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## Delineation of Groundwater Potential Zones Using Geoinformatics and AHP Techniques in Central Erbil Sub-basin, Kurdistan Region, Iraq

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### Abstract

The most dependable source of fresh water is groundwater. Several factors, including urbanization, industry, and population growth, seriously endanger groundwater supplies. The amount and quality of groundwater supplies are significantly impacted by climate change. The Erbil sub-basin is the area of the study, where groundwater rather than surface water is the primary supply for agricultural and residential purposes. To determine the possible groundwater zones, many parameters such as rainfall, elevation, slope, drainage density, land use and cover, and lineament density are created as separate layers using GIS techniques and then put through a weighted overlay analysis. The analytical hierarchy process (AHP) was utilized to assign the weights for the different layers. In addition, the three categories of high, moderate, and low zones were stated in the GWPZ final map. Based on the data, the "High GWPZ" covers approximately 575.44 km<sup>2</sup> (21.24%), the "Moderate GWPZ" covers 1836.40 km<sup>2</sup> (67.80%), and the "Poor GWPZ" covers 296.81 km<sup>2</sup> (10.96%). Furthermore, the study's findings showed that the rainfall factor had the zone with the most substantial and adequate groundwater potential. The effect of rainfall served as the primary groundwater storage source. Thus, groundwater recharge rises conversely with increasing rainfall intensity. In addition, a strong connection was seen between the results and the well-static water level data used to validate the results. As dependable findings were produced with the proposed technique, future management plans incorporating natural and artificial recharge practices may be created in these locations with effectiveness.

**Keywords:** GWPZ, AHP, GIS, central Erbil, Kurdistan Region.

### تحديد مناطق المياه الجوفية المحتملة باستخدام تقنيتي المعلوماتية الجغرافية والتسلسل الهرمي التحليلي لحوض أربيل المركزي، إقليم كردستان، العراق

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### الخلاصة

إن المصدر الأكثر اعتماداً للمياه العذبة هو المياه الجوفية. وتتعرض إمدادات المياه الجوفية لخطر شديد بسبب عدد من العوامل، بما في ذلك التوسع الحضري والصناعة والنمو السكاني. وتتأثر كمية ونوعية إمدادات المياه الجوفية بشكل كبير بتغير المناخ. أضف الى ذلك، تتأثر المتغيرات التي تؤثر على إعادة شحن المياه

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الجوفية بشكل ملحوظ بالتغيرات في المناخ. وكثيراً ما يتفاقم انخفاض مستويات المياه الجوفية بسبب الرياح الموسمية غير المنتظمة وإمدادات المياه السطحية ذات الجودة الرديئة. ويشكل حوض أربيل الفرعي منطقة الدراسة، حيث تشكل المياه الجوفية وليس المياه السطحية المصدر الأساسي للأغراض الزراعية والسكنية. ولتحديد مناطق المياه الجوفية المحتملة، يتم إنشاء العديد من المعالم مثل هطول الأمطار والارتفاع والمنحدر وكثافة الصرف واستخدام الأراضي والغطاء وكثافة الخطوط كطبقات منفصلة باستخدام تقنيات نظم المعلومات الجغرافية ثم يتم إخضاعها لتحليل تراكمي مرجح. وتم استخدام عملية التسلسل الهرمي التحليلي لتعيين الأوزان للطبقات المختلفة.

ومما يجدرنكره، تم تحديد الفئات الثلاث للمناطق المرتفعة والمتوسطة والمنخفضة على الخريطة النهائية لمنطقة المياه الجوفية. وبناءً على البيانات، تغطي "منطقة ذات إمكانات عالية للمياه الجوفية" ما يقرب من 575.44 كيلومترًا مربعًا (21.24%)، وتغطي "منطقة ذات إمكانات متوسطة للمياه الجوفية" 1836.40 كيلومترًا مربعًا (67.80%)، وتغطي "منطقة ذات إمكانات مياه الجوفية ضعيفة" 296.81 كيلومترًا مربعًا (10.96%). وأضيف إلى ذلك، أظهرت نتائج الدراسة أن عامل

هطول الأمطار تعد المنطقة ذات الإمكانيات الأكبر والأكثر ملاءمة للمياه الجوفية. وكان تأثير هطول الأمطار بمثابة المصدر الأساسي لتخزين المياه الجوفية. و نتيجة لذلك، يرتفع معدل إعادة شحن المياه الجوفية بشكل معاكس مع زيادة شدة هطول الأمطار. بالإضافة إلى ذلك، لوحظ وجود ارتباط قوي بين النتائج وبيانات مستوى المياه الثابتة في البئر التي تم استخدامها للتحقق من صحة النتائج. ونظرًا لأن النتائج الموثوقة تم التوصل إليها باستخدام التقنية المقترحة، فقد يتم إنشاء خطط إدارة مستقبلية تتضمن ممارسات إعادة الشحن الطبيعية والاصطناعية في هذه المواقع بفعالية.

## 1. Introduction

Groundwater represents one of the most intensively used natural resources in the world. Groundwater extraction has increased substantially over the past few decades due to easily accessible drilling and pumping technology [1-3]. The most significant source of freshwater for industry, agriculture, and household use is groundwater [4-6]. The primary supply of freshwater is groundwater. However, the resource is in danger since policymakers have not paid enough attention to the lack of a systematic examination of its economic significance [7]. Roughly 43% of all water extracted for agriculture and 49% for household use worldwide comes from groundwater. Up to 55% of irrigated lands in the Middle East and South Asia, where irrigation has been essential to agriculture, rely on groundwater [7, 8].

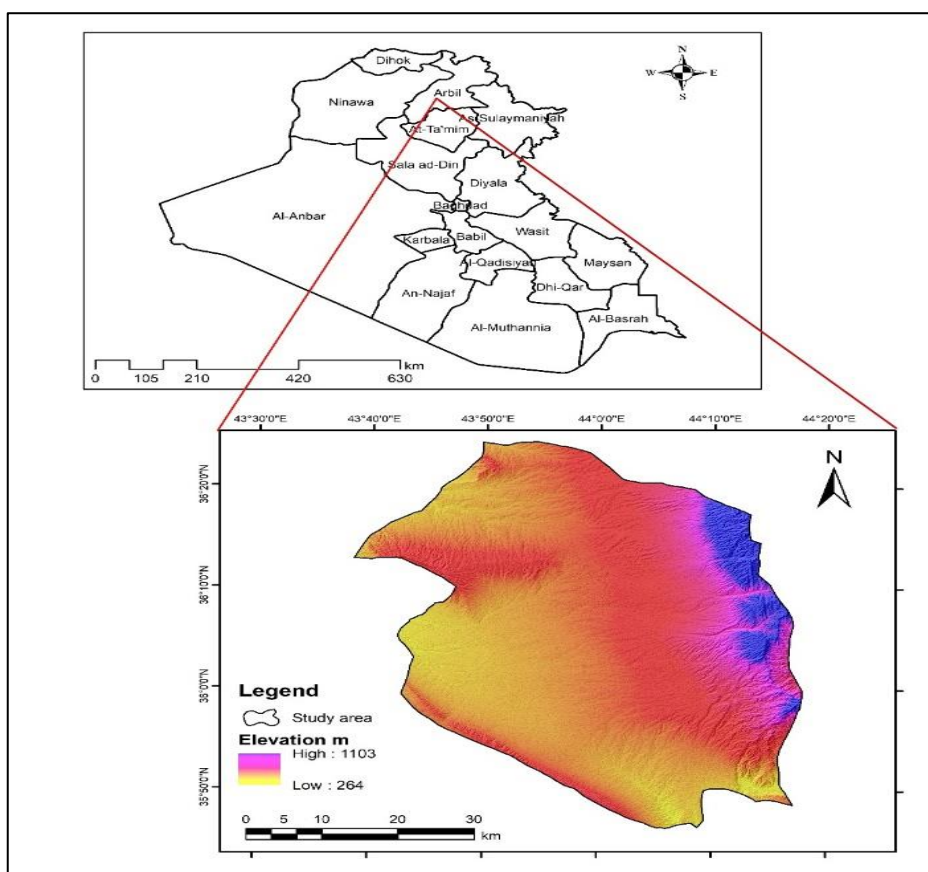
Iraq has suffered from a shortage of groundwater over the past 30 years, and there have been significant changes to Iraq's hydrological conditions due to pressures arising from the high demand for water resources and a continuing fall in their quantity rates [9]. The unanticipated decline in water reservoir, lake, and river levels is reflected in the decline in precipitation and surface water levels during the past three decades. The Tigris and Euphrates Rivers, the primary water source for the entire country, are now less than one-third of their original levels. As per the Ministry of Water Resources assessment, a significant scarcity of potable water has affected millions of Iraqis [10]. This study focuses on Erbil's central sub-basin in the Kurdistan Region of Iraq.

The analytic hierarchy processes AHP, GIS, and satellite remote sensing data, which are the best tools for understanding the delineation of the groundwater potential zone. By applying Numerous criteria elements and scenarios, the AHP technique delineates groundwater potential zones and results in complicated decision-making processes; in particular, it integrates all aspects of the decision problem into a single Target feature [11].

[12] have used GIS and AHP to delineate groundwater potential zones in Karnataka, India; likewise, AHP and GIS were used to detect groundwater potential zones for a tropical River Basin in the Western states of India [13]. [14] have used AHP to assess the groundwater potential zone in the Erbil basin, Iraq. [15] have used AHP and GIS to classify the suitability of groundwater for agriculture in the Lesser Zab River basin in Iraq. In addition, [16] has used AHP and GIS to delineate groundwater zones in Zakho, Iraq. The main aim of this study is to use GIS, remote sensing, and AHP approaches to determine the Central-Erbil basin groundwater potential zones for sustainable Development and management.

## 2. Study area

The Central-Erbil Sub-basin in Northern Iraq is located between latitudes  $35^{\circ} 40' N$  and  $36^{\circ} 20' N$  and longitudes  $43^{\circ} 40' E$  and  $44^{\circ} 10' E$ . The total area is around  $2726 \text{ km}^2$  (Figure 1). Due to its semi-arid environment, the study area has cold winters and dry, hot summers. There is a mean of 400 mm of rainfall each year from October to May, mainly rainfall. Groundwater, rainfall, and surface water represented by the Greater Zab River (GZR) are the three main water sources in the Erbil basin. The primary aquifer system is composed of Miocene-Pliocene strata and recent alluvial deposits. According to [10], this intergranular aquifer system is often very productive. The selected area contains the greatest groundwater reservoirs in the Erbil province and is one of Iraq's most significant groundwater aquifers. The aquifer comprises conglomerates, sandstones, sand, and gravel [17].



**Figure 1:** Map shows the location of study areas.

## 3. Materials and Methodology

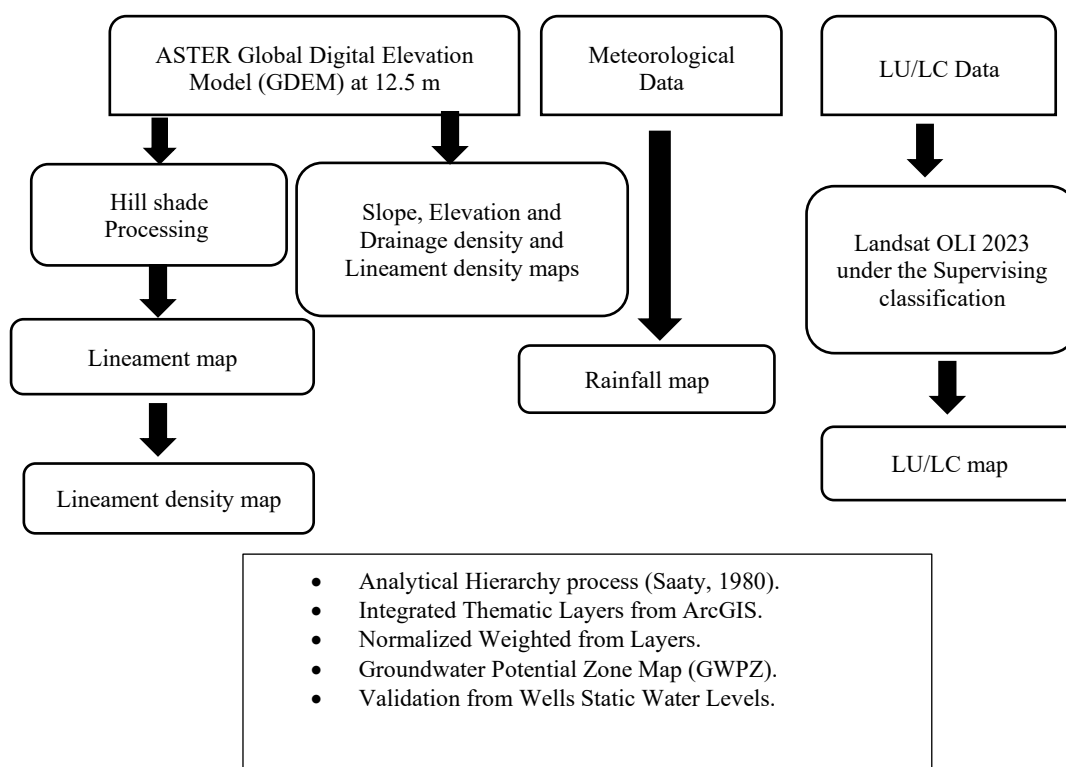
### 3.1 Data Acquisition

This study used different factors to determine Erbil's groundwater potential zone (GWPZ). For this purpose, seven elements that manage groundwater recharge were identified: rainfall,

elevation, slope, land use land cover (LULC), drainage-length density (DD), and lineament-length density (LD). The ASTER Global Digital Elevation Model (ASTER GDEM) with 12.5m resolution was obtained from the United States Geological Survey (USGS). Elevation, slope, drainage length, and lineament-length density were mapped from a digital elevation model. The Landsat operational land imager (OLI) acquired in 2023 was used for the land use land cover map. Using the Kriging interpolation method, the rainfall map was created from four weather stations in Erbil. Kriging is the most used technique for estimating rainfall spatially. The General Directorate of Meteorology and Seismology of the Kurdistan Region of Iraq provided the rainfall data. Finally, The Director of Groundwater in Erbil province provided the static water level data collected from 43 monitoring wells randomly dispersed throughout the study area. These data were used to validate the GWPZ map.

### 3.2 Methodology

The obtained data was used to create a themed map for each of the seven factors. Thus, the integrated GIS and the AHP approach were used to assign the weights of various themes and their relevant attributes. Then, raster computation overlapped the seven created thematic layers to map and determine possible recharging zones. Then, the recommended approach was validated by comparing the map produced with the static water level map. Figure 2 shows the flow chart generated by the methodology of the GIS-AHP model.



**Figure 2:** Flow chart of GIS-AHP Model creation.

#### 3.2.1 Delineation of Thematic Layers

##### 3.2.1.1 Rainfall

The main source of recharging is rainfall. Rainfall is a crucial hydrologic element due to how it affects the quantity of water that may percolate through the structure of groundwater [18]. Five categories were created from the resulting map: 320-370, 380-420, 430-490, 500-590, and 600-680 mm/year (Figure 3a). The study showed a significant correlation between GWPZ and rainfall, with rainfall receiving the highest AHP weight.

### 3.2.1.2 Elevation

Elevation is important in creating slope maps, drainage networks, and basin delineations. [19, 20] have found an inverse connection between elevation and groundwater recharge, meaning that surface water prefers to flow towards lower elevations and that the probability of surface water collection and infiltration increases with decreasing height. The height of the research region is divided into five classes such as < 400, 400-600, 600-800, 800-1000, and > 1000 meters above sea level (Figure 3b).

### 3.2.1.3 Slope

The slope is the ground surface inclination of a terrain, expressed in degrees between 0 and 90. Based on [21, 22], the slope is a crucial component that influences the direction of the flow of water and regulates the processes of recharge of groundwater and discharging. On the other hand, mountainous regions with steep slopes have less capacity for infiltration and an enormous potential for runoff [23]. There are noticeable variations in the slope's geographical distribution between the northeastern and southwest regions of the study area. Also, in the study area, the slope layer was divided into five classes, which are < 2°, 2° to 6°, 6° to 10°, 10° to 15°, and > 15° degrees (Figure 4a).

### 3.2.1.4 Land Use / Land Cover

LULC is another criterion for indicating suitable locations for artificial groundwater recharge, which is land cover [23]. Erbil is becoming an increasingly urbanized city, which has increased the potential impact of human activity. Different land cover types result in different evapotranspiration levels, infiltration, and runoff. According to [24], agricultural land has higher rates of infiltration and fewer components of runoff, while barren and built-up areas often have higher runoff and lower rates of infiltration and recharging. In the study area, soil and vegetation are usually replaced by built-up areas. Five categories were created from the land cover map: hilly area, built-up area, bare soil, agricultural area, and vegetation (Figure 4b).

### 3.2.1.5 Drainage-length Density

The frequency of streams within the drainage basin is called the drainage density. Drainage density is calculated technically by dividing the total length of streams by the drainage basin area, measured in (km/km<sup>2</sup>) [25]. The lithology, geological structure, soil characteristics, slope angle, infiltration rate, and plant cover are some factors that affect how a drainage system forms. Rainfall infiltration decreases with increasing drainage density and inversely as well. The development, surface runoff, rock permeability, and infiltration rate of a channel system will be determined using DD. Following its importance in identifying suitable locations for groundwater recharge, the DD map was divided into five categories: (very poor, poor, medium, high, and very high) (Figure 5a).

### 3.2.1.6 Lineament-length Density (LD)

A visible curving or straight linear pattern on the ground is called a lineament. It might be geological features such as faults, folds, river systems, fractures, and different discontinuity surfaces or man-made constructions like highways and canals. Additionally, lineaments could be identified by remotely sensed data or through surveys in the field. According to [26], the lineament map is a crucial resource for groundwater studies, as evidenced by the numerous successful groundwater studies conducted to identify drilling locations. According to [27], an intersection of lineaments defines a possible zone for groundwater recharge. Location with a high LD also has great potential for groundwater recharge since it has a higher secondary

porosity. The LD map is categorized into four groups such as (very poor, poor, medium, and high) (Figure 5b).

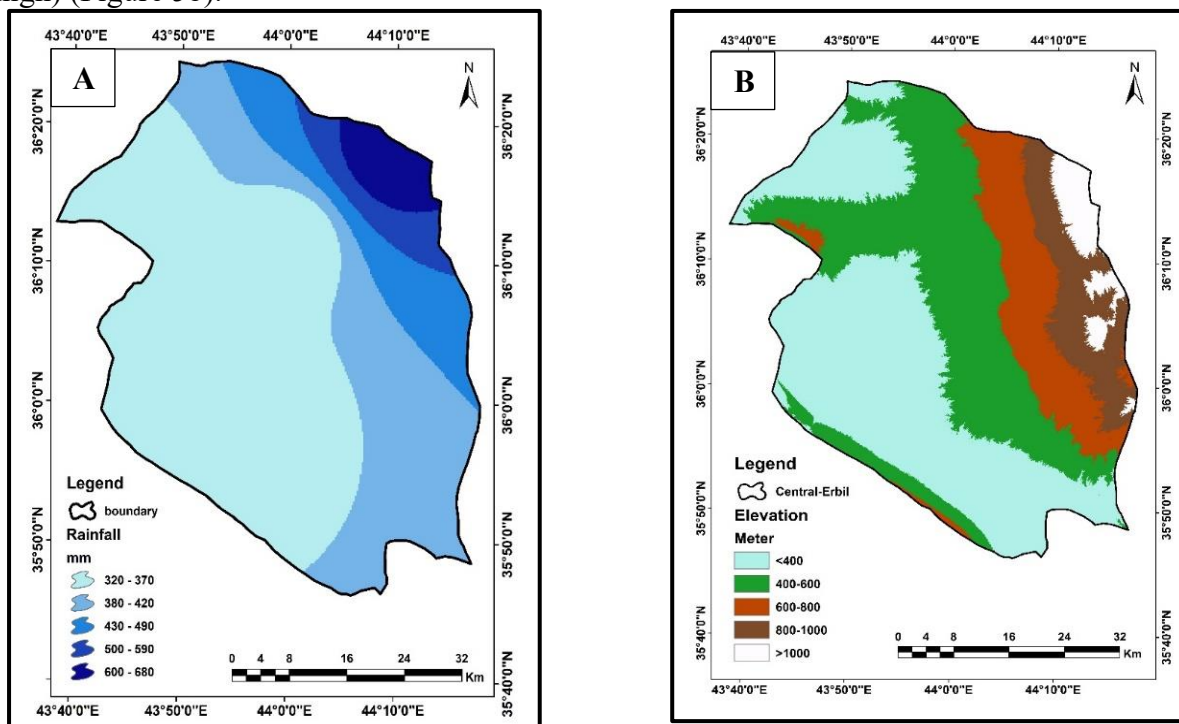


Figure 3: A: Rainfall interpolation map and B: Elevation distribution map.

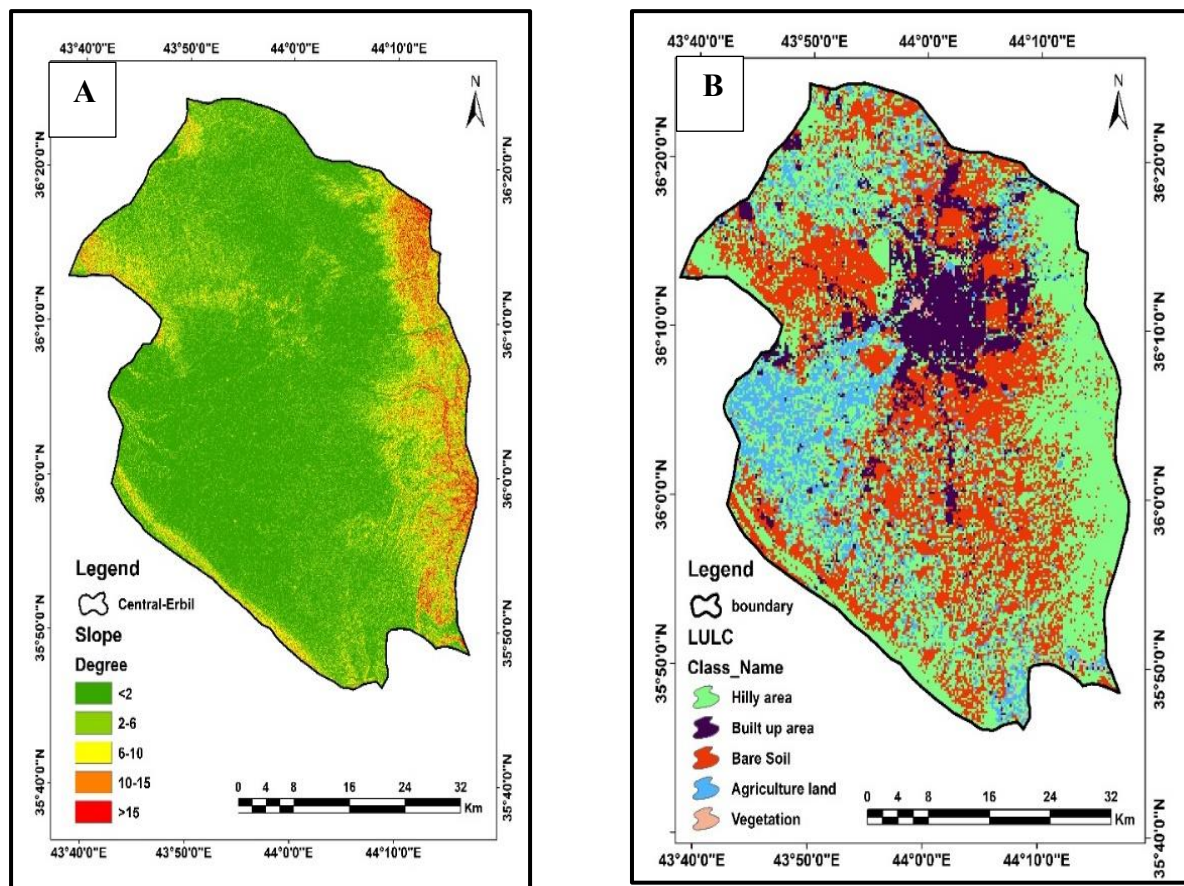


Figure 4: A: Slope distribution map in degree and B: LU/LC map.

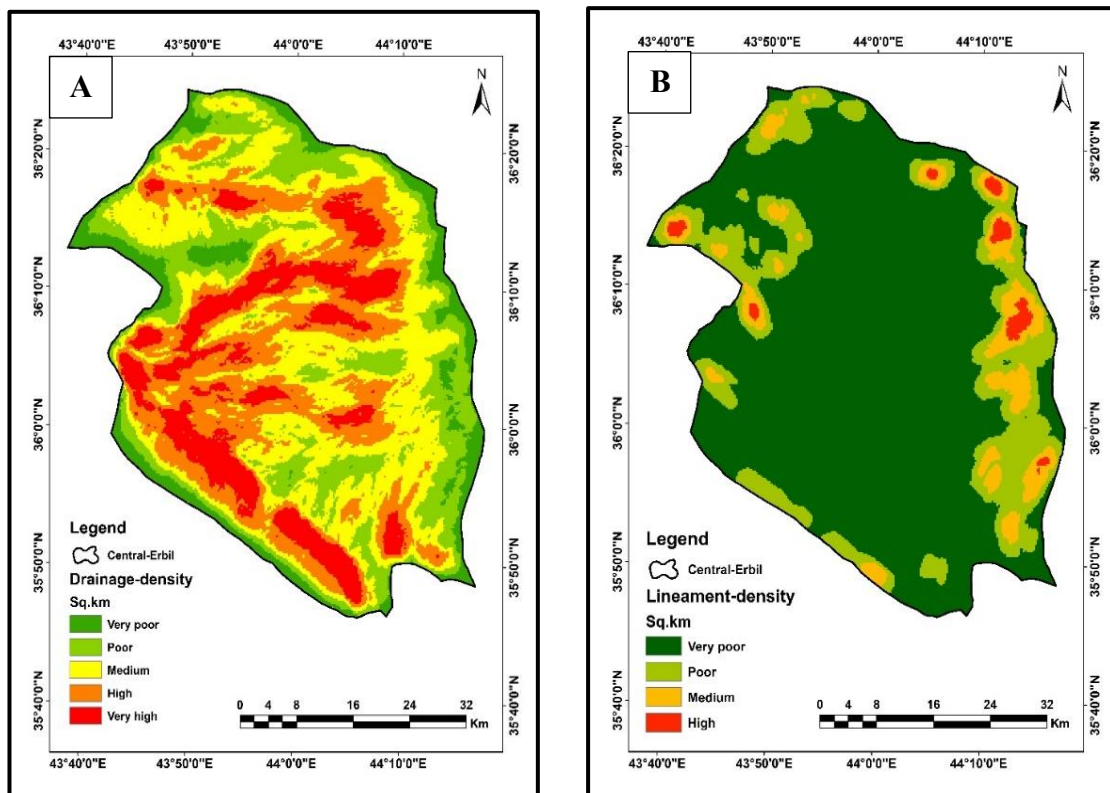


Figure 5/ A: drainage density map and B: lineament density map.

3.2.2 Analytic Hierarchy Process (AHP)

AHP is an effective strategy for establishing objectives and reaching the right conclusion in a decision-making process considering qualitative and quantitative factors [11]. This approach evaluates several parameters based on standards to resolve intricate decision-making situations [28]. The hierarchy and other parameters may vary from higher to lower levels. Both subjective and objective criteria can be considered in this method; additionally, the AHP uses a pairwise comparison of several parameters to determine GWPZ. In this study, a pairwise comparison matrix was created to evaluate the weight or rank of each parameter and its sub-classes. A pairwise comparison matrix was created to evaluate the weight or rank of each parameter and its subclasses. Next, each parameter and its sub-classes were rated against the other parameters and their sub-classes using a pairwise Saaty comparison scale ranging from one to nine (Table 1) [28]. Equation one is representing the Pairwise comparison matrix:

$$M = \begin{pmatrix} 1 & a_{12} & a_{13} & \dots & \dots & a_{1n} \\ a_{21} & 1 & a_{22} & \dots & \dots & a_{2n} \\ a_{31} & a_{32} & 1 & \dots & \dots & \dots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix} \tag{1}$$

Equation (2) is used to determine the weighting.

$$a_{ij} = \frac{\text{weight of attribute } i}{\text{weight of attribute } j} \tag{2}$$

**Table 1:** The one-to-nine scale of factors impact according to [23].

Strength of Significance	Explanation
1	Equal significance
3	Medium significance
5	Strong
7	Very strong significance
9	Maximum significance
2,4,6 and 8	Interim number between two adjacent numbers

**Table 2:** Calculating the normalized weights percentage for thematic layers.

Factors	R	E	S	DD	LULC	DL	Normalized weight	Normalized weight (%)
Rainfall	1	2	2	3	3	4	0.302	30.20
Elevation	0.5	1	4	3	3	6	0.282	28.20
Slope	0.4	0.25	1	3	3	5	0.185	18.50
DD	0.34	0.5	0.5	1	2	3	0.117	11.70
LULC	0.25	0.34	0.5	0.5	1	2	0.070	7.00
DL	0.17	0.17	0.2	0.34	0.5	1	0.044	4.40
Sum.	2.66	4.26	8.2	10.84	12.5	21	1	100.00

### 3.2.3 The Integration of Thematic Layers

This study considered six factors affecting GWPZ: rainfall, elevation, slope, DD, LULC, and DL. Every aspect affects GWPZ scenarios differently, so it is important to consider and evaluate each one's effect on GWPZ. A pairwise comparison matrix was created, and the [11] rating scale was used to compare each factor to the other (Table 1). For example, rainfall is specified as a higher weight on the comparison scale than other elements because it directly predicts GWPZ in the area. Elevation was also assigned the second-highest value after slope according to its significance. After assigning values, each criterion's effect on GWPZ was examined to determine its weight. Table 2 shows the factor weights and the effects of the pairwise comparison matrix. Finally, Table 3 shows the factors' weights.

**Table 3:** Arrangement of factors controlling the GWPZs in the study area.

Factor	Class	Groundwater Potentiality	Class Rank	Normalized Weight (%)
<b>Rainfall (mm)</b>	< 370	Very low	2	30.20
	380-420	Low	3	
	430-490	Moderate	4	
	500-590	High	5	
	> 590	Very high	7	
<b>Elevation (m)</b>	< 400	Very high	8	28.20
	400-600	High	6	
	600-800	Moderate	5	
	800-1000	Low	3	
	> 1000	Very low	2	
<b>Slope (Degree)</b>	< 2	Very high	7	18.50
	2-6	High	6	
	6-10	Moderate	4	
	10-15	Low	3	
	> 15	Very low	1	
<b>Drainage density (Dd)</b>	Very poor	Very high	7	11.70
	Poor	High	5	
	Moderate	Moderate	4	
	High	Low	3	
	Very high	Very low	1	
<b>LULC</b>	Hilly area	Very low	3	7
	Built up area	Very low	2	
	Bare soil	Moderate-High	4	
	Agricultural area	High	6	
	Vegetation	Very high	7	
<b>Lineament density (DI)</b>	Very poor	Very low	1	4.40
	Poor	Low	3	
	Moderate	Moderate	5	
	High	High	6	

## 4. Results

### 4.1 Groundwater Potential Zone Mapping

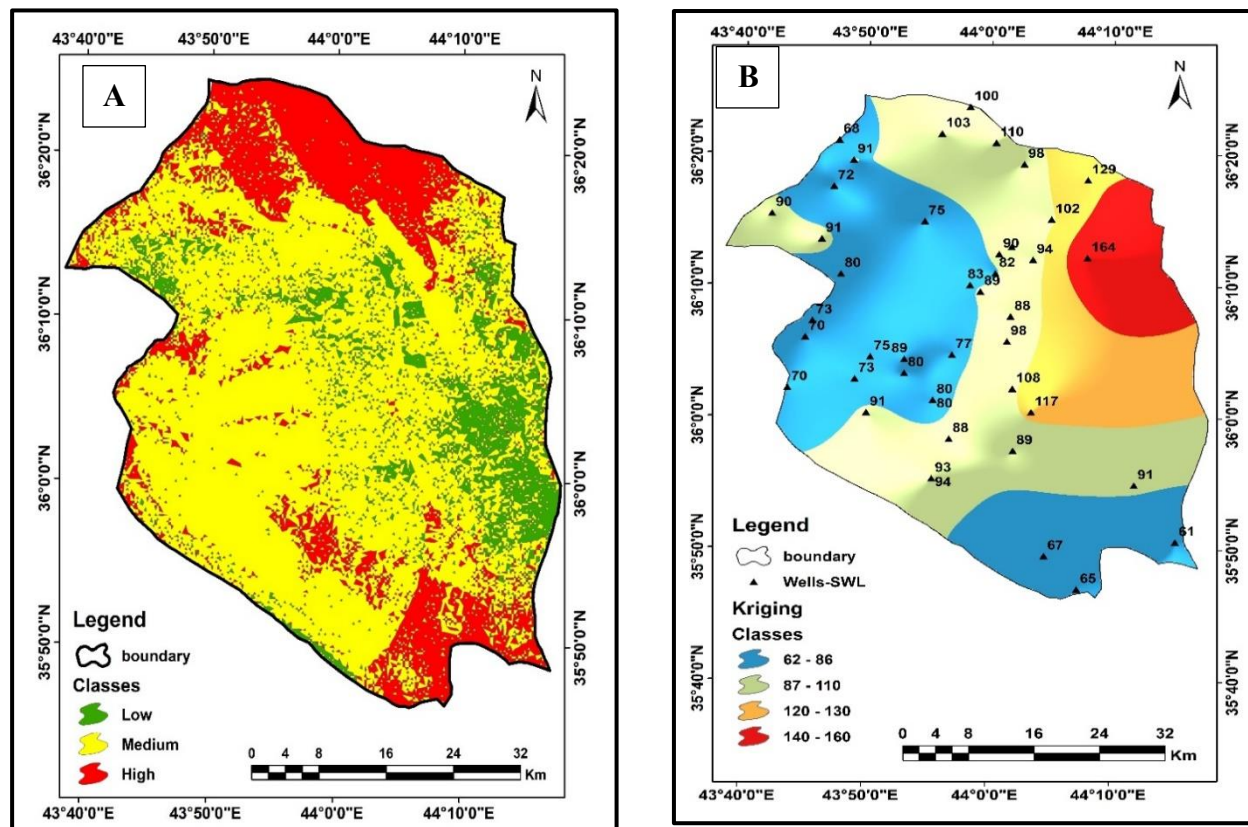
The weights of the parameters computed from the AHP and sub-criterion scores were utilized to create a map of GWPZ in the Erbil sub-basin using the weighted overlay analysis method (Table 3). This study identifies three classes in the final map: poor, moderate, and high (Figure 7a). The results show that high GWPZ covers 575.44 km<sup>2</sup> (21.24%) of the study area. These areas are located in the north and south of the study area. A significant amount of vegetation, elevation above 650 meters, moderate to steep slopes, bedrock mainly composed of limestone and dolomitic limestone, well-drained soils, and minimal human activity are all associated with these regions. Around 1836.40 km<sup>2</sup> (67.80%) of the area is classified as moderate GWPZ, mostly located in the central and western parts of the study area. These regions contain moderate slopes, limited vegetation cover, 400–300 mm of rainfall, heights between 450 and 600 m covered in recent deposits, and a significant level of human activity. Finally, the result shows 296.81 km<sup>2</sup> (10.96%) is under the poor GWPZ, which covers the

eastern and some patches of the central part of the study area. There is less vegetation cover and less rainfall in these locations. These are generally gently sloped, with an elevation of less than 500 meters, are covered in recent deposits and mudstone, and are heavily impacted by industrial and urbanization activities.

According to the findings, groundwater in the Erbil basin flows from east to west according to the area's geography. Furthermore, the eastern part of the study area has deeper groundwater levels than the western part, which has shallower groundwater levels. Human activities, varied lithology, elevation variations, and unpredictable or low rainfall will likely affect GWPZ in the Erbil sub-basin. Because of the erratic or infrequent rainfall in the area, droughts and the resulting vegetation degradation are frequent occurrences.

#### 4.2 Validation of GWPZ maps

Static water level data was utilized for the validation. For this purpose, data from 43 monitoring wells drilled in the studied area were used (Figure 7b). Apart from the visual comparison between the GWPZ and the static water level, the interpolation map was utilized to confirm the precision of the model utilized in locating appropriate locations for artificial aquifer supply.



**Figure 7** A: Groundwater potential zones map (GWPZ) of the study region and B: Static water level map of the study area.

## 5. Discussion

The potential of AHP and GIS-based modeling is shown in GWPZ delineation based on the study's results. This approach was carried out by integrating the slope, LULC, rainfall, elevation, drainage, and lineament density. The research area's topography and land types are characterized by many parameters that influence the delineation of the GWPZ. The AHP approach was applied in this study to assign weights to these criteria. This result shows that

all parameter weights were generated consistently and that the pairwise comparison matrix for GWPZ had good stability [11]. The model output dependency was also repeatedly examined using various input parameter weights to observe how the output results changed. As a result, several criteria weights were applied to determine the GWPZ. According to the sensitivity analysis, rainfall was the most sensitive parameter, followed by elevation, slope, DD, LULC, and DL. Analyzing these delicate parameters is a valuable way to assess the validity and robustness of the results. According to the results, the Northwestern and Southeastern areas are identified as points where groundwater intersects with surface water bodies, exhibiting high recharge potential. The Northeastern and Southwestern parts of the study area experience higher rainfall, elevated terrain, and increased drainage density factors that significantly contribute to the groundwater recharge processes.

Additionally, geological characteristics, particularly the occurrence of Sandy gravel deposits in the northeastern and southwestern regions, play a crucial role in enhancing groundwater recharge mechanisms. Conversely, the central portion of the study area demonstrates lower potential due to diminished rainfall, lower elevation, and reduced slope gradients, which collectively limit groundwater recharge. Furthermore, the proliferation of urbanization exacerbates surface runoff and diminishes water infiltration capacities, further impeding groundwater recharge in the central region. The generated GWPZ map was validated by comparing it with static water level data for 43 monitoring water wells. Static water level data was used in a semi-arid ecosystem in Southern Iraq to validate GWPZ using a similar methodology [29].

In the northeastern portion of the study area, the static water level tends to be elevated compared to the middle and southwestern regions, primarily attributable to the higher terrain in this area. The findings indicate a predominant groundwater flow pattern from the Northeast towards the Northwest in the upper elevation zones, while in the lower elevations, there is a directional shift of groundwater movement from the Northwest towards the southeast. This hydrological movement emphasizes the influence of topographical gradients on the groundwater dynamics, with groundwater generally following the landscape's natural contours.

The main limitation of AHP is that it relies mainly on expert opinion; the weights given to various characteristics are frequently determined by expert opinion, which might add subjectivity to the study. Moreover, discrepancies may arise from the pairwise comparisons utilized in AHP, particularly when many criteria are involved [30-32]. Therefore, the weights and ratings need to be assigned carefully and appropriately.

In conclusion, by giving local governments and researchers the necessary data, the AHP and GIS-based decision-making for GWPZ mapping in the Erbil sub-basin described in this study offers a chance to reduce water scarcity. Therefore, the final GWPZ map can inform decisions about land development in this area by helping urban planners better understand how GWPZ might be used.

## 6. Conclusion

GWPZ was mapped due to multiple interrelated factors. These factors could work differently in various geoclimatic zones through six criteria. These six factors were merged using AHP and GIS-based modeling to quantify and measure the GWPZ. The groundwater potential zone is divided into three main classes in the area; the "high GWPZ" covers around 575.44 km<sup>2</sup> (21.24%), "moderate GWPZ" covers 1836.40 km<sup>2</sup> (67.80%), and 296.81 km<sup>2</sup> (10.96%) is under the "poor GWPZ." Additionally, the results indicated that the zone with the most appropriate and significant groundwater potential was the rainfall component. The main

source of storage for groundwater was the influence of rainfall. Accordingly, groundwater recharge increases with increasing precipitation intensity and inversely.

### References:

- [1] E. Barbier, *The water paradox: overcoming the global crisis in water management*: Yale University Press, 2019.
- [2] C. Oberghell, M. Bakker, and K. Maas, "Identification and explanation of a change in the groundwater regime using time series analysis," *Groundwater*, vol. 57, pp. 886-894, 2019.
- [3] P. L. Younger, *Groundwater in the environment: an introduction*: John Wiley & Sons, 2009.
- [4] N. Carrard, T. Foster, and J. Willetts, "Groundwater as a source of drinking water in southeast Asia and the Pacific: A multi-country review of current reliance and resource concerns," *Water*, vol. 11, p. 1605, 2019.
- [5] I. Tlili, T. A. Alkanhal, M. Othman, R. N. Dara, and A. Shafee, "Water management and desalination in KSA view 2030: case study of solar humidification and dehumidification system," *Journal of Thermal Analysis and Calorimetry*, vol. 139, pp. 3745-3756, 2020.
- [6] I. Al-Shamaa and B. Ali, "hydrological relationship between surface and groundwater in Badra-Jassan Basin," *Iraqi Journal of Science*, vol. 53, pp. 335-340, 2012.
- [7] A.-S. Rodella, E. Zaveri, and F. Bertone, "The hidden wealth of nations," 2023.
- [8] H. Niazi, T. B. Wild, S. W. Turner, N. T. Graham, M. Hejazi, S. Msangi, et al., "Global peak water limit of future groundwater withdrawals," *Nature Sustainability*, pp. 1-10, 2024.
- [9] S. A. Saleh, N. Al-Ansari, and T. Abdullah, "Groundwater hydrology in Iraq," *Journal of Earth Sciences and Geotechnical Engineering*, vol. 10, pp. 155-197, 2020.
- [10] Z. Stevanovic and A. Iurkiewicz, "Groundwater management in northern Iraq," *Hydrogeology journal*, vol. 17, p. 367, 2009.
- [11] T. L. Saaty, "The analytic process: planning, priority setting, resources allocation," New York: McGraw, 1980.
- [12] S. Saravanan, T. Saranya, J. J. Jennifer, L. Singh, A. Selvaraj, and D. Abijith, "Delineation of groundwater potential zone using analytical hierarchy process and GIS for Gundihalla watershed, Karnataka, India," *Arabian Journal of Geosciences*, vol. 13, p. 695, 2020.
- [13] S. Das, J. Mukherjee, S. Bhattacharyya, P. P. Patel, and A. Banerjee, "Detection of groundwater potential zones using analytical hierarchical process (AHP) for a tropical river basin in the Western Ghats of India," *Environmental Earth Sciences*, vol. 81, p. 416, 2022.
- [14] O. Al-Kekey, A. Othman, and B. Merkel, "Identifying potential sites for artificial groundwater recharge using GIS and AHP techniques: A case study of Erbil basin, Iraq," *Kuwait Journal of Science*, vol. 50, 2023.
- [15] M. A. Al-Dabbas and A. A. Al-Shammari, "Groundwater Suitability for Agriculture using GIS Techniques in the Lower Part of Lesser Zab River Basin," *Iraqi Journal of Science*, vol. 56, pp. 3141-3150, 2015.
- [16] W. H. Sulaiman and Y. T. Mustafa, "Geospatial Multi-Criteria Evaluation Using AHP–GIS to Delineate Groundwater Potential Zones in Zakho Basin, Kurdistan Region, Iraq," *Earth*, vol. 4, pp. 655-675, 2023.
- [17] N. Al-Ansari, "Water resources of Iraq," *Journal of Earth Sciences and Geotechnical Engineering*, vol. 11, pp. 15-34, 2021.
- [18] K. Adiat, M. Nawawi, and K. Abdullah, "Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool—a case of predicting potential zones of sustainable groundwater resources," *Journal of Hydrology*, vol. 440, pp. 75-89, 2012.
- [19] H. A. K. Ahmed and S. J. Jirjees, "Morphometric Analysis of Taqtaq Watershed/Koysinjaq District, Iraqi-Kurdistan Region," *Zanco Journal of Human Sciences*, vol. 26, pp. 206-220, 2022.
- [20] S. G. Salar, A. A. Othman, and S. E. Hasan, "Identification of suitable sites for groundwater recharge in Awaspi watershed using GIS and remote sensing techniques," *Environmental Earth Sciences*, vol. 77, p. 701, 2018.
- [21] S. Jirjees, S. Seeyan, and I. O. Hassan, "Morphometric Analysis of the Rawandoz River Basin, Erbil, Kurdistan Region, Iraq," *The Iraqi Geological Journal*, pp. 157-172, 2022.
- [22] A. A. Saidu, A. Aldrees, S. Danazumi, and S. I. Abba, "Groundwater Potential Mapping in Semi-arid Region of Northern Nigeria by Integrating Analytic Hierarchy Process and GIS," 2024.

- [23] A. Singh, S. Panda, K. Kumar, and C. S. Sharma, "Artificial groundwater recharge zones mapping using remote sensing and GIS: a case study in Indian Punjab," *Environmental management*, vol. 52, pp. 61-71, 2013.
- [24] R. T. Mzuri, A. A. Omar, and Y. T. Mustafa, "Spatiotemporal analysis of vegetation cover and its response to terrain and climate factors in Duhok Governorate, Kurdistan Region, Iraq," *The Iraqi Geological Journal*, pp. 110-126, 2021.
- [25] H. Gao, F. Liu, T. Yan, L. Qin, and Z. Li, "Drainage density and its controlling factors on the eastern margin of the Qinghai–Tibet Plateau," *Frontiers in Earth Science*, vol. 9, p. 755197, 2022.
- [26] H.-F. Yeh, C.-H. Lee, K.-C. Hsu, and P.-H. Chang, "GIS for the assessment of the groundwater recharge potential zone," *Environmental geology*, vol. 58, pp. 185-195, 2009.
- [27] D. Jhariya, T. Kumar, M. Gobinath, P. Diwan, and N. Kishore, "Assessment of groundwater potential zone using remote sensing, GIS and multi criteria decision analysis techniques," *Journal of the Geological Society of India*, vol. 88, pp. 481-492, 2016.
- [28] T. L. Saaty and L. G. Vargas, "How to make a decision," in *Models, methods, concepts & applications of the analytic hierarchy process*, ed: Springer, 2001, pp. 1-25.
- [29] A. M. Atiaa and A. H. Al-Aboodi, "Simulation of Flow Regime of Dibdibba Dandy Aquifer in Safwan-Zubair Area, South of Iraq," *Iraqi Journal of Science*, vol. 47, pp. 119-137, 2006.
- [30] I. Melendez-Pastor, J. Navarro-Pedreño, M. Koch, I. Gómez, and E. I. Hernández, "Evaluation of land degradation after forest fire using a fuzzy logic model," *Environmental Engineering & Management Journal (EEMJ)*, vol. 12, 2013.
- [31] R. T. Mzuri, Y. T. Mustafa, and A. A. Omar, "Land degradation assessment using AHP and GIS-based modelling in Duhok District, Kurdistan Region, Iraq," *Geocarto International*, pp. 1-19, 2021.
- [32] S. Albhadili, A. K. Al-Ali, and D. S. Karem, "Mapping Of Potential Areas of Groundwater Zones in the Najaf-Karbala Alluvial Fan Using Remote Sensing and GIS Technology," *Iraqi Journal of Science*, 2025.