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Wastewater treatment plant site selection using GIS and multicriteria decision analysis

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Abstract

Purpose – Cesspits are the means for each house to dispose of wastewater in the Bani Kinanah District (BKD) of Jordan, which creates severe environmental complications. This research aimed to find a suitable site for a wastewater treatment plant (WWTP) in BKD.

Design/methodology/approach – Geographic Information System (GIS)-based multicriteria decision analysis (MCDA) was used for an optimal site selection for a sewage treatment plant. Several datasets were obtained to prepare the maps of the criteria influencing the choice of the most suitable site for the WWTP. The analytic hierarchy process was used to apply the weights for each factor.

Findings – Five classes of suitability were generated: 0.23% very high suitability, 8.49% high suitability, 47.12% moderate suitability, 37.67% low suitability and 6.49% very low suitability. According to Analytical Hierarchy Process (AHP) results, the elevations, slope and groundwater depth have high importance; where their weights 21%, 19% and 17%, respectively. The most suitable site for establishing a WWTP was found in the northern part of the study area, where it is characterized by relatively low elevations (−90 to −93 m), low slope (0–2.5 %), distance from groundwater level (47–82 m) and the space is sufficient for building the plant (25328 m^2, 8861 m^2 and 8586 m^2).

Research limitations/implications – This research is limited by the availability of data.

Practical implications – The research is invaluable for decision makers involved in urban planning.

Social implications – Wastewater treatment plants are essential for communities with limited resources such as Jordan. It has also profound impacts on the surrounding environment.

Originality/value – From the present study, it can be concluded that GIS is essential in urban utility establishment, like urban domestic wastewater treatment site selection. Although the study area has adequate potential areas for establishing WWTP, further assessment of flood vulnerability, wastewater amount quantification, population growth and urban expansion must be seriously considered before implementation.

Keywords Wastewater treatment plant, Multicriteria decision analysis, Analytical hierarchy process, Geographic information system, Jordan

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Nomenclature

BKD	Bani Kinanah District
WWTP	Wastewater Treatment Plant
GIS	Geographic Information System
AHP	Analytical Hierarchy Process
MCDA	Multi-Criteria Decision Analysis
UTM	Universal Transverse Mercator
a.s.m.l.	Above Sea Mean Level
LULC	Land Use/Land Cover
ESRI	Environmental Systems Research Institute
ESA	The European Space Agency
DEM	Digital Elevation Model
ASF	Alaskan Satellite Facility
CI	Consistency Index
CR	Consistency Ratio

1. Introduction

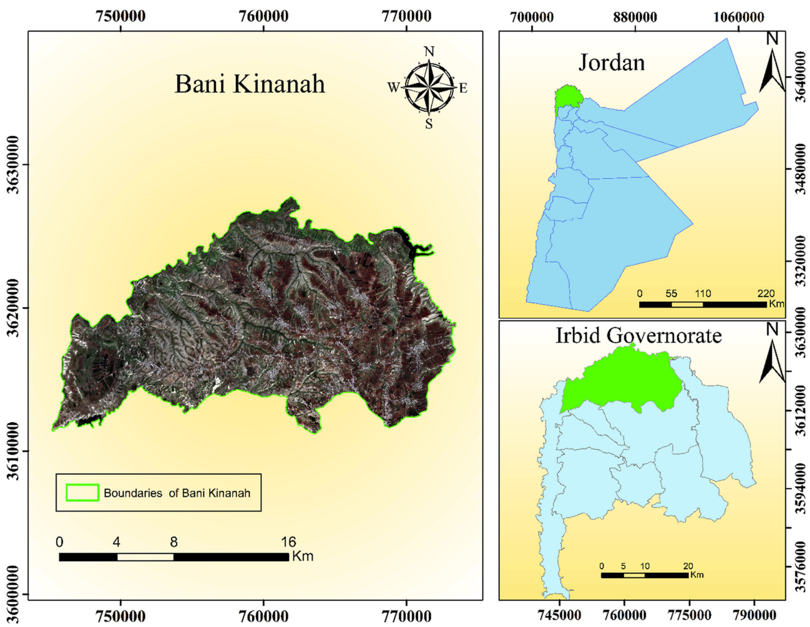
The treatment of wastewater poses a significant challenge in major cities worldwide (Malik, Hsu, Johnson, & de Sherbinin, 2015). Developing nations reportedly discharge 90% of their wastewater directly into water bodies like rivers, lakes or seas (Corcoran, 2010). This practice places substantial pressure on surface water bodies, with agricultural, industrial and household effluents adversely affecting the ecosystems (Kambole, 2003). The appropriate siting of wastewater plants profoundly influences the surrounding environment (Asefa & Mindahun, 2019), and this decision is based on an integrated methodology incorporating various parameters. In Jordan, despite the significant population of the BKD (156,000), the absence of a WWTP leads to the use of individual cesspits, heightening the vulnerability of soil and groundwater to contamination.

The successful application of the analytical hierarchy process (AHP) and geographic information system (GIS) for site selection is well-documented (Abdelouhed, Ahmed, Abdellah, Yassine, & Mohammed, 2022). GIS, being a robust tool, is frequently employed in the selection of sites for wastewater treatment plants (WWTPs), enabling efficient data manipulation and visualization (Şener, Süzen, & Doyuran, 2006). AHP, a multicriteria decision analysis (MCDA) method, aids decision-makers in complex problems with conflicting and subjective criteria (Løken, 2007). By evaluating various options based on diverse criteria and objectives, it assists in addressing decision-making challenges (Dekan Abbasl & Jassima, 2019). Coupled with GIS, the MCDA technique facilitates the classification, analysis and organization of spatial planning data (Alzouby, Nusair, & Taha, 2019). The WWTP's site map serves as a valuable resource for planners and decision-makers in formulating effective wastewater management strategies. Abdalla and El Khidir (2017) developed a decision-making model for selecting the best WWTP location in Omdurman city (Sudan) by integrating remote sensing and GIS data with MCDA. Asefa and Mindahun (2019) utilized GIS techniques to identify suitable WWTP sites in Debre Berhan Town (Ethiopia) using multiple criteria. Nigusse *et al.* (2020) aimed to determine optimal sites for urban domestic wastewater treatment in Mekelle city (Ethiopia) based on several parameters.

In conclusion, the integrated approach of using GIS and MCDA for the site selection of WWTPs is fundamental. This method allows for the comprehensive assessment of various spatial and nonspatial factors, contributing to sustainable urban planning and environmental management. The incorporation of GIS aids in the spatial analysis and visualization of datasets, offering an in-depth understanding of the geographical context. The integration of MCDA ensures an objective and transparent decision-making process, facilitating optimal site selection. This study seeks to identify a suitable site for a WWTP in the BKD, employing GIS-based MCDA and AHP, considering various criteria.

2. Study area

The Bani Kinanah district (BKD) is one of the nine districts of the Irbid Governorate that covers an area of 278 km^2 (Figure 1). It is bounded by the UTM coordinates 361100–362800 m north



Source(s): Figure by authors

Figure 1. Location map of Bani Kinanah District

and 745500 – 774000 m east. Topographically, the terrain varies between 210 m and 582 m a.s.m.l. There are 23 villages in the district with a population estimated at 156 thousand, according to the 2022 estimated (Department of Statistics (DOS), 2022). It is characterized by a Mediterranean climate, with an annual rainfall in the range 380-420 mm for the period 2008-2018 (Water Authority of Jordan, 2021). The terrain of the study area varies with flat lands in the eastern part and lands of different terrains with a low elevation in the western part. The study area is located in two basins, the Yarmouk River Basin and the Wadi Al-Arab Basin.

3. Methodology

Figure 2 illustrates the procedure followed in site selection of a WWTP in BKD. Site selection was determined by following three main steps: (1) data collection and preprocessing, (2) data preparation and analysis, and (3) suitability map of the WWTP.

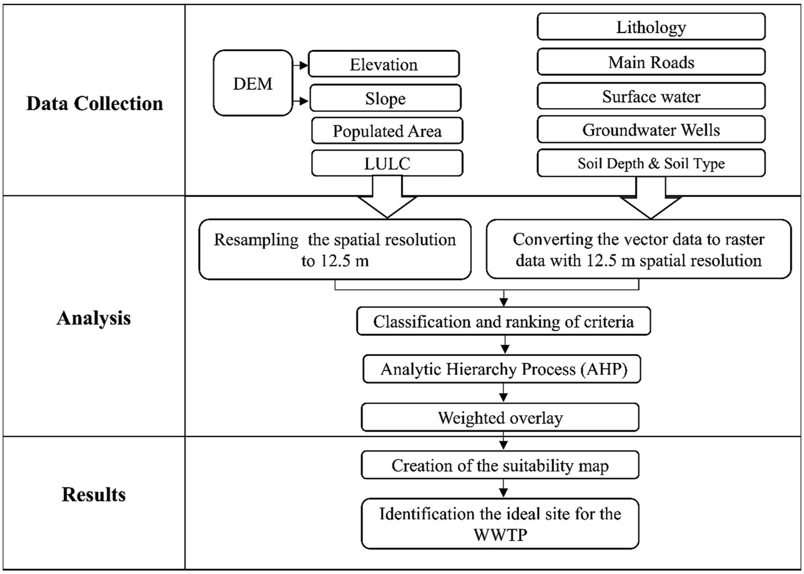
3.1 Data collection and preprocessing

Numerous datasets (Table 1) were used from several data sources to achieve the objectives of this study.

(1) The land use/land cover (LULC) map was downloaded from ESRI's Land Cover products (Karra *et al.*, 2021) with spatial resolution 10 m. This dataset was established by Environmental Systems Research Institute (ESRI) and the European Space Agency (ESA) based on Sentinel-2 images and artificial intelligence.

(2) A digital elevation model (DEM) with 12.5 m spatial resolution was downloaded from Alaska Satellite Facility (Gens, 2015).

(3) The lithology map of the study area was obtained from the NRA-Natural Resources Authority (1997), which represents several geologic units such as alluvial sediment,



Source(s): Figure by authors

Figure 2.
Flowchart of the methodology

Table 1.
Descriptions of the data used in this study

No.	Types of data	Sources	Spatial resolution/Scale
1	Elevation	Alaskan Satellite Facility (ASF)	12.5 m
2	Lithology	NRA-Natural Resources Authority (1997)	1:50000
3	Groundwater depth	Ministry of Water and Irrigation	–
4	Land use/land cover	ESRI Land Use/Land Cover Time series (2021)	10 m
5	Soil (type and thickness)	Ministry of Agriculture (1993)	1:25000/1:50000
6	Road networks	Open Street Map	–
7	Surface water (river/dam)	Google Earth	–
8	Populated area	ESRI Land Use/Land Cover Time series (2021)	10 m

Source(s): Table by authors

Umm Rijam-Chert Limestone, basalt, Muwaqqar Chalk Marl and Wadi Shallala Chalk.

(4) The groundwater data in the study area were obtained from the Ministry of Water and Irrigation in Jordan to determine the depth of groundwater.

(5) The soil data (type and thickness) presented in the study area have been obtained from the Ministry of Agriculture (1993).

(6) The road network was downloaded from Open Street Map (2023).

(7) The map of rivers and dams in the study area were digitized from Google Earth (2023).

(8) The population areas were extracted from ESRI Land Cover map.

3.1.1 Pre-processing of satellite data. All data were resampled or rasterized to match the spatial resolution of the digital elevation model data (12.5 m). All data have been reprojected to the system UTM zone 36N.

3.2 Data preparation

Considering their significance, each of the ten criteria directly impacts the appropriate location of the WWTP. These criteria encompass elevation, slope, depth to groundwater, land use/land cover, lithology, soil width, soil type, distance to mean roads, distance to populated areas and distance to water bodies. Based on the expert's experience and depending on the literature, each criterion was classified into five levels of suitability: very high, high, moderate, low and very low or unsuitable (Table 2) according to literature and local experts.

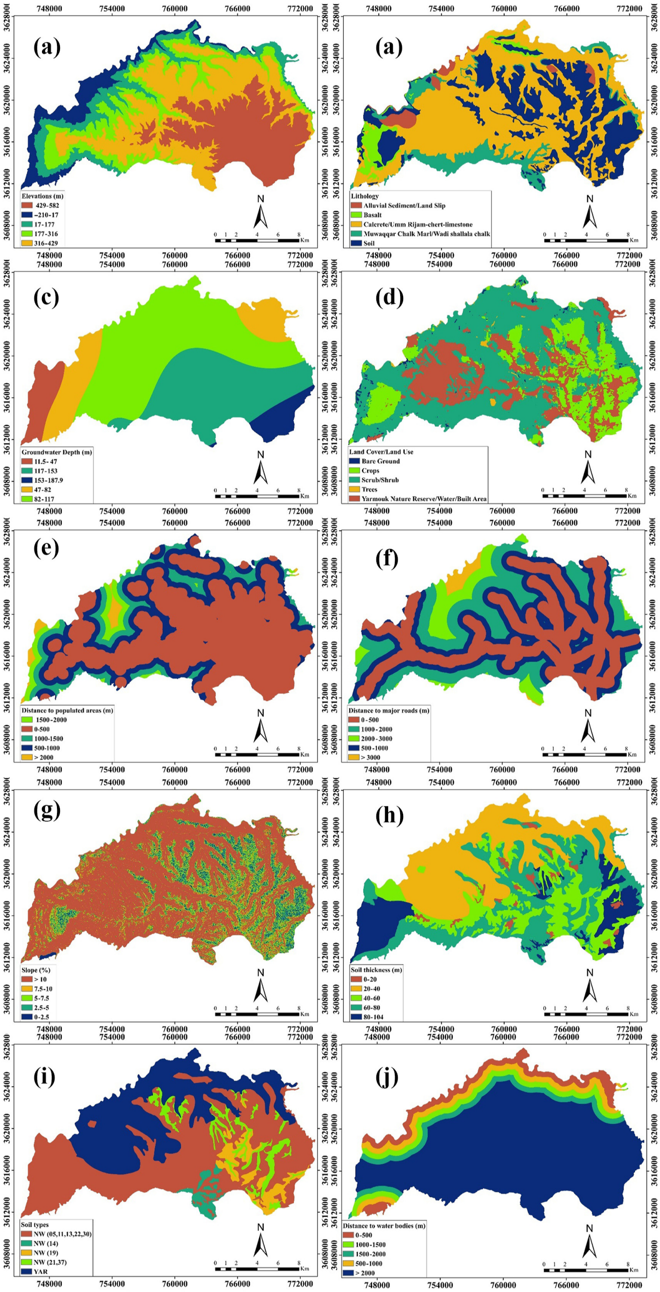
3.2.1 Natural environment criteria. The environmental criteria of this study comprised multiple layers: topography, lithology, soil, groundwater, land use/land cover (LULC) and the distance to water bodies. Among all the criteria, the elevation criterion holds the most significance, carrying the highest weight in determining the suitable site for the WWTP. This is primarily due to the fact that water naturally flows downhill from higher elevations to lower ones. It is widely acknowledged that flatter, lower-lying areas are more appropriate for the placement of WWTPs (Nigusse, 2020). In the study area, elevations range from 210 to 582 m, and according to the criteria, elevations between 210 and 17 m are deemed optimal for constructing a WWTP. The suitability classification of the elevation is depicted in Figure 3a, revealing the prevalence of lower-elevation zones in the north and northeast of the study area. Slope, which refers to the rate of height change on a given surface, was calculated as a percentage. Costs for excavation and embankment increase significantly when a wastewater treatment facility is situated on steeply sloped terrain (Lin & Kao, 1999). The ideal slope for a WWTP should fall within 0 and 2.5% (Abdalla & El Khidir, 2017). Slopes steeper than 10% do not facilitate proper runoff and are unsuitable for civil construction. Figure 3g displays the suitability map of slope, showcasing the prevalence of steeply sloped areas throughout the study area.

Figure 3b illustrates the distribution of lithological units in the study area (NRA-Natural Resources Authority, 1997). Although alluvial sediment and landslides are not suitable for WWTPs, they demonstrate good water absorption capabilities. Alluvial sediment layers primarily consist of sand and gravel, boasting high permeability. Calcrete and Umm Rijam Chert Limestone, on the other hand, are among the least favorable lithological units for WWTP locations due to their high permeability. Calcrete comprises a blend of sand and silt cemented by calcite, oxide, halite, gypsum and ferric dolomite. The Umm Rijam Chert Limestone Formation (Eocene) encompasses most of the study area, characterized by the alternation of chalky limestone, marly limestone and kerogenous limestone in its lower massive member, and with a significant presence of chert (beds and concretions) in its upper bedded member. Basalts possess moderate permeability, with limited water adsorption capacity. Muwaqqar Chalk Marl, Wadi Shallala Chalk, and soil demonstrate exceptionally low permeability, rendering them highly suitable units for the placement of a WWTP. The Muwaqqar Chalk Marl comprises massive marly-chalky cliffs in its lower section and a sequence of alternating soft chalk and chalky limestone in its upper section. The Wadi Shallala Chalk Formation is characterized by massive bituminous and wispy laminated barite concretions at the base (NRA-Natural Resources Authority, 1997). Within the study area, there are nine soil units denoted by the prefix NW (05, 11, 13, 14, 19, 21, 22, 30, 37) with a scale of 1:50000 and one soil unit (YAR) with a scale of 1:250000 (Ministry of Agriculture, 1993). This differentiation is due to the former map not encompassing the entire study area. Table 3 summarizes the characteristics of each soil unit.

Criteria	Weights (%)	Sub-criteria Values	Rank	Suitability
Elevation (m)	21	−210–17	5	Very high
		17–177	4	High
		177–316	3	Moderate
		316–429	2	Low
		429–582	1	Very low
Slope (%)	19	>35	5	Very high
		25–35	4	High
		15–25	3	Moderate
		5–15	2	Low
		<5	1	Very low
Groundwater depth (m)	17	153–187.9	5	Very high
		117–153	4	High
		82–117	3	Moderate
		47–82	2	Low
		11.5–47	0	Unsuitable
Lithology	12	Soil	5	Very high
		Muwaqqar Chalk Marl/Wadi Shallala Chalk	4	High
		Basalt	3	Moderate
		Calcrete/Umm Rijam-Chert-Limestone	2	Low
		Alluvial Sediment/Land Slip	1	Very low
Soil Type	8	YAR	5	Very high
		NW (14)	4	High
		NW (21,37)	3	Moderate
		NW (19)	2	Low
		NW (05,11,13,22,30)	1	Very low
Soil thickness (cm)	7	80–104	5	Very high
		60–80	4	High
		40–60	3	Moderate
		20–40	2	Low
		0–20	0	Unsuitable
Distance to populated areas (m)	6	500–1,000	5	Very high
		1,000–1,500	4	High
		1,500–2,000	3	Moderate
		>2,000	2	Low
		0–500	0	Unsuitable
Distance to water bodies (m)	5	>2,000	5	Very high
		1,500–2,000	4	High
		1,000–1,500	3	Moderate
		500–1,000	2	Low
		0–500	0	Unsuitable
Land cover/land use	3	Bare Ground	5	Very high
		Scrub/Shrub	4	High
		Crops	3	Moderate
		Trees	2	Low
		Yarmouk Nature Reserve/Water/Built Area	0	Unsuitable
Distance to main roads (m)	2	500–1,000		Very high
		1,000–2,000		High
		2,000–3,000		Moderate
		>3,000		Low
		0–500		Unsuitable

Source(s): Table by authors

Table 2.
The weights and the suitability for each criterion



Source(s): Figure by authors

Figure 3.
Maps of selected criteria used in this study: (a) elevation, (b) lithology, (c) ground water depth, (d) LULC, (e) distance to populated areas, (f) distance to major roads, (g) slope, (h) soil thickness, (i) soil types and (j) distance to water bodies

Soil unit	Characteristics
NW 05	Undulating to rolling high plateaux and bench terraces on basalt at the edge of the escarpment, mostly covered by deep or medium-deep colluvium
NW 11	rolling plain mod. deep to deep colluvium; some cracking clay
NW 13	steep-sided valleys; long, mass-movement slopes; very diverse soils and much deep colluvium
NW 14	rounded ridge crests and upper convex slopes on limestone: shallow and stony soils, with associated pockets of deep colluvium
NW 19	strongly rolling terrain: convex upper slopes and interfluves: shallow to moderately steep, stony colluvium cover
NW 21	steep-sided minor valleys and convex upper slopes; shallow and stony colluvium
NW 22	Plateaux at the top of the escarpment, and convex upper slopes mostly rocky and shallow, but some deep colluvial pockets
NW 30	undulating plains, deep colluvial/aeolian mantle weathered to cracking clays
NW 37	low limestone hillocks at the edge of the plain and pockets of deep colluvium
YAR	stony to very stony clay loam, clay and silty clay loam

Source(s): Table by authors, Ministry of Agriculture (1993)

Table 3.
Characteristics of the soil units in study area

The soil must possess a sufficiently low permeability to effectively slow down the removal of leachate from the site (Addis, 2021). As the soil's permeability increases, the site's suitability for the WWTP will proportionately decrease, leading to an increase in its vulnerability. Soil types were categorized into five categories (Table 2) based on the permeability characteristics of each type (Figure 3i). Additionally, there is notable variation in soil thickness across the study area, ranging from 0 cm (bare soil) to 104 cm. Locations with greater soil thickness offer higher capacity for wastewater purification compared to shallower soil areas, making them more favorable for land application sites such as WWTPs (Meinzinger, 2003). Soil thicknesses have been divided into five classes based on the thickness of each type (Figure 3h). The depth of groundwater is a crucial factor in reducing the risk of groundwater contamination. Data from existing groundwater wells in the study area were utilized to generate the groundwater depth map using the inverse distance weighting (IDW) interpolation method. Groundwater depths in the study area vary between 153 and 188 m. The ratings for the depth of groundwater are illustrated in Figure 3c. The land use/land cover (LULC) in the study area is presented in Figure 3d. Major LULC categories in the study area include built areas, water, the Yarmouk Natural Reserve, trees, scrub/shrub, crops and bare ground (Table 2). The most suitable lands for WWTPs are agricultural land and bare ground (Kanwal *et al.*, 2020). The WWTP site should be situated at a considerable distance from populated areas to minimize the risk of nuisance and odors. Built areas, water bodies and the Yarmouk Natural Reserve were classified as unsuitable, while bare ground was labeled as highly suitable. The WWTP should be distanced from various water bodies to prevent pollution and other environmental issues. Its discharge location should not be close to water bodies such as rivers, lakes, streams, ponds or swamps (Addis, 2021). Greater distances from water bodies are more favorable, hence the reclassification of the distance to water bodies into five distinct classes. The most desirable locations for a WWTP are those situated more than 2000 m away from water bodies (Figure 3j), whereas those within 500 m are deemed unsuitable.

3.2.2 Maps of human-related criteria. The human-related criteria were classified into two types: the first being the distance to populated areas, and the second being the distance to major roads. To minimize the system's impact on local residents, Mara, Mills, Pearson, and Alabaster (1992) recommends keeping no component closer than 200 m (preferably 500 m) to any dwelling. Conversely, economic considerations must also be considered, and the WWTP should be positioned close enough to populated areas to ensure that sewer lines leading to the plant do not incur exorbitant construction costs. Therefore, the distance to populated areas was divided into five categories. The most suitable areas were those located 500–1000 m away, as they strike a balance between being sufficiently distant and relatively close to populated areas, with areas less than 500 m deemed unsuitable for constructing WWTPs (Figure 3e). Furthermore, the distance of a WWTP impacts the landscape, climate, and public health. Studies have indicated that the distance to main roads should fall within the range of 500–1000 m (Shahmoradi & Isalou, 2013). This is all aimed at reducing the costs of supplies and facilitating access and transportation to theWWTP. The most suitable distance to roads in the district is 500–1000 m (Figure 3f).

3.3 Site selection of the wastewater treatment plant

To select the site of the WWTP, there were two main steps: (1) using the AHP to derive weights for each criterion that have been used; and (2) deriving the suitability map for the WWTP.

3.3.1 Analytical Hierarchy Process (AHP). The AHP based heuristic approach has been used to assign preferences consistently based on a numerical scale developed by Saaty (1994). The potential of AHP-based MCDA can handle complex situations that have applications in decision-making across many domains (Chabuk *et al.*, 2017). Based on previous study results and expert views the relative weight of each criterion was determined. Each criterion for determining the best location for a WWTP, were rated on a scale from 1 to 9, 9 being the most suitable option for the WWTP site (Table 4). All criteria have been compared to one another based on a pairwise comparison matrix (Table 5). This technique helps reduce the possibility

Scale	Degree of preference
1	Equal importance
3	Moderate importance
5	Essential or strong importance
7	Very strong or demonstrated importance
9	Extremely high importance
2,4,6,8	Intermediate values
Reciprocals	Opposite

Source(s): Satty (1988)

Table 4. Fundamental scale for pairwise comparisons

	A	B	C	D	E	F	G	H	I	J
A. Elevation	1	1	2	3	3	3	5	5	5	7
B. Slope	1	1	2	3	3	4	4	5	5	4
C. Groundwater depth	1/2	1	1	2	4	4	3	3	5	5
D. Lithology	1/3	1/3	1/2	1	2	4	3	5	5	5
E. Soil type	1/3	1/3	1/4	1/2	1	1	4	3	3	5
F. Soil thickness	1/3	1/4	1/4	1/4	1	1	3	2	3	4
G. Distance to populated areas	1/5	1/4	1/3	1/3	1/4	1/3	1	2	5	3
H. Distance to water bodies	1/5	1/5	1/3	1/5	1/3	1/2	1/2	1	5	3
I. LULC	1/5	1/5	1/5	1/5	1/3	1/3	1/5	1/5	1	2
J. Distance to main roads	1/7	1/4	1/5	1/5	1/5	1/4	1/3	1/3	1/2	1

Note(s): *Letters in the top row correspond to those in the columns
Source(s): Table by authors

Table 5. The pair-wise comparison matrix*

of measurement mistakes, by allowing individual evaluation of each criterion contribution and redundancy. It was possible to estimate the consistency index (CI), a measure of the reliability of a comparison of judgments, following Eq. (1):

$$CI = \frac{\lambda \text{Max} - n}{n - 1} \tag{1}$$

where n is the total number of criteria and λ Max is the maximum eigenvalue of the matrix. CI as a measure of consistency ratio (CR) was derived using Eq. (2):

$$CR = \frac{CI}{RI} \tag{2}$$

where RI is a random consistency index computed using the reciprocal matrices at the 1/9, 1/8. . ., 1. . ., 8, 9 scales, as illustrated in Table 6.

Inconsistency can be acceptable if the consistency ratio is less than or equal to 0.10, but if it's larger than 0.1, a better expert opinion can be obtained and then edit the values again (Saaty, 1977). The consistency ratio (CR) in this research was 9%, which is within the acceptable maximum threshold (10%). Therefore, AHP has been used to give relative importance to each criterion depending on how well they were expected to contribute to making the chosen location a suitable WWTP. AHP Excel template (SCB Associates website, 2016) was used to calculate the weights for the criteria. Table 6 represents the result for the pair-wise comparison matrix.

3.3.2 The suitability map. Based on the results of the AHP matrix for the weight distribution of the criteria, these criteria were combined to obtain a result that includes the best site to build WWTP. The results were classified to determine the best site of WWTP in the study area. The site suitability index for each cell in a final map was prepared by using the weighted linear combination (WLC) method in GIS by using the weighted sum function of the ArcGIS application. This process can be represented by Eq. (3).

$$\text{Site Suitability Index} = \sum_{j=1}^{n} (Rj * Wj) \tag{3}$$

where Rj denotes the rank for factor j, and Wj denotes the weight of a class of factor j.

4. Results and discussion

4.1 AHP results

The evaluation of the ten data layers was carefully conducted through an in-depth examination of relevant literature, ensuring that each criterion was accurately ranked according to its significance for the WWTP site, and subsequently assigned appropriate weights. The results derived from the AHP emphasized the pronounced importance of elevations, slope and groundwater depth, with their corresponding weights established at 21%, 19% and 17%, respectively (Table 2). Conversely, the significance of lithology was deemed moderate, holding a weight of 12%. On the other hand, the importance of factors such as soil type, soil thickness, distance to populated areas, distance to water bodies, LULC

Table 6. Random consistency index

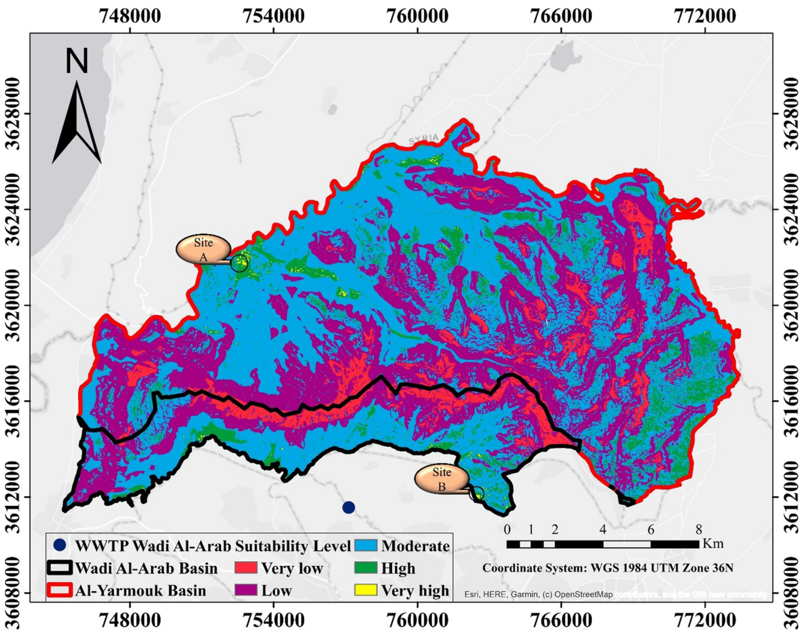
n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	0.12	1.24	1.32	1.41	1.45	1.49

Source(s): Table by authors

and distance to major roads was comparatively low, with weights of 8%, 7%, 6%, 5%, 3% and 2%, respectively. These findings align closely with the outcomes of various studies, including the work by Nigusse *et al.* (2020), which highlighted the fundamental role of elevation and slope in determining the optimal location for the WWTP, while indicating that factors such as LULC, soil thickness, distance to roads, and water bodies have a comparatively minimal impact on site selection. Similarly, the research by Asefa and Mindahun (2019) underlined the significance of elevation and slope in determining the plant's location, with the distance to water bodies and major roads demonstrating a moderate effect. They also indicated that LULC, groundwater depth, and lithology had relatively lesser influence on the selection process. Kanwal, Sajjad, Gabriel, and Hussain (2020) contributed to the demonstrated that slope and soil type play a central role in determining the most suitable WWTP site, while the depth of the water table, LULC and soil permeability exert a moderate effect, and the distance from roads and rivers exhibit minimal influence. Lastly, Abdalla and El Khidir (2017) emphasized the substantial impact of slope and lithology on the selection of the WWTP site, while revealing that the distance from roads and populated areas had a relatively lower effect.

4.2 Suitability map

The site susceptibility map of the WWTP in BKD was prepared based on the fuzzy AHP using the ten conditioning factors is represented in Figure 4. The levels of suitability were divided into five levels as follows: 0.225% very high suitability, 8.49% high suitability, 47.12% moderate suitability, 37.67% low suitability and 6.49% very low suitability. The most suitable sites for locating WWTP forms 8.71% (24.05 km^2) of the study area



Source(s): Figure by authors

Figure 4. Wastewater treatment plant suitability map of Bani Kinanah district

(Table 7). These results confirmed what came from previous studies on the same subject (Asefa & Mindahun, 2019; Nigusse *et al.*, 2020), where the very high and high suitability areas were the least allocated areas for building WWTP. This is due to the multiplicity of criteria adopted to reach the most suitable site for building a WWTP in the Bani Kinanah district. It can be noticed that most of suitability areas are far from the populated areas toward the low elevations. These areas mainly are distributed in two locations, one in the north (Site A) and the other in the south (Site B) of the district, in a relatively low-elevation area of the study area. Because of the presence of the study area on two basins, it is proposed to consider the site that is in the northern part of the study area, which is in the Yarmouk basin as the southern part of the study area may rely on the pre-existing station (WWTP of Wadi Al-Arab). Site A is characterized by sufficient spaces (25328 m^2, 8861 m^2, or 8586 m^2) for building a WWTP, low elevations (−90 to −93 m), low slope (0–2.5 %), and at distance from groundwater level in the range 47–82 m.

5. Conclusions and recommendations

Multi-criteria decision analysis is a useful tool for assessing complex choices with incompatible data or criteria. The research discussed the importance of having a WWTP in BKD for regulating wastewater and preserving the environment. The methodology combined the AHP matrix and GIS technology to make the study easier and get the weight value of each criterion in the study area. Elevation, slope, groundwater wells, land use/land cover, lithology, soil thickness, soil type, distance to main roads, distance to populated area and distance to water bodies were the ten criteria used for locating the best site for a WWTP in Bani Kinanah district. The AHP matrix was used to get a single weight for each criterion. The elevations, slope and groundwater depth have high importance; where their weights 21%, 19% and 17%, respectively. The parameters with low importance are soil type (8%), soil thickness (7%), distance to populated areas (6%), distance to water bodies (5%), LULC (3%) and distance to major roads (2%). The suitability map of the WWTP was categorized into five different levels, where 8.71% of the study area has high and very high suitability. These areas are characterized by their sufficient spaces (25328 m^2, 8861 m^2, or 8586 m^2) for building a WWTP, relatively low elevations (−90 to −93 m), low slope (0–2.5 %) and distance from groundwater level (47–82 m). Although the city has adequate potential areas for establishing WWTP, further assessment of flood vulnerability, wastewater amount quantification, population growth and urban expansion need to be seriously considered before implementing. Moreover, conducting an environmental assessment to understand the impact of the existing cesspit system is essential before making any decisions, given that the construction expenses associated with a WWTP are a significant factor in a developing country like Jordan.

Table 7. The area and percentages for each level of suitability

Suitability	Area (km^2)	Area (%)
Very low	17.89	6.5
Low	103.85	37.67
Moderate	129.90	47.12
High	23.43	8.49
Very high	0.62	0.225

Source(s): Table by authors

References

Abdalla, O. O., & El Khidir, S. O. (2017). Site selection of wastewater treatment plant using RS/GIS data and multi-criteria decision analysis (MCDA): Case study Omdurman city, Khartoum state, Sudan. *Geoscience Journal*, *1*, 94–107.

Abdelouhed, F., Ahmed, A., Abdellah, A., Yassine, B., & Mohammed, I. (2022). GIS and remote sensing coupled with analytical hierarchy process (AHP) for the selection of appropriate sites for landfills: A case study in the province of Ouarzazate, Morocco. *Journal of Engineering and Applied Science*, *69*(1), 19.

Addis, A. (2021). Selection of wastewater treatment plant site for Bahir dar town, Ethiopia using multi-criteria analysis on GIS platform. *Civil and Environmental Research*, *13*(3), 9–16. doi: 10.7176/CER/13-3-02.

Alzouby, A. M., Nusair, A. A., & Taha, L. M. (2019). GIS based multi criteria decision analysis for analyzing accessibility of the disabled in the Greater Irbid Municipality Area, Irbid, Jordan. *Alexandria Engineering Journal*, *58*(2), 689–698.

Asefa, B., & Mindahun, W. (2019). Geospatial based optimum site selection for wastewater treatment plant: The case of Debre Berhan town, Amhara Regional state, Ethiopia. *Journal of Geosciences*, *7*(3), 97–104.

Chabuk, A., Al-Ansari, N., Hussain, H. M., Knutsson, S., Pusch, R., & Laue, J. (2017). Combining GIS applications and method of multi-criteria decision-making (AHP) for landfill siting in Al-Hashimiyah Qadhaa, Babylon, Iraq. *Sustainability*, *9*(11), 1932.

Corcoran, E. (Ed.) (2010), *Sick water? the central role of wastewater management in sustainable development: a rapid response assessment*. UNEP/Earthprint.

Dekan Abbasl, Z., & Jassima, O. (2019). Application of GIS and AHP technologies to support of selecting a suitable site for wastewater sewage plant in Al Kufa city. *Al-Qadisiyah Journal for Engineering Sciences*, *12*(1), 31–37.

DOS (Department of Statistics). (2022). *Estimated population for the end of 2022*. Available from: https://dosweb.dos.gov.jo/DataBank/Population/Population_Estimares/PopulationEstimates.pdf (accessed 15 August 2023).

Gens, R. (2015). *ASF radiometric terrain corrected products: Algorithm theoretical basis document*. Fairbanks, AK: Alaska Satellite Facility.

Google LLC. (2023). Google Earth Pro (Version 7.3.6.9345). Available from https://www.google.com/earth/ (accessed 26 April 2023).

Kambole, M.S. (2003). Managing the water quality of the Kafue river. *Physics and Chemistry of the Earth, Parts A/B/C*, *28*(20-27), 1105–1109.

Kanwal, S., Sajjad, M., Gabriel, H. F., & Hussain, E. (2020). Towards sustainable wastewater management: A spatial multi-criteria framework to site the land-FILTER system in a complex urban environment. *Journal of Cleaner Production*, *266*, 121987.

Karra, K., Kontgis, C., Statman-Weil, Z., Mazzariello, J. C., Mathis, M., & Brumby, S. P. (2021). Global land use/land cover with Sentinel 2 and deep learning. In *2021 IEEE international geoscience and remote sensing symposium IGARSS* (pp. 4704–4707). IEEE.

Lin, H. Y., & Kao, J. J. (1999). Enhanced spatial model for landfill siting analysis. *Journal of Environmental Engineering*, *125*(9), 845–851.

Løken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews*, *11*(7), 1584–1595.

Malik, O. A., Hsu, A., Johnson, L. A., & de Sherbinin, A. (2015). A global indicator of wastewater treatment to inform the Sustainable Development Goals (SDGs). *Environmental Science and Policy*, *48*, 172–185.

Mara, D. D., Mills, S. W., Pearson, H. W., & Alabaster, G. P. (1992). Waste stabilization ponds: A viable alternative for small community treatment systems. *Water and Environment Journal*, *6*(1), 72–78.

Meinzinger, F. (2003). GIS-based site identification for the land application of wastewater: Christchurch City, New Zealand. (Doctoral dissertation, Lincoln University).

Ministry of Agriculture (1993). The soils of Jordan. National soil map and land use project. Hunting Technical Services Ltd, in association with Soil Survey and Land Research Center, vol 2-level 2. Main Report, Amman, Jordan.

Nigusse, A. G., Adhaneom, U. G., Kahsay, G. H., Abrha, A. M., Gebre, D. N., & Weldearegay, A. G. (2020). GIS application for urban domestic wastewater treatment site selection in the northern Ethiopia, Tigray Regional state: A case study in Mekelle city. *Arabian Journal of Geosciences*, *13*(8), 1–13.

NRA-Natural Resources Authority. (1997). *Geological map of Irbid district, scale 1:50,000, map sheet No. 3155 II*. Amman: Geological Mapping Division.

OpenStreetMap contributors. (2023). OpenStreetMap. Available from https://www.openstreetmap.org/ (accessed 17 January 2023).

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281, 605. doi: 10.1016/0022-2496(77)90033-5.

Saaty, T. L. (1988). What is the Analytic Hierarchy Process?, In Mitra, G., Greenberg, H. J., Lootsma, F. A., Rijkaert, M. J., & Zimmermann, H. J. (Eds), *Mathematical Models for Decision Support* (*48*, pp. 109–121). Berlin, Heidelberg: Springer.

Saaty, T. L. (1994). *Fundamentals of decision making and priority theory with the analytic hierarchy process*. Pittsburgh: RWS Publications.

SCB Associates website. (2016). Analytic hierarchy process, AHP. Available from: https://www.scbuk.com/ahp.html (accessed 20 April 2023).

Şener, B., Süzen, M. L., & Doyuran, V. (2006). Landfill site selection by using geographic information systems. *Environmental Geology*, *49*, 376–388.

Shahmoradi, B., & Isalou, A. A. (2013). Site selection for wastewater treatment plant using integrated fuzzy logic and multicriteria decision model: A case study in Kahak, Iran. *Journal of Advances in Environmental Health Research*, *1*(1), 51–61.

Water Authority of Jordan (2021), "The precipitation by the Water Authority of Jordan for years (2008–2018)", Unpublished Manuscript.

Further reading

Cheng, C., & Thompson, R. G. (2016). Application of boolean logic and GIS for determining suitable locations for Temporary disaster waste management sites. *International Journal of Disaster Risk Reduction*, *20*, 78–92.

Echogdali, F. Z., Boutaleb, S., Elmouden, A., & Ouchchen, M. (2018). Assessing flood hazard at River Basin scale: Comparison between HECRAS-WMS and flood hazard index (FHI) methods applied to El Maleh basin, Morocco. *Journal of Water Resource and Protection*, *10*(9), 957–977.

Sammy, D. N. (2018). Use of geospatial technologies in the selection of suitable sites for a wastewater treatment plant case study: Loitokitok town. (Doctoral dissertation, University of Nairobi).

Şener, Ş., Sener, E., & Karagüzel, R. (2011). Solid waste disposal site selection with GIS and AHP methodology: A case study in senirkent–uluborlu (Isparta) basin, Turkey. *Environmental Monitoring and Assessment*, *173*, 533–554.

Smith, J. E. (2006). *Process design manual for land treatment of municipal wastewater* (*EPA/625/R-06/016*). Washington, DC: US Environmental Protection Agency.

Zhu, X. (2016). *GIS for environmental applications: A practical approach* (pp. 490). London: Routledge.

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