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# Environmental capability assessment for MSW landfill site using geographic information system and multi criteria evaluation

**Morteza Ghobadi**

*Department of Environmental Engineering, Faculty of Natural Resources, Lorestan University, Iran*

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**ABSTRACT**

The proper management of municipal solid waste (MSW) is a critical challenge in land use planning and environmental sustainability. The selection of suitable landfill sites is a pivotal component of MSW management, considering different environmental factors. This study evaluated the effectiveness of two Multi-Criteria Decision-Making (MCDM) methods, Step-wise Weight Assessment Ratio Analysis (SWARA) and Best-Worst Method (BWM), in combination with Geographic Information Systems (GIS) for landfill site selection. SWARA and BWM were employed as MCDM tools to assess landfill sites based on ten criteria. The results demonstrate that SWARA exhibited superior performance over BWM in terms of its ability to identify and prioritize optimal landfill sites. SWARA offered a more accurate and reliable decision-making framework, taking into account both the quantitative and qualitative aspects of site selection criteria. Additionally, SWARA demonstrated better sensitivity to changes in input data and provided more consistent results. The findings emphasize the importance of choosing an appropriate MCDM approach to enhance the decision-making process, ultimately leading to more sustainable and environmentally responsible waste management practices in urban areas. By adopting and continually refining such methodologies, urban planners and waste management authorities can contribute to more efficient, responsible, and sustainable urban development.

## 1. Introduction

Managing municipal solid waste is a complex and pressing issue that challenges urban planners, policymakers, and environmentalists worldwide [1,2]. As urban populations continue to grow, MSW is increasing at an alarming rate, straining existing waste management infrastructure and posing significant environmental and health risks [2]. Proper MSW disposal, particularly the selection of suitable landfill sites, is pivotal in addressing these challenges [5]. Landfill site selection is an MCDM problem involving a diverse range of factors, such as environmental, economic, and social considerations [6,7]. Decision-makers have

*Corresponding author:
E-mail: ghobadi.m@lu.ac.ir; ghobadim93@gmail.com
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increasingly turned to Geographic Information Systems in conjunction with MCDM methods to make informed and sustainable decisions regarding landfill site locations [8]. GIS technology has revolutionized spatial analysis and decision-making [9]. It allows the integration and visualization of spatial data, enabling users to create, manage, analyze, and interpret information related to geographic locations [9,10]. GIS enables decision-makers to visualize complex spatial relationships. This visualization aids in the identification of potential landfill sites and allows stakeholders to assess the impact of different criteria on the selection process [11]. While GIS provides the spatial context for landfill site selection, MCDM techniques serve as the decision-making engine by systematically evaluating and ranking potential sites based on multiple criteria [12]. MCDM methods can harmoniously combine quantitative and qualitative criteria, often with varying degrees of importance [13]. MCDM techniques enable the assignment of weights to criteria based on their relative importance. This weighting process ensures that critical factors carry a more significant influence on the decision-making process [14]. MCDM techniques, in combination with GIS, facilitate dynamic decision-making, allowing adjustments as new data becomes available or priorities change [15]. The integration of GIS and MCDM techniques has emerged as a vital approach for addressing the complex task of MSW landfill site selection [16]. Comparative studies that evaluate the performance of MCDM methods within GIS-based landfill site selection have been widely applied in recent years [16-18]. These studies aim to determine which MCDM method is more suitable for this specific application, considering factors such as accuracy, robustness, and user-friendliness. Literature reviews underscore the significance of this integration and the necessity for comparative analyses to determine the most effective MCDM method in the context of GIS-based landfill site selection. Prior research provides valuable insights into the potential advantages and limitations of these methods [17,19]. Some studies have directly compared SWARA and BWM in land suitability assessment scenarios. Karakuş [20]conducted a comparative analysis and found that SWARA exhibited better sensitivity to changes in criteria weights and provided more consistent results, making it a preferred choice for suitable assessment. Other researchers have proposed hybrid models that combine SWARA and BWM or integrate them with other MCDM techniques. These hybrid approaches seek to capitalize on the strengths of each method to enhance decision-making accuracy [21]. SWARA, known for its ability to handle complex decision problems, employs pairwise comparisons to determine criteria weights and ranks alternatives based on a step-wise assessment of criteria importance [22,23]. Some studies have highlighted its advantages, including a straightforward calculation process and the ability to capture qualitative aspects [24]. BWM, on the other hand, is lauded for its simplicity and robustness. It identifies the best and worst criteria and alternatives iteratively, allowing for the determination of criteria weights and alternative rankings [25]. Comparative studies have directly compared SWARA and BWM in landfill site selection scenarios [19,23]. Ghoushchi et al. [23] found that SWARA exhibited better sensitivity to changes in criteria weights, providing more consistent results that made it a preferred choice for landfill site selection. Sensitivity analysis is another crucial capability offered by MCDM techniques. It enables decision-makers to assess the robustness of their choices by examining how variations in criteria weights or data inputs affect the final outcome [26]. This feature ensures that decisions remain valid and relevant even as circumstances change, an essential aspect in the dynamic field of MSW management. Moreover, the transparency and accountability inherent in MCDM methods enhance the decision-making process. They provide a systematic and well-documented approach, which is particularly important when justifying decisions to stakeholders and the public. The transparent nature of MCDM empowers stakeholders by involving them in the decision-making process, fostering a sense of ownership and accountability. Integrating GIS and MCDM techniques empowers decision-makers to consider a wide range of criteria, evaluate potential sites comprehensively, and make informed, transparent, and sustainable choices. Comparative analyses between MCDM methods, such as SWARA and BWM, continue to provide valuable insights, aiding decision-makers, and researchers in their pursuit of sustainable waste management practices. Ultimately, this integrated approach represents a powerful tool to manage MSW effectively and promote responsible landfill site selection practices in urban areas.

## 2. Materials and methods

### *2.1. Case study*

Aligudarz is located within a mountainous region in the eastern part of Lorestan Province, Iran, marked by geographical coordinates at 49° 42′ longitude and 33° 23′ latitude (Figure 1). The area spans an elevation range from approximately 583 to 4054 meters above sea level. Aligudarz has an estimated population of around 137,534 people. It is characterized by cold winters and pleasant, moderate weather in spring and summer [27] with an average temperature of 14 ºC; the region receives an average annual precipitation of 430 mm. These climatic conditions play a crucial role in shaping the environmental and living conditions in the area, influencing agriculture, infrastructure, and the daily life of its residents. Figure 1 was created using GIS software, utilizing GIS data from the National Geographical Organization of Iran.

### *2.2. Methodology*

This study employed a comparative research design to evaluate the performance of two MCDM methods including SWARA and BWM, in the context of municipal solid waste landfill site selection using GIS. The research design involved a structured approach to data collection, analysis, and evaluation (Figure 2). The research process in this paper involved four key steps:

1- Data Collection and Preparation:

Gather geospatial data, criteria, and case study information. Clean and preprocess the data, ensuring its quality and consistency. Criteria for landfill site selection were identified, including slope, elevation, geology, and distance from the (D.F.) river, D.F. Road, soil, D.F. protected areas, D.F. fault, D.F. human settlement, and land use (Table 1). Relevant data for these criteria were collected and compiled. All geospatial data was converted to a common format and integrated within the GIS environment.

2-Criteria Weighting:

SWARA and BWM were chosen as the MCDM methods for criteria weighting. In both methods, criteria weighting is determined through a structured process involving expert opinions and pairwise comparisons. In this study, a group of experts consisting of 30 individuals divided into two groups played a crucial role: 15 academic experts and 15 executive experts. The selection of these experts was guided by specific criteria, including their extensive knowledge and expertise in waste management and spatial analysis for landfill site selection.

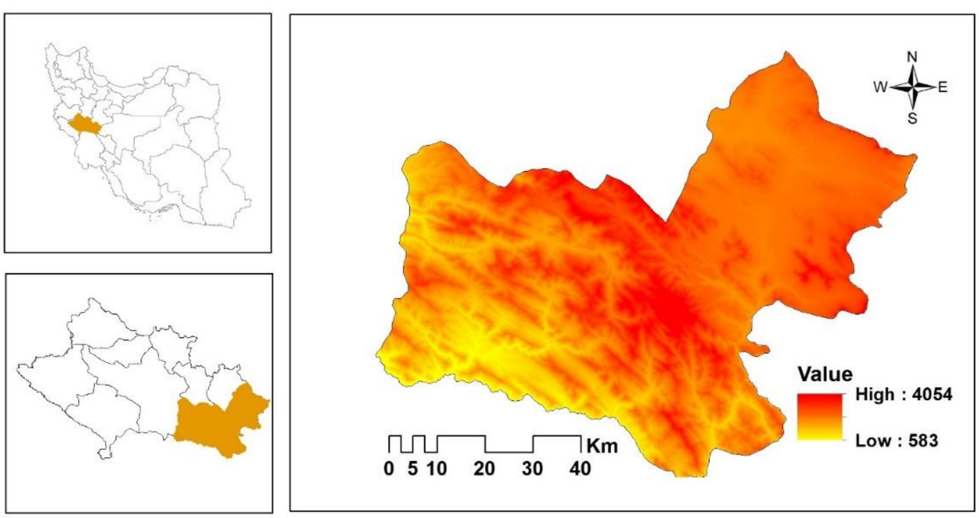


**Fig. 1.** Location of case study.

**Table 1.** Criteria classification for landfill site selection.

| Criteria | Slope | Elevation | Geology | D.F. river | D.F. road | Soil | D.F. protected areas | D.F. fault | D.F. human settlement | Land use |
|---|---|---|---|---|---|---|---|---|---|---|
| Very high | 0-5 | <800 | Very low permeability | 2< | 1-5 | Very high clay | 20< | 3< | 1-2 | barren lands |
| High | 5-15 | 800-1000 | Low permeability | 1.5-2 | 5-10 | High clay | 15-20 | 2-3 | 2-5 | poor rangelands |
| Moderate | 15-30 | 1000-1200 | Moderately permeability | 1-1.5 | 10-15 | Moderatel y clay | 10-15 | 1.5-2 | 5-10 | mainly dry land |
| Low | 30-45 | 1200-1500 | High permeability | 0.5-1 | 15-20 | Low clay | 5-10 | 1-1.5 | 10-15 | agricultural land |
| Very low | 45< | 1500< | Very high permeability | <0.5 | <1 and 20< | Very low clay | <5 | <1 | <1 and 15< | Forest lands |

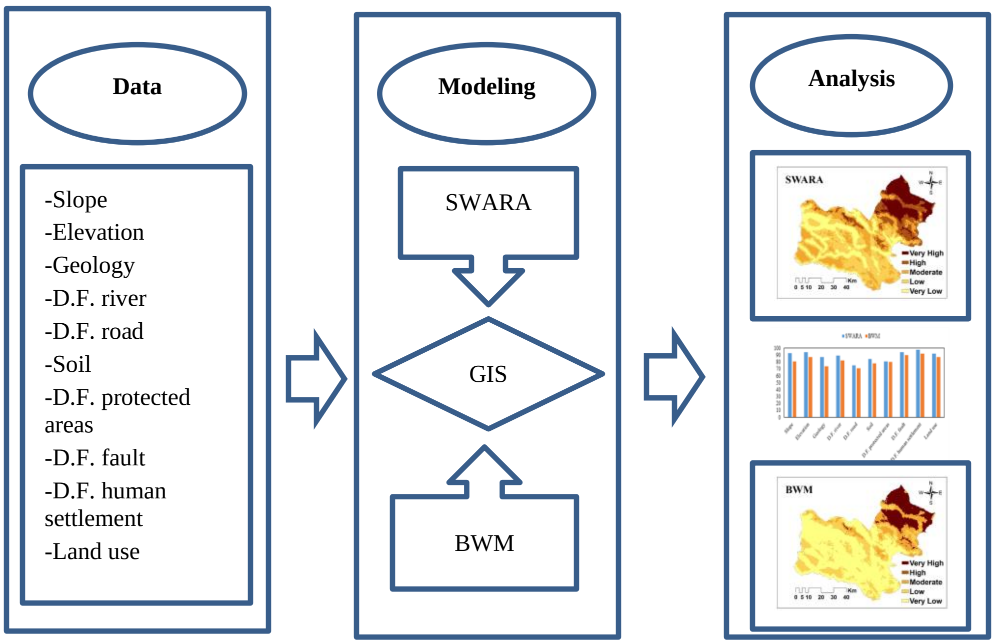


**Fig. 2.** Research process flowchart.

3-Site Selection:
Each MCDM method ranked potential landfill sites based on the established criteria and their respective weights. The results were compared to identify similarities, differences, and trends in site prioritization.
4-Sensitivity Analysis:
Sensitivity analysis was conducted to assess the stability of the results. Variations in criteria weights and data inputs were systematically tested to determine the robustness of the decision outcomes.

### *2.3. The SWARA method*

SWARA, a multi-criteria decision-making technique, systematically evaluates and prioritizes alternatives and criteria. Its process involves several steps [28]. First, decision-makers identify relevant criteria that capture essential factors for alternative evaluation. Then, they conduct pairwise comparisons among criteria to establish their relative importance, often using a 1 to 9 scale. This results in a pairwise comparison matrix. Next, the weights for each criterion are computed based on this matrix, typically using the geometric mean method. SWARA is a versatile method that accommodates both quantitative and qualitative aspects of complex decision problems [28,29]. Its step-wise structure provides a systematic and structured decision-making approach, making it a valuable tool in diverse fields.

### *2.4. The BWM method*

BWM is an approach within MCDM that systematically assesses and ranks criteria. This method can be summarized in several steps [30]. Initially, all relevant criteria for the decision problem are identified. These criteria represent the essential factors for consideration when evaluating alternatives. Decision-makers assign weights to each criterion to denote their relative importance. These weightings convey the significance of each criterion in the decision-making process, with higher weights indicating greater importance. In the subsequent step, decision-makers systematically discern the "best" and "worst" criteria within each pair. The "best" criterion is the one that holds the highest preference or importance relative to the other, while the "worst" is considered the least preferred [31]. Scores are then computed for each criterion based on the results of the best-worst scaling procedure. The "best" criterion receives the highest score, while the "worst" criterion is attributed to the lowest score. The BWM approach's structured method allows for the methodical evaluation and ranking of alternatives, considering multiple criteria and their respective degrees of importance in the decision-making process.

## 3. Results and discussion

The results indicated the criteria weights obtained using the SWARA and BWM methods for the evaluation of landfill site selection (Figure 3). These criteria weights are essential because they reflect the relative importance of each criterion in the decision-making process. Table 2 shows a breakdown of the criteria weights obtained with each method. In the SWARA method, each criterion is assigned a weight that reflects its relative importance in the decision-making process for landfill site selection. Among the criteria, the D.F. River held the highest weight at 0.213, indicating its significant influence. Following closely was Soil with a weight of 0.174, highlighting its considerable importance. D.F. fault and Land use also carried notable weights at 0.103 and 0.146, respectively, signifying their substantial roles in the decision process. Other criteria, such as D.F. protected areas (0.085), D.F. Road (0.053), and Slope (0.039), held comparatively lower but still significant weights. Geology was assigned a weight of 0.112, indicating its moderate importance. Elevation (0.027) and D.F. human settlement (0.048) had the lowest weights, suggesting their relatively lesser influence in this context. These weights collectively guided the evaluation and ranking of potential landfill sites, emphasizing the critical role of each criterion in the decision-making process. In the BWM, the criteria weights assigned to each criterion indicated their relative importance within the context of landfill site selection. Land use held the highest weight at 0.243, signifying its paramount significance in the decision-making process. The D.F. River criterion followed closely with a weight of 0.191, highlighting its substantial impact on the decision. Geology (0.144) and Soil (0.101) also carried considerable weights, underlining their significant roles. Criteria such as D.F. protected areas (0.102) and elevation (0.047) possessed moderate weights, indicating their importance but to a lesser extent than the previously mentioned criteria. D.F. fault and D.F. human settlement shared an identical weight of 0.051, suggesting their relatively lower influence on the decision process. Finally, the Slope (0.033) and D.F. Road (0.024) had the lowest weights among the criteria, implying their lesser importance in guiding the evaluation and ranking of potential landfill sites. When comparing the two sets of criteria weights, differences in the perceived importance of each criterion between the SWARA and BWM methods were observed. In the SWARA method, the criteria D.F. river (0.213) and soil (0.174) carried higher weights, indicating their greater significance in the decision-making process; in the BWM method, land use (0.243) had the highest weight. These differences could have a significant impact on the final site selection outcome. The choice of criteria weights influences how alternatives are ranked and selected. Therefore, it is crucial to consider these variations when interpreting and using the results for landfill site selection. Additionally, sensitivity analysis can be conducted to assess the stability of the results under different weight scenarios, providing further insights into the robustness of the decision outcomes. Based on the SWARA method, roughly 15.1% of the study area, which translates to 784.06 km², was categorized as highly suitable for landfill site selection, while approximately 32.7% of the study area, amounting to 1697.93 km², was classified as entirely unsuitable for landfill sites. On the other hand, the BWM method produced somewhat divergent outcomes. It designated roughly 13.4% of the study area, equivalent to 695.79 km², as highly suitable for landfill site placement. Meanwhile, a more substantial segment, approximately 48.3% of the study area, encompassing 2507.95 km², was categorized as wholly unsuitable for landfill sites (Figure 4). It is evident that the SWARA and BWM methods provided slightly different results for landfill site suitability. The SWARA method identifies a smaller area as very highly suitable and a larger area as completely unsuitable compared to the BWM method. These differences could be attributed to variations in the weightings and assessment criteria used in the two methods, as well as the inherent subjectivity in the site selection process. It is essential to consider these variations and the specific criteria used when making decisions regarding landfill site selection. In the sensitivity analysis of the BWM and SWARA methods, both methods consistently demonstrated robust performance, with sensitivity values exceeding 75% (Figure 5). Notably, SWARA outperformed BWM, achieving higher sensitivity scores. Sensitivity analysis assesses the methods' ability to maintain reliable results when input data varies, highlighting SWARA's superior stability and suitability for handling input data fluctuations. These findings underscore the robustness of the SWARA method in comparison to BWM in the context of sensitivity analysis. The key insight here is that SWARA outperformed BWM in this sensitivity analysis, suggesting that SWARA was more dependable when confronted with fluctuations or uncertainties in the input data. In the context of landfill site selection, SWARA is the method of choice for decision-makers seeking a robust and reliable approach. Landfill site selection involves numerous variables and factors. These factors can change over time or may be subject to varying degrees of uncertainty. Therefore, a method like SWARA, which demonstrates superior sensitivity, is better equipped to handle these dynamic conditions and provide consistent and trustworthy recommendations for landfill site selection.

**Table 2.** Comparison of criteria weights: SWARA vs. BWM Methods.

| Criteria | | Slope | Elevation | Geology | D.F. river | D.F. road | Soil | D.F. protected areas | D.F. fault | D.F. human settlemen | Land use |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Weight | SWARA | 0.039 | 0.027 | 0.112 | 0.213 | 0.053 | 0.174 | 0.085 | 0.103 | 0.048 | 0.146 |
| | BWM | 0.033 | 0.047 | 0.144 | 0.191 | 0.024 | 0.101 | 0.102 | 0.064 | 0.051 | 0.243 |

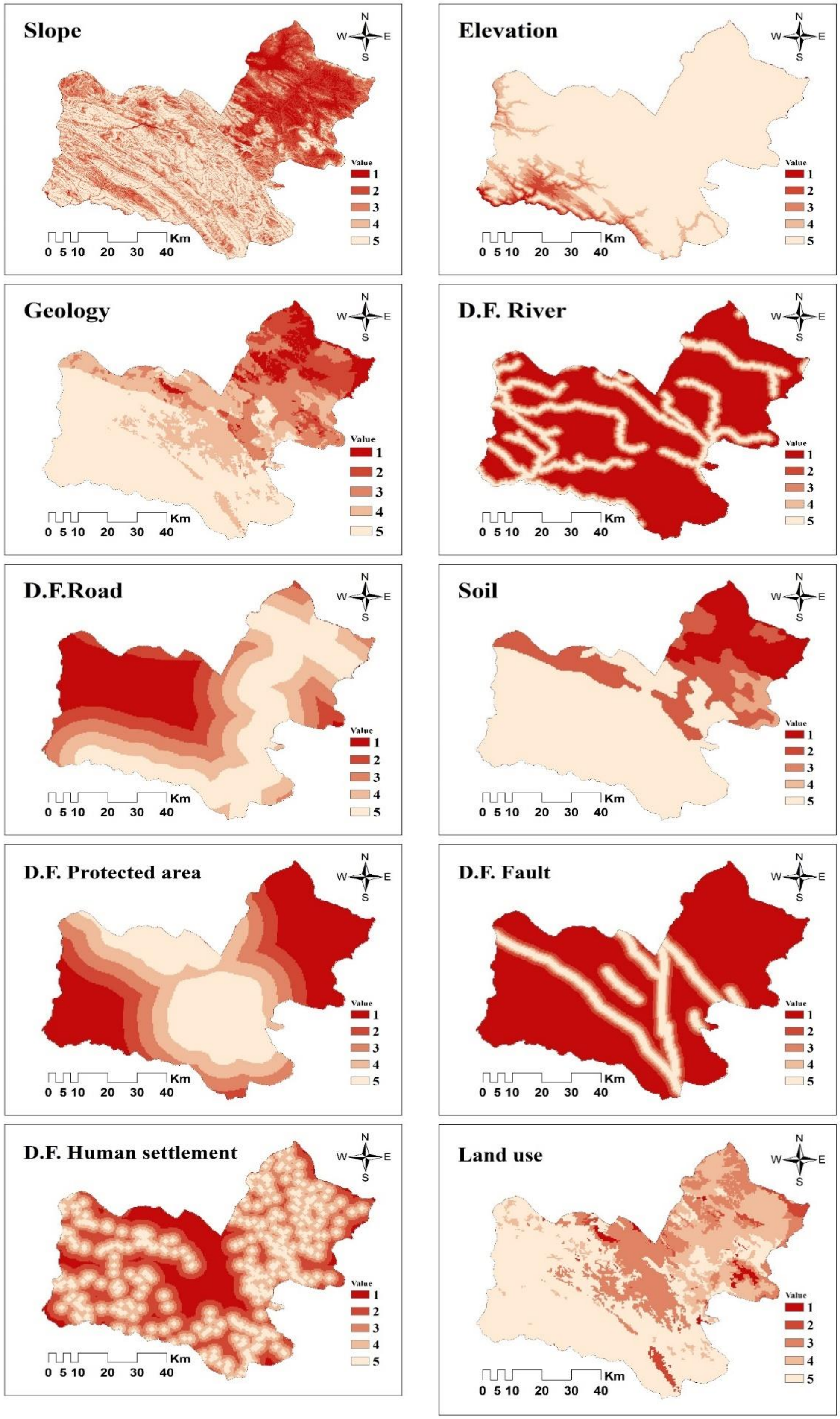


**Fig. 3.** Effective criteria classification maps for landfill site selection.

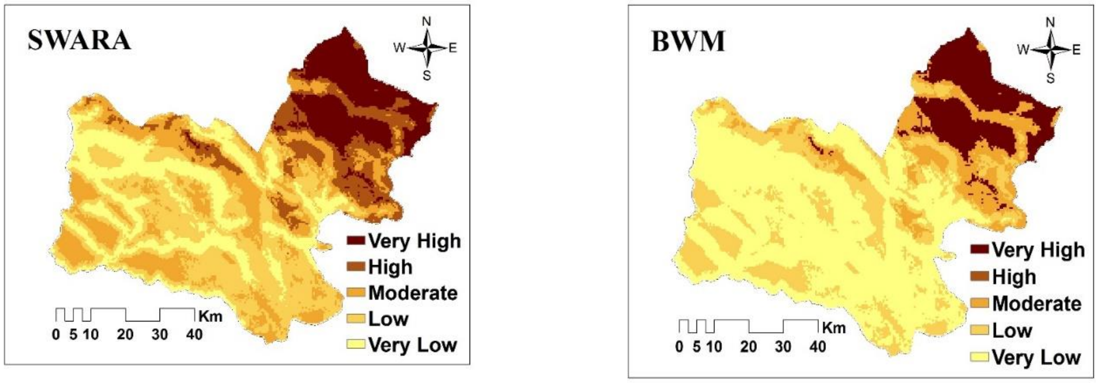


**Fig. 4.** Landfill suitability zones: BWM and SWARA comparison.

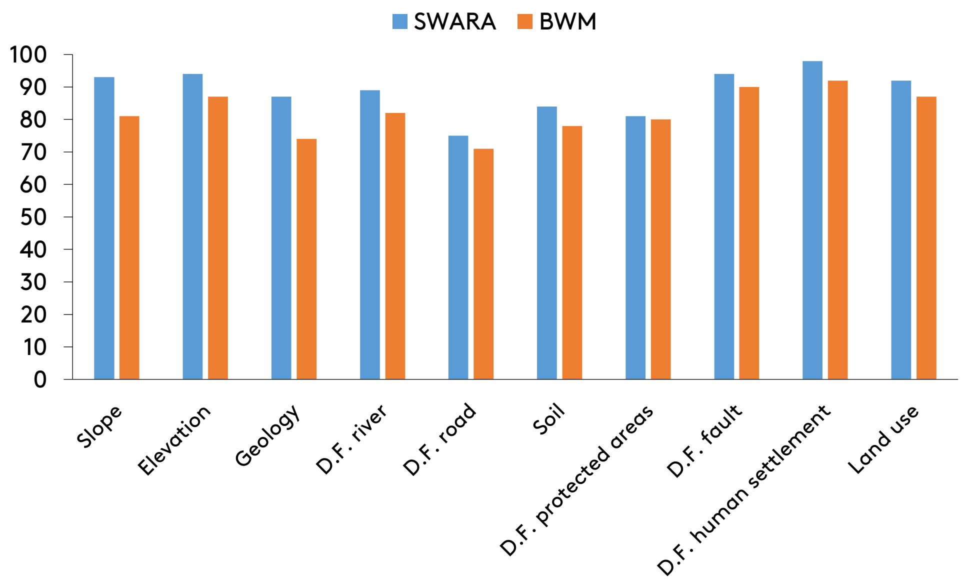


**Fig. 5**. Sensitivity analysis of BWM and SWARA methods.

The process of landfill site selection is a pivotal element of sustainable waste management strategies, especially in the face of growing environmental concerns and urbanization. With the increasing volume of global waste, it is crucial to identify suitable locations for landfills that minimize environmental impact, optimize resource utilization, and adhere to regulatory requirements [17]. Geographic information systems have emerged as indispensable tools in the realm of landfill site selection, as they facilitate the integration of spatial data and decision-making processes [12]. This study compares the BWM and SWARA methods in combination with GIS for the MSW landfill site. The primary focus lies in assessing their performance in sensitivity analysis, a critical step in evaluating the reliability and stability of MCDA methods when confronted with variations in input data. In the research, both SWARA and BWM consistently exhibited robust performance in landfill site selection, with sensitivity values exceeding the established threshold of 75%. Sensitivity analysis serves as a litmus test for MCDA methods, assessing their ability to produce consistent results under changing conditions [33,34]. However, what stands out in our study is the clear superiority of SWARA over BWM in terms of sensitivity analysis. SWARA consistently achieved higher sensitivity scores, underscoring its greater stability and suitability for handling fluctuations in input data. This significant finding has profound implications for the landfill site selection process and related decision-making procedures. The criteria weights obtained in the study, derived from both SWARA and BWM methodologies, hold a pivotal role in the decision-making process for landfill site selection. These weights essentially represent the relative importance of each criterion, guiding the evaluation and ranking of potential landfill sites [19,23]. By analyzing these weights, stakeholders gain valuable insights into the significance of various criteria within the specific context of our study [22]. However, one must acknowledge that one of the fundamental constraints in landfill site selection research is the availability and quality of input data. Accurate and up-to-date data pertaining to various criteria, including environmental factors, land use patterns, and infrastructure availability, are indispensable for effectively applying MCDA methods like SWARA and BWM. Limited or outdated data can lead to suboptimal results and undermine the overall reliability of the decision-making process [18,24]. Moreover, the integration and interoperability challenges within the GIS framework can pose additional constraints, necessitating meticulous data preprocessing and standardization efforts to ensure the successful application of the selected MCDA methods. While this study highlights the advantages of SWARA in sensitivity analysis for landfill site selection, there remains a need for further research to delve into the methodological nuances of both SWARA and BWM. Future studies could explore the specific criteria and weighting schemes employed by each method, as these factors can significantly influence their performance in sensitivity analysis. Furthermore, it is imperative to recognize that the choice between SWARA and BWM should not be viewed as a one-size-fits-all decision. The selection of the most appropriate MCDA method depends on the unique characteristics of the landfill site selection project at hand. Factors such as the availability and quality of data, the preferences of decision-makers, and the specific objectives of the project should all be considered when making this choice. Each method has its strengths and weaknesses, and their applicability may vary based on the context and constraints of the project. Wind patterns also play a crucial role in assessing environmental impact and risk. Future research and environmental practitioners should consider utilizing available data from nearby weather stations or meteorological databases, even when such data is not perfectly aligned with the specific site under evaluation. Employing interpolation techniques becomes essential in such cases to estimate wind patterns at the target location. The evolution of these methodologies holds profound importance in the formulation of landfill site selection strategies that embody sustainability, efficiency, and environmental responsibility. In the ever-shifting landscape of waste management and environmental concerns, collaborative efforts among researchers, policymakers, environmental experts, and local communities stand as a linchpin. Within this framework, individuals in positions of authority and environmental planners assume pivotal roles in propelling the enhancement of landfill site selection techniques. Their leadership is instrumental in steering these practices toward the twin objectives of environmental preservation and public health protection. By prioritizing these goals, decision-makers and environmental strategists contribute significantly to crafting a blueprint for a sustainable future, one that transcends current boundaries and serves as a legacy for generations to come. This shared commitment to responsible waste management, shaped by the evolution of methodologies and guided by collaboration, ensures that the choices made today resonate positively with the needs and aspirations of the future.

## 4. Conclusions

The process of landfill site selection is a complex and multifaceted task that requires the integration of various criteria, data sources, and decision-making tools. The study sheds light on the significance of employing multi-criteria decision analysis (MCDA) methods, specifically SWARA and BWM, in conjunction with Geographic Information Systems (GIS) to navigate this intricate landscape. Sensitivity analysis demonstrated that SWARA outperformed BWM in handling variations in input data, thus enhancing the reliability and stability of the landfill site selection process. However, it is essential to underscore that the choice between these methods should not be absolute but contingent on the specific context of each project. The real-world application of SWARA and BWM in landfill site selection projects demands careful consideration of factors such as data availability, project objectives, and stakeholder preferences. The adaptability and flexibility of these methods allow for their tailored use, ensuring that the most appropriate decision-making framework is chosen to address unique project constraints. Refinements, adaptations, and innovations in these methodologies are essential to develop more sustainable, efficient, and environmentally responsible solutions for landfill site selection and waste management as a whole. In this ever-changing landscape, collaboration between researchers, policymakers, environmental experts, and communities is paramount. Decision-makers and environmental planners have the potential to pave the way for enhanced landfill site selection practices, with a focus on minimizing environmental impact, safeguarding public health, and fostering a cleaner, more sustainable future for future generations.

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**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that would influence this paper.

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