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Landfill site selection using analytical hierarchy process and GIS: a case study in Al-Zubair district, Basrah, Iraq

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Abstract

Al-Zubair district is located in the southwestern part of Basrah governorate and is considered the largest region administratively. Due to the rapid urbanization, rapid population growth, high waste productivity, and inexistence of landfills in Al-Zubair district, a sanitary landfill is needed to accommodate the produced solid waste and avoid any potential environmental problems. Hence, this study has been conducted to propose the best location for the sanitary landfill in Al-Zubair district and solve the waste problem scientifically, thus, a total of nine influencing criteria were adopted (water surface, agricultural lands, residential area, soil types, slope, roads, railways, power lines, and the oil fields) then processed using the Geographical Information System (GIS) to generate the map of suitability index and find the most candidate sites for the landfill based on the weights of criteria that derived from the Analytical Hierarchy Process (AHP) method. This study expected that the cumulative volume of solid waste through (2025-2050) would be about 18658259 m^3, requiring a landfill's area of at least 9.33 km^2 to accommodate this volume. The most suitable candidate site for landfill was identified in the middle of Al-Zubair district with an area of 124.63 km^2 in a way safe enough from the restricted zones of all criteria reducing the aesthetic destruction, physical pollution, travel time, construction cost and demonstrating the ability to accommodate the cumulative solid waste even after 2050 sustainably. The prior advantages of the proposed landfill's location would benefit the solid waste management in the study area effectively and efficiently.

Keywords: *Al-Zubair district, Analytical Hierarchy Process (AHP), Geographic Information System (GIS), Multi-Criteria Decision Making (MCDM), Sanitary Landfill.*

1. Introduction

Globally, the disposal of solid waste from the municipal is becoming a serious problem causing dangerous effects on the public health and environmental field [1-2]. Nowadays, this problem has become worse, especially in the developing countries, due to increasing in the industrial activities, rapid population growth, socio-economic growth, and uncontrolled migration, all the previous factors caused unplanned rapid urbanization [3], thus, the produced solid waste amount globally reached up to 3 million tons per day [4], of which more than 70 % from the low and middle-income countries like Iraq [5]. The intelligent management of solid waste resources involves various treatment methods like waste reduction, reusing, use in energy generation, recycling, and waste incineration. Despite the efficiency of the above methods, the sanitary landfill is still the most common, simpler, easier, and cheaper than other methods, however, the residual of other methods still needs to be exposed revealing the importance of sanitary landfills in any way [1, 6].

It is considered very complicated and time-consuming when it comes to the right location of the landfill because the decision-making needs to be interconnected with various fields of knowledge represented by social, political, environmental, geological, topological, technical, economic, and engineering parameters defined by criteria, as well as, the decision making relies on the governmental regulations, funding, land availability, general awareness about the environmental policies, public health regulations, and the population density [5-7].

According to the diversity of criteria in the landfill site selection process, the Geographical Information System (GIS) is used to deal with the layers of criteria spatially because of its ability to manage a huge volume of data with time and cost-efficiency [5, 7]. Multi-Criteria problems require Multi-Criteria Decision Making (MCDM) processes to evaluate each available alternative and solve the problem based on the logical-mathematical concepts, the MCDM involves a lot of methods like the Analytical Network Process (ANP) [8], Best Worst Method (BWM) [9], Simple Multi-Attribute Rating Technique (SMART)

[10], System Redesigning to Creating Shared Value (SYRCS) [11], Weighted Sum Model (WSM) and Weighted Product Model (WPM) [12]. Additionally, the Analytical Hierarchy Process (AHP), which is sometimes integrated mathematically to be more developed-complicated technique and called Fuzzy-Analytical Hierarchy Process (Fuzzy-AHP) [13], is one of the most common methods of the MCDM processes used to look for the best solution for the complex problems mathematically with enough simplicity and sturdiness to get very reasonable results in comparison with the other methods [14]. The AHP method is invented by Thomas Saaty in the 1970s to provide a structural computational technique to reduce the problems of multi-level criteria into simpler problems by using a logical framework to evaluate the adopted criteria or alternatives by taking the expert's opinions and then construct a pairwise comparison matrix to explore the relative weight or priority of each criterion hierarchically, as well as, check the consistency of the pairwise comparison matrix [6, 15, 16].
According to the capabilities of GIS and the advantages of AHP method, this study used the combination of the GIS-AHP as an effective system to achieve the study purpose. A lot of researchers have used the concepts of the GIS and AHP in their studies to identify the best suitable locations for sanitary landfills [17-28]. Meanwhile, many researchers used the GIS environment and various methods of the MCDM to find the most suitable answers in various studies applications [29-33]. This study used the GIS-AHP approach to find the best location for the sanitary landfill proposed to be constructed in Al-Zubair district within Basrah governorate due to the absence of any landfill in the study area and the huge volumes of solid waste produced annually. Nine criteria have been taken to meet all the necessary regulations required to achieve the best location scientifically as a part of the good management of the produced solid waste materials, these adopted criteria were the oil fields, residential area, water surface, agricultural lands, soil types, slope, roads, railways, and the power lines due to the direct impact of them on the landfill site selection in the study area.

2. Study area

Al-Zubair district (9913.256 km^2) represents approximately the southwestern part of Basrah governorate (19070 km^2) extended from 29°10′00″ N to 30°45′00″ N in latitudes and from 46°35′00″ E to 48°00′00″ E in longitudes [34], see Figure 1. Al-Zubair district is a flat region with a very gentle slope for almost every area toward the northeast of the region [35]. Administratively, Al-Zubair district contains Al-Zubair, Umm Qasr, and Safwan as the main cities [36]. Geomorphologically, the study area contains some shallow valleys and sand dunes in the southern and western parts, also 150 meters above sea level elevation of Jabal Sanam near Safwan city.

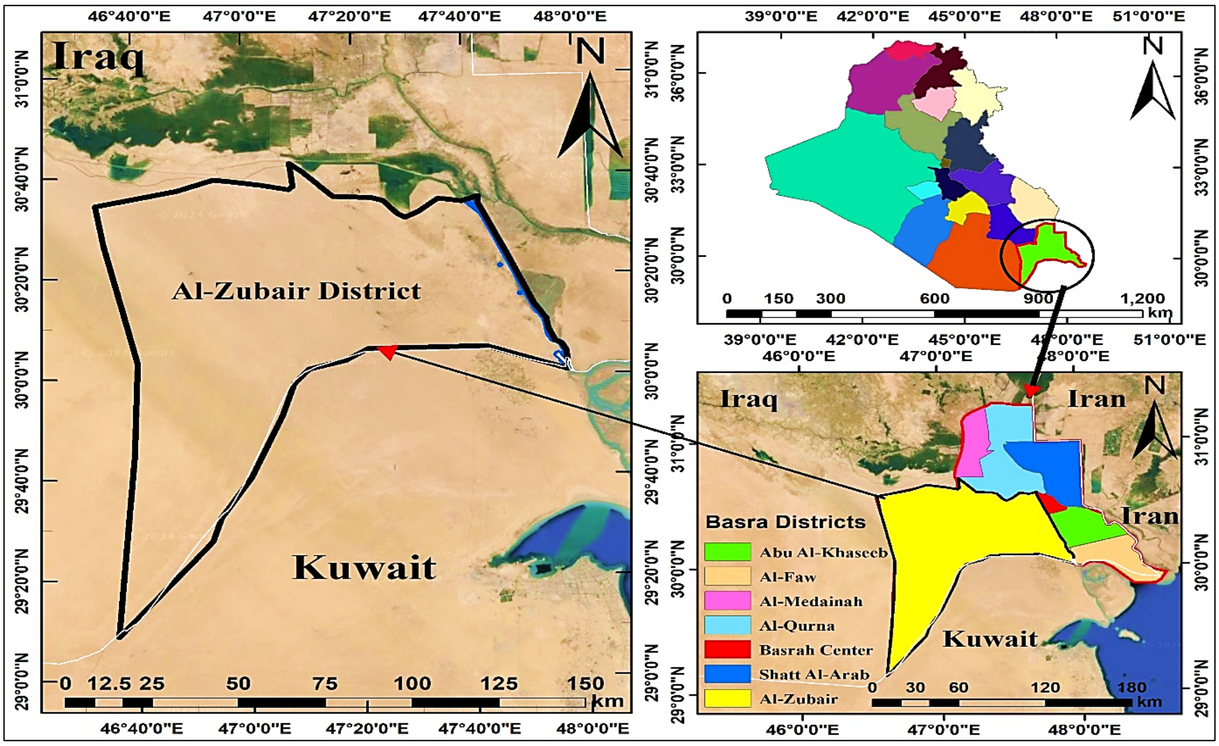

Fig .1: Location of Al-Zubair district in Iraq

Hydrologically, the main aquifer in Al-Zubair is located in the upper parts of the Dibdiba formation which consists of sedimentary rocks composited from the Cenozoic era [37], in general, the groundwater is considered the main source of the water supply in Al-Zubair district [36], but nowadays, the contamination level of the groundwater is increased due to the industrial activities by the oil-related institutions [34], thus, many researchers studied the groundwater in Al-Zubair district to assess the water quality in different locations [38-40].
Finally, the study area has an arid climate with long-hot-dry summer season and short-rainy winter season, the average annual rainfall, minimum temperature, and maximum temperature are 148 mm, 19.6 C°, and 33.3 C° respectively [36].

3. Materials and methods

The GIS-AHP combination is considered the main methodology used in this study to allocate the best location for the landfill in the study area based on the most significant criteria that have considerable effects on the sanitary landfill's site selection process. The spatial analysis tools of the Arc GIS 10.5 were played as important tools for preparing and digitizing the layers of criteria, whereas, the AHP approach was used to dedicate the appropriate weights for those criteria. Generally, the landfill site selection model has followed the next steps below.

1. Using the GIS environment to prepare the digital layer maps of the criteria.
2. Creating the necessary buffer zones for the criteria using some spatial buffering tools in the Arc GIS.
3. Specifying weights for the sub-criteria based on the literature, judgement of experts, and governmental regulations.
4. Specifying the appropriate weights for each criterion using the AHP method based on the judgement of experts mainly.
5. Using the 'Map Algebra' tool to overlay the weighted layers and find the optimum site location for the sanitary landfill.

But before any development in the direction of GIS-AHP combination, there is a need to take into account the population and solid waste produced through the study period to understand the present and future conditions of the study area from these two viewpoints, hence, understand the actual problem and significance of the landfill construction seriously.

3.1. Population growth rate and solid waste production

According to the Iraqi Ministry of Planning [41], the population of Al-Zubair district in 2019 was about 524688 inhabitants and the annual average of waste productivity was about 1 kg/capita/day, thus, the total amount of solid waste was about 191511 tons in 2019, which is increased now drastically due to the rapid population growth (reach to 2.75 %) leading to a serious environmental problem, moreover, the density of compacted solid waste is considered about 0.45 ton/m^3 [42]. Based on the previous, this study estimated the population and amount of solid waste by tons for every single year till 2050 based on Eq. 1 and Eq. 2 respectively [43], while the annual volumes of solid waste were calculated based on the estimated amount and the density of solid waste. This study attempts to solve the problem of huge waste volumes produced annually by establishing a sanitary landfill in the study area.

$$P_t = P_o (1 + r)^t \quad (1)$$

$$Q_{sw} = \frac{W_p \times P_t \times 365}{1000} \quad (2)$$

Where; P_t: is the population of the target year, P_o: is the population of the base year (2019), r: is the population growth rate (2.75%), t: is the number of years, Q_{sw}: is the quantity of solid waste in the target year (tons), and W_p: is the solid waste productivity (kg/capita/day).

3.2. Hierarchical multi-level scheme for landfill site selection process

The decision-making process of this study depends on many criteria belong to various influencing factors, the influencing criteria on the landfill site selection were selected based on the experts' opinions, previous studies, available data, and governmental regulations [1]. All criteria were formed hierarchically in a multi-level scheme as illustrated in Figure 2.

The first level in the proposed scheme includes two main categories: natural environmental factors and artificial factors, while the second level contains six sub-categories: land, hydrological, topographical, accessibility, social-cultural, and infrastructure sub-categories. The third level includes all the nine significant criteria in the study: soil types, agricultural lands, water surface, slope, roads, railways, residential area, power lines, and the oil field criteria.

The soil types criterion concerning the texture was used to protect the underground soil structure, as well as, the groundwater from the potential pollution by the leachate from solid waste materials [1,7], therefore the landfill usually needs to be supplied with an artificial double liners system, dewatering system, and leachate collection system for this purpose [44]. However, four classes of soil types were identified in the study area ranging from sandy soil to loamy soil in the texture attribute. In general, the lower permeability of soil means better soil for the landfill location because of the lower leaking of the leachate from solid waste materials. On the other hand, the agricultural lands criterion was taken in this study to protect the green lands and farmers from any potential contamination [5, 45, 46].

Water surface represents a significant criterion that should be taken in the decision-making because of its direct impact on human health and other fields, therefore, a sufficient distance from the landfill should be provided to protect the water surface from the pollutants and the served community by this water from the potential adverse effects [6, 16, 47], generally, the only water surface is represented by Shatt AL-Basrah River in the eastern part of the study area. Regarding the slope, this criterion was taken due to its direct impact on the total cost of the project, since the steep slope makes the construction and transportation processes more difficult, as well as, causes leachate drainage from the upper to lower lands [1, 6, 7, 48]. For the roads and railways, which belong to the accessibility sub-category in the second level, were adopted for many considerations relating to the cost and aesthetic impacts [5, 46]. The landfill location should be located at an adequate distance from both roads and railways to facilitate the transportation of the solid waste, but not so close as to cause unrequired visual intrusion, and not so far as to cause an additional cost for the transportation process [46, 49].

For the residential area, whether it was urban centres or villages, it is considered a very important criterion that can't be exceeded in the studies regarding the locations of landfills. The sanitary landfills should be located at a proper distance from the borders of the residential area according to the governmental regulations and the environmental recommendations to preserve the public health of the people firstly, protect the aesthetic perspective secondly, and ensure the ease of any future expansion thirdly [16]. At the same time, the landfill shouldn't be located so far from the residential area because of the additional cost impact on the construction, operation, and transportation processes [46, 47]. Regarding the power lines criterion, this criterion was selected to be at an adequate distance from the landfill site to provide the required electricity power for the landfill but also avoid any potential danger from the power lines network [5, 16, 48].
Finally, the oil fields are distributed widely in the south of Iraq, especially in Basrah governorate, and particularly extending in almost Al-Zubair district area. These fields are owned by the Iraqi Oil Ministry and have many important infrastructures regarding the oil industry like the oil and gas pipelines, huge tanks, expensive pumps, and the multinational companies' centres. According to the previous, this study adopted an adequate distance from the oil fields criterion to protect the important infrastructures in the fields from any potential danger by the solid waste treatment processes, as well as, to ensure the sustainability of the landfill location without any disruption to the Oil Ministry activities [47].

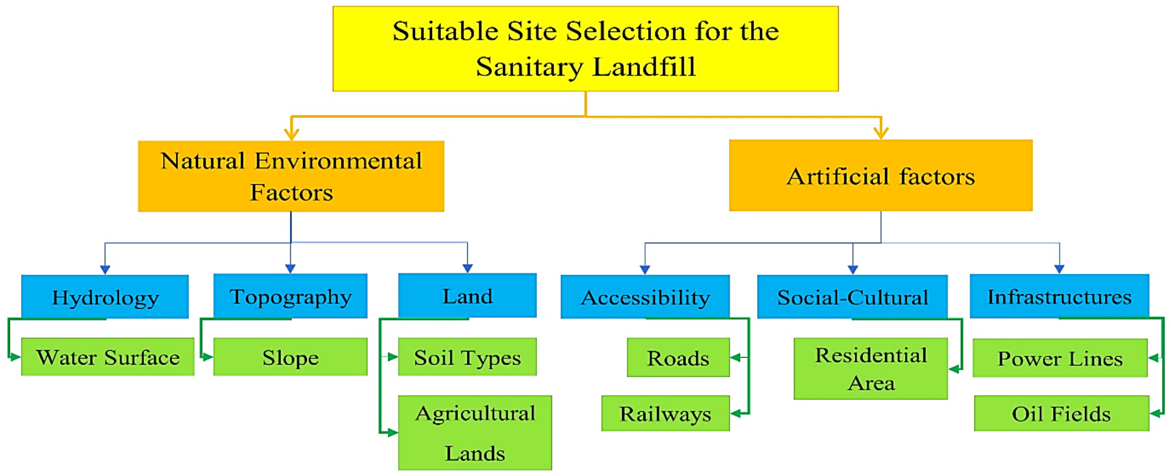

Fig. 2: Diagram of the multi-level criteria for the sanitary landfill site selection process

3.3. Data sources

To achieve this study, many spatial data layers that are related to the adopted criteria in this study must be prepared to obtain the final layer of the optimum sanitary landfill location. All these layers were processed by the ArcGIS 10.5 software using spatial analysis tools. The required layers of this study were obtained from two main data sources. The first source was the local authorities and governmental offices, the spatial data obtained from this source were the layers of roads, railways, power lines, and the oil fields criteria. Whereas the second source was the websites of trusted international organizations and institutions, the first spatial data obtained from the second source was the soil types layer prepared by the Food and Agricultural Organization (FAO) [50]. The water surface, residential area, and agricultural land layers were obtained from the land use/ land cover (LULC) layer that was earned from the Environmental System Researches Institution (ESRI) [51]. The last criterion layer obtained from the second data source was the slope layer, which was obtained by processing the Digital Elevation Model (DEM) layer downloaded from the United States Geological Survey (USGS) [52].

3.4. Buffer zones and sub-criteria classification

Generally, buffer zones are represented by the restricted areas created around specific geographic features of the criteria within the GIS environment using the spatial analysis tools, buffer zones represent the not-allowable sites in the study area for each criterion to construct the infrastructure of the landfill due to the potential negative effects on the public health, environmental system, cost of the project, as well as, to comply the general governmental regulations in the study area [46]. Based on the literature review and experts' opinions, buffer zones, sub-criteria, and the appropriate rating grades were selected for all of the criteria as illustrated in Table 1. After rasterizing the criteria, each criterion was divided into sub-criteria, and then each category of the resulting sub-criteria was ranked with the proper suitability rating value from zero to ten.
In general, to achieve the landfill location many steps have been followed using the spatial analysis tools of the Arc GIS 10.5 software like (Buffer, Clip, Extract, Convert, Euclidian Distance, Reclassify, and Map Algebra) functions. All criteria, sub-criteria, and the corresponding rating are detailed in Table 1, Figure 3, and Figure 4.

Table 1: Suggested buffer zones for the criteria and rating grades for the sub-criteria

No.	Criteria	Buffer Zones	References of Buffer Zones	Sub-Criteria	Ranking
1	Water Surface	1 km	[1, 5, 7, 15, 26, 46, 47, 53, 54]	0-1 km	0
				1-2 km	6
				2-3 km	8
				> 3 km	10
2	Residential Areas	5 km	[5, 15, 46, 47, 53, 42]	0-5 km	0
				5-10 km	10
				10-15 km	7
				> 15 km	4
3	Agricultural Lands	300 m	[45, 49]	0-300 m	0
				300-600 m	3
				600-1000 m	5
				1000-2000m	7
				> 2000 m	10
4	Roads	500 m	[1, 5, 7, 42, 46, 47, 48, 53]	0-500 m	0
				500-1000 m	7
				1000-1500m	8
				1500-2000m	10
				2000-3000m	5
				> 3000 m	3
5	Railways	500 m	[15, 46, 53, 42]	0-500 m	0
				> 500 m	10
6	Soil Types	Excluding sandy soil	[7, 21, 47]	Sandy soil	0
				Sandy loam	3
				loam	5
				Sandy clay loam	7
7	Slope	Excluding 15 deg	[1, 7, 21, 47, 48, 55]	0-5°	10
				5-10°	8
				10-15°	6
				> 15°	0
8	Power Lines	30 m	[5, 46, 47, 53, 42, 48]	0-30 m	0
				> 30 m	10
9	Oil Fields	5 km	[28, 47]	0-5 km	0
				> 5 km	10

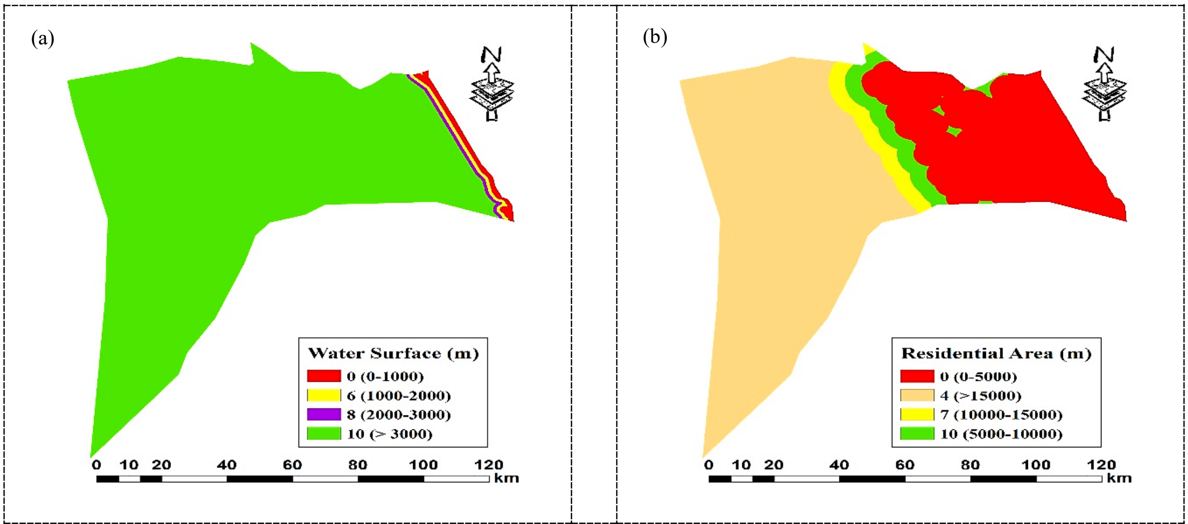

Fig. 3: Criteria, buffer zones, and relative weights of sub-criteria for, (a) water surface, and (b) residential area.

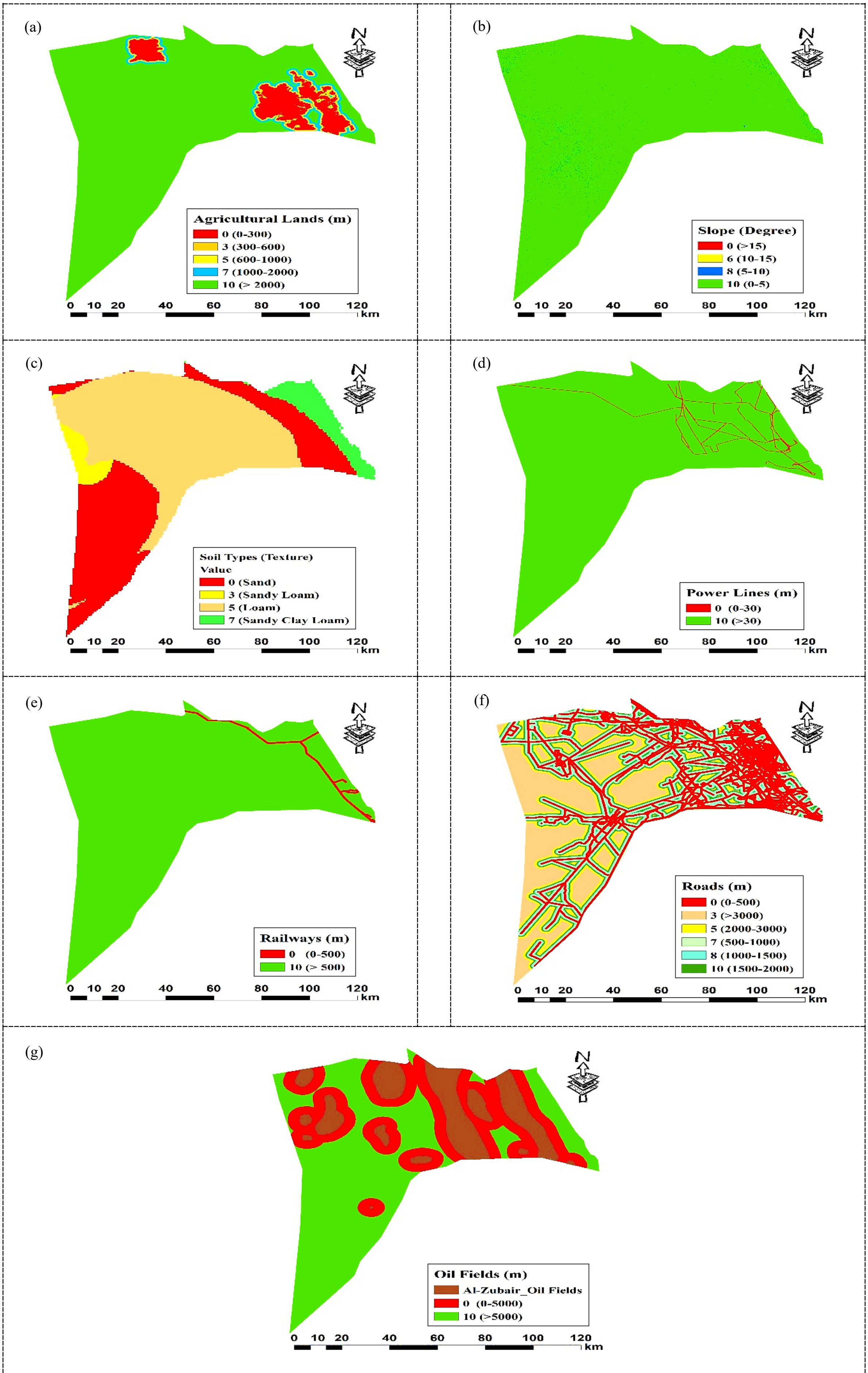

Fig. 4: Criteria, buffer zones, and relative weights of sub-criteria for, (a) agricultural lands, (b) slope, (c) soil types, (d) power lines, (e) railways, (f) roads, and (g) for the oil fields in the study area

3.5. Analytical hierarchy process method

The Analytical Hierarchy Process (AHP) is considered one of the most common approaches of the Multi-Criteria Decision Making (MCDM) methodology, this mathematical method was introduced by T. Saaty in 1977 for solving complex decision problems that consist of multi-criteria controlled the right decision-making [22, 56]. Generally, the AHP method is used to compute the weights, importance degree, or priority of the criteria that contribute to the main objective in any problem or application due to its simplicity and sturdiness in this process, hence, the AHP method could be used effectively to help the decision makers in different fields like the quality management, resource allocation, suitability analysis, and the applications of site selection like this study [14]. The pairwise comparison is considered the core process in the AHP method to derive the relative weights of criteria based on the potential materialistic and non-materialistic aspects [53], this process comprehensively compares the degree of significance of each criterion against every other criterion to achieve the study's objective in the form of binary comparisons [1, 14, 47]. The binary comparisons process of criteria is done using the 9-point scale that is suggested by T. Saaty to compute the preferability or importance level of one criterion over the others as numerical values from 1 to 9, where 1 means equal importance and 9 means extreme importance of one criterion over the other [57], see Table 2.

Table 2: Numerical scale of importance in the AHP method [3, 56, 58, 59]

Importance Grade	Definition of the Importance Grade
1	'Equal importance'
3	'Moderate importance'
5	'Strong importance'
7	'Very strong importance'
9	'Extreme importance'
2, 4, 6, 8	'Intermediate values between other grades of importance'

Then, the results of binary comparisons between the criteria are used to generate a square matrix called the pairwise comparisons matrix (or judgment matrix), the judgment matrix consists of rows represented by (m) and columns represented by (n), where the numbers of rows and columns are equal to the number of criteria [1, 47]. In the same context, any value of (a_{ij}) in the judgment matrix, where i = 1, 2, …, m and j = 1, 2, …, n, represents how much importance of the criterion in row (i) is more than the criterion in column (j) [21]. However, the judgment matrix must respect the term of reciprocity for values located in the upper and lower diagonal triangles of the matrix [47, 60], as mathematically illustrated in Eq. 3 below.

$$a_{ij} = \frac{1}{a_{ji}} \tag{3}$$

The typical form of the judgment matrix and weights vector of the criteria are represented by the following system in (4) [5].

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & a_{ij} & \cdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ \cdots \\ W_n \end{bmatrix} \tag{4}$$

The geometric mean concept was used to calculate the eigenvalue for any row (i) by multiplying all values in that row under the nth root as following in Eq. 5 [47].

$$Eg_i = \sqrt[n]{a_{i1} \times a_{i2} \times a_{i3} \times a_{ij} \times a_{in}} \tag{5}$$

Where; Eg_i : is the eigenvalue of the row (i), and n: is the number of criteria.

After calculating the eigenvalues of all rows in the matrix the AHP weights, priorities, or the normalized eigenvalues vector were calculated by dividing the eigenvalue of each row by the sum of all eigenvalues of the matrix according to Eq. 6 [5, 47].

$$Pr_i = \frac{Eg_i}{\sum_{i=1}^{n} Eg_i} \tag{6}$$

Where; Pr_i: is the priority or AHP-weight of criterion corresponding to the row (i).

Then, the maximum eigenvalue or maximum lambda (λ_{max}) was calculated by the summation of products between the AHP weights (priorities of criteria) and the sum of values of the corresponding columns as illustrated mathematically by Eq.7 [61].

$$\lambda_{max} = \sum_{j=1}^{n} \left[W_j \sum_{i=1}^{m} a_{ij} \right] \tag{7}$$

Where; λ_{max}: is the maximum eigenvalue of the matrix, W_j: is the AHP weight or the priority of a criterion, and $\sum a_{ij}$: is the sum of the values in the column that is corresponding to the criterion's weight.

For checking the coherence of judgments and the random probability in the AHP method, due to the potential inconsistency in the decisions of experts, the constancy ratio (CR) was calculated by Eq. 8 [22, 26, 60].

$$CR = \frac{CI}{RI} \tag{8}$$

Where; CR: is the consistency ratio, CI: is the constancy index, and RI: is the randomness index.

The CR value of the matrix must be equal to or lower than 0.1 to accept the judgment of experts, otherwise, the values of the judgment's matrix are considered inconsistent and the re-evaluation process of the criteria must be done [14, 22, 57]. The Consistency Index (CI), which is the mean deviation of the comparison elements [47, 53], was calculated by Eq. 9, and the Randomness Index (RI), which is defined as the mean deviation of randomness [46, 53], was obtained from Table 3.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{9}$$

Where; CI: is the constancy index, λ_{max}: is the maximum lambda, and n: is the number of criteria.

Table 3: Random indices based on the size of the matrix [46, 53, 58]

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.14	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

By combining the grading (rating) values of sub-criteria and the AHP weights of each criterion using the 'Map-Algebra' tool in the GIS, the suitability index of the potential area (illustrated spatially in Figure 5) was calculated based on Eq. 10 [47, 61].

$$A_i = \sum_{j=1}^{n} W_j \times C_{ij} \tag{10}$$

Where; A_i: is the suitability index of the potential area, W_j: is the AHP weight of the criterion, C_{ij}: is the grading value of that criterion according to the sub-criteria divisions, and n: is the number of criteria.

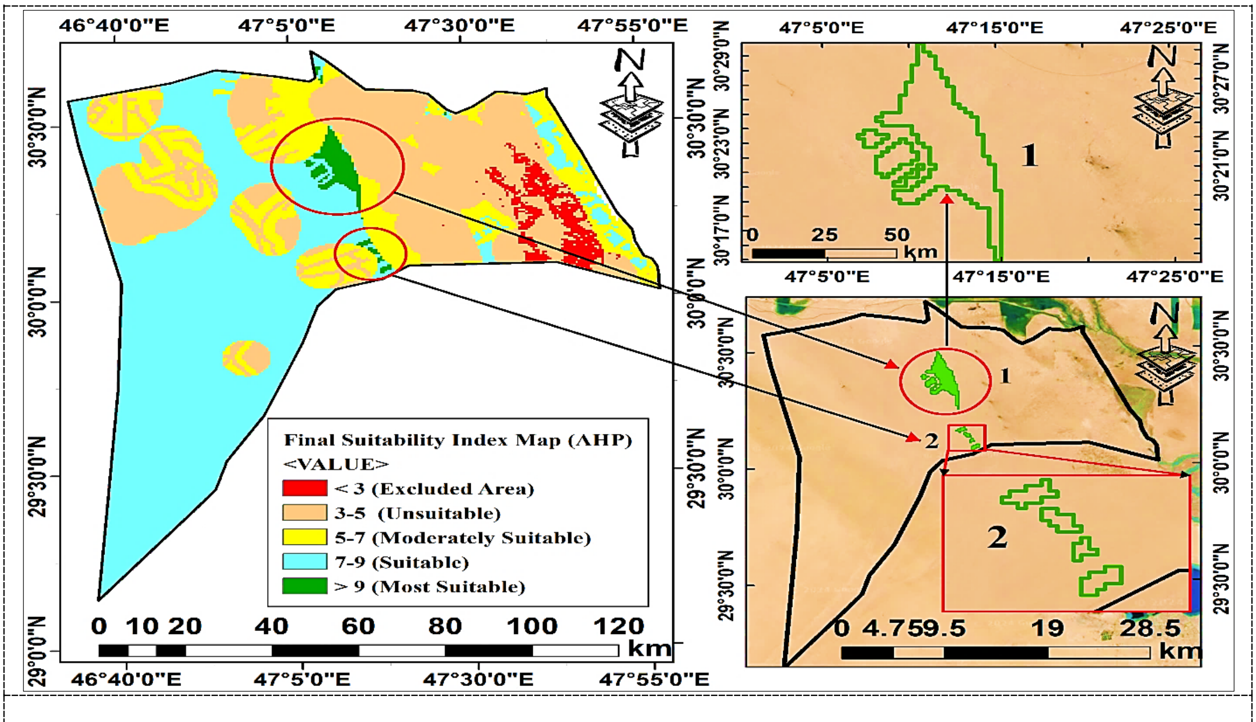

Fig. 5: Final suitability index map and the locations of candidate sites for the sanitary landfill in Al-Zubair district

4. Results and discussion

According to the AHP approach and based on Eq.5 and Eq.6, the priorities vector or the AHP weights of each criterion were calculated, see Table 4, then λ_{max}, CI, and RI were calculated and have the values of 9.082, 0.0103, and 1.45 respectively. Thereby, CR was calculated successfully and it was 0.007 (< 0.1) revealing the high consistency and coherence of judgments in this study, hence, the pairwise matrix with all of its content in Table 4 could be adopted successfully.

Table 4: Judgment matrix and the AHP-weights of criteria

Criteria	A	B	C	D	E	F	G	H	I	Pr_i %
A	1	2	2	4	4	6	6	8	8	30.4113
B	0.5	1	1	2	2	4	4	6	6	17.7378
C	0.5	1	1	2	2	4	4	6	6	17.7378
D	0.25	0.5	0.5	1	1	2	2	4	4	9.4544
E	0.25	0.5	0.5	1	1	2	2	4	4	9.4544
F	0.167	0.25	0.25	0.5	0.5	1	1	2	2	4.8808
G	0.167	0.25	0.25	0.5	0.5	1	1	2	2	4.8808
H	0.125	0.167	0.167	0.25	0.25	0.5	0.5	1	1	2.7214
I	0.125	0.167	0.167	0.25	0.25	0.5	0.5	1	1	2.7214

Where; A: oil fields, B: residential area, C: water surface, D: roads, E: agricultural lands, F: soil types, G: slope, H: power lines, and I: railways criteria. The term (Pri %) represents the AHP weight of the corresponding criterion.

According to Table 4, the oil fields criterion was the most important and has a priority of more than 30 % due to its high and dangerous effect on the landfill site selection from the viewpoint of experts, then, the residential area and water surface criteria occupied the second highest order of priority with more than 17 % due to the negative environmental impact of the landfill on these criteria, lastly, the remain criteria were all have less than 10 % of priority, but, the power lines and railways criteria were have the least priorities with just 2.7 % due to the limited effect of these criteria on the landfill site location.

After deriving the weights of nine criteria using the AHP method, checking the consistency of the pairwise matrix, and dedicating the proper relative weights for the sub-criteria of each criterion based on the expert's opinions as illustrated in Table 1, the 'Map Algebra' spatial tool in the ArcGIS 10.5 was used to generate the final suitability index map of the sanitary landfill in Al-Zubair district by overlaying the layers of all criteria on top of each other in way that every cell would have a specific percentage from the AHP weights of all criteria based on the relative weights of sub-criteria existing in that cell.

The resulting output map of the suitability index was divided into five categories as illustrated in Figure 5, these categories were the 'excluded' area with about 316.72 km^2 (3.19 %), 'unsuitable' area with about 3121.51 km^2 (31.48 %), 'moderately suitable' area with about 1680.39 km^2 (16.95 %), 'suitable' area with about 4654.58 km^2 (46.95 %), and the 'most suitable' area with about 140.06 km^2 (1.41 %) from the total area under study.

According to the adopted population growth rate, solid waste productivity, density of the compacted solid waste, as well as, based on Eq. 1 and Eq. 2 the expected population, produced solid waste quantities (by tons), and the corresponding volumes (by m^3) are presented below in Table 5 for specific years under study.

Table 5: Estimated population, solid waste amount, and the volumes of solid waste for specific years till 2050

Year	Population	Solid Waste (Quantity by tons / Volume by m^3)	Year	Population	Solid Waste (Quantity by tons / Volume by m3)
2019	524688	191511 tons / 425580 m^3	2035	809861	295599 tons / 656887 m^3
2020	539117	196778 tons / 437284 m^3	2040	927512	338542 tons / 752316 m^3
2025	617436	225364 tons / 500809 m^3	2045	1062255	387723 tons / 861607 m^3
2030	707133	258104 tons / 573564 m^3	2050	1216572	444049 tons / 986776 m^3

According to Table 5, the expected populations for 2025 and 2050 are 617436 and 1216572 respectively, the expected amounts of solid waste for the same years are 225364 and 444049 tons respectively, while the cumulative quantity of solid waste for every single year from 2025 to 2050 is about 8396217 tons. By taking the waste density as 0.45 ton/m^3, the volumes of solid waste materials for 2025, 2050, and the period of (2025-2050) are 500809, 986776, and 18658259 m^3 respectively.

For the required area calculations, the effective depth of landfill must be taken into consideration, the effective depth is highly influenced by the groundwater level in the study area. The groundwater level in Al-Zubair district is considered varied spatially, but in general, it has a shallow depth from the ground surface, thus, this study adopted 2 m below the ground surface as a safe depth for the candidate sites based on the local literature review. According to the previous, the required area for the candidate site must be at least 9.33 km^2 to accommodate the cumulative volumes of solid waste from 2025 to 2050.

This study revealed two clusters of area with a suitability index of more than 9, which represent the most suitable class, as illustrated in Figure 5. The first cluster of area, which is assigned with number 1, is located in the middle of Al-Zubair district (47º12′5.2″ E for the longitude and 30º22′48.7″ N for the latitude) and has a total area equal to 124.63 km^2 of which about 108 km^2 for the largest area in this cluster. The second cluster of area, which is assigned with number 2, is located in Al-Zubair district near the national borders between Iraq and Kuwait (47º17′7.8″ E for the longitude and 30º7′17″ N for the latitude) and has a total area equal to 15.4275 km^2 distributed into four single areas separated by roads.

According to the previous, the largest area (108 km^2) in cluster 1 is considered the most qualified candidate site for the sanitary landfill in the study area, however, it could be used for a long time even after 2050 because of the following reasons, firstly, the huge area provided in this site in proportion to the required area is considered an adequate for the study area, secondly, the location of this site in the middle of Al-Zubair district makes it reachable equally from any point in Al-Zubair district, thirdly, the location of this site is situated safe enough from the restricted zones of all criteria reducing the aesthetic destruction, physical pollution, travel time, and the construction cost in a way demonstrating the ability of this site to accommodate the cumulative produced solid waste of the study area even after 2050 sustainably. The prior advantages of the proposed landfill's site location would benefit the solid waste management in the study area effectively and efficiently, in addition, the remaining area in cluster 1 could be used for the future development of the landfill.

The area in cluster 2 is considered not valid as a location for the sanitary landfill because every individual area in this cluster has an area lesser than 9.33 km^2, however, those areas could be used as temporary collection sites for the solid waste that comes from Umm-Qasr and Safwan cities before it through away to the sanitary landfill in cluster 1 permanently. It should be noted that political and governmental permissions from the local and central authorities must be provided for any utilization of the area in cluster 2 because of the proximity of this site to the national borders between Iraq and Kuwait to avoid any unpleasant situations between the two countries.

5. Conclusion

This study seeks to find the best location for the sanitary landfill in Al-Zubair district to accommodate the huge amount of municipal solid waste produced in the study area (more than 200000 tons annually since 2021) specifically from 2025 to 2050 due to the absence of any landfill in the study area. Therefore, this study adopted nine influencing criteria for the site selection process, these criteria were the water surface, agricultural lands, residential area, soil types, slope, roads, railways, power lines, and the oil fields criteria. The AHP-GIS is considered a powerful combination to generate the suitability index map for the sanitary landfill due to its simplicity and high accuracy in this field. The AHP method was used to derive the weights of the above criteria based on the opinions of experts, whereas, the GIS was used to prepare the spatial layers of criteria due to its ability to deal with a large volume of data effectively. As a result of the AHP method, the weight of the oil fields criterion was the highest among other criteria with more than 30 % of priority due to its high effect on the landfill location and environment, while the weights of power lines and railways network criteria were the lowest with about 2.7% of priority. After processing the layers of criteria using the AHP-GIS combination, the final map of suitability index for the landfill was done and just two candidate sites (two clusters of area) were identified. The cumulative volume of solid waste from 2025 to 2050 was expected to be about 18658259 m^3 and the required area for the landfill to accommodate this volume was about 9.33 km^2. The first candidate site is located in the middle of Al-Zubair district with an area of 124.63 km^2, while the second one is located near the national borders between Iraq and Kuwait with an area of 15.43 km^2. By observing both sites using satellite images, it was obvious that the first site (cluster 1) is extremely suitable for the location of the landfill since it complies successfully all the requirements of the landfill like the area adequacy, location accessibility, and the safe distance from landfill to the restricted zones of criteria in a way reducing the aesthetic destruction, physical pollution, travel time, and the construction cost required for the landfill. The second site (cluster 2) is considered not valid for this matter due to its proximity to the national borders between Iraq and Kuwait, however, any utilization of the second site must be pre-authorized politically by the local and central authorities to avoid any unpleasant situations between the two countries. Finally, this study recommends the decision makers to supply the proposed sanitary landfill's location (site 1) with appropriate monitoring equipment and an effective lining system to protect the soil structure and the groundwater from any potential contamination, consequently, the sanitary landfill could be used even after 2050 safely and sustainably.

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