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Site Selection Optimisation Using Fuzzy-GIS Integration for Wastewater Treatment Plant

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Abstract: Municipal management involves making decisions on various technical issues, and one such crucial aspect is the multicriteria decision-making process. When choosing suitable locations for wastewater treatment plants, it becomes necessary to consider a range of factors such as technical feasibility, economic viability, environmental impact, ecological aspects, and management requirements. However, evaluating these criteria and dealing with uncertainties can be complex. To address this challenge in the Tabuk region, a combination of two powerful analytical methods, the fuzzy analytical hierarchy process (FAHP) and geographical information system (GIS), were employed. The FAHP methodology allows for considering uncertainties and subjective judgements, while GIS provides spatial analysis capabilities. By combining FAHP and GIS, a thorough evaluation of potential wastewater treatment plant locations was conducted by determining the relative weights for each geospatial parameter. These weights were then used to generate a suitability map, visually representing the most favourable areas for site selection. The FAHP analysis resulted in higher importance given to the treatment plant's distance to urban areas, followed by the distance to roads among the seven investigated parameters. The integrated FAHP-GIS model results show that the western parts of the region are most suitable for constructing wastewater treatment plants. These findings are valuable in facilitating multicriteria decision-making for identifying the optimum site in the area. In summary, integrating FAHP and GIS in the assessment process enables decision-makers to consider various technical, economic, environmental, ecological, and management aspects, thereby providing a comprehensive framework for site selection that can be replicated in other regions with different conditions. This approach enhances the decision-making process in municipal management and promotes more informed and effective planning in the Tabuk region.

Keywords: geographical information system (GIS); fuzzy analytical hierarchy process (FAHP); multicriteria decision-making (MCDM); Tabuk region; wastewater treatment plant

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1. Introduction

In recent years, there has been an increasing awareness of the importance of considering environmental impacts when designing and implementing infrastructure projects.

This approach not only aims to minimise the negative effects on the environment but also contributes to the overall sustainable development of communities. One such area where the selection of design alternatives for infrastructure projects is crucial is the Tabuk region, located along the northwestern coast of the Kingdom of Saudi Arabia (KSA), with an area of 146,072 km^2 and a population of 910,030 [1]. With its diverse ecosystems, including pristine beaches, lush forests, and delicate aquatic habitats [2], it is essential to prioritise environmental considerations to ensure the region's long-term well-being.

This study focuses on the selection process between regional alternatives for infrastructure projects in Tabuk, with a primary emphasis on the high weightage assigned to the environmental effects of establishing and operating the facility. It seeks to create a comprehensive framework that allows decision-makers to assess different options throughout the project lifecycle, considering the potential environmental consequences at each stage. By incorporating this approach, the aim is to ensure that infrastructure projects in Tabuk are developed in a manner that is sustainable, environmentally responsible, and aligned with international standards and best practices. The project aims to identify the governing factors between design alternatives of infrastructure projects in Tabuk and constructing key design selection criteria. These governing factors are evaluated in the research based on the geospatial analysis of their impact.

Wastewater treatment is a critical component of a sustainable and clean environment. It involves the process of eliminating pollutants and contaminants from wastewater to ensure it is safe for disposal or reuse [3]. Additionally, wastewater treatment plays a crucial role in protecting public health and preventing the spread of waterborne diseases [4]. Wastewater treatment is a key requirement for protecting the public health and the environment. The location of the treatment plant has a direct impact on water resources, ecosystems and human health [5]. Therefore, the site selection for wastewater treatment plants plays a significant role in efficient and effective treatment processes, and it is a necessity to optimise the site selection of the treatment plant. Due to the rise in population and the growth of economies, the significance of wastewater treatment is progressively increasing in many countries. The lack of wastewater management and treatment in rural areas increases the spread of health hazards, which hinders the development of societies. A high portion of wastewater in underdeveloped nations is discharged directly into water bodies, contaminating the life below water [6]. Furthermore, the discharges from the treatment plants have the potential to contaminate both surface and subsurface water bodies through seepage, hence worsening environmental challenges and impacting the condition of the surrounding water resources [7].

The site selection of such plants has many effects in the long and short terms, which makes it a multicriteria decision-making (MCDM) problem. Any MCDM problem involves ambiguities in weighing the effect of a certain criterion over another. To enhance the decision-making process, multiple conflicting criteria are evaluated by identifying specific, effective, and reasonable ranking of options and alternatives [5,8]. Different methods are used to solve MCDM problems, including Data Envelopment Analysis (DEA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Analytic Hierarchy Process (AHP). Among these methods, AHP is the most widely used MCDM approach to solving complex problems of diverse criteria due to its ease of use and systematic calculations [9]. It is a low-cost method that uses expert judgements to assess the contribution of criteria and factors while considering the hierarchical overall view of the complex MCDM problem [5,10]. The fuzzy analytical hierarchy process (FAHP) is an MCDM method that weights and evaluates the degree of importance of experts' opinions on a certain subject while dealing with judgement uncertainties.

Traditional site selection methods consider direct technical, economic, and environmental aspects but fail to oversee the inherent uncertainty and imprecision associated with decision-making processes. To overcome these limitations, the integration of fuzzy logic and geographic information system (GIS) has emerged as a promising approach for optimising site selection for wastewater treatment plants. FAHP models multiple expert opinions using fuzzy numbers rather than crisp values. This method comprehensively accounts for the uncertainty, subjectivity, and ambiguity in expert judgement, as the technique incorporates a check of the judgement consistency. The complex computational procedure of this model is then conducted using GIS tools to present a proper ranking of alternatives. The uncertainty in remotely sensed images might result in issues of image classification and sensitivity errors. However, fuzzy logic can be used for imprecise data modelling using the membership functions [11]. Therefore, an integrated FAHP-GIS model helps solve complex MCDM problems.

A geographic information system (GIS) is a practical approach for storing, accessing, manipulating, analysing, and mapping geographic data. Raster and vector are the two types of coverage representation that GIS uses to host and create comprehensive information about a particular geographic area. The data are organised, structured, and standardised since they are kept in a geodatabase. GIS is an effective tool for gathering and organising spatial data, as shown by multiple successful examples of locating potential wastewater treatment plant locations [10,12–14]. Jajac, et al. [15] stated that the AHP method provides a suitable way to simultaneously give all stakeholders the possibility to express their opinions and be a part of the compromise solution. According to Gohil, et al. [16], the use of GIS to apply the results of fuzzy analysis reflects the interdependency of parameters and accelerates the information delivery process to decision-makers.

Hamlat et al. [5] created a suitability map for an alternative wastewater treatment plant site in Laghouat City, Algeria. Their research evaluated alternative sites for plant implementation using AHP and GIS tools. Their work concentrated on the environmental aspects of the given criteria to evaluate the topography, type of soil, geology type, land use, and land cover, as well as distances from the settlement, water resources and main roads. The research of [17] used AHP to evaluate the wastewater treatment plant location suitability in Phnom Penh, Cambodia, using five indicators: slope change, flow direction, distance from the roads, distance from the river, wind direction, and land type. Lefta and Hamdan [18] assessed suitable sites for wastewater treatment plants using an integrated FAHP-GIS model for a case study in Iraq. They considered ten spatial parameters, including slope, soil type, distance to roads, railways, land use, groundwater, and outfall, as categorised within the three main criteria of environmental, economic, and social aspects.

Mansouri, et al. [19] in their study of wastewater treatment plant site selection using AHP and GIS for the case of Falavarjan in Esfahan, reported that three groups of data, including environmental, geological, and economic criteria and a total of nine parameters, were used for selecting a suitable location for the construction of a wastewater treatment plant. Likewise, they considered seven parameters of faults: population, main river, streams, floodplain, road, underground water sources, and transmission network as excluding parameters. Deepa and Krishnaveni [20] combined the Analytical Hierarchy Process and other tools to perform multicriteria analysis. Six types of maps were used: population density, land use, slope, soil, cost, and technology. Each thematic map was assigned to a different class. A paired comparison matrix for the criteria classes was created using AHP, and the individual class weights and map scores were calculated. These weights were used in a linear summation equation to create a weight map of appropriate weights for each input variable. All weighted maps were ultimately classified to find the ideal location for decentralised treatment plants.

The work of [21] categorised the social indicators for evaluating wastewater treatment plants' performance as water saving and equity, community engagement, local employment, urban landscape, consumers' health concerns, and household expenses. According to [22], these sociocultural indicators depend on the economic, political, and behavioural context of the studied society.

In this research, FAHP analysis is used to compare distinctive design parameters for site selection of a wastewater treatment plant in Tabuk, with an emphasis on the geographical impact of these design criteria. The integration of FAHP and GIS techniques aids in assessing, categorising, and analysing spatial data while calculating the FAHP priorities that help in planning infrastructure projects. The objectives of this research work are summarised in the following points:

- Selecting geospatial parameters to present the economic, environmental, ecological, management, engineering, technical, and social criteria of the wastewater treatment plant site selection process in the Tabuk region, KSA.
- Analysing the relative priority of geospatial parameters using the Fuzzy Analytic Hierarchy Process (FAHP).
- Processing the geographic information of the Tabuk region under a GIS environment.
- Implementing the FAHP model to GIS processes to create a suitability map of viable locations for wastewater treatment plants to assess the decision-making official entities in the urban developing sector.

2. Materials and Methods

This study presents another stage of an infrastructure alternative design project run by the University of Tabuk. An earlier stage of this project [23] defined and evaluated the decision-making criteria for optimising the site selection process of wastewater treatment plants in the Tabuk region. The project's previous FAHP evaluation resulted in relative weights of site selection optimisation criteria: 8% for the economic criterion, 3% for environmental, 33% for ecological and management, 16% for social, and 40% for the engineering and technical criterion. These criteria were chosen to reflect the most appropriate set of influencing parameters within the scope of the Tabuk region, as per the previously performed analysis. In the current study, the geological impact of these decision-making criteria is assessed based on the previously conducted FAHP analysis.

A case study was developed to evaluate the geographical impact of wastewater treatment plant site selection optimisation in the Tabuk region, northwest of the Kingdom of Saudi Arabia. The region extends between longitudes of 34.6° E and 39.9° E and latitudes of 24.6° N and 29.97° N. The arid region has an area of 146,072 km^2 and a population of over 900,000 inhabitants, with a long coastline along the Red Sea and an annual rainfall of 40 mm. Urban development in Tabuk is directly connected to the agricultural industry and the NEOM project. Therefore, careful infrastructure planning is needed to adapt to the expected increase in the population. Currently, there are seven wastewater treatment plants in the western part of the region, with an annual average capacity of 131,665 m^3/day. Figure 1 shows the case study location, with the extent of the Tabuk region highlighted in green.

Fuzzy logic provides a flexible and robust method for dealing with uncertain and imprecise information. Introducing fuzzy sets and linguistic variables allows the decision-making process to capture the vagueness and ambiguity associated with site selection criteria. Fuzzy logic helps transform linguistic expressions into numerical values, facilitating the evaluation of the suitability of potential sites for wastewater treatment plants. By integrating GIS with fuzzy logic, the site selection process becomes more advanced and efficient. QGIS software (version 3.22.14) provides a platform to acquire, preprocess, and visualise various data layers required for site selection, such as land use, topography, hydrological features, transportation networks, and environmental constraints. The integration of FAHP and GIS enables the development of a comprehensive decision-support system for wastewater treatment plant site selection. FAHP-GIS integration leverages the spatial analysis capabilities of GIS to process and integrate different data layers. GIS allows for multi-data source input, unifying the data types and integrating different layers for the studied location, calculating spatial relationships and patterns, identifying analytical preference conditions, performing measurements and overlaying diverse criteria. By integrating FAHP membership functions into GIS operations, the site selection process becomes more dynamic and adaptable. The FAHP-GIS integration for optimising the site selection of wastewater treatment plants offers several benefits, such as improved decision-making under uncertainty and imprecision, simultaneous analysis of multiple criteria and constraints, adaptability to changing conditions through flexible FAHP rules, spatial visualisation of results for enhanced understanding and communication, and reduction in time, cost, and effort required for the site selection process.

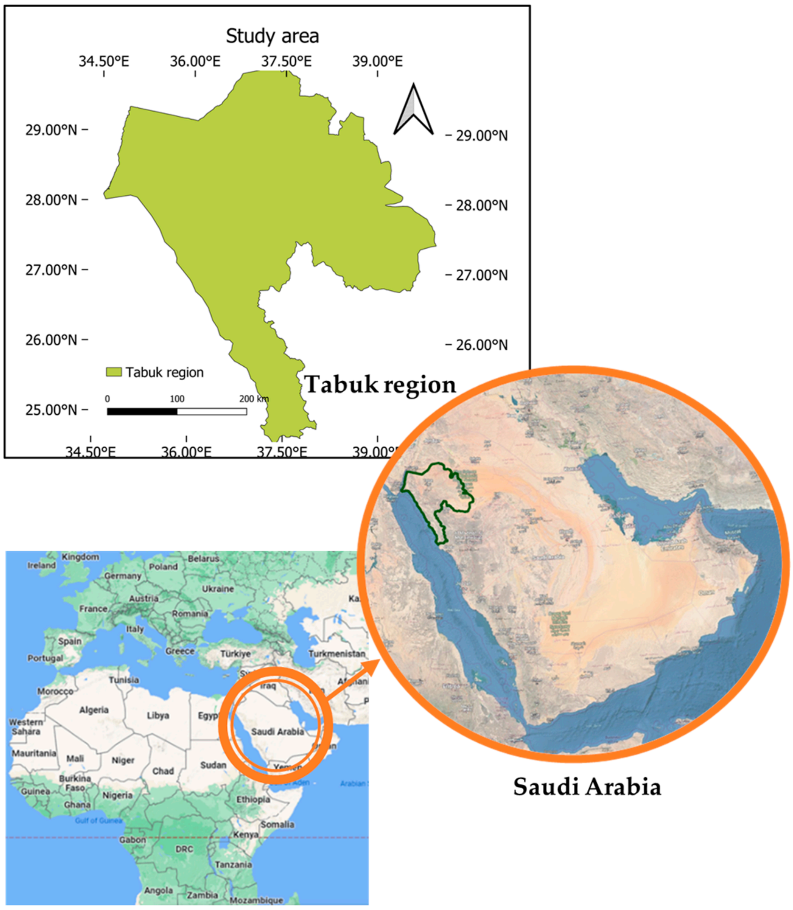

Figure 1. Case study location.

An integrated FAHP-GIS decision-making model was used to assess and rank alternative locations for wastewater treatment plants. The problem's complexity can extend beyond the computational power of the current project. Therefore, the specific technical, economic, environmental, ecological, and management factors considered in the evaluation of potential wastewater treatment plant locations in the Tabuk region were addressed via seven geospatial parameters, including distance to the main road network, distance from airports, distance from urban areas, distance from the coast, distance from wetlands, distance from waterways, and distance from protected areas. Table 1 maps the spatial parameters under consideration with the main optimisation criteria. It is observed that each parameter contributes to more than one selection criterion, which makes this an MCDM problem. Tabuk is a coastal city with major agricultural land and wildlife-protected areas. The environmental risk of Lechatte pollutants contaminating the surface and underground water, along with the possibility of soil and air pollution, reflects the minimum acceptable distance to main roads, airports, urban areas, coast, wetlands, waterways, and protected areas. Economic criteria require proximity to main roads for plant accessibility. Social acceptance is associated with unpleasant odours and pollutants when the plant is constructed near urban areas and waterways. The constraint values of these geospatial parameters, as adopted from the literature [18,19], along with their data types and data sources, are also included in Table 1.

Table 1. Evaluation parameter constraints and data sources.

Parameter	Abbreviation	Constraint Value	Mapping of Criteria	Data Type	Data Source
Distance to the main road network	P1	1 km ≤ distance ≤ 3 km	Environmental: Soil pollution and increase in moisture content. Economic: access to the plant. Social: local employment.	Vector	OSM
Distance from airports	P2	distance ≥ 5 km	Environmental: Dispersal pollution of air.	Vector	OSM
Distance from urban areas	P3	5 km ≤ distance ≤ 10 km	Environmental: Air pollution, noise, and odours. Social: Public acceptance, community engagement, local employment, consumers' health concerns.	Vector	OSM
Distance from coast	P4	distance ≥ 5 km	Engineering and Technical: Climatic factors (rain, wind, etc.) affect the effectiveness of the plant. Environmental: Leachate pollutants and salt intrusion. Ecological and management: Response to coastal disasters.	Vector	OSM
Distance from wetlands	P5	distance ≥ 300 m	Environmental: Leachate pollutants and eutrophication. Social: Public acceptance, urban landscape.	Vector	OSM
Distance from waterways	P6	distance ≥ 300 m	Environmental: Pollution of groundwater and leachate pollution. Social: Public acceptance, water saving and equity.	Vector	HydroSHEDS
Distance from protected areas	P7	distance ≥ 50 m	Environmental: Environmental hazards to ecology. Social: Governmental permissions.	Vector	OSM, Google Earth

The methods used for optimising wastewater treatment plant site selection in the study area are shown in Figure 2. The FAHP analysis would feed into the GIS analysis at an advanced stage. Fuzzy analysis was conducted to determine the weights of each geospatial parameter within the five main criteria under consideration. The fuzzy analysis used the geometric mean method, as shown in Equations (1)–(6) [24].

$$Fuzzy\ Geometric\ Mean, r_i = \left(\prod_{j=1}^{n} A_n\right)^{1/n} \tag{1}$$

$$Fuzzy\ Weight,\ w_i = r_i \bigotimes (r_1 \oplus r_2 \oplus \ldots r_n)^{-1} \tag{2}$$

$$Defuzified\ weight,\ M_i = \frac{l+m+u}{3} \tag{3}$$

$$Normalized\ weight,\ N_i = \frac{M_i}{\sum M_i} \tag{4}$$

$$Consistency\ Index,\ CI = \frac{\lambda_{max} - n}{n-1} \tag{5}$$

$$Consistency\ Ratio,\ CR = \frac{CI}{RI} \tag{6}$$

where: A_n = the fuzzy number of the nth parameter, n = the number of parameters, r_i = the fuzzy geometric mean value of the ith parameter, λ_{max}= the principal eigenvalue, RI = random inconsistency index. This index is directly dependent on the number of analysed parameters (n) and can be deduced from Table 2 [24].

Table 2. Random inconsistency index values.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Aggregated results of fuzzy weights were used to create adjusted weights of the studied geospatial parameters as per influencing criteria. The normalised aggregated weight w_{ag} is calculated in Equation (7).

$$w_{ag} = \sum_{j=1}^{m} N_i \cdot x_j \tag{7}$$

where x_j = score of the jth criterion and m = number of criteria.

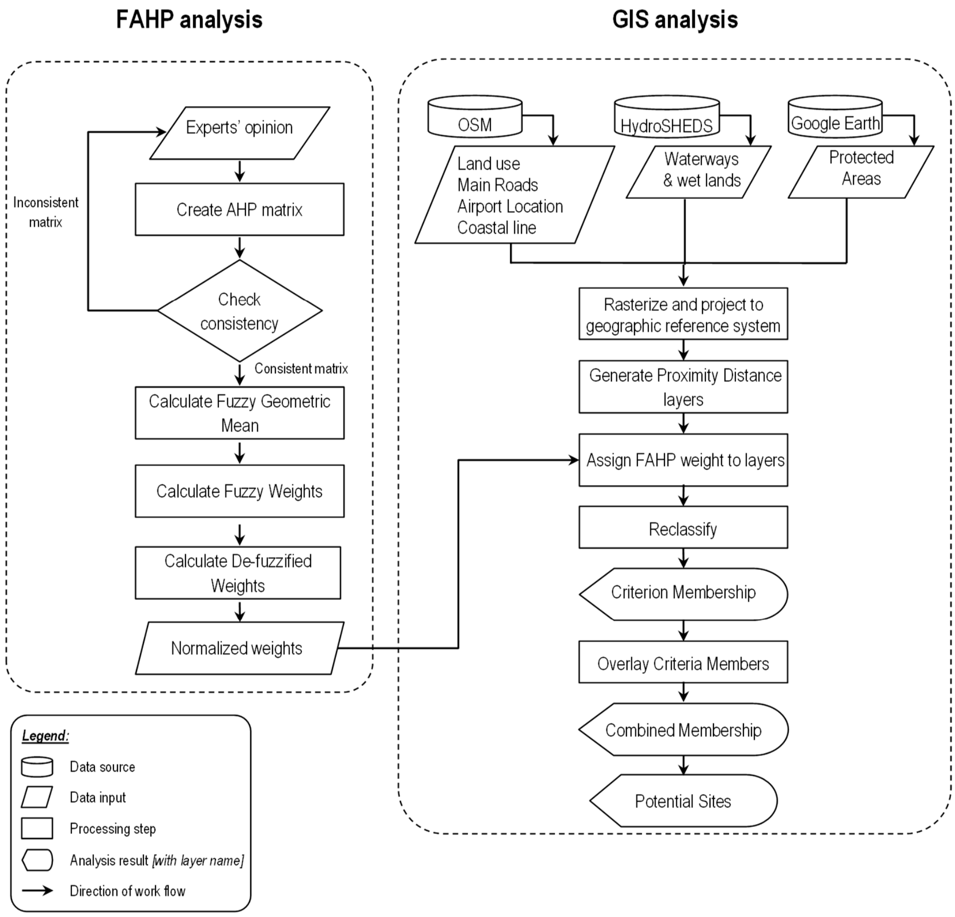

Figure 2. Workflow of Site Selection Multicriteria Analysis.

GIS analysis was initiated by obtaining the required raw data from different data sources, namely the open street database (OSM) [25], Google Earth [26], NASA Earth data [27] and HydroSHEDS [28]. OSM database provided vector-format data of various land uses. The NASA Earth data sets offered 20 years of satellite measurements for hourly wind speeds, elevation maps and land cover. Active water stream data were obtained in a raster format of 5 × 5 degree tiles from the HydroSHEDS database. Data gathering ensured that all raster datasets were of the same resolution of 12.5 m × 12.5 m pixel size. Vector and polygon data were rasterised using QGIS software to the same resolution. All layers were then projected onto the selected geographic reference system (WGS 84/UTM zone 37N; EPSG:32637). The proximity algorithm was used to create maps of distance from source data in each layer, which were then normalised by reclassifying them into equal proximity classes. These spatial algorithms resulted in seven processed layers of relevant geospatial importance. Table 1 was combined with the normalised layers to set the constraint values of the FAHP membership categories, leading to reclassifying the layers into five membership values, to be discussed later.

The FAHP weights were applied to the parametric layers using raster calculations within the QGIS software. Raster calculation and image analysis were then used to create the final site suitability map, which ranked the areas within the Tabuk region for their suitability for wastewater treatment plants.

3. Results and Discussions

3.1. Fuzzy Analysis

For each site selection criterion, a pairwise comparison matrix was created to evaluate the relative importance of the studied parameters. Triangular Fuzzy Numbers (TFN) were used to rank the experts' opinions on the relative importance analysis, such that TFN is expressed as $A = (l, m, u)$, where l is the lower value, m is the mean and u is the upper value of the triangular fuzzy bound. A reciprocal of a TFN is denoted $A^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right)$. The geometric mean method was used to calculate the fuzzy weight of each parameter; then the weights were de-fuzzified and normalised to find the crisp weights of the evaluated parameters. Pairwise comparison matrixes were developed to determine the relative priority of the seven geospatial parameters under each of the five main criteria. All these matrixes were checked for consistency, with a random index (RI) of 1.32 for a seven-parameter matrix as read from Table 2. Tables 3–7 show these pairwise comparison matrixes. All resulting matrixes were checked for consistency to address any decision bias from the evaluators. The analysis under the environmental criteria was highly consistent, offering a homogenous distribution of weights per parameter.

Table 3. Pairwise comparison matrix for the economic criterion.

Parameter	P1	P2	P3	P4	P5	P6	P7
P1	1	9	1/2	9	9	9	8
P2	1/9	1	1/9	1/2	1/3	1/3	1/9
P3	2	9	1	9	8	8	5
P4	1/9	2	1/9	1	1/2	1/2	2
P5	1/9	3	1/8	2	1	1	1
P6	1/9	3	1/8	2	1	1	1
P7	1/8	9	1/5	1/2	1	1	1
Consistency	λ_{max} = 7.75, CI = 0.125 CR = 0.095 < 0.1 → Reasonably consistent matrix.						

Table 4. Pairwise comparison matrix for the environmental criterion.

Parameter	P1	P2	P3	P4	P5	P6	P7
P1	1	1/2	1/9	1/9	1/8	1/8	1/9
P2	2	1	1/9	1/9	1/9	1/9	1/9
P3	9	9	1	2	1/2	1/2	1/2
P4	9	9	1/2	1	1/2	1/2	1
P5	8	9	2	2	1	1	1
P6	8	9	2	2	1	1	1
P7	9	9	2	1	1	1	1
Consistency	λ_{max} = 7.28, CI = 0.046 CR = 0.035 < 0.1 → Reasonably consistent matrix.						

Table 5. Pairwise comparison matrix for the ecological and management criterion.

Parameter	P1	P2	P3	P4	P5	P6	P7
P1	1	2	1/5	1/7	1/6	1/6	1/2
P2	1/2	1	1/9	1/7	1/8	1/8	1/7
P3	5	9	1	7	2	2	2
P4	7	7	1/7	1	1/4	1/4	2
P5	6	8	1/2	4	1	1	2
P6	6	8	1/2	4	1	1	2
P7	2	7	1/2	1/2	1/2	1/2	1
Consistency	λ_{max} = 7.69, CI = 0.115 CR = 0.087 < 0.1 → Reasonably consistent matrix.						

Table 6. Pairwise comparison matrix for the social criterion.

Parameter	P1	P2	P3	P4	P5	P6	P7
P1	1	2	1/7	1/8	1/3	1/3	1/5
P2	1/2	1	1/9	1/9	1/7	1/7	1/5
P3	7	9	1	2	3	3	2
P4	8	9	1/2	1	7	7	2
P5	3	7	1/3	1/7	1	5	1/2
P6	3	7	1/3	1/7	1/5	1	1/2
P7	5	5	1/2	1/2	2	2	1
Consistency	λ_{max} = 7.76, CI = 0.127 CR = 0.096 < 0.1 → Reasonably consistent matrix.						

Table 7. Pairwise comparison matrix for the engineering and technical criterion.

Parameter	P1	P2	P3	P4	P5	P6	P7
P1	1	9	1/2	7	7	7	9
P2	1/9	1	1/9	1/7	1/7	1/5	1/2
P3	2	9	1	7	7	7	9
P4	1/7	7	1/7	1	2	2	5
P5	1/7	7	1/7	1/2	1	2	5
P6	1/7	5	1/7	1/2	1/2	1	5
P7	1/9	2	1/9	1/5	1/5	1/5	1
Consistency	λ_{max} = 7.79, CI = 0.132 CR = 0.099 < 0.1 → Reasonably consistent matrix.						

The methodology described for the fuzzy geometric mean method (Equations (1)–(7)) was used to calculate the weights of each parameter per criterion. The FAHP analysis results are listed in Tables 8–12. The defuzzified weight converts the triangular fuzzy weight to a crisp value; however, the summation of all defuzzified weights per analysis may exceed 100%. Therefore, the normalised weight is calculated to ensure a 100% total.

Table 8. FAHP results for the economic criterion.

Parameter	Geometric Mean (r_i)	Fuzzy Weight (w_i)	Defuzzified Weight (M_i)	Normalised Weight (N_i)	Rank
P1	(3.704, 4.278, 4.804)	(0.271, 0.359, 0.481)	37.02%	35.85%	2
P2	(0.224, 0.258, 0.336)	(0.016, 0.022, 0.034)	2.39%	2.32%	7
P3	(3.85, 4.715, 5.304)	(0.282, 0.396, 0.531)	40.27%	39.00%	1
P4	(0.39, 0.534, 0.756)	(0.029, 0.045, 0.076)	4.96%	4.81%	6
P5	(0.589, 0.701, 0.802)	(0.043, 0.059, 0.08)	6.07%	5.88%	4
P6	(0.589, 0.701, 0.802)	(0.043, 0.059, 0.08)	6.07%	5.88%	4
P7	(0.651, 0.732, 0.85)	(0.048, 0.061, 0.085)	6.47%	6.27%	3

Table 9. FAHP results for the environmental criterion.

Parameter	Geometric Mean (r_i)	Fuzzy Weight (w_i)	Defuzzified Weight (M_i)	Normalised Weight (N_i)	Rank
P1	(0.178, 0.195, 0.235)	(0.015, 0.02, 0.029)	2.13%	2.03%	7
P2	(0.208, 0.23, 0.265)	(0.018, 0.023, 0.033)	2.46%	2.34%	6
P3	(1.131, 1.537, 2.192)	(0.095, 0.155, 0.273)	17.46%	16.59%	4
P4	(1.131, 1.392, 1.873)	(0.095, 0.14, 0.234)	15.64%	14.87%	5
P5	(1.777, 2.246, 2.564)	(0.15, 0.227, 0.32)	23.20%	22.04%	1
P6	(1.777, 2.246, 2.564)	(0.15, 0.227, 0.32)	23.20%	22.04%	1
P7	(1.811, 2.068, 2.192)	(0.152, 0.209, 0.273)	21.15%	20.10%	3

Table 10. FAHP results for the ecological and management criterion.

Parameter	Geometric Mean (r_i)	Fuzzy Weight (w_i)	Defuzzified Weight (M_i)	Normalised Weight (N_i)	Rank
P1	(0.282, 0.361, 0.469)	(0.022, 0.037, 0.064)	4.09%	3.72%	6
P2	(0.184, 0.21, 0.255)	(0.015, 0.021, 0.035)	2.35%	2.14%	7
P3	(2.119, 3.061, 3.81)	(0.168, 0.311, 0.516)	33.18%	30.20%	1
P4	(0.783, 0.981, 1.199)	(0.062, 0.1, 0.162)	10.81%	9.84%	5
P5	(1.662, 2.119, 2.661)	(0.132, 0.216, 0.361)	23.59%	21.47%	2
P6	(1.662, 2.119, 2.661)	(0.132, 0.216, 0.361)	23.59%	21.47%	2
P7	(0.689, 0.981, 1.575)	(0.055, 0.1, 0.213)	12.26%	11.16%	4

Table 11. FAHP results for the social criterion.

Parameter	Geometric Mean (r_i)	Fuzzy Weight (w_i)	Defuzzified Weight (M_i)	Normalised Weight (N_i)	Rank
P1	(0.283, 0.361, 0.462)	(0.021, 0.035, 0.06)	3.89%	3.54%	6
P2	(0.195, 0.22, 0.271)	(0.015, 0.021, 0.035)	2.39%	2.17%	7
P3	(2.119, 3.016, 3.747)	(0.161, 0.294, 0.487)	31.40%	28.59%	2
P4	(2.535, 3.212, 3.97)	(0.193, 0.313, 0.516)	34.05%	31.01%	1
P5	(0.906, 1.14, 1.486)	(0.069, 0.111, 0.193)	12.43%	11.32%	4
P6	(0.575, 0.72, 0.944)	(0.044, 0.07, 0.123)	7.88%	7.18%	5
P7	(1.086, 1.584, 2.284)	(0.082, 0.154, 0.297)	17.79%	16.20%	3

Table 12. FAHP results for the engineering and technical criterion.

Parameter	Geometric Mean (r_i)	Fuzzy Weight (w_i)	Defuzzified Weight (M_i)	Normalised Weight (N_i)	Rank
P1	(3.337, 3.907, 4.568)	(0.235, 0.324, 0.462)	34.04%	32.61%	2
P2	(0.195, 0.22, 0.271)	(0.014, 0.018, 0.027)	1.98%	1.90%	7
P3	(3.904, 4.762, 5.344)	(0.275, 0.395, 0.54)	40.35%	38.67%	1
P4	(0.869, 1.162, 1.426)	(0.061, 0.096, 0.144)	10.06%	9.64%	3
P5	(0.743, 0.953, 1.219)	(0.052, 0.079, 0.123)	8.49%	8.13%	4
P6	(0.599, 0.745, 1)	(0.042, 0.062, 0.101)	6.84%	6.55%	5
P7	(0.248, 0.296, 0.357)	(0.017, 0.025, 0.036)	2.60%	2.49%	6

When considering the economic criterion, the distance to urban areas (P3) and roads (P1) have noticeably higher weights than the other parameters. This is due to their direct contribution to the construction costs of establishing the treatment plant and its related network. In the environmental criteria, the probable contamination of waterways, wetlands and protected areas is reflected in the higher weights of these parameters. It is also noticeable that the distance to urban areas is present in the highest weights in all the other three criteria. This reflects the complications of decision-making when considering the long-term impact of a system-thinking approach.

The aggregated results of the parametric weight were calculated by incorporating the global weight value determined by [23]. These final weight values were obtained by multiplying the local weight of a parameter at the second level by the global weight of the category at the first level, as shown in Table 13.

Table 13. Global FAHP results for the site selection criteria.

Parameter	Weights					Aggregated Results
	Economic	Environmental	Ecological and Management	Social	Engineering and Technical	
Global Criteria	8%	3%	33%	16%	40%	
Roads	35.85%	2.03%	3.72%	3.54%	32.61%	18%
Airports	2.32%	2.34%	2.14%	2.17%	1.90%	2%
Urban areas	39.00%	16.59%	30.20%	28.59%	38.67%	34%
Coast	4.81%	14.87%	9.84%	31.01%	9.64%	13%
Wetlands	5.88%	22.04%	21.47%	11.32%	8.13%	13%
Waterways	5.88%	22.04%	21.47%	7.18%	6.55%	12%
Protected areas	6.27%	20.10%	11.16%	16.20%	2.49%	8%

When accounting for all criteria, the distance from urban lands has a higher impact on wastewater treatment plant site selection, followed by the distance from roads. Distance from the coast, wetlands and waterways has a relatively similar impact, while the distance to protected areas and airports has the least impact on the decision-making process. These results are in line with the findings of [29], as they ranked land use of higher importance (20%) for selecting suitable sites for landfills, followed by distance from water bodies (12.5%) and distance from airports (3.2%), among other criteria of relevance to their study. Furthermore, the ranking of the criteria in Table 13 is coherent with the results of [18], as they investigated the environmental, economic, and social aspects of the geospatial criteria for wastewater treatment plant sites. The resulting importance was the distance from oil and gas fields (28.3%), groundwater wells (11.6%), agricultural lands (11.6%), residential areas (9.1%), roads (8.9%), railways (3.2%), and rivers (2.9%). It is worth mentioning that the nature of the primary use of the case study area affects the types of selected criteria and their associated weights.

The FAHP analysis within the GIS platform required creating membership classifications, as shown in Table 13. The input raster value is transformed into a 1–5 scale, indicating the membership strength. The high proximity of wastewater treatment plants to densely populated areas, coasts, wetlands, roads, and protected areas is not recommended due to the risk of environmental contamination and public health issues. However, from a functionality and economic point of view, the construction of wastewater treatment plants should be near roads and urban areas to reduce transport costs. The balance of environmental and economic considerations leads to defining the five membership categories in Table 14, from poor membership to extremely preferred membership. The linguistic scale was translated to a scale of 1 to 5 in the QGIS software. A raster calculation tool is used to overlay membership layers and perform fuzzy calculations.

Table 14. Categories of the FAHP-GIS memberships.

Parameter	Poor (1)	Moderately Preferred (2)	Strongly Preferred (3)	Very Strongly Preferred (4)	Extremely Preferred (5)
Distance to main road network	From 0 to 500 m	More than 5000 m	From 4000 m to 5000 m	From 3000 m to 4000 m	From 500 m to 3000 m
Distance from airports	From 0 to 1250 m	From 1250 to 2500 m	From 2500 to 3750 m	From 3750 to 5000 m	More than 5000 m
Distance from urban areas	From 0 to 500 m	More than 20,000 m	From 10,000 m to 20,000 m	From 5000 m to 10,000 m	From 500 m to 5000 m
Distance from coast	From 0 to 1250 m	From 1250 m to 2500 m	From 2500 m to 3750 m	From 3750 m to 5000 m	More than 5000 m
Distance from wetlands	From 0 to 75 m	From 75 m to 150 m	From 150 m to 225 m	From 225 m to 300 m	More than 300 m
Distance from waterways	From 0 to 75 m	From 75 m to 150 m	From 150 m to 225 m	From 225 m to 300 m	More than 300 m
Distance from protected areas	From 0 to 125 m	From 125 m to 250 m	From 250 m to 375 m	From 375 m to 500 m	More than 500 m

3.2. GIS Analysis

Data sets imported from the open street database [25], Google Earth [26], and NASA Earth data [27] were analysed via QGIS software. The different datasets were processed to be properly presented and analysed in the GIS environment under the current case study requirements. The cross-reference of mutual information from these datasets verified the geographical bases of the created FAHP-GIS model. The calculated distances from various sources resulted in the maps of proximity range shown in Figures 3–8. These maps presents the information needed to perform further analysis of distance measurements and suitability memberships. It should be noted that the map scale colours were unified for all created proximity files to be measured in metres, with the red colour indicating a shorter distance to the measured criteria than the blue spectrum.

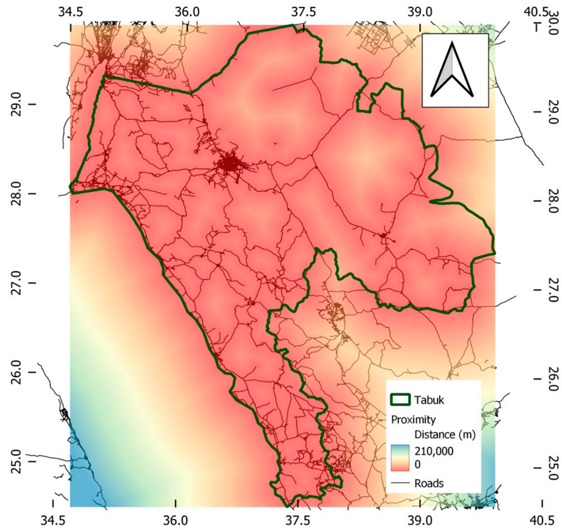

Figure 3. Proximity to the main road network.

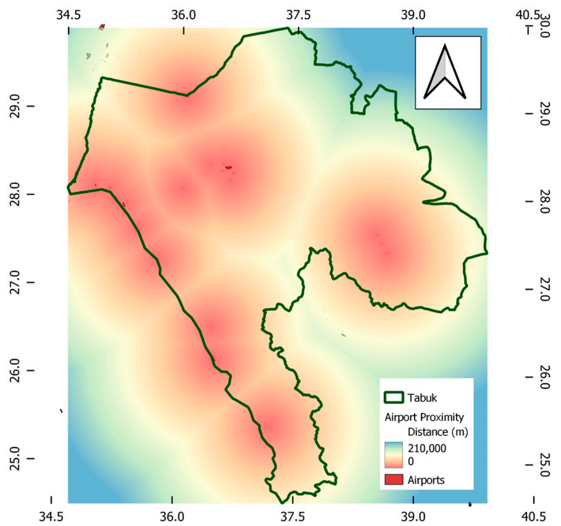

Figure 4. Proximity to airports.

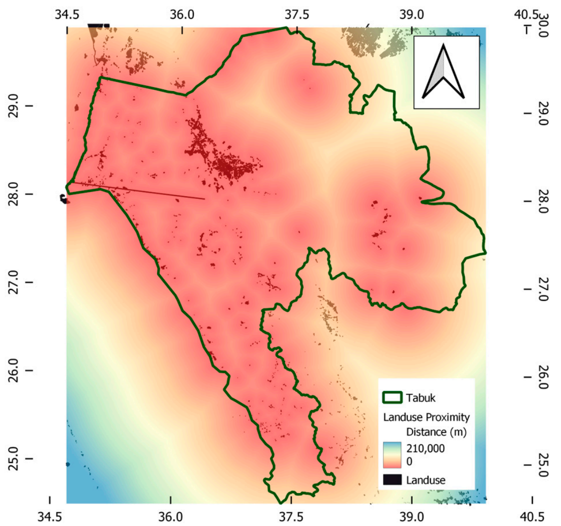

Figure 5. Proximity to urban areas and different land use.

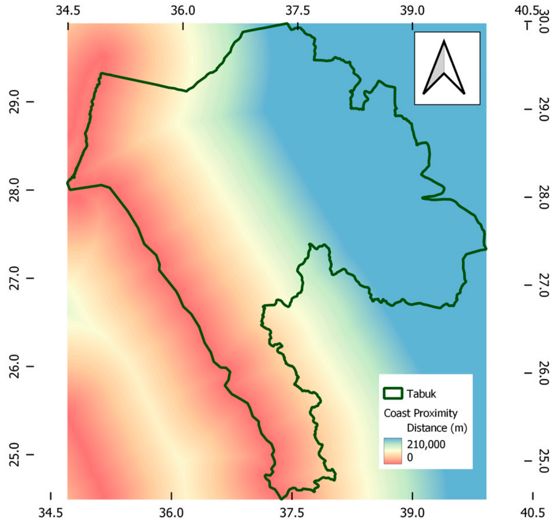

Figure 6. Proximity to coastline.

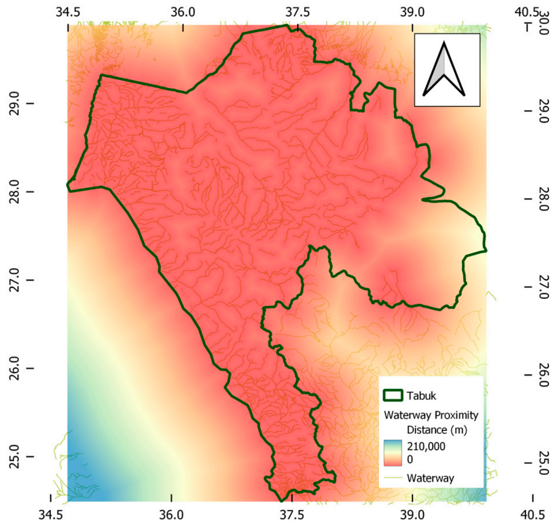

Figure 7. Proximity to waterways and wetlands.

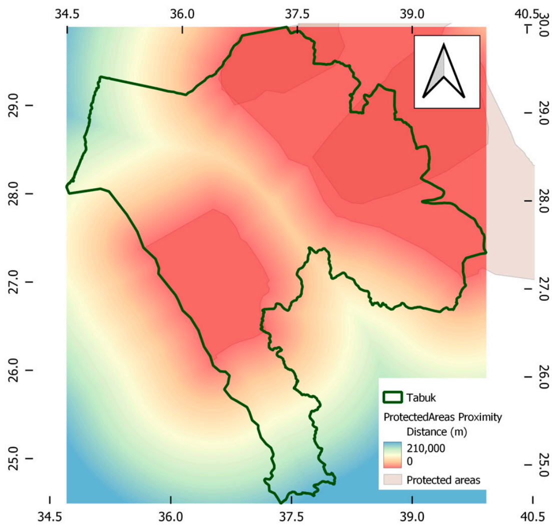

Figure 8. Proximity to protected areas.

As listed in Table 13, five suitability degrees for constructing wastewater treatment plants were established to consider the geospatial data distribution of the parameters. Land categories were ranked so that one reflected poor suitability and five indicated an extremely preferred degree of suitability for the analysed parameter's membership. Figures 9–15 show the membership classifications of roads, airports, land use, coastlines, waterways, wetlands, and protected areas. When considering road infrastructure membership, as seen in Figure 9, most of the study area is moderately preferred for constructing the treatment plant, as a careful balance needs to be established between the ease of access to the facility and its environmental and technical issues. The locations of international and private airports created the extremely preferred membership map in Figure 10. As shown in Figure 11, it is preferred that the treatment plant be located near urban areas. In Figures 12–14, the membership excludes narrow land directly adjacent to the coast, waterways, and wetlands, classifying most of the region with extreme preference to create the treatment plant. The protected lands provide a nearly strict membership division, as seen in Figure 15, dividing the region into poor or extremely preferred areas.

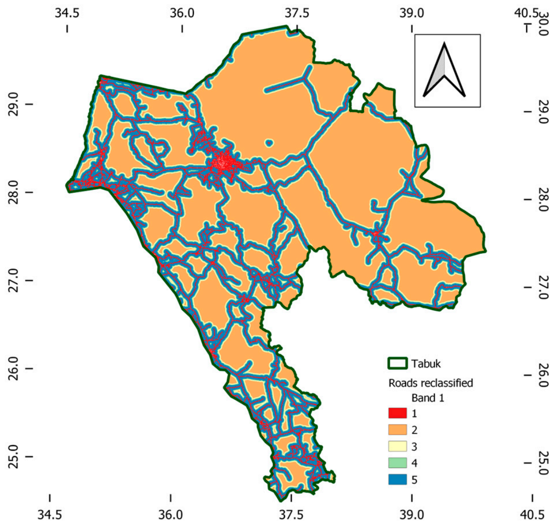

Figure 9. Roads membership map.

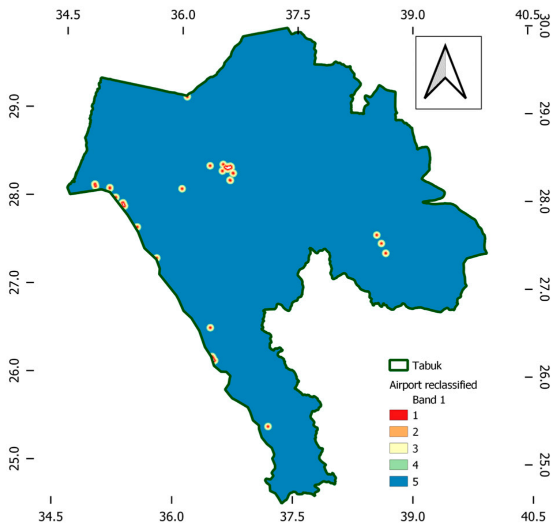

Figure 10. Airport membership map.

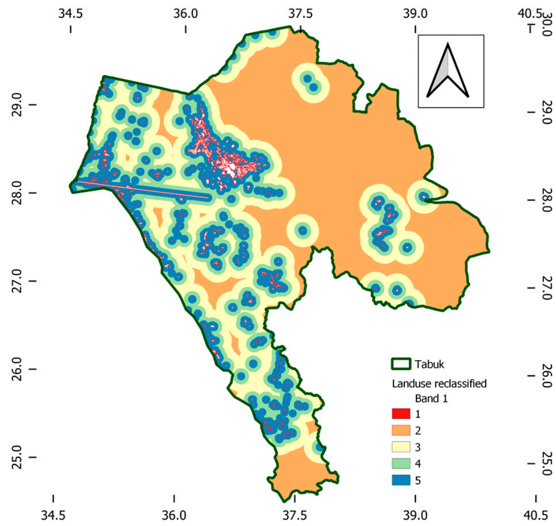

Figure 11. Urban and Land use membership map.

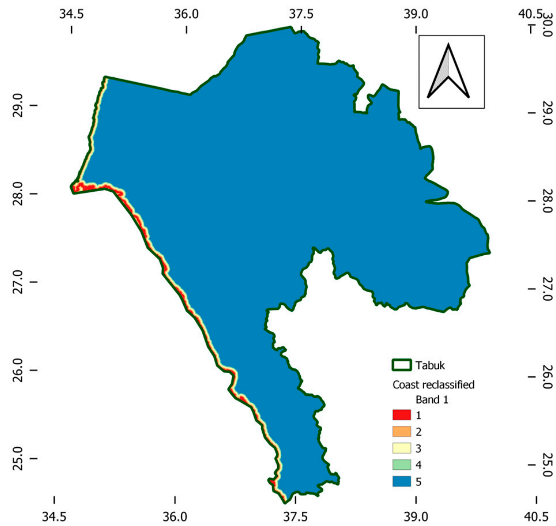

Figure 12. Coastline membership map.

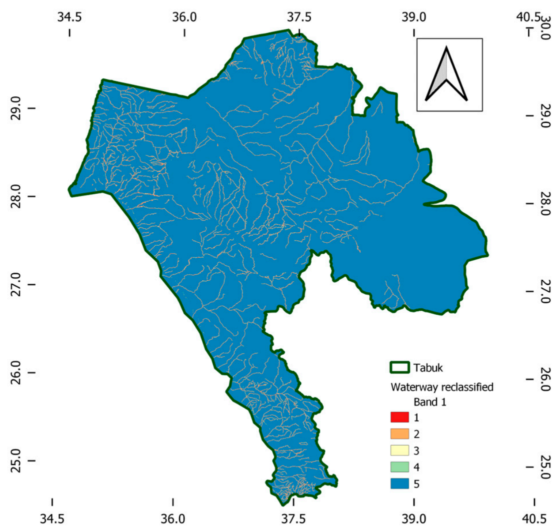

Figure 13. Waterway membership map.

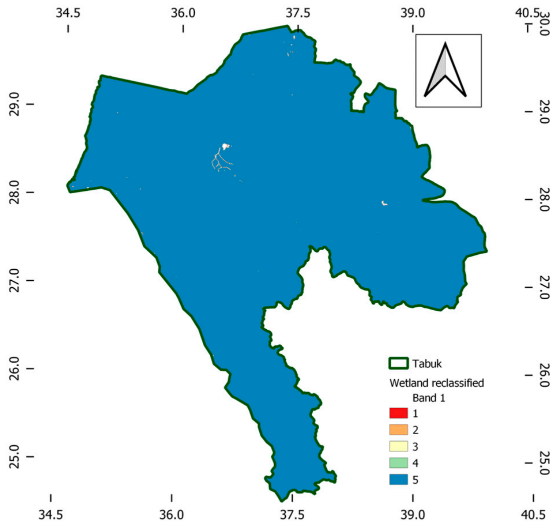

Figure 14. Wetland membership map.

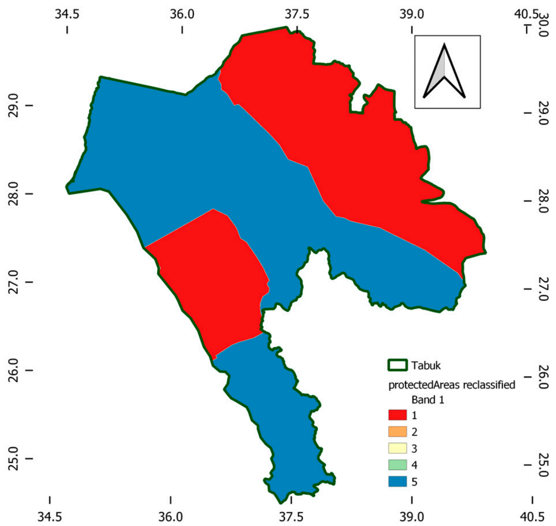

Figure 15. Protected area membership map.

The FAHP membership categories in Table 3 were then applied using different GIS techniques, including layer overlay, raster conversion, and clipping processes. Each layer was reclassified to convert the raster values to membership classes.

A suitability map for the placement of the wastewater treatment plant in the Tabuk region was eventually developed by merging the criteria weights from FAHP with the parametric proximity maps using the raster calculator tool in the QGIS software. The spatial analysis module of QGIS (Raster Calculator) was used to multiply the membership values of each layer by its aggregated FAHP weights, then adding these results to overlay the Criteria Maps to integrate GIS and FAHP weights. Layers of land use, distance from wetlands and waterways, distance from roadways and airports, and distance to the coast are inputs of the performed MCDM analysis. The result of the raster calculation was then reclassified into five categories to reflect the suitability criteria from poor to extreme preference for land. Figure 16 shows a suitability map for the selected case study. The existing wastewater treatment plants are observed to be located within extremely preferred parts of the region. However, more facilities are needed for infrastructural development in the far southern and eastern parts of the regional community.

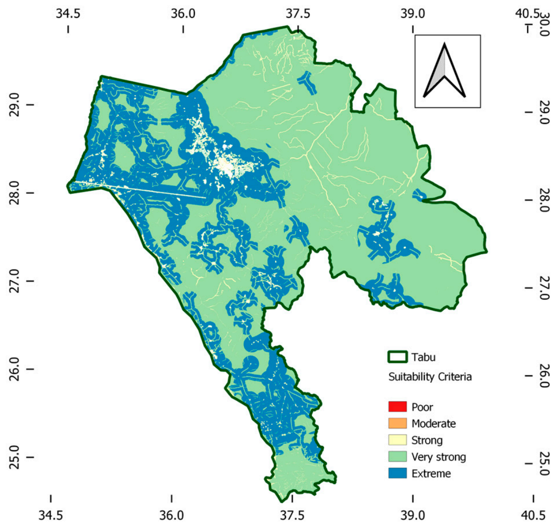

Figure 16. Suitability map for wastewater treatment plant sites in the Tabuk region.

High suitability regions of preferred to extremely preferred criteria are dominant in the region. The weight-based multiplication of layers excluded environmentally protected areas, which covered approximately half of the studied region. It can be seen in Figure 16 that the preferred areas for constructing wastewater treatment plants are focused on the northwest and southwest parts of the Tabuk region, with a buffer zone between the suitable sites and the urban areas, coast and protected areas of 500 m, 1250 m and 125 m, respectively. Table 14 shows the area of different suitability memberships as a percentage of the total region area. The results in Figure 16 and Table 15 identify the most favourable areas for a wastewater treatment plant site. This helps create effective, supported decision-making by reducing the candidate area for implementing wastewater treatment plants to nearly 31% of the region.

Table 15. Percentage of suitability memberships in the Tabuk region.

Suitability	Percentage of Area
Poor	0%
moderately preferred	0.01%
strongly preferred	2.74%
Very strongly preferred	66.44%
Extremely preferred	30.82%

In this study, the preferred areas for constructing wastewater treatment plants were determined by FAHP-GIS analysis using a range of search criteria. The decision-making process in municipal management is case-sensitive, as it depends on local parameters and preferences. In this research, seven parameters were evaluated under five main categories. The complexity of the multicriteria decision-making quest was significantly reduced when using an integrated FAHP-GIS model, making it computationally doable. The analysis accounted for conflicts with urban areas, nature reserves, intense planting, agricultural production, and forestry activities. Such site data are presented so that local administrative bodies and project developers can make supported, informed, and effective infrastructure planning decisions. The research area's conditions are essential for choosing a location for a wastewater treatment plant. Pixel size selection is a component that must be evaluated against the working region, and the use of the model is useful in terms of study explanations. This study showed that GIS is an efficient analytical system among alternative decision-support tools. This result is consistent with research on wastewater treatment plant site suitability in Iraq, confirming that GIS is a reliable analytical tool for environmental management decisions. The research results emphasise the significance of integrating GIS into decision-making processes for infrastructure development projects.

The developed framework of integrated FAHP-GIS analysis, as presented in Figure 2, can be used to solve any site selection optimisation problem. In the case of wastewater treatment plants, five main criteria were considered, as per previous studies. The geospatial parameters associated with the selected criteria depend on the case study location, social factors, and primary land use activities (industrial, agricultural, mining, etc.). Once these parameters are determined, a professional survey can be distributed to gather experts' opinions on a pairwise comparison basis. Therefore, incorporating these judgements with the methodology used in this research will result in an optimised solution for the MCDM problem.

4. Conclusions

From this research work, the following conclusions emerged:

- The optimisation of the site selection process is influenced by a variety of parameters. Spatial analysis of a given area needs to be developed to thoroughly consider all potential alternatives. FAHP analysis makes it simple to examine a wide range of potential solutions to the issue for a range of criteria.
- Multicriteria analysis of wastewater treatment plant locations considers complex factors of economic, technological, managerial, environmental, and social impacts.
- In this study, seven geospatial parameters were used to reflect the MCDM factors. GIS and FAHP tools were used to identify the ideal locations for a wastewater treatment facility in the Tabuk region. GIS is a crucial tool for resolving environmental issues due to its capacity to work with enormous amounts of spatial data.
- The results of the FAHP analysis can be incorporated into powerful GIS tools to create suitability maps that support the decision-making process.
- According to the analysis findings, the optimal location for the wastewater treatment facility required less investment and was far from the sewage receiver. The variant selection was unaffected by the weighting of the criteria being equalised.
- More geospatial parameters can be introduced to increase the model complexity, as it can be implemented in regions with similar municipal management challenges.

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References

1. General Authority for Statistics. Saudi Census: Population 2010–2022. 2024. Available online: https://portal.saudicensus.sa/portal/public/1/15?type=TABLE (accessed on 11 May 2024).
2. Abid, A.A.; Zahid, H.S.; Alatawi, F.A.; Alharbi, B.M.; Alotaibi, A.S. An Assessment of Biodiversity in Tabuk Region of Saudi Arabia: A Comprehensive Review. *Sustainability* **2022**, *14*, 10564. [CrossRef]

3. Yang, Y.; Tang, J.; Duan, Y.; Qu, Y.; Sun, F.; Li, Z. Study on the Relationship between Different Wastewater Treatment Technologies and Effluent Standards in Jilin Liaohe River Basin Based on the Coupled Model of AHP and Fuzzy TOPSIS Method. *Sustainability* **2023**, *15*, 1264. [CrossRef]
4. Oztaysi, B.; Onar, S.C.; Seker, S.; Kahraman, C. Water treatment technology selection using hesitant Pythagorean fuzzy hierachical decision making. *J. Intell. Fuzzy Syst.* **2019**, *37*, 867–884. [CrossRef]
5. Hamlat, A.; Kadri, C.B.; Sekkoum, M.; Guidoum, A.; Remada, A. Multi criteria decision making approach for selecting an alternative wastewater treatment plant site in urban areas of Laghouat (North-Central Algeria). *Euro-Mediterr. J. Environ. Integr.* **2022**, *7*, 511–530.
6. Obaideen, K.; Shehata, N.; Sayed, E.T.; Abdelkareem, M.A.; Mahmoud, M.S.; Olabi, A.G. The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus* **2022**, *7*, 100112. [CrossRef]
7. Singh, N.; Poonia, T.; Siwal, S.S.; Srivastav, A.L.; Sharma, H.K.; Mittal, S.K. Challenges of water contamination in urban areas. In *Current Directions in Water Scarcity Research*; Srivastav, A.L., Madhav, S., Bhardwaj, A.K., Valsami-Jones, E., Eds.; Elsevier: Amsterdam, The Netherlands, 2022; Volume 6, pp. 173–202.
8. Nzotcha, U.; Kenfack, J.; Manjia, M. Integrated multi-criteria decision-making methodology for pumped hydro-energy storage plant site selection from a sustainable development perspective with an application. *Renew. Sustain. Energy Rev.* **2019**, *112*, 930–947. [CrossRef]
9. Liu, Y.; Eckert, C.M.; Earl, C. A review of fuzzy AHP methods for decision-making with subjective judgements. *Expert Syst. Appl.* **2020**, *161*, 113738. [CrossRef]
10. Awawdeh, M.; Al-Rousan, Z.; Alkaraki, K. Wastewater treatment plant site selection using GIS and multicriteria decision analysis. *Arab. Gulf J. Sci. Res.* **2023**. *ahead-of-print*. [CrossRef]
11. Lyimo, N.N.; Shao, Z.; Ally, A.M.; Twumasi, N.Y.D.; Altan, O.; Sanga, C.A. A Fuzzy Logic-Based Approach for Modelling Uncertainty in Open Geospatial Data on Landfill Suitability Analysis. *Int. J. Geo-Inf.* **2020**, *9*, 737.
12. Ghorbani, N.; Makian, H.; Breyer, C. A GIS-based method to identify potential sites for pumped hydro energy storage-Case of Iran. *Energy* **2019**, *169*, 854–867. [CrossRef]
13. Villacreses, G.; Gaona, G.; Martínez-Gómez, J.; Jijón, D. Wind farms suitability location using geographical information system (GIS), based on multi-criteria decision making (MCDM) methods: The case of continental Ecuador. *Renew. Energy* **2017**, *109*, 275–286. [CrossRef]
14. Wu, Y.; Zhang, T.; Xu, C.; Zhang, X.; Ke, Y.; Chu, H.; Xu, R. Location selection of seawater pumped hydro storage station in China based on multi-attribute decision making. *Renew. Energy* **2019**, *139*, 410–425. [CrossRef]
15. Jajac, N.; Marović, I.; Rogulj, K.; Kilić, J. Decision support concept to selection of wastewater treatment plant location—The case study of the town of Kutina, Croatia. *Water* **2019**, *11*, 717. [CrossRef]
16. Gohil, M.; Mehta, D.; Shaikh, M. An integration of geospatial and fuzzy-logic techniques for multi-hazard mapping. *Results Eng.* **2024**, *21*, 101758. [CrossRef]
17. Zhou, Y.; Song, Y.; Qin, W.; Sun, J. Optimal location of wastewater treatment plants considering multiple factors: A case study of Phnom Penh. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2022**, *10*, 93–100. [CrossRef]
18. Lefta, F.A.; Hamdan, A.N.A. Integrated fuzzy logic and multicriteria decision model methods for selecting suitable sites for wastewater treatment plant: A case study in the center of Basrah, Iraq. *Open Eng.* **2024**, *14*, 20220439. [CrossRef]
19. Mansouri, Z.; Moghaddas, N.H.; Dahrazma, B. Wastewater treatment plant site selection using AHP and GIS: A case study in Falavarjan, Esfahan. *Geopersia* **2013**, *3*, 63–72.
20. Deepa, K.; Krishnaveni, M. Suitable site selection of decentralized treatment plants using a multicriteria approach in GIS. *J. Geogr. Inf. Syst.* **2012**, *4*, 19598.
21. Monica, S.; Luigia, P.; Raggi, A.; Alberto, S.; Guglielmo, I. Social life cycle assessment of an innovative industrial wastewater treatment plant. *Int. J. Life Cycle Assess.* **2021**, *26*, 1878–1899.
22. Starkl, M.; Brunner, N.; Das, S.; Singh, A. Sustainability Assessment for Wastewater Treatment Systems in Developing Countries. *Water* **2022**, *14*, 241. [CrossRef]
23. Elsadig, E.H.O.; Abdalla, G.M.T.; Eltahir, M.M.; Hayder, G.; Lakhouit, A.; Abdel-Magid, I.M.; Abdel-Magid, H.I.; Messaoud, A.B.; Yasin, A.H.A.; Sayed, O.A.; et al. Application of Fuzzy Analytical Hierarchy Process for Revising OIU Main-Campus Masterplan to Ensure Sustainable Environment. In *Sustainability Challenges and Delivering Practical Engineering Solutions: Resources, Materials, Energy, and Buildings*; Springer International Publishing: Cham, Switzerland, 2023; pp. 83–90. [CrossRef]
24. Noori, A.; Bonakdari, H.; Hassaninia, M.; Morovati, K.; Khorshidi, I.; Noori, A.; Gharabaghi, B. A reliable GIS-based FAHP-FTOPSIS model to prioritize urban water supply management scenarios: A case study in semi-arid climate. *Sustain. Cities Soc.* **2022**, *81*, 103846. [CrossRef]
25. OpenStreetMap Foundation. Open Street Map. 2023. Available online: https://www.openstreetmap.org (accessed on 8 February 2023).
26. Google, LLC. *Google Earth Pro*; Google: Mountain View, CA, USA, 2023.
27. NASA. Earth Data. 2023. Available online: http://search.earthdata.nasa.gov/search (accessed on 8 February 2023).

28. HydroSHEDS. HydroSHEDS Core Data Downloads, HydroSHEDS Project. 2024. Available online: https://www.hydrosheds.org/hydrosheds-core-downloads (accessed on 12 March 2024).
29. Singh, V.; Sardar, P.; Samadder, S. Landfill site selection in a mining dominated area using a fuzzy AHP and DRASTIC vulnerability based multicriteria decision analysis: A case study of Dhanbad, India. *Environ. Monit. Assess.* **2023**, *195*, 1172. [CrossRef] [PubMed]