

Geographic analysis of landfill suitability in Fez, Morocco: a multi-criteria approach

Tarik Chafiq¹ · Mohamed Hmamou¹ · Imrane Ouhammou¹ · Allal Labriki² · Mourad ElHabchi³ · Mohammed Raji¹

Received: 8 July 2023 / Accepted: 27 September 2023

Published online: 09 October 2023

© The Author(s) 2023 [OPEN](#)

Abstract

Solid waste management poses a significant challenge to sustainable development. Locating suitable landfill sites is a key difficulty. This study utilizes the Analytical Hierarchy Process (AHP) with a Geographic Information System (GIS) to identify potential landfill locations in Fez province, Morocco. Nine criteria were evaluated for the study area's suitability, including distance from surface water, distance from buildings, distance from roads, distance from protected areas, distance from forests, distance from farmland, elevation, slope, and slope direction. AHP determined criteria weights, and the Consistency Ratio (CR) ensured judgment reliability. Results highlight proximity to residential areas as the most critical factor, followed by distance from surface water and roads. The suitability map indicates the south and southeast of the province as more suitable for landfill placement than the urban areas, parks, and gardens in the north and northwest. These findings aid decision-makers in improving solid waste management practices in Fez province, Morocco.

Keywords Landfill · Solid waste management · Sustainable development · AHP · GIS

1 Introduction

The increase in population and urbanization causes an increase in the amount of waste produced [1], which requires the construction of landfills considering many factors. Landfills that are randomly located have harmful and sometimes dangerous consequences (bad smells, water pollution, soil pollution) on the environment and society [2]. Therefore, many factors must be considered to avoid environmental and social crises in locating a landfill. The protection of water networks and groundwater [3], the protection of forests and agricultural lands [4], the distance from parks and tourist sites [5] and the protection of the quality of the area in the cities [6] are among the essential factors in locating a landfill; other factors can be taken into account to reduce the costs (distance from roads, etc.).

For example, the presence of water surfaces near the landfill was a significant concern because it influenced the quality of the surrounding water. Similarly, the area's topography, including elevation, slope and slope direction, was crucial to understanding water flows; the proximity of residential areas can increase risks to human health and generate worries about security. Protected areas, forests and farmland are often sensitive to pollution and environmental degradation; the proximity of a landfill can have a negative impact on biodiversity.

✉ Tarik Chafiq, Tarik.chafiq1@gmail.com; Mohamed Hmamou, si.hmamou1@gmail.com; Imrane Ouhammou, imraneouhammou17@gmail.com; Allal Labriki, labriki.allal@gmail.com; Mourad ElHabchi, mouradelhabchi@gmail.com; Mohammed Raji, mhedraji@gmail.com | ¹LGAGE, Faculty of Sciences Ben M'Sik, University Hassan II of Casablanca, Casablanca, Morocco. ²LDSBGC, Faculty of Sciences Ben M'Sik, University Hassan II of Casablanca, Casablanca, Morocco. ³LTI Lab, Faculty of Sciences Ben M'Sik, Hassan II University of Casablanca, Casablanca, Morocco.



The AHP is a multi-criteria method based on a pair-wise comparison approach proposed by Saaty [7, 8], which enables comparing items two by two according to their relative importance based on the Saaty scale. Many studies that have been conducted to locate a landfill have used other methods, such as Fuzzy AHP [9–11], The PROMETHEE method [12, 13] (Preference Ranking Organization Method for Enrichment Evaluation), the ELECTRE [14, 15] method (Elimination And Choice Translating Reality), and the TOPSIS [16, 17] method (Technique for Order Preference by Similarity to Ideal Solution). The integration of GIS and AHP is an approach that is also widely used in other installations such as solar panels, wind farms, etc.

Recent studies on landfill site selection have seen significant developments in the factors considered and implemented. These studies have taken a holistic approach, integrating information from various sources, including geospatial data environmental and socio-economic factors. For example, several studies have implemented Geographic Information Systems (GIS) to integrate data relating to topography, water surface, proximity to populated and protected areas, and other factors vital to the landfill site selection process. In addition, the Analytic Hierarchy Process (AHP) methodology has been increasingly used to classify these factors according to their respective importance, enabling more objective decision-making based on well-defined criteria.

This study developed a GIS-based model to identify appropriate areas to locate a solid waste landfill by considering nine criteria using the AHP method. Most studies have used the integration of Geographic Information Systems (GIS) and the analytical hierarchy process (AHP) as a search methodology to locate a landfill.

2 Materials and methods

2.1 Study area

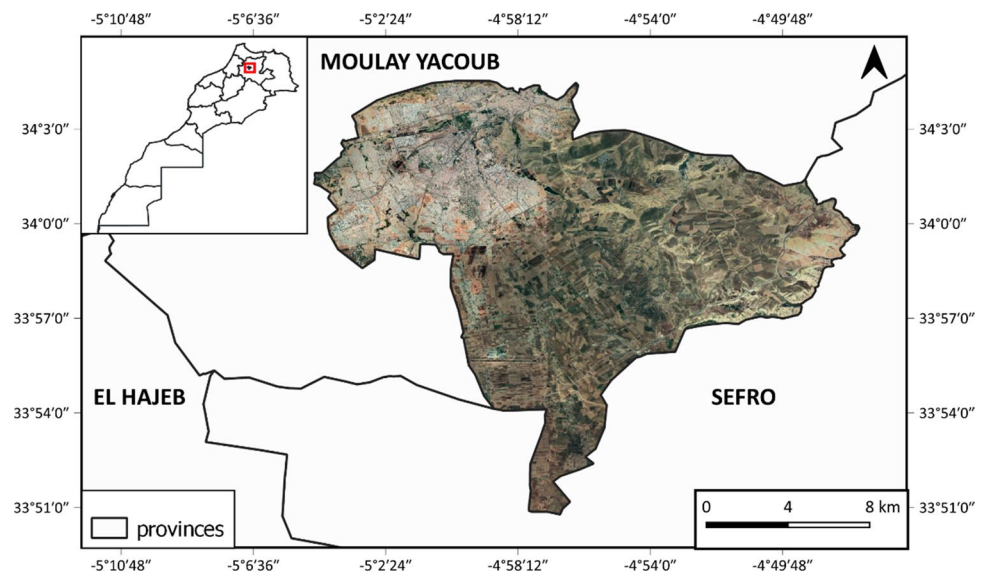
The province of Fez is located in the region of Fez-Meknes in the northern part of Morocco (Fig. 1) [18]; according to the High Commission of the Plan of Morocco (HCP) in 2014, the total population of the province was about 1,146,478 inhabitants. It is the largest population of the region Fez-Meknes [19]. Therefore, the province of Fez is considered one of the most urbanized provinces in Morocco, which produces large amounts of waste. This urbanization has adverse effects on the environment and society.

2.2 Data collection and processing

The criteria used in this study were chosen to protect the province of Fez from environmental and social crises resulting from the wrong location of a waste landfill and minimize costs.

The data and methodology used in this study to select suitable areas for locating a solid waste landfill are presented in Fig. 2. First, before starting the process, it is essential to understand the context of the study, including the geographical

Fig. 1 Geographic location of Fez province



area in which the landfill is located and the specific environmental issues associated with it. These may include geographical, climatic, economic, social or political factors influencing the impact and management of the landfill. This is known as the Contextual relevancy principle. So, nine criteria are selected and examined, including distance from residential areas, distance from surface water, distance from protected areas (parks and gardens), distance from forests, farmlands, elevation, slope, the direction of the slope and distance from roads.

Then, the collection of these criteria is done from different sources, The data for residential areas, surface water areas, forests, farmland, protected areas and roads were extracted from OpenStreetMap (OSM), an online mapping database powered by contributors worldwide. The elevation data was obtained from the United States Geological Survey (USGS), a US government agency specializing in mapping and geology, from which the slope and slope direction were calculated. Finally, the input data and reclassification processing are done using GIS software.

The criteria were then subdivided into sub-criteria, and the importance of each criterion concerning the other criteria was identified using the Saaty Scale to identify the weights of the criteria using the AHP method. Finally, the map of suitable areas for the location of a solid waste landfill was developed by considering all criteria with their weight.

2.3 Methodology and applications

The AHP method was applied to identify the weight of each criterion after data preparation and processing. First, the Saaty scale, a scale from 1 to 9 [20, 21], was used to identify the importance of each criterion to another (Table 1); this scale was used to calculate the pairwise comparison matrix; the weights are calculated by normalizing the comparison matrix, so the more critical the criterion is the higher the weight.

In order to maintain the consistency of judgments, we employed the consistency index (CI), which was derived from the comparison matrix. The CI serves as a metric to gauge the level of consistency among the judgments provided by decision-makers [22]. To calculate the CI, we subtracted the number of criteria (n) from the geometric mean of the

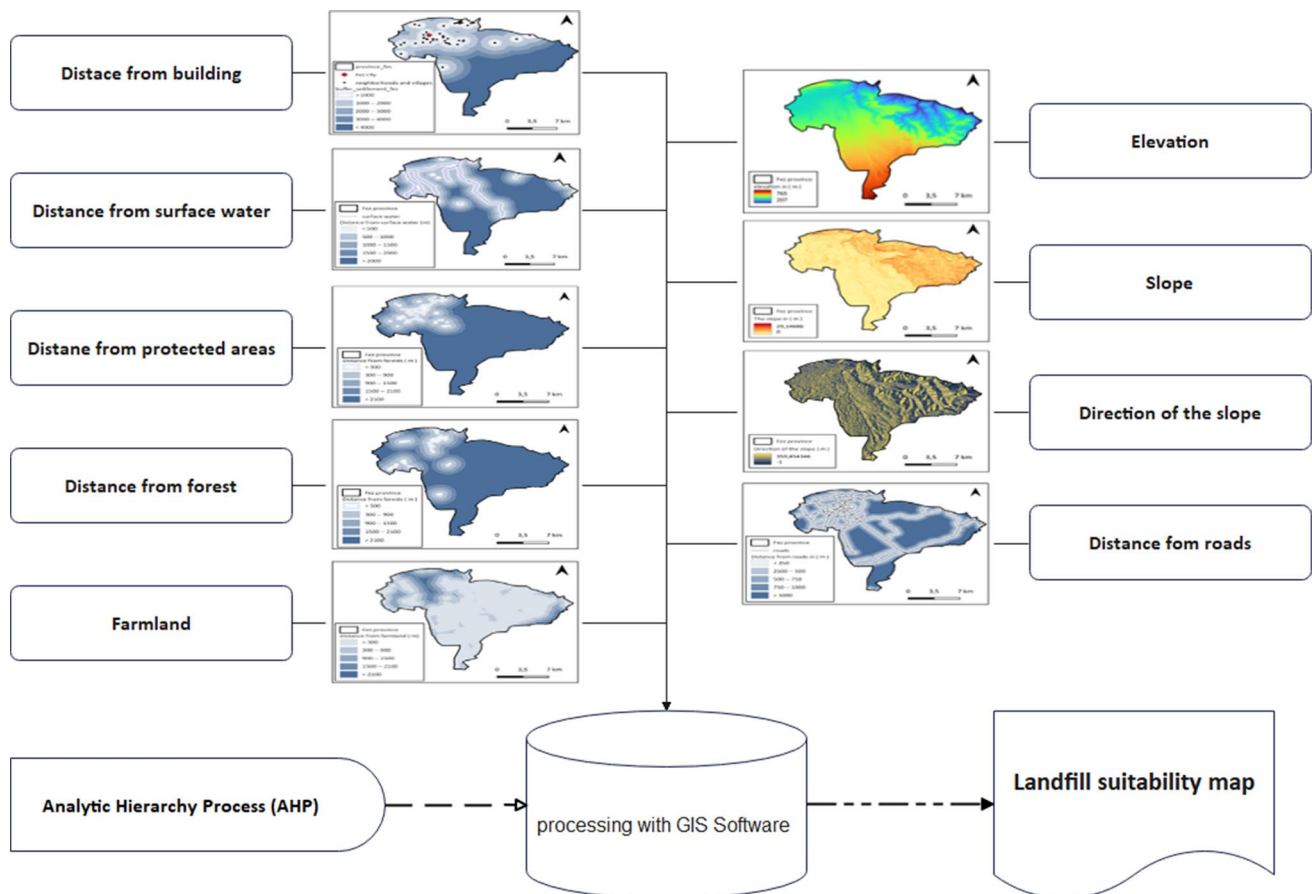


Fig. 2 Flowchart of the methodology for selecting suitable areas for landfill location

Table 1 AHP scale for pairwise comparison [25]

| Intensity of importance | Definition |
|-------------------------|--|
| 1 | Factor (a) is equally important to factor (b) |
| 3 | Factor (a) is slightly more important than factor (b) |
| 5 | Factor (a) is strongly more important than factor (b) |
| 7 | Factor (a) is very strongly more important than factor (b) |
| 9 | Factor (a) is extremely more important than factor (b) |
| 2, 4, 6, 8 | Intermediate values between the two adjacent judgments |

eigenvectors (L_{max}) and then divided the result by $n - 1$. A CI value below 0.1 is acceptable, whereas values exceeding 0.1 indicate inconsistent judgments. The formula (1) for CI is expressed as follows:

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

The Consistency Ratio (CR) is an essential indicator that measures the consistency of the judgments made in the pairwise comparison matrix [23]. To ensure the reliability of the judgments, the CR should be less than or equal to 0.1. Conversely, if the CR value is more significant than 0.1, the judgments are inconsistent and may need to be revised.

The Consistency Index (CI) is divided to calculate the CR by the Random Index (RI). The RI is a reference threshold value used to calculate the CR [24]. It is determined based on the size of the pairwise comparison matrix. The RI is calculated using a random set of comparison matrices of the same size and averaging their CI values.

The CR formula (2) is as follows:

$$CR = \frac{CI}{RI} \quad (2)$$

The input data was of two types—shapefile and raster. There were six shapefile data layers: surface water, residential areas, roads, protected areas, forests, and farmland. The other data layers were raster type: elevation, slope, and direction.

The raster data layers were reclassified directly, while the shapefile data layers required an additional step to calculate buffer zones. The buffer zones were calculated for each shapefile data layer in five classes. The distances chosen for each class were based on specific criteria. For example, for protected areas, farmland, and forests, the distances were less than 300 m for the first class, between 300 and 900 m for the second class, between 900 and 1500 m for the third class, between 1500 and 2100 m for the fourth class, and more than 2100 m for the fifth class. Similarly, for surface water, the distances were less than 500 m for the first class, between 500 and 1000 m for the second class, between 1000 and 1500 m for the third class, between 1500 and 2000 m for the fourth class, and greater than 2000 m for the fifth class. Each class was set at a distance of 1000 m for residential areas, while for roads, each class was set at 250 m.

After calculating the buffer zones for the shapefile data, the resulting data was converted to raster format with a specified cell size of 30 m and reclassified. This grid size was chosen to ensure an appropriate level of spatial resolution for our analysis. This step was necessary to ensure that all the criteria were in the same format, making it easier to analyze and compare them.

The resulting data in raster format for all the criteria were combined into a single map, as shown in Fig. 3. This map was then used to identify suitable sites for the solid waste landfill using the AHP approach based on GIS.

3 Results and discussion

The CR value of 0.056 obtained in this study (Fig. 2) indicates that the pairwise criteria comparisons were consistent and reliable. The CR values for the sub-criteria were also satisfactory, with all values less than 0.10 (Fig. 2). The CR value for elevation, slope, and distance from roads was found to be 0.015. In contrast, the direction of the slope had a CR value of 0.056. The other criteria had a CR value of 0.039, which indicates their reliability.

Table 2 presents the weight of each criterion, with the distance from residential areas being the essential criterion with a weight of 0.344. This indicates that locating a solid waste landfill far away from residential areas is crucial to minimize the impact on human health. The second most important criterion was the distance from surface water,

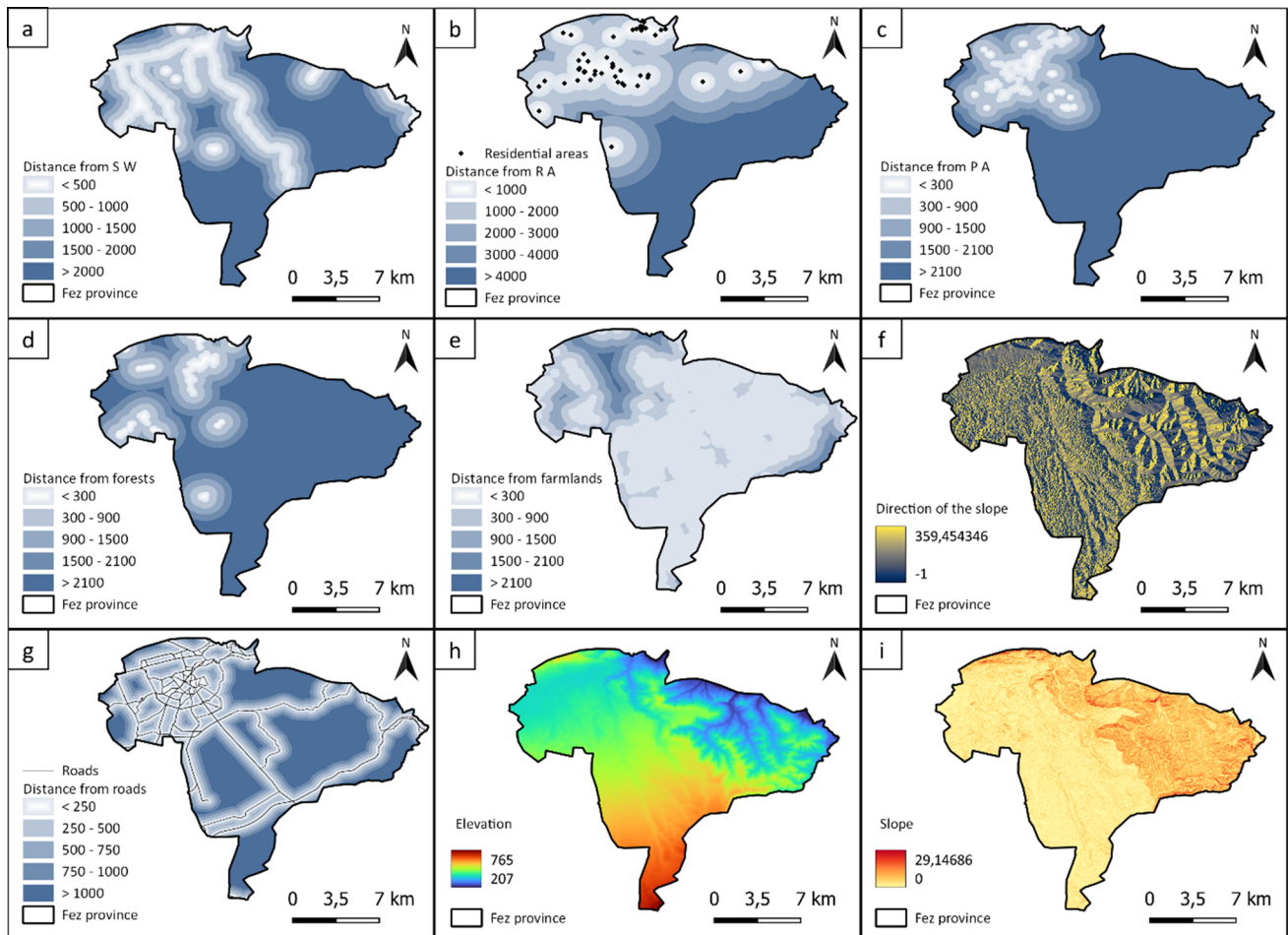


Fig. 3 Criteria considered in the study: distance from surface water (a), distance from residential areas (b), distance from protected areas (c), distance from forests (d), farmland (e), direction of the slope (f), distance from roads (g), elevation (h) and slope (i)

with a weight of 0.219. This is because surface water is a valuable resource that should be protected from contamination. The distance from roads also had a significant weight of 0.160, as it is necessary to minimize the transportation cost of waste.

Moreover, the distance from protected areas was also crucial, weighing 0.078. This indicates the need to avoid locating a solid waste landfill near parks, gardens, and tourist areas to preserve their ecological value. The remaining criteria, including forests, farmland, and residential areas, had varying levels of importance.

Figure 4 illustrates the suitability map for locating a solid waste landfill in the province of Fez. The map clearly shows that the northern and northwestern parts of the province, where urban areas, parks, and surface water are located, are unsuitable for landfill sites. These areas are represented in red color, indicating the lowest suitability. On the other hand, the southern and southeastern parts of the province have a large area that is moderately suitable for landfill sites, represented in yellow and orange colors. Interestingly, the map also shows two areas with the highest suitability for landfill sites, represented in green color, in the southern and southeastern parts of the province. These areas are far from residential areas to protect the public from pollution, and they are also located away from surface water, protected areas, and forests to preserve the natural environment and resources. In addition, the two areas are situated near the road, making transporting the waste more accessible and more cost-effective.

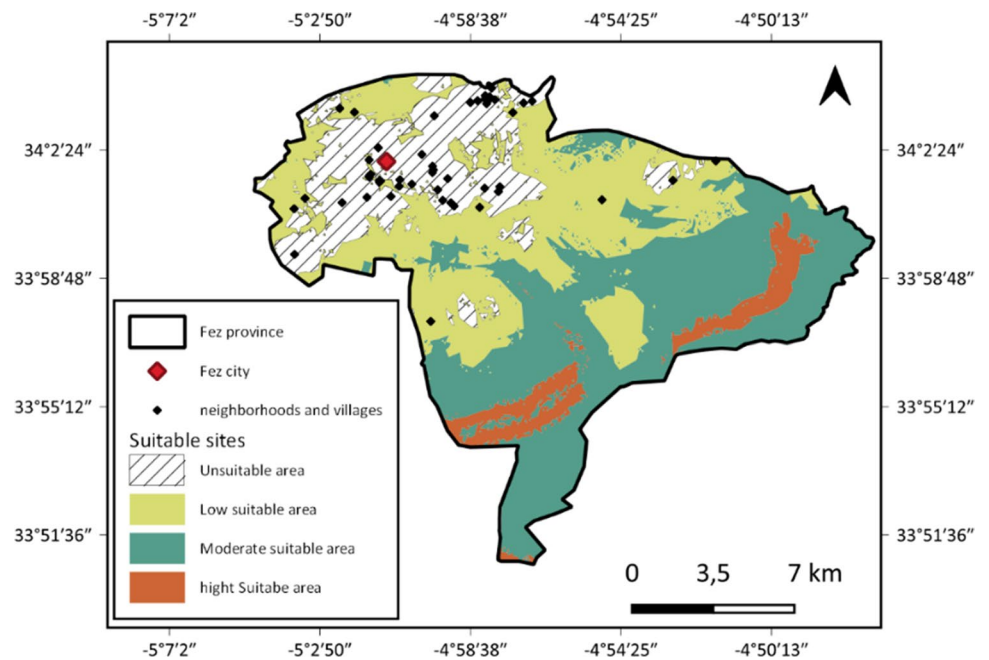
The suitability map provides valuable information for decision-makers and stakeholders to identify suitable locations for landfill sites considering environmental, social, and economic factors. It also highlights the importance of using advanced spatial analysis tools, such as GIS and AHP, to support decision-making processes in solid waste management.

Several significant implications and applications arise from this research. By better understanding the factors influencing the landfill situation in the province of Fez, the results of this study can also be used to identify high-risk areas, enabling appropriate preventive measures to be put in place. In addition, our methodology can be adapted to

Table 2 Weights of criteria and sub-criteria

| Criteria | Criteria weights | CR | Sub-criteria | Weight | CR |
|-------------------------------------|------------------|-------|--------------|--------|-------|
| Elevation (m) | 0.047 | 0.056 | 202–344 | 0.416 | 0.015 |
| | | | 344–424 | 0.262 | |
| | | | 424–502 | 0.161 | |
| | | | 502–589 | 0.099 | |
| | | | 589–765 | 0.062 | |
| Slope (°) | 0.041 | | 0–3 | 0.416 | 0.015 |
| | | | 3–6 | 0.262 | |
| | | | 6–10 | 0.161 | |
| | | | 10–14 | 0.099 | |
| | | | 14–30 | 0.062 | |
| Direction of the slope | 0.029 | | SW and flat | 0.309 | 0.056 |
| | | | NE | 0.032 | |
| | | | NW | 0.161 | |
| | | | SE | 0.038 | |
| | | | N | 0.071 | |
| | | | E | 0.040 | |
| | | | S | 0.100 | |
| | | | W | 0.248 | |
| Distance from surface water (m) | 0.219 | | < 500 | 0.038 | 0.039 |
| | | | 500–1000 | 0.085 | |
| | | | 1000–1500 | 0.155 | |
| | | | 1500–2000 | 0.235 | |
| | | | > 2000 | 0.488 | |
| Distance from roads (m) | 0.160 | | 202–344 | 0.416 | 0.015 |
| | | | 344–424 | 0.262 | |
| | | | 424–502 | 0.161 | |
| | | | 502–589 | 0.099 | |
| | | | 589–765 | 0.062 | |
| Distance from residential areas (m) | 0.344 | | < 1000 | 0.038 | 0.039 |
| | | | 1000–2000 | 0.085 | |
| | | | 2000–3000 | 0.155 | |
| | | | 3000–4000 | 0.235 | |
| | | | > 4000 | 0.488 | |
| Distance from forests (m) | 0.056 | | < 300 | 0.038 | 0.039 |
| | | | 300–900 | 0.085 | |
| | | | 900–1500 | 0.155 | |
| | | | 1500–2100 | 0.235 | |
| | | | > 2100 | 0.488 | |
| Distance from protected areas (m) | 0.078 | | < 300 | 0.038 | 0.039 |
| | | | 300–900 | 0.085 | |
| | | | 900–1500 | 0.155 | |
| | | | 1500–2100 | 0.235 | |
| | | | > 2100 | 0.488 | |
| Farmland (m) | 0.025 | | < 300 | 0.038 | 0.039 |
| | | | 300–900 | 0.085 | |
| | | | 900–1500 | 0.155 | |
| | | | 1500–2100 | 0.235 | |
| | | | > 2100 | 0.488 | |

Fig. 4 Suitability map for locating a solid waste landfill in the Province of Fez



other environmental problems, providing a replicable model for similar assessments in different regions. Ultimately, the research aims to contribute to the protection of the environment, the preservation of public health, and the well-being of the inhabitants of Fez by providing usable information for more effective waste management.

4 Conclusion

The results of this study indicate that integrating GIS with the AHP technique is a feasible strategy for determining appropriate sites for solid waste disposal facilities. The findings indicate that the proximity of residential areas, surface water, and road networks are the primary variables to consider while determining a landfill location. The regions towards the province's south and southeast have been identified as the most suitable locations for establishing a landfill. Conversely, the north and northwest regions, encompassing urban areas, parks, and gardens, have been deemed less appropriate. In addition, integrating a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) can facilitate decision-making by prioritizing and evaluating diverse social, environmental, and economic factors. This approach can lead to the identification of optimal landfill sites, as they minimize the adverse effects on the environment and society. The evaluations of specialists in environmental and socio-economic domains who participate in the decision-making process may impact the outcomes of appraisal models that rely on the Analytical Hierarchy Process (AHP) technique. The present study's outcomes can provide significant perspectives to policymakers in the Moroccan province of Fez and other territories facing similar difficulties in managing solid waste. The methodology proposed in this investigation has the potential to make a valuable contribution to the advancement of sustainable development by ensuring the optimal siting of waste disposal sites while simultaneously reducing negative ecological and health consequences.

Author contributions H-JK, BK, and J-HP conceived and designed the study. H-JK, SK, JMY, HK, and BC analyzed and interpreted the data. H-JK and BK, wrote this paper and J-HP reviewed the paper.

Data availability The datasets used during the current study are available from the corresponding or first author on reasonable request.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

1. Chen Y-C. Effects of urbanization on municipal solid waste composition. *Waste Manage.* 2018;79:828–36.
2. Badi I, Kridish M. Landfill site selection using a novel FUCOM-CODAS model: a case study in Libya. *Sci African.* 2020;9:e00537.
3. Idowu IA, et al. An analyses of the status of landfill classification systems in developing countries: sub Saharan Africa landfill experiences. *Waste Manage.* 2019;87:761–71.
4. Karimi N, et al. Thermal heterogeneity in the proximity of municipal solid waste landfills on forest and agricultural lands. *J Environ Manag.* 2021;287:112320.
5. Rezaeisabzevar Y, Bazargan A, Zohourian B. Landfill site selection using multi criteria decision making: Influential factors for comparing locations. *J Environ Sci.* 2020;93:170–84.
6. Mishra S, et al. Impact of municipal solid waste landfill leachate on groundwater quality in Varanasi, India. *Groundw Sustain Development.* 2019;9:100230.
7. Güngör Z, Serhadlioğlu G, Kesen SE. A fuzzy AHP approach to personnel selection problem. *Appl Soft Comput.* 2009;9(2):641–6.
8. Wong JK, Li H. Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Build Environ.* 2008;43(1):108–25.
9. Beskese A, et al. Landfill site selection using fuzzy AHP and fuzzy TOPSIS: a case study for Istanbul. *Environ Earth Sci.* 2015;73:3513–21.
10. Islam M, Kashem S, Morshed S. Integrating spatial information technologies and fuzzy analytic hierarchy process (F-AHP) approach for landfill siting. *City Environ Interact.* 2020;7:100045.
11. Mallick J. Municipal solid waste landfill site selection based on fuzzy-AHP and geoinformation techniques in Asir Region Saudi Arabia. *Sustainability.* 2021;13(3):1538.
12. Mohammadi Seif Abad P, et al. Application AHP-PROMETHEE technic for landfill site selection on based assessment of aquifers vulnerability to pollution. *Iran J Sci Technol Trans Civil Eng.* 2021;45:1011–30.
13. Wu Y, et al. An extended TODIM-PROMETHEE method for waste-to-energy plant site selection based on sustainability perspective. *Energy.* 2018;156:1–16.
14. Aydi A, Zairi M, Dhia HB. Minimization of environmental risk of landfill site using fuzzy logic, analytical hierarchy process, and weighted linear combination methodology in a geographic information system environment. *Environ Earth Sci.* 2013;68:1375–89.
15. Saeedi M, et al. Landfill site selection for solid drilling wastes (case study: Marun oil field, southwest Iran). *Int J Environ Sci Technol.* 2020;17:1567–90.
16. Hanine M, et al. An application of OLAP/GIS-Fuzzy AHP-TOPSIS methodology for decision making: location selection for landfill of industrial wastes as a case study. *KSCE J Civ Eng.* 2017;21:2074–84.
17. Alao MA, et al. Multi-criteria decision based waste to energy technology selection using entropy-weighted TOPSIS technique: the case study of Lagos. *Niger Energy.* 2020;201:117675.
18. Kessabi R, et al. Homogenization and trends analysis of monthly precipitation series in the Fez-Meknes Region, Morocco. *Climate.* 2022;10(5):64.
19. HCP. Données Démographiques et Socio-économiques: Fiches Régionale, Préfectorales, Provinciales et Communales. 2014. https://www.hcp.ma/region-fes/Fiches-Communales-RGPH-2014_r13.html. Accessed 4 May 2023.
20. Zhang Z, Liu X, and S. Yang. A Note on the 1–9 Scale and Index Scale in AHP. In *Cutting-Edge Research Topics on Multiple Criteria Decision Making: 20th International Conference, MCDM 2009, Chengdu/Jiuzhaigou, China, June 21–26, 2009*. Proceedings. Springer. 2009.
21. Coffey L, Claudio D. In defense of group fuzzy AHP: A comparison of group fuzzy AHP and group AHP with confidence intervals. *Expert Syst Appl.* 2021;178:114970.
22. Kazibudzki PT. An examination of performance relations among selected consistency measures for simulated pairwise judgments. *Ann Oper Res.* 2016;244(2):525–44.
23. Liu F, Zou S-C, Li Q. Deriving priorities from pairwise comparison matrices with a novel consistency index. *Appl Math Comput.* 2020;374:125059.
24. Nachappa TG, et al. Flood susceptibility mapping with machine learning, multi-criteria decision analysis and ensemble using Dempster Shafer theory. *J Hydrol.* 2020;590:125275.
25. Saaty T. *The analytic. New York: Hierarchy Process-McGraw-Hill Book Company; 1980.*

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.