Article
JOURNAL OF UNIVERSITY OF BABYLON
For Pure and Applied Sciences (JUBPAS)
Vol.31; No.4.| 2023

Determination of The Optimal Groundwater Recharge Regions in The Eastern Part of Nineveh

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تحديد مناطق التغذية المثلى للمياه الجوفية في الجزء الشرقي من نينوى

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Accepted: 30 /9 /2023 **Published:** 31 /12 /2023

ABSTRACT

Background:
The process of groundwater recharge is considered as one of the most important processes for the management of water resources, both surface and groundwater.

Materials and Methods:
The current study uses the application of the Analytical Hierarchical Process (AHP) model in geospatial analysis to delineate potential areas for groundwater recharge. The foundations of this model were laid by Saaty. The analytical method was used to calculate the natural weight of the factors individually, according to the size of the groundwater recharge potential. Each factor within the GIS environment was reclassified according to the AHP technique.

Results:
The results show that in large regions of the study area, about 38.7% have poor to very poor recharge potential, 29.3% of the area is moderate, 19.5% of the area has good recharge potential, and the remaining area (12.3%) has very good potential for groundwater recharge. The soil factor showed that it was the most influential factor in the delineation of groundwater recharge areas for the study area.

Conclusion:
The potential zones of very good and good groundwater occupy 312.67 and 495.70 km^2, respectively, which are 12.3% and 19.5% of the study area. It appears from the map of groundwater potential zones that the areas of good and very good recharge are mostly prominent in the sedimentary plains with low slopes and high drainage density. Also, a small part of it appears in the mountainous areas, which represent the main recharge areas for the falling rainwater.

Key words: Groundwater recharge, GIS, AHP, Overlay analysis, Nineveh.

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1. INTRODUCTION

Groundwater is considered as one of the main elements of the hydrological cycle, and this important element has recently been subjected to a significant depletion in its quantity due to the increasing demand and the urgent need for it by the population in the various uses of life. The water pressure caused by the large increase in population and urbanization in large cities has led to several negative impacts on groundwater resources [1]. The phenomenon of a lack of groundwater recharge or storage during a certain period in a particular area can be called a groundwater drought [2]. The increasing demand for groundwater, along with its decreasing availability over time, especially in rock-hard aquifers, requires sustainable management to ensure its availability in the future [3]. Therefore, to preserve groundwater resources, it is necessary to identify the most appropriate recharge areas [4]. Potential areas for groundwater recharge are identified as locations where the surface of the earth allows water to infiltrate and filter through soil-rock pores into the ground [5].

The groundwater recharge area is defined as the area where rainwater seeps into the soil and then turns into groundwater [6]. The phenomenon of groundwater recharge and accumulation is one of the most important fundamental components of hydrological systems, and it result from the infiltration of rainwater through different layers of rocks and soils in watersheds [7]. The groundwater recharge potential of a region depends on many factors, including rainfall, soils, drainage intensity, geology, land use and land cover, tectonic fault sites, slope, river order, and stream energy index [8], [9]. The GIS and RS technology of aquifer recharging potential studies hidden hydrogeological features, deals with surface factors such as the rock structure, density of drainage networks, frequency of lines, and land cover, and provides more accurate results and empirical evaluation of the recharging potential of groundwater.

There are many studies and research projects that have classified the groundwater recharge potential zones (GWRPZ) using different methods and techniques. We mention what is close to the study area as follows: [10] studied the effects of some climate elements on the varying levels of groundwater recharge in the Al-Hamdaniya district, and it was found that the water recharge of wells is high in the winter season, especially in January, due to rainfall and low evaporation rates and temperatures, while it is non-existent in the summer due to the lack of rain and the high rates of evaporation and temperatures. [11] classified groundwater recharge zones in the Khazir River basin into four zones: low, medium, high, and very high. The results indicate that approximately 89% of the study area is located within a region with a very high elevation or groundwater potential. [12] studied the potential area for groundwater recharge in the Erbil Basin, and after analyzing the results, he concluded that nearly a third of the studied areas have medium to very high groundwater recharge potential.

Due to the decrease in seasonal rains in the region, especially in Iraq, as it is among the region's most affected by climatic changes, coinciding with the increase in consumption, which led to a decrease in groundwater levels. It necessitated the need to think about ways to benefit from rainfall in the winter season and to choose the optimal sites to recharge water in the groundwater which leads to raising its levels. The research aims to choose the optimal recharge sites using the GIS software and with the help of the Hierarchical Analysis Technique (AHP).

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JOURNAL OF UNIVERSITY OF BABYLON
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2. DESCRIPTION OF THE STUDY AREA

The research area is situated within the Nineveh Plain, to the northeast of the city of Mosul. It is bordered on the west by the course of the Tigris River and on the east by the course of the Great Zab River. Geographically, it lies between longitudes 43°12'19" and 43°42'40"E and latitudes 36°09'40" and 36°24'16"N (Fig. 1). The study area is about 2536.92 km^2. Topographically, it ranges from high-altitude mountainous lands to undulating lands and ends with low-sloping plain lands, where the slope ranges from 190 meters to 1047 meters.

3. MATERIALS AND METHODS

The methodology adopted in this study requires accurate knowledge of the processes affecting groundwater recharge. The described methodology is followed over a series of steps until a final estimate of potential groundwater recharge areas can be reached. Geospatial technologies such as geographic information systems (GIS) and remote sensing (RS) were relied upon for processing and integrating data that affected the identification of potential areas for groundwater recharging in the studied area. Figure 2 represents the presentation of the systematic flow chart adopted in this study. The research methodology begins with identifying and collecting data on the factors affecting the possibility of groundwater recharge, followed by the creation of objective map layers for each factor and calculating the effect of the weight for each influencing factor separately, with the effect of the weight for each individual objective layer and its categories based on the importance of each layer for the possibility of recharge groundwater. The data collected for the variables under study were weighted with the help of the analytical hierarchical process (AHP) technique according to the strength of their impact on determining the optimal sites for charging groundwater.

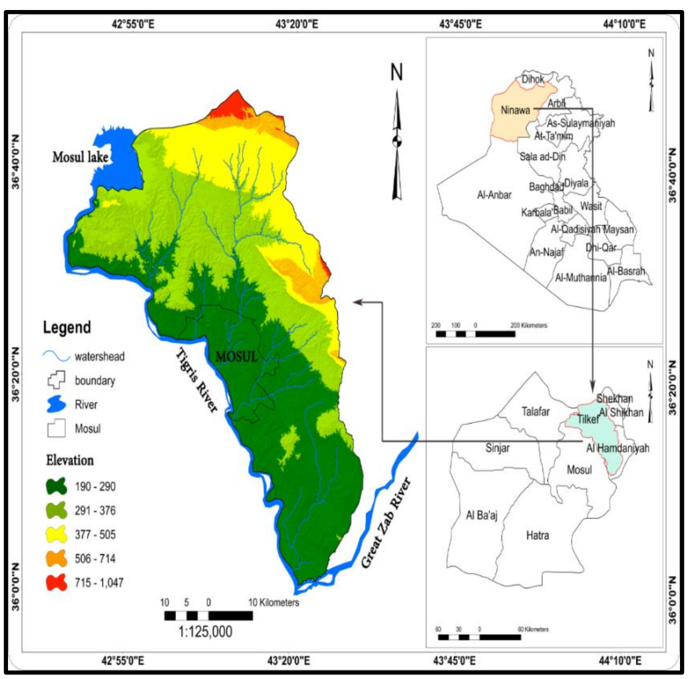

Fig. 1. Location of the study area.

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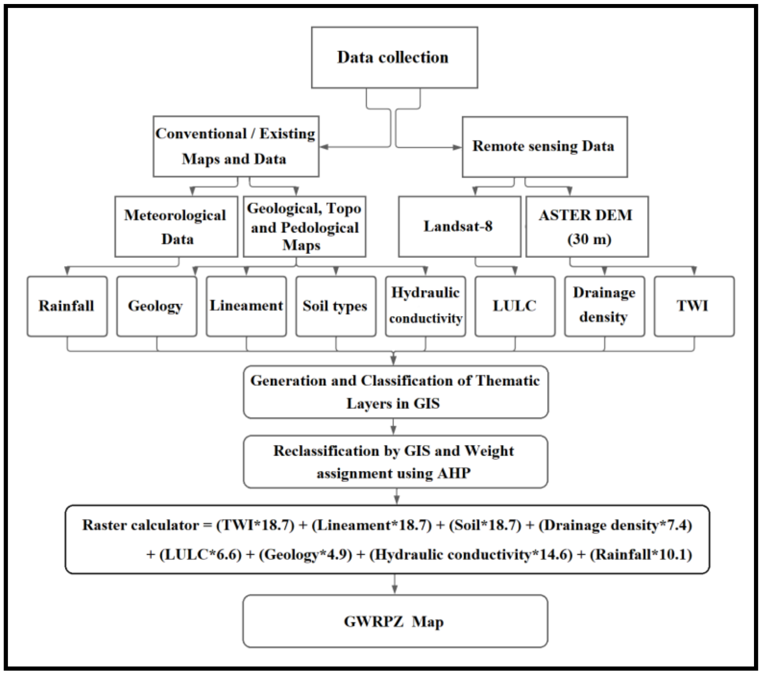

Fig. 2. The flow chart shows the processed steps.

The Analytical Hierarchical Process (AHP) technique is used to extract the weight of the variables. The weights assigned to the factors affecting groundwater recharge are based on the opinions of hydrogeologists and the field study. Table 1 shows the importance of the factors affecting the possibility of groundwater recharge based on a nine-point scale[13]. The standard weights of the objective classes and those of their attributes were examined for consistency based on Saaty (1980). Saaty proposed the Computational Consistency Ratio (CR) for this purpose, and the following steps were followed to calculate the CR for each trait [14]:

1. Calculate the eigenvalue matrix (λmax) of the parameters.
2. Calculate the consistency index (CI) from the following equation:

$$CI = \frac{\lambda \max - 1}{n - 1} \quad (1)$$

Where, n is the number of criteria or factors.

3. Calculate the consistency ratio (CR) to verify the accuracy of the relative weights resulting from the comparison matrix, and it is done by the following equation:

$$CR = \frac{CI}{RI} \quad (2)$$

Where, RI is the random index.

The consistency ratio (CR) must be less than number 1. The relative weights of the variables must be recalculated. A summary of the extracted relative weights for the three purposes is tabulated in Table (2). The weights of factors vary in terms of their impact on groundwater recharge. Among the eight factors, lineament density, TWI, and soil type have the highest factor

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of (15%) for each factor, followed by drainage density (7.4%), LULC (6.6%), rainfall (10.1%), and hydraulic conductivity (14.8%). Minimum scores for geological formations are (5%).

Finally, The final groundwater recharge potential zones (GWRPZ) were created by reclassifying, weighting, overlaying, and combining the topic layers of various factors using the GIS Weighted Overlay Analysis tool, after applying the following equation:

$$GWRPZ = \sum_{w=1}^{m} \sum_{i=1}^{n} (w_j \times x_i) \quad (3)$$

Where, w_j is the normalized weight of the j-th factor, x_i is the normalized weight of the i-th class of factor, m is the total number of factors, and n is the total number of classes in a factor.

Table 1. Saaty's scale for weight assignment of factors [13].

Degree of Importance	Description
1	Equal of Importance
3	Moderate of Importance
5	Essential or Strong Importance
7	Importance of Very Strong
9	Extreme of Importance
2, 4, 6, 8	Values of Intermediate between the two adjacent judgements

Table 2. The weightage of thematic layers extracted from the AHP technique.

No.	Groundwater recharge potential factor	Classes	Ranking (words)	Ranking (numbers)	Weightage (%)
1	Lineament density	2.9 - 6.3	very low	1	18.7
		6.4 - 7.5	low	2	
		7.6 - 8.9	medium	3	
		9 - 10.6	high	4	
		10.7 - 15.5	very high	5	
2	TWI	0 - 0.7	very low	1	18.7
		0.8 - 2	low	2	
		3 - 4	medium	3	
		5 - 7	high	4	
		8 - 9	very high	5	
3	Soil type	D	low	1	18.7
		C	medium	3	
		B	high	5	
4	Drainage density	0.073 - 0.667	very low	5	7.4
		0.668 - 0.969	low	4	
		0.97 - 1.237	medium	3	
		1.238 - 1.53	high	2	

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		1.531 - 2.208	very high	1	
5	LULC	Urban	very low	1	6.6
		Rocky	low	2	
		Forest	medium	3	
		Agriculture	high	4	
		Water Bodies	very high	5	
6	Geology Formations	Lower Fars	very low	1	5
		upper Fars	low	2	
		Bakhtiari	medium	3	
		Pila spi	high	4	
		Quaternary	very high	5	
7	Hydraulic conductivity	0.05 - 1.6	very low	1	14.8
		1.61 - 3.15	low	2	
		3.1 - 4.74	medium	3	
		4.75 - 7.93	high	4	
		7.94 - 12.01	very high	5	
8	Rainfall	241 - 296	very low	1	10.1
		297 - 333	low	2	
		334 - 366	medium	3	
		367 - 400	high	4	
		401 - 449	very high	5	

4. RESULTS AND DISCUSSION

4.1. Factors Affecting Groundwater Recharge

To determine the potential zones of groundwater recharge in the study area, the thematic layers of the control factors were used. The eight thematic layers include lineament density, topography wetness index (TWI), soil type, drainage density, geology, land use/land cover, hydraulic conductivity, and rainfall to generate the GWRPZ final map, as in the following:

4.1.1. Lineament density

The lineaments are geological features that are linear or curved and are of great importance in the occurrence and movement of groundwater [3]. And they are linear geomorphic features that indicate the surface representation of regions of weakness or structural movement in the earth's crust. These are defined as "significant landscape lines that reveal the hidden architecture of the rock basement". They are the physiognomy of the earth. These characteristics could be deep-seated faults, fractures and joint sets, drainage lines, or boundary lines of distinct rock formations. All of these linear features are determined from satellite data, and a lineament map for the research area is created. Lineaments are any linear visible characteristics as lines in aerial or satellite images. Lineament data is obtained from satellite imagery, and then a lineament density map is created.

Lineament density varies for the study area from 0 to 9 km/km^2 (Fig. 3a). The lineament density has been reclassified into five categories: very low (0-0.7 km/km^2), low (0.8-2 km/km^2), medium (3-4 km/km^2), high (5-7 km/km^2), and very high (8-9 km/km^2). Most of the study area falls under the category of very low density, which means that the possibility of groundwater recharge will be poor.

4.1.2. Topography wetness index (TWI)

The TWI factor is used to measure topographic control in hydrological processes. This factor simulates the behavior of water as a mass at any spill point, as well as the preparedness of gravitational forces for the transport of that water downstream [15]. TWI reflects the proclivity of water to accumulate at any place in a catchment (in terms of a) as well as the proclivity of gravitational forces to transfer that water downslope (in terms of tanβ). The TWI value is extracted by Arc GIS software and from the following equation:

$$TWI = In[\boldsymbol{\alpha} / \boldsymbol{tan\beta}] \tag{4}$$

where, a is the local upslope drainage area per unit contour length, and tanβ is the local slope in degrees. TWI has been classified into five categories, as shown in Figure 3b. Its value ranged from 2.9 to 15.5, as the mountainous regions witnessed a low value, while the value increased in the plain regions.

4.1.3. Soil type

The movement and transport of groundwater are greatly affected by the soil [16]. Soil is one of the natural resources that must be considered when describing probable groundwater zones. It contributes significantly to groundwater recharge and provides the basic needs of all agricultural production. Black soils, often known as black cotton soils, are notable for their capacity to retain moisture, and have adequate impacts as a regulatory element for groundwater existence and recharge potential in the study area. However, the soil element can prevent water for a reasonable period from percolating through its layers into the aquifers [17]. Areas with less slope are considered good for groundwater storage because of their low runoff and high penetration.

The soil map of the study area was classified into three main categories based on the hydrological soil groups (Fig. 4a). The first category (D) was represented by the low recharge of groundwater because of its clay texture that does not allow the water to infiltrate into the aquifers, and the advantages of the second category (C) with medium recharge of the groundwater because it has a mixture texture that contains equal proportions of clay, sand and silt, while the third category (B) was described as having high groundwater recharge because it consists of a mixture of sand, which allows a large percentage of water to penetrate the aquifers.

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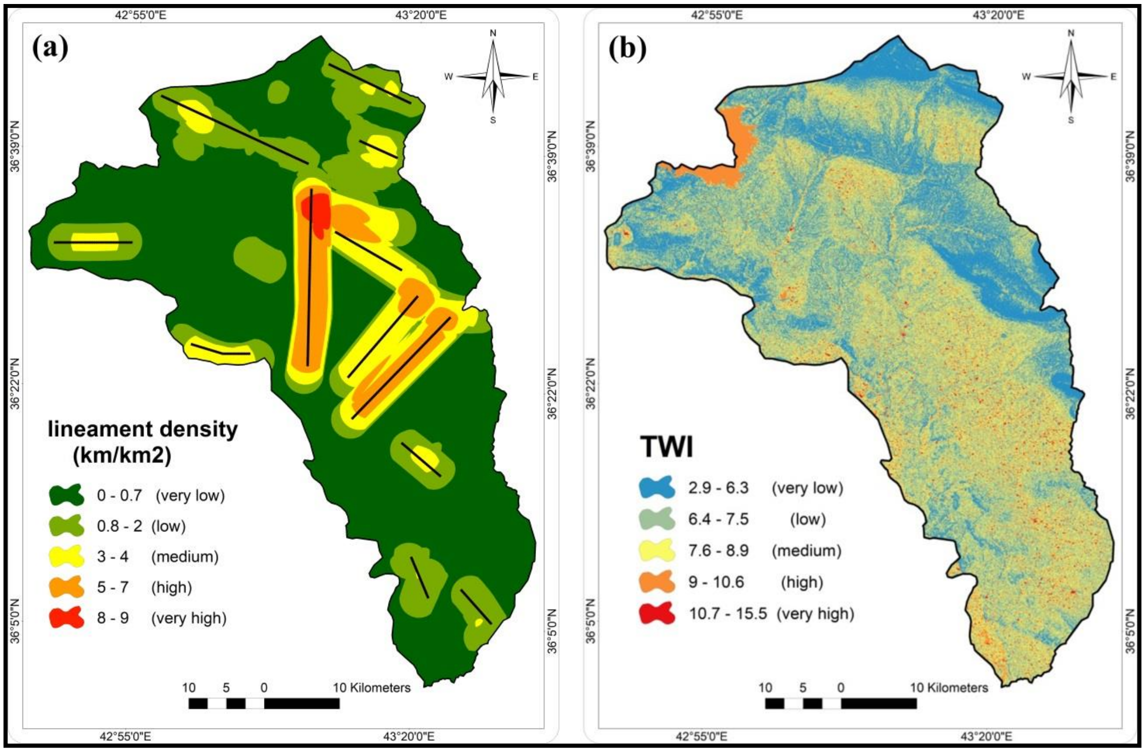

Fig. 3. (a) Lineament density, and (b) Topography Witness Index (TWI).

4.1.4. Drainage density

Drainage density can be defined as the total length of streams divided by the total area of the basin [18]. Drainage density factor helps to determine water infiltration characteristics in the river basin [19]. Additionally, it indirectly indicates the groundwater recharge [20]. The high drainage density is an important indicator of the high volume of surface runoff and low water penetration into the aquifers. This means that the higher the value of drainage density, the lower the probability of water infiltration.

The drainage density map was calculated using Arc GIS software and based on the digital elevation model (DEM) (Fig. 4b). Drainage density values were classified as very low (0.073-0.667km/km^2), low (0.668-0.969km/km^2), high (1.238-1.53km/km^2), and very high (1.531-2.208km/km^2). The drainage density map shows that the studied area is experiencing poor groundwater recharge.

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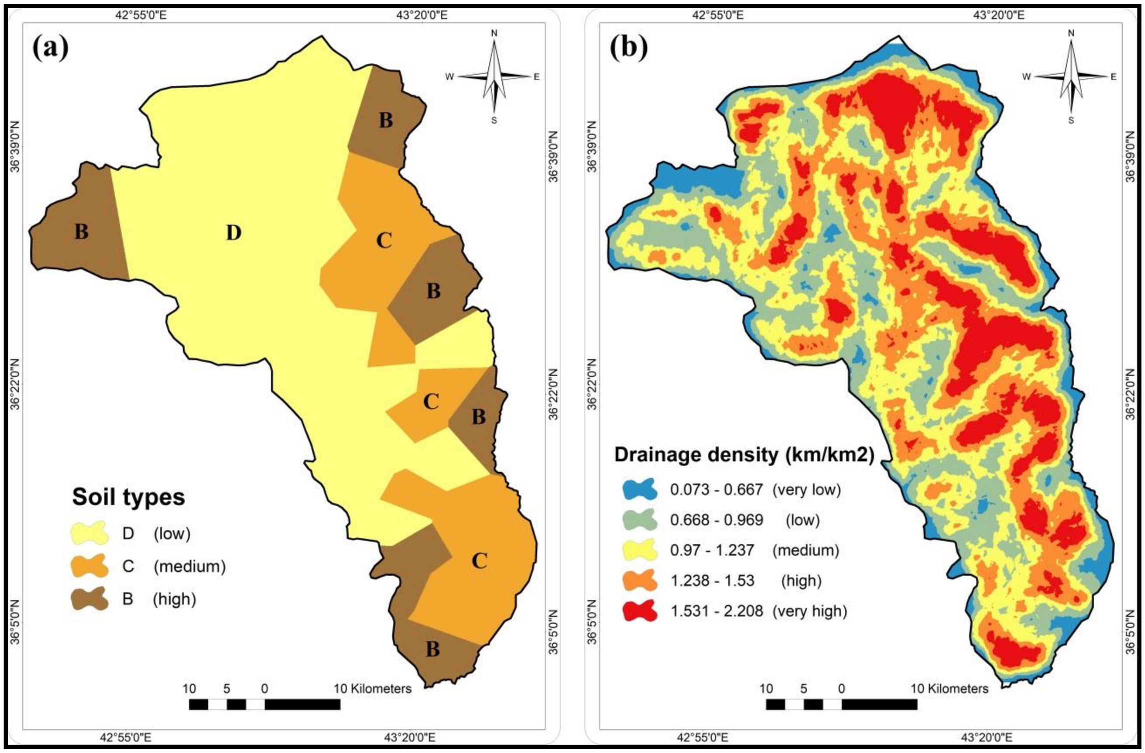

Fig. 4. (a) Soil type, and (b) Drainage density.

4.1.5. Land use/land cover (LULC)

The land use/land cover factor plays a very important role in the occurrence and distribution of groundwater [21]. The LULC is one of the most important factors affecting groundwater recharge [22]. Sometimes, changes in LULC lead to variations in recharge volume, timing, and quantity, which may affect the volume of groundwater resources [23]. Areas with high vegetation cover indicate good groundwater recharge, while areas without vegetation cover have poor groundwater recharge [3]. The LULC was extracted using Arc GIS software based on the Landsat 8 satellite image obtained from Earth Explorer (USGS) with a spatial resolution of 30 meters. The LULC map of the study area appears in Figure 5a and indicates a variation in land types that included five categories. Urban and rocky areas witnessed poor recharge of groundwater due to the rapid flow of water on the surface, thus reducing the chance of water penetration into the ground. While the areas with high vegetation cover (agricultural lands and forests), which represented the largest part of the study area, indicate high groundwater recharge due to obtaining more time for infiltration and thus increasing the possibility of recharging for groundwater.

4.1.6. Geology

The study area has many of exposed geological formations, as the northern and northeastern regions represent the "Pilaspi Formation", which contains many joints, faults, and cracks that help the infiltration of rainwater. In the central region, it is dominated by "residual soil", which results from the erosion of the exposed geological formations. In the subdued areas, in the southern and southeastern areas, it is dominated by the Fatha Formation and parts of the Injana

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Formation, which is evident in the fold areas present in the region and represents the main formation of water storage in the study area.

The distribution of groundwater is significantly influenced by lithological composition [24]. The occurrence and movement of groundwater are affected by some chemical rock properties, especially chemical weathering. Moreover, the physical properties are represented mainly by the secondary porosity in terms of fractures, faults and fissures in the rocks [25]. Geological data were obtained through field observations and the article of two researchers Sissakian and Saeed [26]. Figure 5b shows a group of geological formations (Upper Fars, Lower Fars, Bakhtiari, Pilaspi, and Quaternary) that covered the study area. These formations differ in terms of their rock characteristics and their ability to penetrate water into the aquifers. The Pilaspi Formation covered a large area of the study area, and its rock components were characterized by high groundwater recharge.

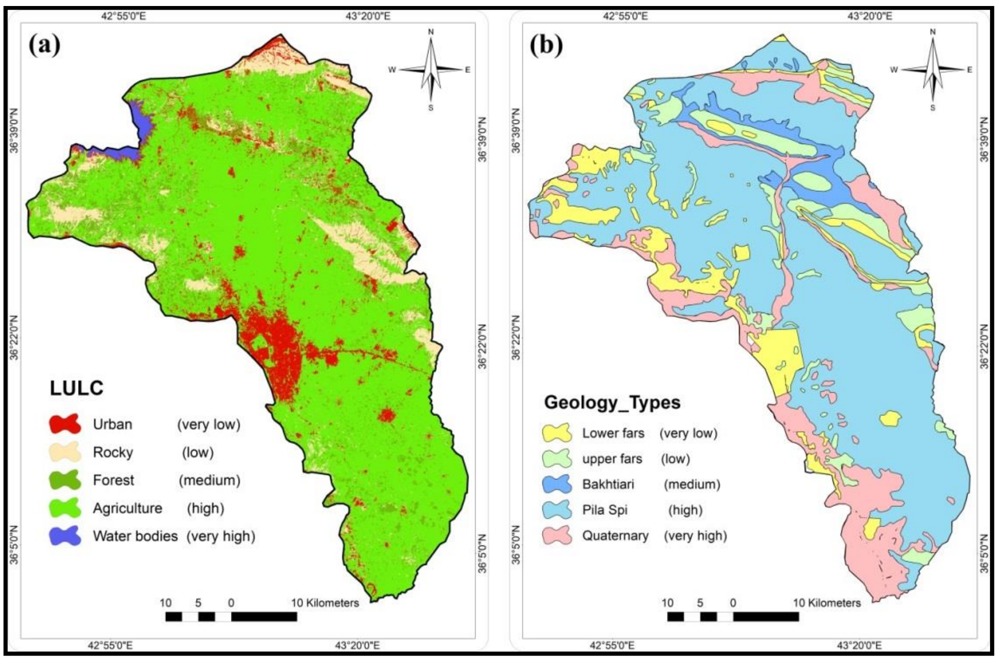

Fig. 5. (a) Land use/land cover (LULC), and (b) Geology.

4.1.7. Rainfall

The rainfall on the surface of the earth plays an important role in the variation in groundwater levels [10]. Groundwater recharge is highly dependent on the rainfall pattern during the wet seasons [27]. The high rate of rainfall contributes to the high groundwater recharge [3].

Annual rainfall data were collected from five climate stations available for the period 2012-2022 from the NASA website (POWER/Data Access Viewer), and the precipitation map was generated using the IDW interpolation technique. The spatial distribution of annual rainfall shows an increasing north-northeast trend (Fig. 6a). Rainfall in the study area was spatially classified into five categories: very low (241-296 mm), low (297-333 mm), moderate (334-366 mm), high (367-400 mm), and very high (401-449 mm).

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4.1.8. Hydraulic conductivity

Hydraulic conductivity is an important factor that indicates the ability of the soil to transfer water into the aquifers [28]. Information from a group of wells was used for hydraulic preparation of the connection layers of the aquifer in the study area using the interpolation method in ArcGIS software.

The hydraulic conductivity map has been classified into five categories (Fig. 6b). These classes spatially vary from very low (0.05-1.6), low (1.61-3.15), medium (3.16-4.74), high (4.75-7.93), and very high (7.94-12.01). The majority of the study area was represented by low to very low hydraulic conductivity, which indicates poor groundwater recharge.

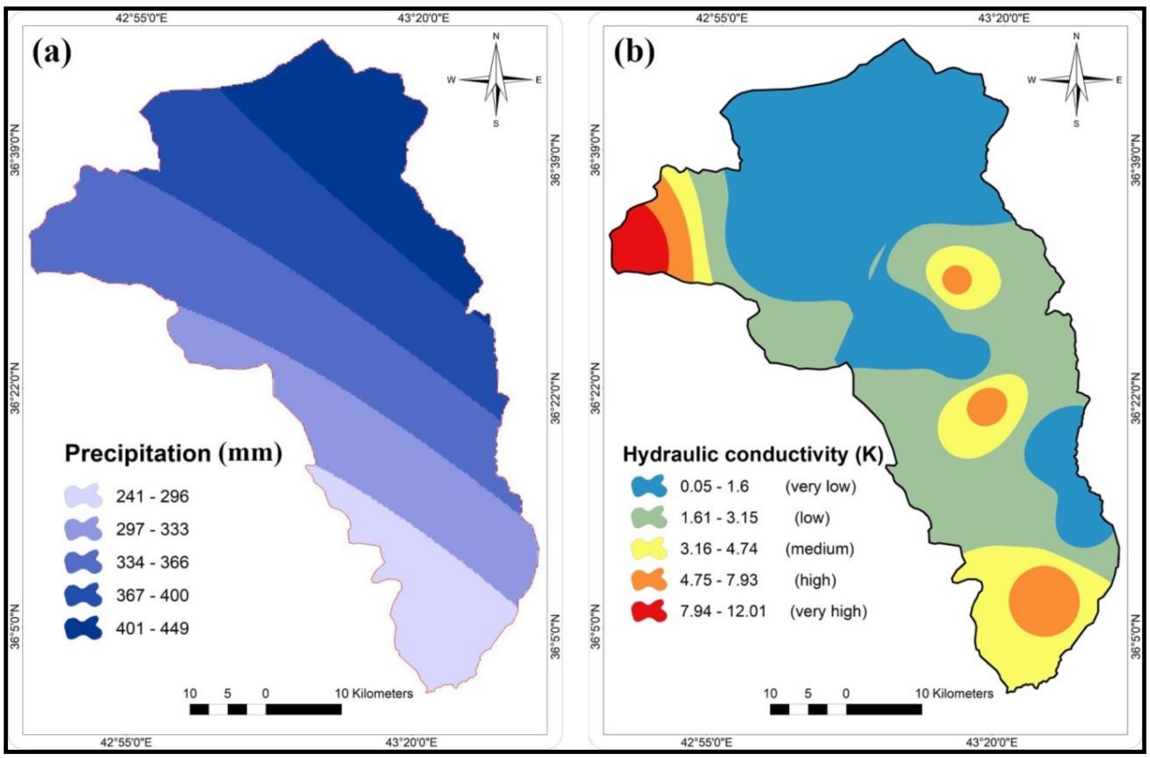

Fig. 6. (a) Rainfall (mm), and (b) Hydraulic conductivity (K).

4.2. Delineation of Groundwater Recharge Potential Zones

The groundwater recharge potential zones (GRPZ) map for the study area was generated using a weighted overlay analysis of cumulative weight ratios that were allocated for maps of the lineament density, TWI, soil type, drainage density, LULC, geology, rainfall, and hydraulic conductivity. A higher weight represents a higher probability of water infiltration into the ground, while a lower weight indicates a lower probability of water infiltration [7]. An integrated assessment of thematic maps using a model based on geographic information system techniques is a suitable method for predicting groundwater recharge potential. The GRPZ map for the study area was classified into five zones based on a weighted overlay analysis: very poor, poor, moderate, good, and very good. Figure 7 shows that in large areas of the study area (38.7%) recharge potential is poor to very poor, 29.3% of the area is moderate, 19.5% of the area has good recharge potential, and the remaining area (12.3%) has very good potential for groundwater recharge (Table 3). After analyzing the results, it became clear that the GRPZ map was significantly affected by the types of hydrological soils in the study area, where the zones with poor to very poor recharge are located within the soil type (D), the zones with moderate recharge are within the soil type (C), and the areas with high to very high recharge are within the soil type (B).

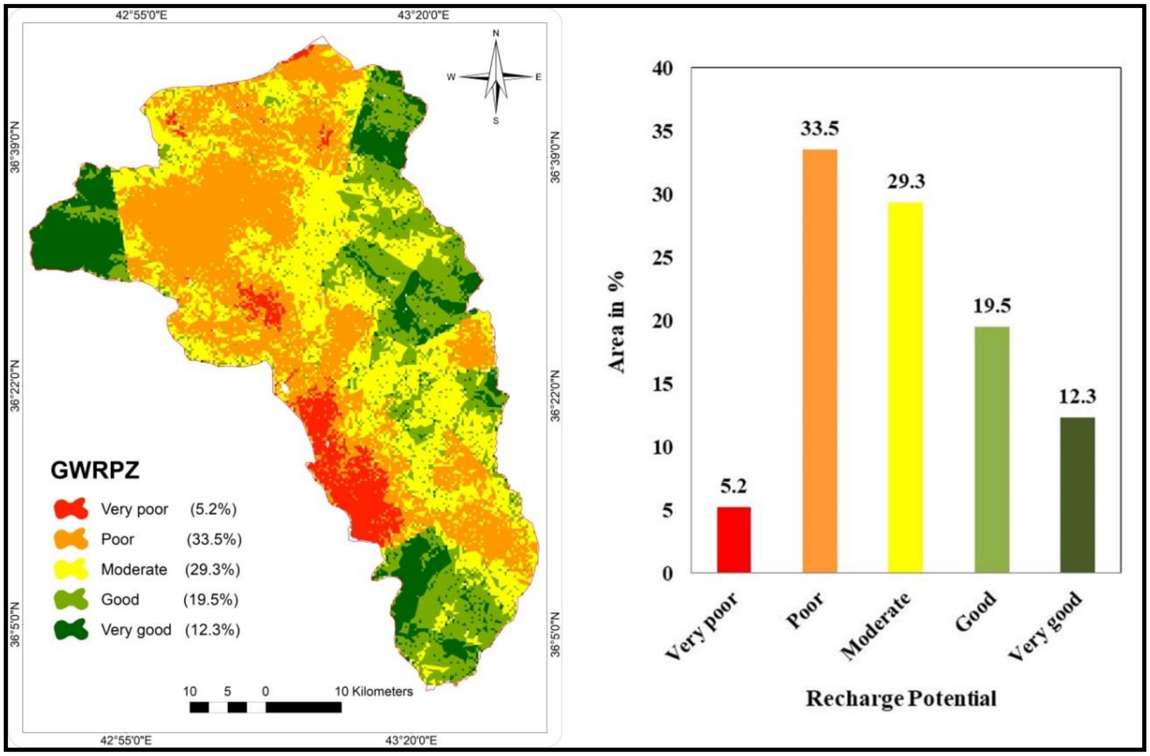

Fig. 7. Potential zones for groundwater recharge of the study area.

Table 3. Reclassification of groundwater recharge potential zones.

No.	Recharge Potential	Area (km^2)	(%) of the study area
1	Very poor	132.18	5.2
2	Poor	851.57	33.5
3	Moderate	744.80	29.3
4	Good	495.70	19.5
5	Very good	312.67	12.3

5. CONCLUSIONS

The potential zones for groundwater recharge were mapped in the study area using Geographic Information Systems (GIS) technology, which provided an effective methodology in terms of time, labor, cost, and accuracy in the results. Eight factors are used in the analysis, such as lineament density, TWI, soil type, drainage density, LULC, rainfall, and hydraulic conductivity. AHP is used to determine rates for classes in a layer and weights for thematic

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layers on a GIS-based multi-criteria evaluation based on Saaty's. The studied area has a dendritic drainage pattern, which allows part of the surface runoff water to more easily infiltrate into the aquifers to be recharged with water, so it has a higher probability of groundwater occurrence.

The potential zones of very good and good groundwater occupy 312.67 and 495.70 km^2, respectively, which are 12.3 and 19.5% of the study area. It appears from the map of groundwater potential zones that the areas of good and very good recharge are mostly prominent in the sedimentary plains with low slopes and high drainage density. Also, a small part of it appears in the mountainous areas, which represent the main recharge areas for the falling rainwater. The weights of the factors affecting groundwater recharge differed, as the soil factor (hydrological soil group) showed that it was the most influential factor in the delineation of groundwater recharge areas for the study area.

The method of this study can help quickly identify potential groundwater areas and this can serve as a guide for integrating the management of water resources. This is done by conducting many detailed hydrogeological surveys, after which it is possible to choose the most suitable sites for drilling wells and obtaining groundwater in a sustainable way.

Acknowledgments

The authors are appreciative and thank the College of Environmental Sciences and Technology at the University of Mosul for providing resources that aided in the improvement of the quality of this study.

Conflict of interests

There are non-conflicts of interest.

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الخلاصة

المقدمة:

تعتبر عملية تغذية المياه الجوفية من أهم العمليات لإدارة الموارد المائية، بنوعيها السطحية والجوفية.

طرق العمل:

تستخدم الدراسة الحالية تطبيق نموذج العملية التحليلية الهرمية (AHP) في التحليل الجغرافي المكاني لتحديد المناطق المحتملة لتغذية المياه الجوفية. وقد تم وضع أسس هذا النموذج من قبل ساعاتي. واستخدام الطريقة التحليلية لحساب الوزن الطبيعي للعوامل على حدة وفقًا لحجم التغذية المحتملة للمياه الجوفية. إذ تم إعادة تصنيف كل عامل في بيئة نظم المعلومات الجغرافية اعتماداً على تقنية AHP.

النتائج:

أظهرت النتائج بان مساحة كبيرة من منطقة الدراسة، اي حوالي 38.7% لديها احتمالية تغذية ضعيفة إلى ضعيفة جداً، و29.3% من المنطقة متوسطة، و19.5% من المنطقة لديها احتمالية تغذية جيدة، والمساحة المتبقية (12.3%) لديها احتمالية تغذية جيدة جداً للمياه الجوفية. وأظهر عامل التربة بانه العامل الأكثر تأثيراً في تحديد مناطق تغذية المياه الجوفية لمنطقة الدراسة.

الاستنتاجات:

تحتل المناطق المحتملة للمياه الجوفية الجيدة والجيدة جداً مساحة تقدر بـ 312.67 و495.70 كيلومتراً مربعاً على التوالي، وهي 12.3 و19.5% من مساحة الدراسة. ويتضح من خارطة المناطق المحتملة للمياه الجوفية أن مناطق التغذية الجيدة والجيدة جداً تظهر غالباً في السهول الرسوبية ذات المنحدرات المنخفضة وكثافة الصرف العالية. وجزء صغير منها في المناطق الجبلية التي تمثل مناطق التغذية الرئيسية لمياه الأمطار المتساقطة.

الكلمات المفتاحية: تغذية المياه الجوفية، GIS ، AHP ، تحليل التراكب، نينوى.

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