

A GIS-Based Analytic Hierarchy Process for the Evaluation of Suitable Locations for the Wastewater Treatment Plant (WWTP) Site Selection in Kirkuk

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ABSTRACT

A major environmental issue in Kirkuk city is the lack of a modern and efficient Wastewater Treatment Plant (WWTP), resulting in untreated sewage being released into the Al-Khassa Stream. The aim of this research is to identify a suitable location for the WWTP in Kirkuk. The methodology involves using Multicriteria Decision Analysis (MCDA) based on Geographic Information Systems (GIS), employing the Analytic Hierarchy Process (AHP). The parameters for selecting the best site were mapped using data from multiple sources. The weights for each factor were assigned using the AHP technique. Ten parameters were considered: (1) Elevations, (2) Wind direction, (3) Land uses, (4) Proximity to rivers and streams, (5) Distance from the city, (6) Groundwater level, (7) Proximity to agricultural lands, (8) Proximity to main roads, (9) Proximity to oil and gas pipelines, and (10) Proximity to valleys. The study area was divided into three zones based on their suitability for the treatment plant, using AHP: (1) Not suitable, approximately 312947433 m²; (2) Moderately suitable, approximately 291443392 m²; and (3) Highly suitable, approximately 754136244 m². The AHP results show that the elevation, oil and gas pipelines, and distance to the city are the most influential factors, each with a weight of 10%–20%. Moderately important factors include the distance to rivers, agricultural lands, and land use, each at 10%. Less significant factors are the distance to main roads (3%), valleys (5%), groundwater level (5%), and wind direction and speed (5%). Ultimately, it was determined that the southwest areas are the best locations for the plant, as they are at lower elevations, which is beneficial from an economic and cost perspective, especially with future urban expansion. Additionally, the presence of agricultural lands allows for the use of treated water for irrigation.

Keywords-GIS; AHP; optimal wastewater treatment; site selection; Kirkuk City

I. INTRODUCTION

Well-managed water and wastewater systems are vital for improving public health and economic growth [1]. However, many regions around the world face sewage treatment challenges, posing a serious threat to the urban populations [2].

Human activities continue to disrupt the natural and urban hydrological cycles. Humans consume water, pollute it, and waste it without considering the long-term consequences [3]. In Kirkuk, Iraq, the problem is particularly severe: the city lacks a central sewage treatment plant, as the main facility is still under construction and no sewage networks exist to transport

wastewater to it. The only existing networks carry rainwater and light sewage, free of solids and waste, which ultimately discharge into a dry river channel running through the city [4]. While the small secondary treatment plants serve certain neighborhoods or complexes, they fail to cover the entire city. Given Kirkuk's hot and dry summers, scarce rainfall in winter, and the absence of major rivers or dams, the wastewater treatment and reuse will play a critical role in the future, particularly for agriculture and industrial applications [5]. With the population growth driving the water demand at nearly twice the rate of the population increase, the need for sustainable wastewater solutions is urgent.

Reliable wastewater collection and treatment systems are essential for protecting both public health and the environment [6]. Wastewater management covers all stages, including generation, storage, transport, treatment, and recovery, and is guided by the principles of health, economics, and environmental protection [7]. A major global challenge today is the growing scarcity of water to meet the needs of the expanding urban populations. One promising solution is the use of decentralized wastewater treatment systems [8]. These on-site facilities provide sustainable opportunities to reuse treated water for groundwater recharge, irrigation, firefighting, vehicle washing, and industrial activities [9]. To ensure that WWTPs operate safely without causing harm to people or the environment, careful planning is required. Site selection is a particularly critical step, as it must consider a wide range of environmental, social, and technical factors [10]. Multicriteria Decision Methods (MCDM) help structure these complex decisions, allowing decision-makers to systematically evaluate the alternatives and adjust the priorities as needed. According to [11], municipal wastewater can pose significant ecological risks, and WWTP operations are subject to strict environmental regulations, especially those related to the air quality. This means that the site selection is not only a technical issue, but also one of environmental sustainability, social acceptance, and financial feasibility [12]. Selecting the most appropriate location for a WWTP involves balancing the environmental rules, social concerns, financial costs, and technical challenges [13]. The land availability within urban boundaries is another important consideration [3]. Once the necessary data are collected, suitable methods can be applied to identify the best sites. In this study, GIS and the AHP are integrated to support decision-making [14]. AHP is an effective tool for evaluating the alternatives and assigning relative importance to different factors [9]. When combined with GIS, it enables an efficient assessment of multiple spatial options within a structured analytical framework [15]. This integration of GIS and MCDA provides a strong approach to evaluating the land suitability [16]. The specific objective of this research is to identify the optimal site for a WWTP in Kirkuk City, Iraq, by applying GIS and AHP techniques. The study evaluates various environmental and spatial factors, such as elevation, proximity to infrastructure, and the potential for treated water reuse, to support sustainable urban development while addressing the city's ongoing water scarcity challenges.

II. STUDY AREA

Kirkuk is located about 250 km² north of Baghdad in north-central Iraq. The Kirkuk Governorate covers an area of 9679 km² and is known for its religious and ethnic diversity. The Khassa Chia River passes through the city, dividing it into eastern and western parts. Kirkuk lies at approximately 35°28'5" N latitude and 44°23'31" E longitude, with an elevation of about 350 m above sea level according to the Universal Transverse Mercator System (UTMS). Administratively, it consists of 13 divisions grouped into four districts: Kirkuk, Dibis, Daquq, and Hawija. The Kirkuk district itself spans about 797 km². In 2010, the city's population was estimated at around 1.6 million. With a history dating back to 1600 B.C., Kirkuk occupies a strategic position linking the northern and central Iraq. It is bordered by the governorates of Sulaimaniyah, Erbil, Nineveh, Saladin, and Diyala. The city holds significant economic importance due to its vast oil and gas reserves, which contribute heavily to Iraq's energy sector. In addition, Kirkuk's fertile plains support extensive agricultural activities, ensuring food security and sustaining the local economy. Its location at major crossroads also strengthens its role in trade and commerce [17]. The total study area for this research covers approximately 1423743627 m², as shown in Figure 1.

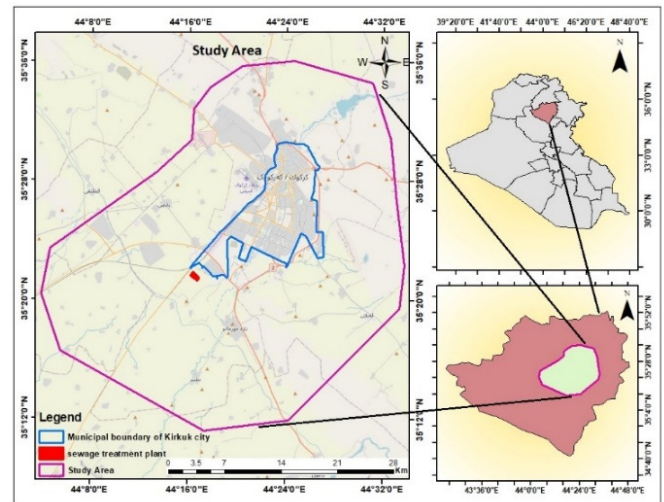


Fig. 1. The study area for the research.

III. MATERIALS AND METHODS

This study applies to ArcGIS software in combination with AHP under an MCDM framework to identify suitable locations for WWTP. The methodology integrates remote sensing and vector data, GIS-based mapping, and statistical analysis to evaluate site suitability. The key GIS tools used include contour mapping, aspect analysis, interpolation, Euclidean distance, reclassification, and map algebra. The data collection involved field visits and consultations with environmental experts in sewage systems, along with an assessment of Kirkuk's existing wastewater management challenges. The research process is summarized in the flowchart presented in Figure 2, which includes the following steps:

- Data collection (satellite imagery and vector data).
- Preprocessing (geo-referencing).
- Extraction of parameters (factors from satellite data).
- Application of AHP under MCDM.
- Modeling and suitability analysis.
- Final evaluation.

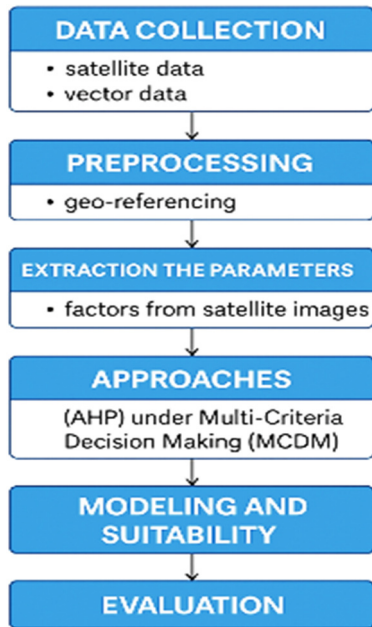


Fig. 2. Methodology flowchart.

IV. SUITABILITY CRITERIA

The selection of the most suitable site for the WWTP depends on the type and number of parameters considered. Identifying the fundamental principles related to the problem is the first step in defining the evaluation criteria [15]. Since there are no standardized techniques for establishing such criteria, the process is typically guided by objectives, literature reviews, analytical studies, and expert opinions [18]. In this study, three main considerations: environmental, economic, and social were used to develop ten parameters for the site evaluation: elevation, wind direction, proximity to rivers, proximity to roads, proximity to agricultural lands, proximity to valleys, distance from oil and gas pipelines, groundwater levels, distance from residential areas, and land use. Defining the upper and lower thresholds for each parameter required reviewing relevant literature, consulting experts, and applying local regulations from the Kirkuk municipality. Based on these sources, weights were assigned to ensure accurate and reliable outcomes.

V. CRITERIA FOR SITE SELECTION

The siting of WWTP must consider numerous criteria, and the site selection is the process of determining a suitable

location for the facilities. The criteria, as defined by most international sources, can be stated as:

A. Elevation

The investigation commenced at the highest altitudes and progressed toward the lower section of Kirkuk city, where the WWTP is proposed for installation. The elevation within the study region varied from 191 m to 644 m above the mean sea level. To derive advantages from reuse, prevent excessive pumping, and reduce working costs, a higher rank was assigned to lower elevation locations. Figures 3-5 illustrate the classification of the elevation, contour line, and aspect map for the study area in Kirkuk city.

B. Distance to River

The proximity to rivers is a key factor for both environmental and economic reasons. If the WWTP is placed too close to a river, it may breach environmental regulations, increasing the risk of contamination and ecological damage. On the other hand, locating the plant too far away can significantly raise pumping, transportation, and infrastructure costs. Therefore, an optimal distance must balance environmental protection with economic efficiency. By applying AHP, appropriate weights can be assigned to achieve this balance, ensuring that site selection supports sustainable wastewater management while minimizing the risks and costs. In this study, the Al-Khassa River and its tributary streams were included as important factors influencing the WWTP site selection, as portrayed in Figure 6.

C. Distance to City

WWTPs should be located at a sufficient distance from residential areas to prevent the negative environmental impacts and unpleasant odors. A cost-benefit analysis of the distance is proposed before the final site selection. For this study, a buffer zone of 2000 m–3000 m from residential areas was applied, in line with the safety standards set by the Kirkuk Environment Directorate. The locations within this range are considered the most suitable. Figure 7 presents the spatial distribution of the distances from urban areas.

D. Distance to Valley

Valleys can offer several advantages for WWTP siting. Natural gravitational flow reduces the need for excessive pumping, lowering the energy costs. Valleys also provide natural drainage systems that support the outflow of the treated water. However, they also pose risks, such as flooding, erosion, and structural instability, which must be carefully evaluated. By assigning appropriate weights in AHP, decision-makers can balance these benefits and risks, identifying sites that improve efficiency while maintaining technical and environmental safety. Figure 8 depicts the distance-to-valley model for the study area.

E. Distance to Main Roads

When planning and designing a WWTP, the proximity to major roads is essential to ensure accessibility. According to the Kirkuk Municipality Directorate, a minimum safety distance of 100 m must be maintained from roadways. In this study, the sites located more than 100 m from the main roads

were given higher rankings. Figure 9 shows the classification of the distances from the main roads in Kirkuk city.

F. Distance to Agricultural Areas

Sites closer to agricultural areas received higher rankings, as proximity enhances the economic benefits of using treated wastewater for irrigation. This is especially important in Kirkuk, where the absence of major rivers forces the reliance on groundwater resources. Treated water from the WWTP could help reduce the pressure on groundwater while supporting agricultural production. Figure 10 illustrates the distribution of the agricultural land across Kirkuk city.

G. Distance to Oil and Gas Pipes

WWTPs must be located at a safe distance from oil and gas pipelines due to the risks associated with leaks or accidents. In this oil-rich region, buffer zones are particularly important. According to regulations from the Iraqi Ministry of Oil (1989, reaffirmed in 2015), a buffer of 75 m-100 m on each side of a pipeline must be observed. The North Oil Company manages the routes of these pipelines. In this study, sites within 100 m of pipelines were excluded to comply with the safety regulations. Figure 11 displays the buffer zones established around the oil and gas pipelines.

H. Wind Direction

The wind direction plays a critical role in minimizing the odors and protecting public health when sitting at WWTP. If a facility is placed upwind of residential or commercial areas, unpleasant odors and reduced air quality can negatively impact communities. To avoid this, prevailing wind patterns must be carefully analyzed so that the emissions are carried away from the populated zones. In this study, wind speed and direction data were obtained from [19] and monitored throughout 2024 and the first quarter of 2025. The analysis showed that the winds generally blow southward for most of the year. Figure 12 presents the wind direction and speed patterns for the study area.

I. Ground Water Level

The WWTP site must be situated away from groundwater sources and wells to prevent the leachate leaks and subsequent contamination; hence, it requires avoidance and safeguarding via a thorough system and diligent monitoring. An expanded buffer zone between subterranean resources and the WWTP site improves the appropriateness for facility construction. The study region was divided into six classifications, as evidenced in Figure 13. Groundwater level points were obtained from the Directorate of Wells and Groundwater in Kirkuk to suit the study area.

J. Land Uses

The Land Use and Land Cover (LULC) map of the study area was classified into four categories using remote sensing imagery from the Esri | Sentinel-2 Land Cover Explorer: built-up areas, barren land, vegetation, and wetlands (Figure 14). Wetlands and streams cover only a small portion of the area, while urban areas, agricultural lands, and vegetation dominate. The classification was performed using a Sentinel-2A image from 2023 (10 m resolution) [20]. A supervised classification

approach, incorporating texture analysis and spectral signatures, was applied to accurately identify the land cover types. The resulting map provides critical insights into the land cover distribution and the impact of human activities on the local environment [21]. Beyond supporting WWTP site selection, the map also serves broader purposes in urban planning, disaster management, and resource allocation. It highlights the areas most vulnerable to environmental stress, enabling better planning and conservation strategies. Thus, the land use map is an essential tool for sustainable development and natural resource management [8].

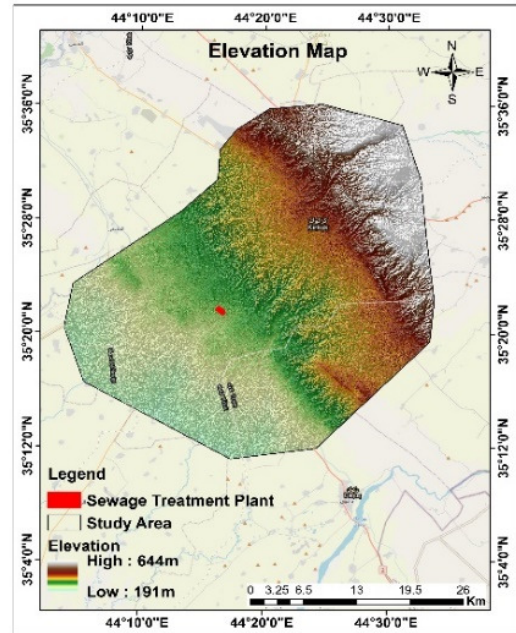


Fig. 3. The elevation map of the study area (Kirkuk city).

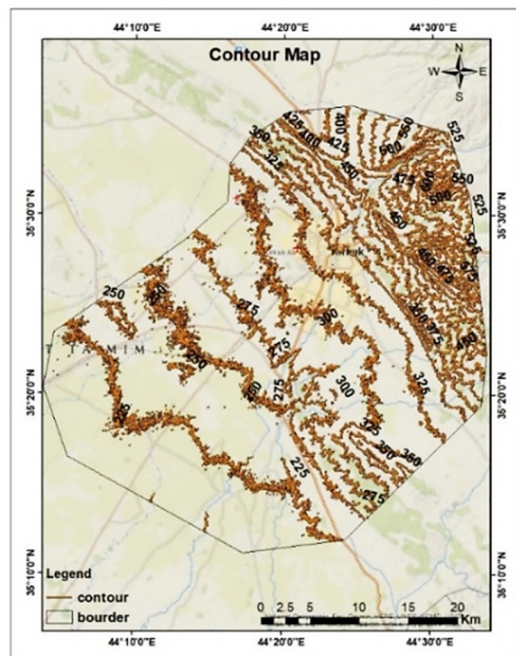


Fig. 4. The contour line map of the study area (Kirkuk city).

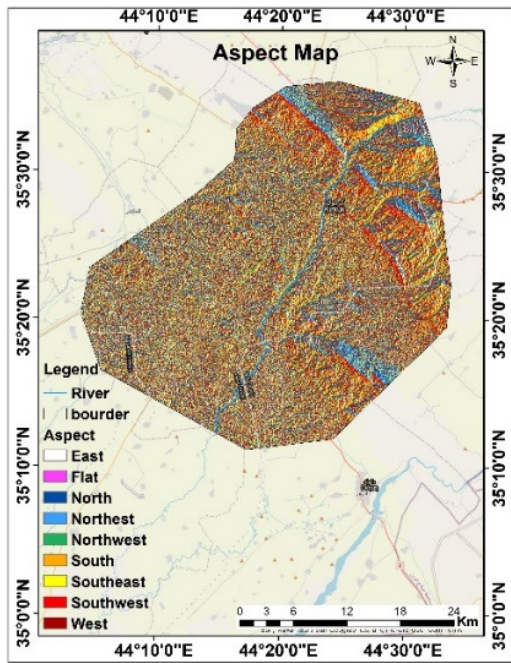


Fig. 5. The aspect map of the study area (Kirkuk city).

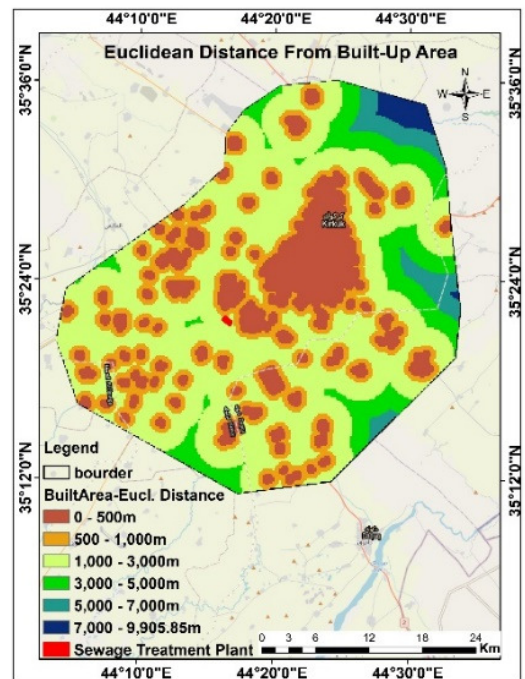


Fig. 7. The distance from the built-up area of the study area (Kirkuk city).

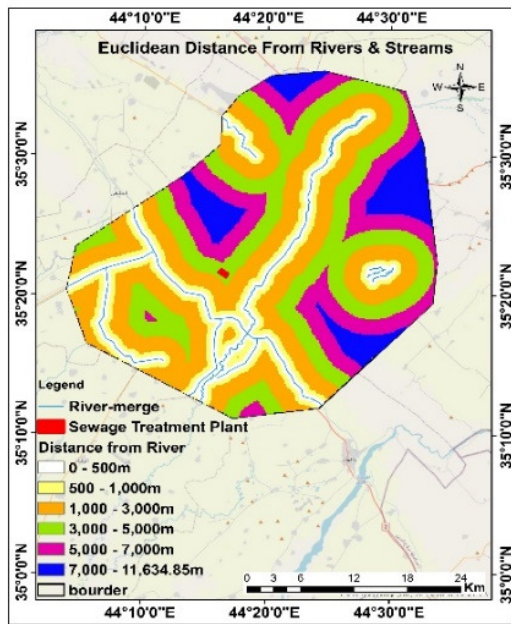


Fig. 6. The distance from rivers and streams of the study area (Kirkuk city).

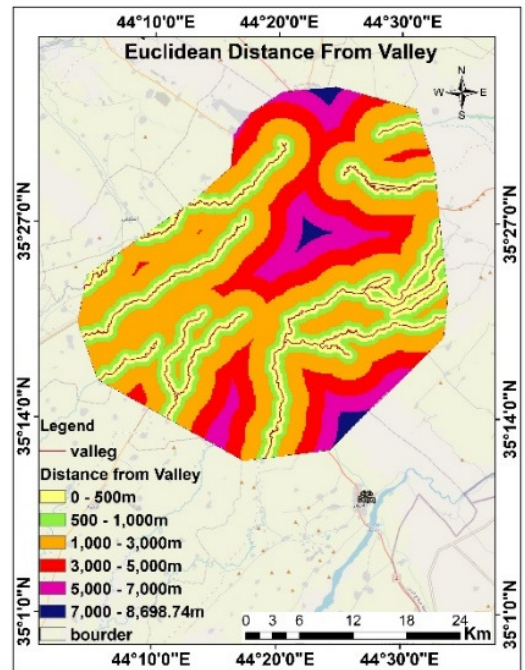


Fig. 8. The distance of the valley area to the study area (Kirkuk city).

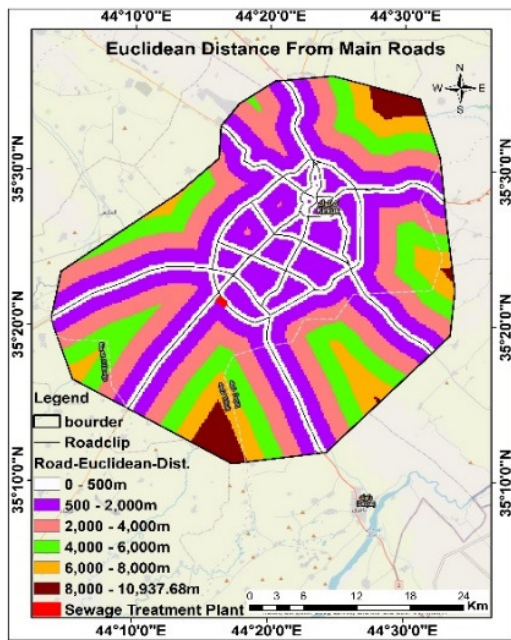


Fig. 9. The distance from the main roads of the study area (Kirkuk city).

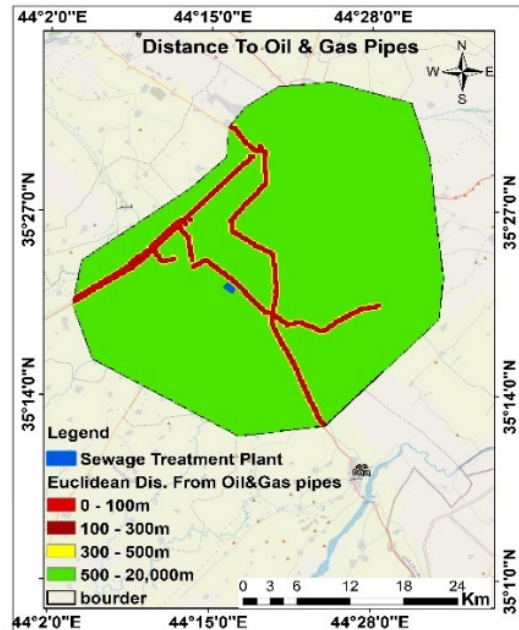


Fig. 11. The distance from oil and gas pipes of the study area (Kirkuk city).

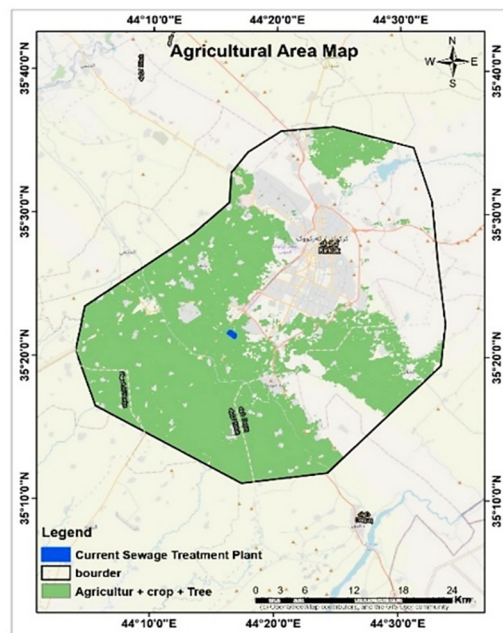


Fig. 10. Agricultural areas over the study area (Kirkuk city).

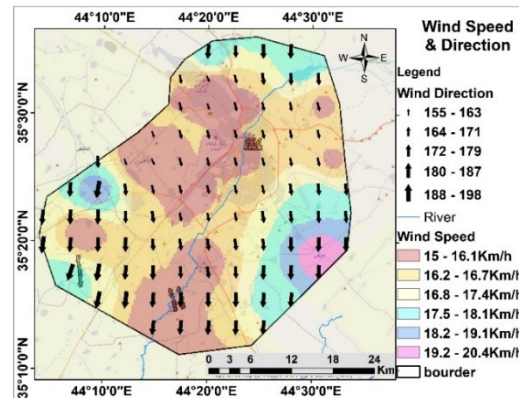


Fig. 12. The wind direction and speed over the study area (Kirkuk city).

VI. DATA DESCRIPTION

The 2010 DEM image for Kirkuk city was utilized for determining the elevations of the research region, which was obtained from the site proposed in [24], together with the sewage lines acquired from the Kirkuk Sewage Directorate. Concerning the river, streams, valley pathways, and the computation of the distances to and from them, the shapefile from the Directorate of Water Resources in Kirkuk was utilized, which served as the basis for the corresponding maps generated. To determine the distance from residential zones, the shapefile from the Real Estate Registration Directorate in

Kirkuk was used, supplemented by OpenStreetMap and a 2024 Satellite image to enhance the data concerning the villages and rural regions surrounding Kirkuk, thereby improving the precision of the maps employed in the calculations. To calculate the distances from major roadways, data provided by Kirkuk’s Municipal and Urban Planning Directorates were used.

A Sentinel-2 satellite image captured on December 4, 2024, at 11:30 a.m. [20], was processed, reclassified, and analyzed to delineate the land cover, crops, and green spaces, as well as to extract the agricultural areas. This image also served as the basis for generating the land use map. In addition, data from the North Gas and North Oil companies in Kirkuk were used to map the pipeline routes. This ensured compliance with mandated buffer zones and helped minimize the risks of water contamination associated with oil and gas infrastructure. The data were sourced from the website [19] to compute the wind direction and speed for about 10 m above the ground surface, and thus generate a corresponding map. The terrain was

observed throughout 2024 and the initial months of 2025 to ensure data accuracy. A visit was conducted to the Wells and Groundwater Department in Kirkuk to acquire a dataset of wells that delineate the elevation and level of the groundwater inside the study area, identifying roughly 80 locations along with their coordinates to enhance the precision of the computations.

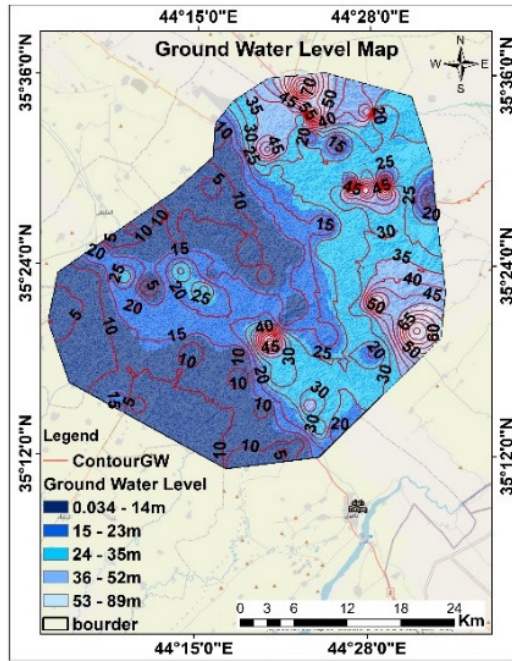


Fig. 13. Groundwater level over the study area (Kirkuk city).

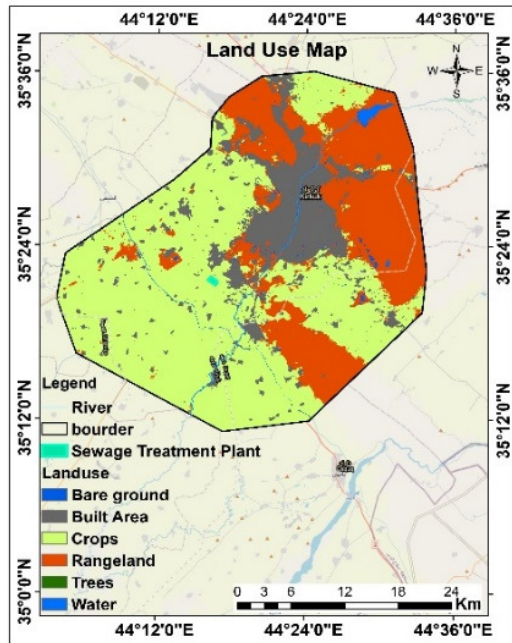


Fig. 14. Land use map over the study area (Kirkuk city).

VII. WWTP SITE SELECTION

The site selection for the WWTP involved two primary steps:

A. Analytical Hierarchy Process

The AHP-based heuristic method was applied to assign preferences using the numerical scale proposed in [23]. AHP, within the framework of MCDA, is widely used for decision-making in situations involving multiple alternatives [15]. It organizes the problem into a hierarchy consisting of goals, criteria, sub-criteria, and alternatives [24]. Pairwise comparisons are then conducted to determine the relative importance of each criterion, producing weighted values and performance measures [25]. If inconsistencies arise in the comparisons, AHP provides a mechanism to improve consistency [16]. In this study, the weights were determined through previous research and expert consultation. Each WWTP sitting criterion was evaluated on a scale of 1-9, where 9 represents the most favorable condition, as depicted in Table I [27]. A pairwise comparison matrix was then developed to compare all criteria against one another. This approach reduces the measurement error and clarifies the contribution of each factor. The reliability of these comparisons was tested using the Consistency Index (CI) [26], calculated by:

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

where (λ_{max}) is the maximum eigenvalue of the matrix and (n) is equal to the total number of criteria.

TABLE I. AHP PAIRWISE FUNDAMENTAL SCALE FOR PAIRWISE COMPARISONS

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very-very strong
9	Extreme importance

The CI of the Consistency Ratio (CR) was calculated by:

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

Reciprocal matrices at scales ranging from 1/9-9 are used to determine the Random-consistency Index (RI), as shown in Table II. If the CR is below 0.10 and the inconsistency is considered acceptable; however, if it surpasses 0.10, it is prudent to consult a more credible expert opinion and then adjust the numbers [16, 27]. Consequently, the AHP has been used to provide comparative significance to each criterion based on its expected contribution to designating the chosen site as a suitable WWTP. The AHP Excel template from the SCB Associates website was utilized to determine the weights for the criteria.

TABLE II. RANDOM CONSISTENCY INDEX

n	1	2	3	4	5	6	7	8	9	10
Random Index/RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

B. WWTP Site Suitability Map

The weights derived from the AHP matrix were combined to generate a suitability map for the WWTP site selection. Figure 15 displays the final output, where the green areas represent highly suitable locations. The classification of the study area into suitability levels was carried out using the Weighted Linear Combination (WLC) method in GIS. The weighted sum function in ArcGIS was deployed to calculate a suitability index for each cell:

$$\text{Site Suitability Index} = \sum_{j=1}^n (R_j \times W_j) \quad (3)$$

where R_j is the rank for factor j and W_j signifies the weight of a class of factor j

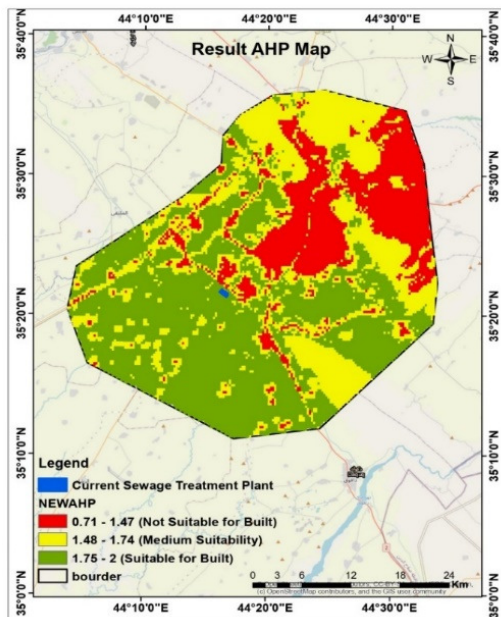


Fig. 15. AHP suitability map.

VIII. RESULTS AND DISCUSSION

The ten input data layers were carefully assessed using relevant literature, ensuring that each criterion was weighted according to its importance for WWTP siting. The AHP results showed that the elevation, oil and gas pipelines, and distance from the city were the most influential factors, with weights of 20%, 20%, and 10%, respectively. Moderate importance was assigned to the river proximity, agricultural lands, and LULC, each weighing at 10%. Factors, such as the groundwater level (3%), wind direction (5%), wind speed (5%), and distance from main roads and valleys (5% each), were found to be less significant. To validate the results, the CR was calculated at 0.1%, which is well below the 10% threshold, confirming the reliability of the rankings. These findings are consistent with those of prior studies. For instance, authors in [28] highlighted

the slope and elevation as major determinants of the WWTP siting, while factors like LULC, soil thickness, distance from highways, and water bodies were less impactful. Similarly, in [6], the slope and elevation were identified as critical parameters influencing the plant distribution. Previous studies found that certain factors had a limited influence on the WWTP site selection. For example, the proximity to water bodies or main roads showed little to no impact, while the land use/land cover, groundwater depth, and lithology were found to have only minor effects. Authors in [29] highlighted the slope and soil type as the most critical factors, noting that the water table depth, soil permeability, and proximity to rivers and roads had only a modest or negligible influence. Similarly, authors in [30] emphasized the slope and lithology as key determinants, with roads and population proximity playing much smaller roles. The AHP results in this study identified three suitability classes:

- Not suitable: approximately 312947433 m² (21.98% of the total area).
- Moderately suitable: approximately 291443392 m² (20.47% of the total area).
- Highly suitable: approximately 754136244 m² (52.95% of the total area).

As illustrated in Figure 15, the northern part of Kirkuk ranges from Unsuitable to Moderately suitable for construction, while the central areas are generally Moderately to Highly suitable. The southern regions, especially the southwest, are the most favorable locations due to their low elevation and natural flow direction. Figure 16 demonstrates the hydrology map of the study area, which confirms the southwest's suitability by supporting both future urban expansion and reduced operational costs.

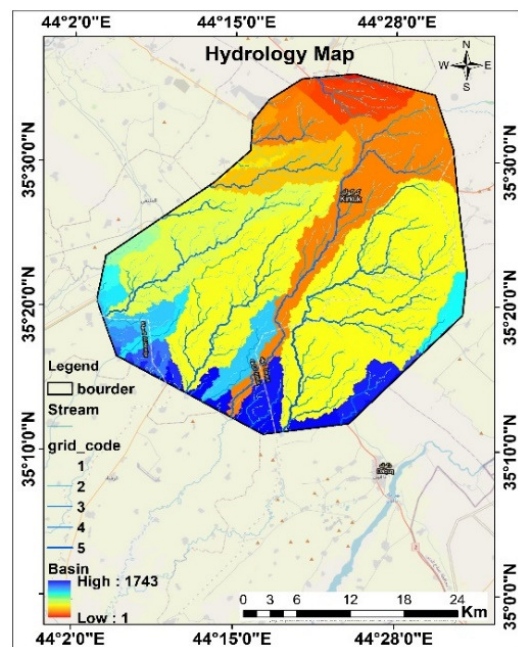


Fig. 16. Hydrology map over the study area (Kirkuk city).

IX. CONCLUSIONS

An effective approach to addressing the water scarcity in Kirkuk is the use of decentralized wastewater treatment units. Careful site selection, based on well-defined criteria, is essential to ensure both environmental safety and economic feasibility. In this study, Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) were applied to identify the suitable sites for Wastewater Treatment Plants (WWTPs) in Kirkuk, using ten criteria: (1) elevation, (2) wind direction, (3) land use, (4) distance from rivers and streams, (5) distance from the city, (6) groundwater level, (7) proximity to agricultural lands, (8) distance from main roads, (9) distance from oil and gas pipelines, and (10) distance from valleys.

The analysis identified three suitability classes:

- Site 1 (red areas): Not suitable.
- Site 2 (yellow areas): Moderately suitable.
- Site 3 (green areas): Highly suitable.

Site 3 proved to be the most favorable due to its low elevation, distance from urban areas, and proximity to agricultural lands, which would benefit from the treated wastewater.

From these findings, the following conclusions can be drawn:

- AHP is an effective tool for improving the accuracy of the site suitability studies by appropriately weighting criteria.
- The most appropriate location for WWTP is at the city's lower elevations.
- Site 3 is the best choice for WWTP placement; however, relocating slightly farther southwest would be preferable to accommodate future urban expansion.
- Treated wastewater offers many potential uses, including groundwater recharge, irrigation of farms and parks, industrial applications, and firefighting.

Finally, this study provides a valuable framework for evaluating the suitable locations not only for WWTPs, but also for other facilities, such as schools, hospitals, dams, or landfills. The criteria can be adapted or expanded based on the specific type of project and local conditions.

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