panel of six domain experts to assess these criteria. Prior to any mathematical modeling, inter-expert agreement was statistically verified using Kendall's Coefficient of Concordance (W = 0.5496), which confirmed moderate-to-good consensus. The criteria were then screened and narrowed down to six high-impact characteristics using the Relative Importance Index (RII) and Standard Deviation (SD): environmental effects, population density, land cover, land use compatibility, soil type, and groundwater depth. In order to reflect the inherent ambiguity of professional judgment, the Fuzzy Criteria Interaction Management and Assessment System (f-CIMAS) was subsequently implemented, utilizing Triangular Fuzzy Numbers and expert weights generated from experience. The findings indicate that land cover (16.91%), land use compatibility (16.62%), soil type and groundwater depth (15.75% each), and environmental effects and population density share the greatest priority weight (17.49% each). This research demonstrates the use of f-CIMAS to landfill site selection, providing a rigorous, impartial framework for decision-making that supports Libya's objectives for cleaner production and sustainable waste infrastructure.

1. INTRODUCTION

Sustainable solid waste management (SWM) has become one of the most important environmental issues of the twenty-first century due to rapid urbanization and industrial expansion.[1] Sanitary landfilling is still the most important and cost-effective way to dispose of municipal solid waste, especially in developing countries, despite the development of sophisticated treatment technology.[2] Libya's shift to cleaner production and circular economy techniques is hampered by major structural and operational challenges in the waste management industry.[3] In coastal areas like Misurata, high population density has put tremendous strain on the infrastructure already in place, frequently resulting in the growth of unplanned open dumps. Establishing a strict, technically-driven site selection process has become a national priority in order to safeguard the ecosystem and guarantee adherence to contemporary environmental requirements. By preventing residual waste from industrial and municipal operations from undermining the ecological baseline required for the success of cleaner production efforts, such infrastructure acts as the ultimate environmental protection.[4].

Choosing sustainable landfill locations is essentially a difficult Multi-Criteria Decision-Making (MCDM) problem that necessitates the concurrent assessment of conflicting geological, environmental, and population factors.[5] In this situation, creating a strong spatial framework requires the extraction of extremely accurate significance coefficients to weigh these characteristics. Rigid deterministic models frequently fail to accurately capture the "confidence radius" of professional intuition because the criteria-weighting phase heavily relies on the qualitative judgments of expert panels, which naturally exhibit a degree of "hesitancy" and "vagueness." This could result in biased or unstable site rankings.[6]

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It is essential to base the evaluation on rigorous statistical validation in order to get beyond these restrictions and guarantee that the importance coefficients are trustworthy and free from individual bias. In order to quantitatively demonstrate the validity and agreement of the expert panel's judgments, use Kendall's Coefficient of Concordance (W).[7] use the Fuzzy Criteria Interaction Management and Assessment System (f-CIMAS) approach to determine the final weights, building on this existing consensus.[8, 9] By taking into account professional reluctance and differing levels of confidence, this sophisticated method enables professionals to create a customizable radius of uncertainty that accurately represents their viewpoints mathematically. This study attempts to give a rigorous geographical and scientific pathway that reduces weight dispersion and directly supports the spatial infrastructure needed to reach cleaner production objectives by putting this integrated methodological framework into practice in Misurata, Libya.

2. LITERATURE REVIEW

This review examines the literature across three thematic areas that collectively define the methodological landscape and identify the gap addressed by the present study: MCDM frameworks for site selection, expert consensus verification and criteria weighting, and fuzzy modeling approaches including the CIMAS family of methods.

2.1 Spatial MCDM and Landfill Site Selection Frameworks

Over the past 20 years, the most popular method for choosing landfill sites has been the integration of Geographic Information Systems (GIS) with Multi-Criteria Decision-Making (MCDM), which has been used in a variety of geographic and regulatory situations. The main factors influencing siting are regularly found to be groundwater depth, soil type, land cover, environmental effect, population density, and land use compatibility. [10, 11] The use of deterministic weighing techniques, namely AHP with equal expert credibility, which are unable to quantify or account for the inherent ambiguity of professional judgment, is a recurring flaw in this corpus of work.[5, 12] Weight dispersion continues to be a structural concern that compromises the accuracy of final site rankings in the absence of systematic criteria screening or consensus verification.[13, 14] table (I) Overview of Spatial MCDM and GIS-Based Landfill Site Selection.

TABLE I. OVERVIEW OF SPATIAL MCDM AND GIS-BASED LANDFILL SITE SELECTION STUDIES

Authors / Year	Objective	Methodology
Şener et al. (2010)[15]	Identify optimal landfill sites in Lake Beyşehir catchment, Turkey.	AHP combined with GIS overlay analysis using physical and environmental criteria.
Eskandari et al. (2012) [16]	Select landfill sites balancing environmental, economic, and socio-cultural conflicts in Iran.	Integrated multi-criteria AHP-GIS approach with stakeholder input.
Gbanie et al. (2013) [17]	Model landfill location suitability in Bo, Sierra Leone.	GIS-MCDA with equal-weight criteria overlay; no formal expert weighting.
Demesouka et al. (2013) [18]	Develop a spatial DSS for MSW landfill suitability in Greece.	Multi-criteria GIS analysis with MCDA scoring; no fuzzy component.
Khorsandi et al. (2019) [19]	Select landfill sites in Naqadeh, Iran integrating spatial and environmental factors.	GIS-AHP with partial criteria filtering; no consensus verification.
Rezaeisabzevar et al. (2020) [20]	Review influential criteria for landfill site selection across multiple countries.	Systematic comparative review of MCDM methods; no unified weighting framework.
Mohamed et al. (2023) [21]	Evaluate landfill site suitability in Hargeisa, Somaliland.	GIS-MCDA integration with AHP; no statistical verification of expert consensus.
Arabeyyat et al. (2024) [22]	Select sustainable landfill sites in Al-Balqa Governorate, Jordan.	AHP and SAW combined with GIS; partial criteria screening, no fuzzy handling.
Yadav et al. (2025) [23]	Optimize landfill site selection in Rewari City, India using geospatial methods.	GIS-based spatial analysis; no MCDM weighting rigor or expert panel.
Aguinaga-Vallejo et al. (2025) [24]	Select solid waste disposal sites in Guayas, Ecuador.	Center of gravity combined with AHP-GIS; equal expert weights, no consensus test.

2.2 Expert Consensus Verification and Criteria Weighting

The statistical confirmation of panel reliability prior to weight computation is an important but sometimes disregarded stage in expert-based MCDM.[6, 25] Well-known in related domains like construction management and building performance evaluation, Kendall's Coefficient of Concordance (W) offers a strict indicator of inter-rater agreement that establishes if the collective expert opinion is a cohesive epistemic input.[7, 26, 27] In a similar vein, the Standard Deviation (SD) and Relative Importance Index (RII) are quantitative screening techniques that reduce weight dispersion in future analysis by separating high-impact criteria from secondary Criteria.[22, 28, 29] The legitimacy and repeatability of the results are directly threatened by the almost complete lack of these verification methods in the landfill siting literature. table (II) Studies on Expert Consensus Verification and Criteria Weighting in MCDM.

TABLE II. STUDIES ON EXPERT CONSENSUS VERIFICATION AND CRITERIA WEIGHTING IN MCDM

Authors / Year	Objective	Methodology
Nas et al. (2010) [30]	Select MSW landfill sites for Konya, Turkey using multi-criteria spatial analysis.	GIS-AHP with fixed criterion weights; no statistical verification of expert agreement.
Bhowmick et al. (2024) [28]	Identify suitable municipal waste dumping sites in Birbhum district, India.	RII used for criteria prioritization, but uniform expert weights applied in weighting phase.
Al Awadh & Mallick (2024) [13]	Develop a decision framework for landfill siting in Saudi Arabia.	Explainable AI combined with MCDM; expert hesitancy and differential credibility not modeled.
Chen et al. (2023) [5]	Assess landfill site suitability using neutrosophic aggregation in China.	Single-valued neutrosophic MCDM with criteria screening; no experience-based expert weighting.
Shaardan et al. (2025) [26]	Investigate expert perspectives on energy performance gaps in green buildings.	Kendall's W applied to verify inter-expert consensus prior to analysis — a transferable model.
Ahmad et al. (2025) [27]	Develop Critical Success Factors for BIM-FMS integration in construction.	Kendall's Coefficient of Concordance used for expert reliability validation; RII for prioritization.
Khodabocus & Seyis (2024) [25]	Build an MCDM risk management model for modular construction projects.	Delphi method with statistical consensus testing; provides methodological precedent for spatial MCDM.
Derse & Polat (2025) [14]	Select MSW landfill sites in Turkey using integrated MCDM and mathematical modelling.	Combined MCDM and optimization model; no fuzzy handling of expert hesitancy.

2.3 Fuzzy Modeling and the CIMAS Framework

By substituting membership functions that account for the language ambiguity present in expert judgment for precise point estimates, fuzzy set theory has greatly improved MCDM.[31, 32] However, even the most popular variation, fuzzy-AHP, gives each panelist identical weight, ignoring the unique significance of domain expertise and professional experience.[12] By calculating experience-derived expert weights before aggregation, the Criteria Importance Assessment System (CIMAS) and its fuzzy variant f-CIMAS overcome this constraint and guarantee that older practitioners have a proportionately larger impact on the final weight Criteria.[8, 28] To the best of the authors' knowledge, f-CIMAS has only been verified in logistics, risk analysis, healthcare, and finance; this is the first time it has been used to landfill site selection. As a result, this study shows how f-CIMAS may be used in a unique way to assist Libya's goals for sustainable waste infrastructure and cleaner output by offering a transparent and rigorous framework for decision-making.[9, 33-36] table (III) Studies on Fuzzy Modeling and the CIMAS Framework in MCDM Applications.

TABLE III. STUDIES ON FUZZY MODELING AND THE CIMAS FRAMEWORK IN MCDM APPLICATIONS

Authors / Year	Objective	Methodology
Santisteban et al. (2024) [12]	Optimize landfill site selection using fuzzy logic and GIS for urban planning.	Fuzzy-AHP with GIS; equal expert trust — experience-based differentiation absent.

Authors / Year	Objective	Methodology
Bošković et al. (2023) [37]	Introduce the FullEX technique for criteria importance assessment in courier selection.	CIMAS method with experience-weighted expert aggregation; validated for MCDM weight extraction.
Bošković et al. (2025) [8]	Advance the CIMAS method for multi-criteria group decision-making in supplier selection.	CIMAS applied with fuzzy linguistic scales; establishes f-CIMAS theoretical foundation.
Badi et al. (2026) [9]	Evaluate barriers to logistics outsourcing in a fuzzy MCDM context.	f-CIMAS with Triangular Fuzzy Numbers and experience-derived expert weights; first application to logistics.
Švadlenka et al. (2024) [33]	Prioritize risks from a crowd-shipping provider's perspective.	CIMAS method for risk weighting; demonstrates applicability across spatial and operational domains.
Gökalp et al. (2026) [34]	Optimize employee awareness strategies for energy efficiency in healthcare.	Picture fuzzy CIMAS combined with SIWEC; confirms robustness of f-CIMAS in multi-domain settings.
Kara et al. (2024) [35]	Analyse financial performance of technology companies using neutrosophic CIMAS.	Single-valued neutrosophic CIMAS-CRITIC-RBNAR model; confirms expert weighting rigor of CIMAS family.
Cheng et al. (2022) [32]	Select sustainable ferry operators using fuzzy multi-criteria methods.	Triangular Fuzzy Numbers with MCDM; demonstrates fuzzy linguistic scale conversion for group decisions.
Wu et al. (2025) [11]	Develop an integrated decision framework for landfill mining site selection in China.	GIS, multi-criteria analysis, and optimization models; deterministic — no fuzzy or experience weighting.

3. PROBLEM DEFINITION

The lack of a regulated technical framework in Libya's present dump site selection procedure frequently leads to ad hoc judgments that put logistical convenience ahead of environmental safety.[3] The main cause of the issue is the lack of a geographical framework for choosing landfill locations that is supported by science, which has resulted in the growth of unofficial dumping sites. Any advancements gained in upstream resource efficiency and waste reduction programs are undermined by the ongoing environmental deterioration caused by these unplanned sites, which also produce secondary pollutants.[20]

The criteria-weighting phase, which heavily depends on expert panels that naturally display "hesitancy" and "vagueness" in their qualitative judgments a phenomenon that traditional, rigid decision-making models fail to capture because of the imposition of "forced precision" exacerbates this issue.[30, 31]

The resulting criteria weights are still susceptible to subjective bias and instability in the absence of sophisticated models like Fuzzy Criteria Interaction Management and Assessment System (f-CIMAS), which could result in incorrect site rankings and irreversible environmental degradation in the Libyan landscape. Table (IV) Criteria landfill site selection.

TABLE IV. THE CRITERIA LANDFILL SITE SELECTION BASED ON THE EXPERTS' OPINIONS AND PRECIOUS STUDIES

No	Criterion	Sym	References
1	Environmental impacts	C1	[16, 20]
2	Population density	C2	[16, 28]
3	Land cover	C3	[17, 22]
4	Land use compatibility	C4	[15, 28]

5	Soil type	C5	[15, 20]
6	groundwater depth	C6	[15, 20]
7	Proximity to water bodies	C7	[15, 17]
8	Elevation	C8	[17, 18]
9	Site accessibility	C9	[16, 28]
10	land value	C10	[16, 17]
11	Economic considerations	C11	[18, 20]

4. METHODOLOGY

In order to assure the methodological dependability and content validity of the framework for spatial decision-making, this study's methodological framework is a multi-stage scientific process that links thorough theoretical inquiry with practical expert validation. This strategy guarantees the methodological reliability and content validity of the framework for spatial decision-making. Figure (1) Methodology Flowchart

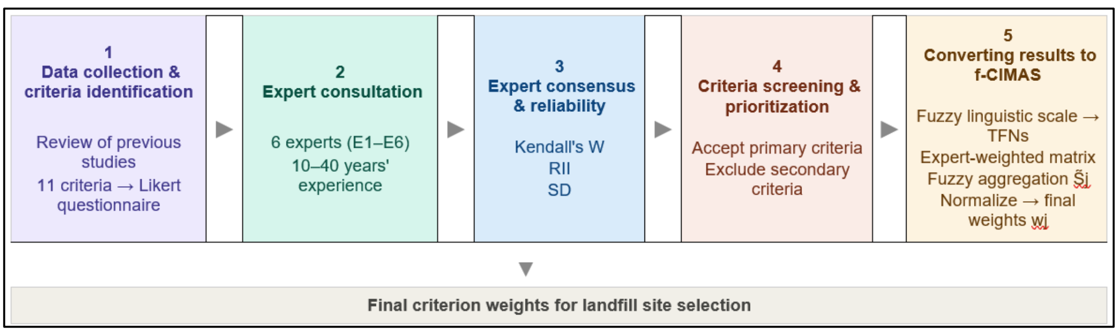

Fig. 1. Methodology Flowchart

4.1 Data Collection and Criteria Identification

A rigorous and comprehensive literature evaluation the results were condensed into 11 key criteria thanks to this analysis. A structured 5-point Likert scale questionnaire with a range of Very High Importance (1) to Very Low Importance (5) was created based on these parameters. The set of assessed criteria $C1, C2, C3, \ldots\ldots. Cn$.

4.2 Authors and Affiliations

The survey instrument was given to a carefully selected panel of six (6) distinguished subject matter. $E1, E2, E3, \ldots\ldots.., Eq$ who will be involved in this study are identified. The Eq. (1) is used for the weight of expert calculation, guaranteeing that the sum of all experts' weights equals one.

$$W^{E_i} = \frac{E_i}{\sum_{i=1}^{q} E_i}, i = 1,2, \ldots \ldots \ldots, q \qquad (1)$$

4.3 Analysis of Expert Consensus and Reliability

To guarantee the reliability of the results, the expert evaluations were subjected to extensive statistical testing prior to the final criterion selection:

1. Kendall's Coefficient of Concordance (W) was used to guarantee the robustness of the criterion selection and the dependability of the expert panel's conclusions. The degree of agreement (concordance) between many raters (m=6 experts) on a set of items (n=11 criteria) is measured using this non-parametric statistical technique. The coefficient ranges from 0 (no agreement) to 1 (complete consensus). Eq. (2) is used for the Kendall's Coefficient calculation

$$W = \frac{12S}{m^2(n^3 - n)} \qquad (2)$$

2. Relative Importance Index (RII): is a widely used metric in academic research to rank criteria based on their perceived significance. Eq. (3) is used for the Relative Importance Index calculation

$$RII = \frac{\sum W}{A \times N} \qquad (3)$$

3. Standard Deviation (SD): serves as a measure of consensus among the six experts. A lower SD indicates a higher level of agreement Eq. (4) is used for the Standard Deviation calculation

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (4)$$

4.4 Criteria Screening and Prioritization

To clearly distinguish between crucial controlling characteristics and secondary criteria methodical screening procedure was developed. In order to minimize weight dispersion in later analytical stages, this methodological step was created to guarantee that the spatial model only concentrates on high-impact variables:

1. Accepting Primary Criteria: According to the approach, criteria with the best mean scores and the lowest standard deviations among the expert panel's assessments would be kept since they showed the highest levels of statistical dependability. These recognized factors serve as the fundamental basis for the ensuing mathematical modeling, which naturally revolves around stringent environmental and geographical limitations.
2. Excluding Secondary Criteria: On the other hand, factors with more variance in expert consensus and lower Relative Importance Index (RII) values were subjected to a systematic analysis. In order to enhance analytical precision and avoid weight dispersion, factors indicating lesser perceived relevance such as simply economic considerations—were painstakingly removed from the final framework based on prior research and to focus the mathematical model.

4.5 Converting Survey Results to f-CIMAS

1. The experts evaluate each criteria's relevance using a predetermined language scale (Table V), and their ratings are compiled into an initial decision matrix (Table VI), where X̃ij is the score that expert Ei assigns to criterion Cj.

TABLE V. SCALE RELATED FUZZY LINGUISTIC ASSESSMENT

Linguistic terms	Lower bound	Mean/Mid-value	Upper bound
Ver Low (VL)	1	1	2
Low (L)	2	3	4
Medium (M)	4	5	6
High (H)	6	7	8
Very High (VH)	8	9	10

TABLE VI. INITIAL DECISION MATRIX

Experts/ Criteria	C1	C2	…	Cj	…	Cp	Expert's weights
$E1$	$\tilde{x}11$	$\tilde{x}12$	…	$\tilde{x}1j$	…	$\tilde{x}1p$	$WE1$
$E2$	$\tilde{x}21$	$\tilde{x}22$	…	$\tilde{x}2j$	…	$\tilde{x}2p$	$WE2$
Ei	…	…	…	$\tilde{x}ij$	…	…	…
Eq	$\tilde{x}q1$	$\tilde{x}q2$	…	$\tilde{x}qj$	…	$\tilde{x}qp$	WEq

2. Expert-weighted matrix calculation: Each fuzzy evaluation is weighted by the expert's unique weight WiE, which is derived from Eq. (1). The weighted fuzzy value ṽij is calculated using Eq. (5)

$$\tilde{v}_{ij} = \tilde{x}_{ij} \otimes W_i^E = (l_{ij}.W_i^E, m_{ij}.W_i^E, u_{ij}.W_i^E) \quad (5)$$

3. Fuzzy Criteria Importance Aggregation. By aggregating the weighted evaluations from all experts using fuzzy addition in Eq. (6), the overall fuzzy significance score S̃j for each criteria Cj is obtained.

$$\tilde{S}_j = \sum_{i=1}^{k} \tilde{v}_{ij} = \left(\sum_{i=1}^{k} l_{ij}W_i^E, \sum_{i=1}^{k} m_{ij}W_i^E, \sum_{i=1}^{k} u_{ij}W_i^E\right) \quad (6)$$

4. To rank the criteria and determine use weights, aggregated fuzzy scores S̃j = (Lj, Mj, Uj) are converted into crisp values Kj. In this study, a center of area (CoA) technique is used, as indicated by Eq. (7).

$$K_j = \frac{L_j + M_j + U_j}{3} \quad (7)$$

5. calculation of final criterion weights. In order to ensure that the total of all weights equals one, the crisp values are eventually normalized. The weight wj for criteria j is calculated using Eq. (8)

$$w_j = \frac{K_j}{\sum_{j=1}^{n} K_j} \qquad (8)$$

5. RESULTS

This section uses a real-world case study on landfill site selection in Libya to illustrate the resilience and practical usefulness of the proposed Fuzzy Criteria Interaction Management and Assessment System (f-CIMAS). The Libyan context is marked by particular geographical limitations and environmental vulnerabilities, despite the urgent need for sustainable municipal solid waste (MSW) management. Our adopted methodology systematically analyzes and prioritizes the critical environmental, demographic, and physical criteria required for optimal site selection in this region, giving environmental authorities and urban planners a data-driven basis for strategic intervention.

A panel of six subject-matter experts with ten to forty years of combined professional expertise in hydrology, urban planning, and environmental engineering was assembled to guarantee the validity and trustworthiness of the results. Six fundamental appropriateness criteria were found by the study using a multi-stage screening procedure described in Section 3. The experts converted qualitative professional judgments into quantitative intuitionistic fuzzy data by using a specific language grading scale to evaluate the relative relevance and interplay of these factors.

Initial Screening: Examining Expert Consensus and Dependability Verifying the consistency of the expert judgments was crucial before using the fuzzy mathematical framework. Kendall's Coefficient of Concordance (W) was used to analyze expert consensus and reliability. A statistically significant "Moderate to Good" agreement among the panel members was shown by the analysis's Kendall's W value of 0.5496 (with a Sum of Squares of Deviations, S = 2176.5). Table (VII) Kendall's Coefficient of Concordance to analyze expert consensus.

TABLE VII. KENDALL'S COEFFICIENT OF CONCORDANCE TO ANALYZE EXPERT CONSENSUS

Metric	Value	Interpretation
Number of Experts (m)	6	Moderate to Good Agreement
Number of Criteria (n)	11	
Sum of Squares (S)	2176.5	
Kendall’s W	0.5496	

The Relative Importance Index (RII) and Standard Deviation (SD) were computed to rank and filter the original criteria once the consensus was confirmed. A crucial indicator for differentiating between main and secondary limitations was the RII. In order to maximize the model's focus, the top six criterion with the highest consensus and priority were selected based on the RII scores, while the other five highly variable or secondary criteria were methodically eliminated. Table (VIII) Relative Importance Index (RII) and Standard Deviation (SD) for Criteria Screening

TABLE VIII. RELATIVE IMPORTANCE INDEX (RII) AND STANDARD DEVIATION (SD)

No	Criterion	Standard Deviation (SD)	Relative Importance Index (RII)
1	Environmental impacts C1	0.41	0.23
2	Population density C2	0.41	0.23
3	Land cover C3	0.52	0.27
4	Land use compatibility C4	0.55	0.30
5	Soil type C5	0.84	0.30
6	groundwater depth C6	0.84	0.30
7	Proximity to water bodies C7	1.10	0.40
8	Elevation C8	0.98	0.43
9	Site accessibility C9	0.98	0.43
10	land value C10	0.89	0.60
11	Economic considerations C11	0.89	0.60

Note on Interpretation: Given the scoring system where 1 represents "Very High" importance, lower RII values in this dataset indicate a higher consensus on the priority of the criterion.

The following fuzzy analysis only considers the six recognized core criteria environmental impacts, population density, land cover, land use compatibility, soil type, and groundwater depth in order to provide a thorough evaluation of the spatial variables determining the operational efficacy and environmental safety of potential landfill sites. Expert weights were determined first, then fuzzy evaluations were aggregated, and finally crisp criterion weights were derived as part of the f-CIMAS operationalization. Each expert's impact was evaluated based on their level of expertise. It was determined that the panel had 143 years of cumulative experience. The computed weight (WiE) for Expert Profiles and Weights is shown in table IX.

TABLE IX. EXPERT PROFILES AND WEIGHTS

Expert Code	Experience (Years)	Yi/T	Contribution (%)
E1	34	0.2378	23.78%
E2	25	0.1748	17.48%
E3	14	0.0979	9.79%
E4	10	0.0699	6.99%
E5	20	0.1399	13.99%
E6	40	0.2797	27.97%

Using the linguistic scale specified in the approach, as indicated in table X, the experts evaluated the six criteria. To create the fuzzy significance score (S̃j) for each criteria, these evaluations were transformed into Triangular Fuzzy Numbers (TFNs), weighed by the corresponding expert weights, and then added together. These scores were then defuzzified using the CoA technique into crisp values (Kj), which were then normalized to get the final global weights (wj).

TABLE X. EXPERTS THE SIX CRITERIA BY LINGUISTIC SCALE

No	Criterion	E1	E2	E3	E4	E5	E6
1	Environmental impacts C1	VH	VH	VH	VH	VH	H
2	Population density C2	VH	VH	VH	H	H	H
3	Land cover C3	VH	VH	VH	VH	H	H
4	Land use compatibility C4	VH	VH	H	M	M	M
5	Soil type C5	VH	VH	VH	VH	H	M
6	groundwater depth C6	VH	VH	VH	VH	H	M

The Aggregated Fuzzy Weights (S̃j) for each of the six primary criteria are shown in table XI. These values are represented as Triangular Fuzzy Numbers (TFNs), which have an upper bound (u), mean/modal value (m), and lower bound (l). This fuzzy representation is essential because it preserves the inherent subjectivity and ambiguity of the expert panel's language evaluations while successfully capturing their collective opinion. The study captures the "fuzziness" of the experts' intuition and the relative intensity of each geographical dimension by keeping the data in this format before defuzzification. In the Libyan context, for example, high-magnitude fuzzy sets like "Environmental impacts" (C1) and "Population density" (C2), which both scored the largest aggregated interval of (46, 52, 58), show a significant consensus about their absolute importance. On the other hand, criteria with somewhat smaller fuzzy intervals, such "Soil type" (C5) and "Groundwater depth" (C6), represent elements that, although crucial, show a little differing level of interaction priority among the decision-makers

TABLE XI. AGGREGATED FUZZY WEIGHTS (SJ)

Expert Ei	C1			C2			C3			C4			C5			C6		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
E1	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
E2	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
E3	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
E4	8	9	10	8	9	10	8	9	10	6	7	8	8	9	10	8	9	10
E5	8	9	10	8	9	10	6	7	8	6	7	8	6	7	8	6	7	8
E6	6	7	8	6	7	8	6	7	8	6	7	8	4	5	6	4	5	6
Σ W̃	46	52	58	46	52	58	44	50	56	42	48	54	42	48	54	42	48	54

The final criteria priority after the defuzzification and normalization stages is shown in table XII. The fuzzy data are transformed into useful metrics for direct comparison by the crisp scores (Kj), which are obtained using the Center of Area approach and offer a single representative value for each criterion. The final global weights (wj), which establish the hierarchical ranking of the obstacles from most to least critical, were obtained by normalizing these values.

TABLE XII. CRISP SCORES, FINAL WEIGHTS, PERCENTAGE AND RANKING

Criteria.no	Crisp Score (Kj)	Final Weight (Wj)	Percentage	Rank
C1	8.4406	0.1749	17.49 %	1
C2	8.4406	0.1749	17.49 %	1
C3	8.1608	0.1691	16.91 %	2
C4	8.0210	0.1662	16.62 %	3
C5	7.6014	0.1575	15.75 %	4
C6	7.6014	0.1575	15.75 %	4
Total		1	100 %	/

The resulting hierarchy derived from the f-CIMAS normalization (Table XII offers a clear stratification of the spatial parameters. It identifies Environmental impacts (C1) and Population density (C2) as the foremost priorities dictating landfill site suitability, while designating Soil type (C5) and Groundwater depth (C6) as relatively lower-priority constraints within the core set. Consequently, this weighted hierarchy provides urban planners and environmental authorities with a data-driven, structured roadmap for strategic spatial decision-making and sustainable waste management intervention.

6. FINDINGS AND DISCUSSION

In order to completely analyze and prioritize the geographical criteria for landfill site selection in Libya, this study offers insights into the implementation of a fuzzy MCDM model. The following factors were determined to be the most crucial using the f-CIMAS methodology: Environmental effects (C1), population density (C2), land cover (C3), compatibility of land use (C4), soil type (C5), and groundwater depth (C6) come next.

The most important factors are population density (C2) and environmental consequences (C1), which both have the greatest priority weight (17.49%). This supports earlier research's conclusions that, in order to protect public health and maintain ecological balance, human, environmental, and physical elements must be integrated.[38] to reduce the detrimental socio-environmental effects, such as smells, noise, and airborne illnesses, which sometimes lead to significant community opposition (the NIMBY-Not In My Back Yard syndrome), high population density locations must be scrupulously avoided. Simultaneously, avoiding the deterioration of nearby ecosystems and guaranteeing the long-term survival of the host community depend heavily on reducing wider environmental consequences.

The second most important criterion (16.91%) is land cover (C3). This conclusion is supported by recent assessments employing GIS and multi-criteria techniques, which show that a land's ecological and financial suitability for trash disposal is largely determined by its physical features and present use.[39] There is an irrevocable loss of biodiversity and agricultural production when landfills are built on important agricultural land, thick vegetation, or sensitive ecological zones. Therefore, in order to minimize ecological impact and protect Libya's few productive and vegetative regions, spatial decision-makers give priority to barren or degraded fields.

Land use compatibility (C4) is the third most important criteria (16.62%). In order to prevent spatial conflict with current infrastructure, communities, and future urban expansion plans, this criteria in regional planning is clearly necessary.[40] When a disposal site is situated close to business centers, residential developments, or cultural heritage areas, it creates structural issues. In order to ensure high land use compatibility, the site must smoothly fit into the larger regional master plan, making sure that landfill activities don't impede the local economy or social functions.

With respective weights of 15.75%, soil type (C5) and groundwater depth (C6) share the fourth place in the priority hierarchy. This weighting is consistent with well-established environmental engineering concepts, which highlight that these hydrogeological and physical limitations are the main natural barriers preventing contaminants from migrating downstream. Subterranean aquifers are shielded from irreparable pollution by keeping a safe vertical distance from the water table. Therefore, independent of any potential logistical or financial benefits, areas lacking these basic geological and hydrological protections are considered technically inappropriate for landfill construction.[40] The calculated weights are in keeping with the essential tenets of Cleaner Production, which emphasize protecting natural capital as a starting point for sustainable growth.[41]

7. CONCLUSIONS AND RECOMMENDATIONS

The f-CIMAS approach was used with a multi-stage statistical screening process in this work to assess and rank the geographical criteria for landfill site selection. A thorough literature analysis was used to first identify eleven spatial and environmental criteria. The assessments of a six-expert panel were subjected to Kendall's Coefficient of Concordance (W), which verified a statistically significant consensus among the members, in order to guarantee scientific rigor and trustworthiness prior to applying the mathematical modeling. Building on this established consensus, the Relative Importance Index (RII) was used as an accurate screening approach that reduced the list to six high-impact core criteria and efficiently distinguished across variables. The f-CIMAS framework's final results showed that the most important factors are population density and environmental effects, which share the greatest priority weight. These factors are followed by land cover, land use compatibility, soil type, and groundwater depth.

The study admits several limitations even though it makes important methodological and practical advances. First, only six experts were allowed to participate, even though the statistical dependability of the panel's findings was confirmed. Second, as each nation or region has distinct environmental and spatial features, the resulting weight coefficients cannot be broadly used since the results are tightly calibrated to the particular hydrological and geographical restrictions of the studied area.

Future research should think about using this integrated technique at larger national or regional levels and increasing the membership of the expert panel. Adopting this methodology in other environmental infrastructure industries would also be beneficial. In order to handle regions with different geographical features, we also suggest that future research focus on a spatial grouping strategy. This will enable the creation of tailored, greener production routes that maximize land utilization and reduce the overall environmental impact across various areas.

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