Solid Waste Assessment and Management Using Remote Sensing Data and GIS Tools: A Case Study of Najran City, KSA

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Abstract. Municipal Solid Waste (MSW) management is a major socio-economic issue in all emerging countries. Cities have their solid waste management regulations, approach, and procedures. They believe that wastelands outside of cities are the greatest places to dispose of solid waste. Such inappropriate location will lead to morphologic changes in the urban region and its surrounding, creating health hazards. The acquisition of data about an object(s) without establishing contact with it is known as remote sensing. The geographic information system (GIS) is a spatial system that creates, maintains, analyses, and maps various kinds of data. GIS software and remote sensing data are extremely valuable for assessing and managing solid wastage. Sentinel-2 satellite images were used to obtain land cover data. Digital elevation model (DEM) from ALOS-PALSAR free data used to describe surface information. Some thematic layers, such as soil, surface slope, drainage density, airport distance, road distance, and land-use, were used as principal input data for Multi-Criteria Decision Analysis (MCDA) to choose the best solid waste locations in Najran city. According to the appropriateness degree of the landfill, locations acquired, 31% and 10.9 percent of the total area were classed as very low and low, respectively, while 25.3 % and 11.9 % were classified as high and very high suitable areas.

Keywords: Landfill locations, AHP, Waste management, DEM, GIS, Remote sensing, MCDA, Site selection.

1. Introduction
The volume of created MSW has increased dramatically over the world. According to World Bank statistics, global municipal trash generation is predicted to reach 2.2 billion tons by 2025 due to rapid population growth. The generated MSW reached above 15.3 million tons per year as the population of Saudi Arabia's cities and semi-urban areas increased to 35.8 million [1]. The trash generation is predicted to be 1.25 to 1.8 kilograms per person each day (Figure 1).
Figure 1. MSW generation rate in the Gulf Arab compared to other countries.

Waste management and assessment, which includes collecting, sorting, and recycling in a scientific way, lead to an economic return, a clean environment, and building sustainable cities [2]. Landfilling is one of the most cost-effective and environmentally sound ways to dispose of MSW [3], [4]. Unfortunately, because of the dependence on social, environmental, technological, economic, and legal considerations, identifying the location of landfill sites is a challenging and complicated task [5]–[7]. Many previous studies have recommended approaches to solve the waste site suitability assessment using remote sensing data and GIS tools [8]–[10]. Because a range of variables is considered in the decision-making process, selecting among alternative sites is a multi-criterion decision-making problem. Decision-making is a type of data mining procedure that uses basic optimization approaches to address day-to-day problems. Although there are various strategies published in the literature, only a few of them are appropriate for site selection. Analytic Network Process (ANP) and Analytic Hierarchical Process (AHP) have the most application to solve the site selection problem, according to various research [11]–[13]. [14] developed the multi-criteria decision analysis (MCDA), which is an AHP process. This method includes breaking down the criteria into sub-criteria which can be scored on a scale ranging in a hierarchy [15]–[17]. Because GIS tools play such an important role in evaluating decision problems, the GIS tool and the MCDA study topics can complement each other. When compared to simple weighted average procedures, this integration provides users with both qualitative and quantitative outcomes [18]–[21].

The purpose of this research is to identify specific MSW sites in Najran City, KSA. To build a healthy and sustainable urban environment.

2. Study area
Najran is a city in Saudi Arabia's southwest that is between latitudes 16–19 N and longitudes 43–48 E (Figure 2). Najran has a hot desert environment, which is typical of the Arabian Peninsula. Rainfall occurs in intermittent bursts and consists of modest individual showers. A 55-km-by-28-km area with moderate to high topography and heights ranging from 1157 m to 1371 m above mean sea level (see Figure 3). From the north, south, and west, the study area is surrounded by towering mountains. It encompasses a wide range of land use activities, such as residential, urban, and agricultural development, as well as transportation networks.

3. Dataset used
Digital elevation model (DEM) and true color for the study area are the main used dataset. the ALOS PALSAR RTC DEM with 12.5 m resolution data for free (Figure 3 left). Lighter areas indicate higher elevation regions. The Universal Transverse Mercator (UTM) zone 38 north is the coordinate system
used. The used Sentinel-2 image was acquired on 11 December 2021 (cloud coverage less than 1%) (Figure 3 right).

![Figure 2. Location of the study area.](image)

**Figure 2. Location of the study area.**

![Figure 3. The remote sensing images datasets, DEM (left) and Sentinel-2 image (right).](image)

**Figure 3. The remote sensing images datasets, DEM (left) and Sentinel-2 image (right).**

There are six theme layers used in this work to obtain landfill sites: soil type, surface slope, drainage density, airport distance, road distance, and land use/cover. The land use, roads, and airport layers were extracted from the true color Sentinel-2 satellite image with 10-meter ground resolution. The drainage density in the region is extracted using DEM. The DEM, on the other hand, is employed by the ArcGIS spatial analysis tool to extract the slope layer. The national geological database portal website (https://ngp.sgs.org.sa/) provided a soil map, Figure 4 shows all used layers.

4. Methodology

Thematic map production, weight factor assignment, weighted overlay analysis using MCD analysis, and site prioritization are all part of this work's methodology. Figure 5 shows the methodological framework's schematic structure. Based on previous experts, there were three major criteria created: environmental, engineering and economic, and sociocultural. Six criteria were created and adopted as a standard for assessment based on three major criteria, soil data, surface slope, drainage, airport, roads
distances and land use/cover. The next step includes obtaining decisions for every level of the decomposed hierarchy. The local rankings were multiplied by the weights of the criterion, and then the overall ratings were calculated.

Figure 4. Thematic used layers, airport distance (A), land use/cover (B), surface slope (C), drainage density (D), roads distance (E), and soil data (F).

5. Results

5.1. AHP calculation for used sub-criteria

The assignee of weighted scores for criteria and sub-criteria based on existing research publications. A score of nine indicates the most significant, one indicates equal importance, and 1/9 indicates the least importance. The weight (w) of each criterion and its sub-criteria are calculated using the normalizing matrix approach. The core value of the comparison matrix divided by the column total determines the value of each cell in the matrix. In a priority list model based on relative data, each cell in the matrix was given weight about the experts’ assessment.
The AHP assists in calculating the weight for each factor using the decision matrix's normalized standard vector (A),

\[
A = \begin{bmatrix}
1 & \cdots & sc_n \\
\cdots & 1 & \cdots \\
sc_n & \cdots & 1
\end{bmatrix}
\]  \hspace{1cm} (1)

A is a reciprocal matrix. A nine-point scale of 1–9 and 1/2–1/9 was employed for direct and inverse relationships, respectively. Table 1 shows the scale from 1 to 9 points.

**Table 1.** Pairwise comparisons scales.

| Main     | The importance of the two sub-elements range             |
|----------|----------------------------------------------------------|
| 1        | Similarly significant / the same                          |
| 3        | Moderate/slight importance                                |
| 5        | Strong/serious importance                                 |
| 7        | Very strong/more serious importance                        |
| 9        | Extreme/absolute importance                               |
| 2,4,6,8  | Intermediate value/the same importance                     |

Reciprocals inversely proportional
Matrix A is called Consistency Matrix (CR) if all of the comparisons are perfect in the DM judgment matrix. The eigenvalues (\( \lambda_{\text{max}} \)) of matrix A are used to determine the consistency of the judgments made. The \( \lambda_{\text{max}} \) is one technique used by the AHP method to calculate the final weights (w). The formula below explains how weights are calculated.

\[
Aw \cong nw \Rightarrow (A - \lambda_{\text{max}} I)w = 0 \Rightarrow \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} = 
\]

where A is the comparison matrix, w is the weight matrix and \( \lambda_{\text{max}} \) is eigenvalues. When n (the number of alternatives or criteria) is large, it is hard for the decision-maker to make a perfect correct judgment in reality. As a result, the performance evaluation consistency index (CI) is calculated as.

\[
CI = (\lambda_{\text{max}} - n)/(n - 1) \Rightarrow w = (w_1, w_2, \ldots, w_n)
\]

The overall consistency ratio (CR) of the used criteria should be less than 10%. Table 3 shows the random consistency index (RI) dependent on the number of used criteria, where N is the number of criteria involved [15].

**Table 2. RI index values for 1–6 criteria.**

| N  | 1   | 2   | 3   | 4   | 5   | 6   |
|----|-----|-----|-----|-----|-----|-----|
| RI | 0.0 | 00  | 0.58| 0.90| 1.12| 1.32|

The CR values are interpreted as

\[
CR = CI/RI
\]

The judgment result in the pairwise comparison matrix is considered inconsistent if the computed CR is above this limit and the procedure must be reconsidered. Table 3 shows major and sub-criteria relative ranges based on previous studies [6], [22], [23]. The final weights of each sub-criterion are calculated (w). As a result, local weights were multiplied by the weights of the criteria, and the overall and global ratings for each layer were calculated.

**Table 3. Values for specified criteria major and minor criteria used in landfill site selection process.**

| Item               | Main criteria | Pairwise | Pairwise comparison matrix | CI  | \( \lambda_{\text{max}} \) | RI  | CR  |
|--------------------|---------------|----------|----------------------------|-----|-----------------------------|-----|-----|
| 1 Distance from the airport | A 1-2 km      | 1 1 1/2 1/5 1/7 1/8 | 0.04 | 0.01 | 6.04 | 1.24 | 0.8% |
|                    | B 2-3 km      | 1 1 1/2 1/4 1/6 1/7 | 0.04 |               |     |     |
|                    | C 3-4 km      | 2 2 1/2 1/4 1/5       | 0.08 |               |     |     |
|                    | D 4-5 km      | 5 4 2 1/2 1/4 1/3     | 0.16 |               |     |     |
|                    | E 5-6 km      | 7 6 4 2 1 1     | 0.31 |               |     |     |
|                    | F >6 km       | 8 7 5 3 1 1           | 0.36 |               |     |     |
| 2 Land use/cover   | A (Water bodies) | 1 1 1/2 1/5 1/7 1/8 | 0.04 |               |     |     |
|                    | B (Forest)    | 1 1 1 1/4 1/6 1/7    | 0.05 |               |     |     |
|                    | C (Settlement) | 2 1 1/3 1/5 1/6      | 0.06 |               |     |     |
|                    | D (Agriculture) | 5 4 3 1 1/2 1     | 0.21 |               |     |     |
|                    | E (Scrubland) | 7 6 5 2 1 1     | 0.32 |               |     |     |
|                    | F (Fallow land) | 8 7 6 1 1 1          | 0.31 |               |     |     |
5.2. AHP calculation for used main-criteria

After normalization of the weights, the weights of main criteria: soil, slope, drainage density, airport distance, road distance, land use are 0.03, 0.05, 0.09, 0.15, 0.25, and 0.43 (see Table 4).

Table 4. Pair by pair comparison matrix for main factors.

| Item | Pairwise | Soil | Slope | Drainage density | Airport distance | Road distance | Land use | W   |
|------|----------|------|-------|------------------|------------------|--------------|---------|-----|
| 1    | Soil     | 1    | 1/3   | 1/4              | 1/5              | 1/6          | 1/8     | 0.03|
| 2    | Slope    | 3    | 1     | 1/3              | 1/4              | 1/5          | 1/6     | 0.05|
Drainage density 4 3 1 1/3 1/4 1/5 0.09
Airport distance 5 4 3 1 1/3 1/4 0.15
Road distance 6 5 4 3 1 1/3 0.25
Land use 8 6 5 4 3 1 0.43

\[ C_l = 0.07, \ A_{\text{max}} = 6.04, \ RI = 1.24, \ CR = 5.6\% \]

6. Conclusions

The current study includes a variety of remote sensing datasets and decision-making approaches in order to give an integrated framework for the landfill suitability site map for a portion of Najran city, Saudi Arabia. Six remote sensing datasets, including soil data, surface slope, drainage density, airport distance, road distance, land use/cover, were chosen for this study after an extensive literature review and expert opinion. To prepare raw remote sensing data and build a final best location landfill map with varied scales and priorities, ArcGIS version 10.7 software is employed. Table 5 shows statistics of landfill location, 31% and 10.9% of the total area were under very low and low LLSI, while 25.3% and 11.9% account to the high and very high potential zone.

| Suitable degree | LLSI (Range) % | Area (pixels 10m*10 m) | Area in % |
|-----------------|----------------|-------------------------|-----------|
| Very low        |                |                         |           |
| Low suitable    |                |                         |           |
| Moderate suitable |              |                         |           |
| High suitable   |                |                         |           |
| Very high suitable |            |                         |           |

Figure 6. Landfill suitability map of Najran city, KSA.
Finally, depending on several areas of knowledge, the study gives thorough spatial information on landfill site availability and suitability level. By adjusting the primary and sub-criteria to reflect the specific local requirements, the obtained map could be used as a guide for making decisions to select the best MSW locations in Najran city.

References

[1] E. S. Gharaibeh, N. M. Haimour, and B. A. Akash, “Evaluation of current municipal solid waste practice and management for Al-Ahsa, Saudi Arabia,” Int. J. Sustain. Water Environ. Syst., vol. 2, no. 2, pp. 103–110, 2011.

[2] M. H. Ghobadi, R. Babazadeh, and V. Bagheri, “Siting MSW landfills by combining AHP with GIS in Hamedan province, western Iran,” Environ. earth Sci., vol. 70, no. 4, pp. 1823–1840, 2013.

[3] H. I. Abdel-Shafy and M. S. Mansour, “Solid waste issue: sources, composition, disposal, recycling, and valorization. Egypt J Petrol 27 (4): 1275–1290.” 2018.

[4] B. Özkaz, E. Özceylan, and I. Sarıçicek, “GIS-based MCDM modeling for landfill site suitability analysis: a comprehensive review of the literature,” Environ. Sci. Pollut. Res., vol. 26, no. 30, pp. 30711–30730, 2019.

[5] V. M. Adamović, D. Z. Antanasijević, M. Đ. Ristić, A. A. Perić-Grujić, and V. V Pocajt, “Prediction of municipal solid waste generation using artificial neural network approach enhanced by structural break analysis,” Environ. Sci. Pollut. Res., vol. 24, no. 1, pp. 299–311, 2017.

[6] S. Kapilan and K. Elangovan, “Potential landfill site selection for solid waste disposal using GIS and multi-criteria decision analysis (MCDA),” J. Cent. South Univ., vol. 25, no. 3, pp. 570–585, 2018.

[7] M. Khodaparast, A. M. Rajabi, and A. Edalat, “Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): a case study in Qom city, Iran,” Environ. earth Sci., vol. 77, no. 2, pp. 1–12, 2018.

[8] G. Sisay, S. L. Gebre, and K. Getahun, “GIS-based potential landfill site selection using MCDM-AHP modeling of Gondar Town, Ethiopia,” African Geogr. Rev., vol. 40, no. 2, pp. 105–124, 2021.

[9] P. Zolfaghary, M. Zakernia, and H. Kazemi, “A model for the use of urban treated wastewater in agriculture using multiple criteria decision making (MCDM) and geographic information system (GIS),” Agric. Water Manag., vol. 243, p. 106490, 2021.

[10] S. Dolui and S. Sarkar, “Identifying potential landfill sites using multicriteria evaluation modeling and GIS techniques for Kharagpur city of West Bengal, India,” Environ. Challenges, vol. 5, p. 100243, 2021.

[11] H. A. Eiseit and V. Marianov, “Location modeling for municipal solid waste facilities,” Comput. Oper. Res., vol. 62, pp. 305–315, 2015.

[12] B. Vučijak, S. M. Kurtagić, and I. Silajdžić, “Multicriteria decision making in selecting best solid waste management scenario: a municipal case study from Bosnia and Herzegovina,” J. Clean. Prod., vol. 130, pp. 166–174, 2016.

[13] V. F. Nascimento, N. Yesiller, K. C. Clarke, J. P. H. B. Ometto, P. R. Andrade, and A. C. Sobral, “Modeling the environmental susceptibility of landfill sites in California,” GIScience
Remote Sens., vol. 54, no. 5, pp. 657–677, 2017.

[14] T. L. Saaty, “Decision making with the analytic hierarchy process,” Int. J. Serv. Sci., vol. 1, no. 1, pp. 83–98, 2008.

[15] T. L. Saaty, “What is the analytic hierarchy process?,” in Mathematical models for decision support. Springer, 1988, pp. 109–121.

[16] T. L. Saaty, “How to make a decision: the analytic hierarchy process,” Eur. J. Oper. Res., vol. 48, no. 1, pp. 9–26, 1990.

[17] O. S. Vaidya and S. Kumar, “Analytic hierarchy process: An overview of applications,” Eur. J. Oper. Res., vol. 169, no. 1, pp. 1–29, 2006.

[18] J. Malczewski, “GIS-based multicriteria decision analysis: a survey of the literature,” Int. J. Geogr. Inf. Sci., vol. 20, no. 7, pp. 703–726, 2006.

[19] A. F. Lukasheh, R. L. Droste, and M. A. Warith, “Review of expert system (ES), geographic information system (GIS), decision support system (DSS), and their applications in landfill design and management,” Waste Manag. Res., vol. 19, no. 2, pp. 177–185, 2001.

[20] O. Al-Jarrah and H. Abu-Qdais, “Municipal solid waste landfill siting using intelligent system,” Waste Manag., vol. 26, no. 3, pp. 299–306, 2006.

[21] V. R. Sumathi, U. Natesan, and C. Sarkar, “GIS-based approach for optimized siting of municipal solid waste landfill,” Waste Manag., vol. 28, no. 11, pp. 2146–2160, 2008.

[22] E. Kazuva, J. Zhang, Z. Tong, X.-P. Liu, S. Memon, and E. Mhache, “GIS-and MCD-based suitability assessment for optimized location of solid waste landfills in Dar es Salaam, Tanzania,” Environ. Sci. Pollut. Res., vol. 28, no. 9, pp. 11259–11278, 2021.

[23] H. Javaheri, T. Nasrabadi, M. H. Jafarian, G. R. Rowshan, and H. Khoshnam, “Site selection of municipal solid waste landfills using analytical hierarchy process method in a geographical information technology environment in Giroft,” J. Environ. Heal. Sci. Eng., vol. 3, no. 3, pp. 177–184, 2006.