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Application of Remote Sensing and GIS to Mapping Groundwater Potential Zones of Khazir River Basin, Northern Iraq

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ABSTRACT

The Khazir River Basin is among the most important areas in terms of agricultural importance and diversity of agricultural crops; therefore, groundwater is extensively pumped in this area which is the main resource of water for domestic and agricultural purposes. The purpose of this research was to locate and map this crucial and significant water resource in order to better understand the occurrence and distribution of groundwater potential in the basin. This can be achieved through utilizing remote sensing data from Sentinel-2B with 10m resolution for obtaining Land use/Landcover (LULC) maps and lineament density., DEM (30m resolution) was used for drainage density and estimating the slope map of the area. In addition, the geological map and interpolated rainfall data were used as well. GIS has also been used for running the model to obtain Groundwater Potential Zones (GWPZs) map. Analytical Hierarchy Process (AHP) method is used for mapping the potential groundwater zones. The results indicate that approximately 89% of the studied region falls inside a zone with a high or very high groundwater potential.

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تطبيق الاستشعار عن بعد ونظام المعلومات الجغرافية لرسم خرائط ألمناطق المحتملة للمياه الجوفية في حوض نهر الخازر، شمال العراق

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الملخص

يعتبر حوض نهر الخازر من أهم المناطق من حيث الأهمية الزراعية وتنوع المحاصيل الزراعية. لذلك ، يتم ضخ المياه الجوفية على نطاق واسع في هذه المنطقة ألذي يعد المورد الرئيسي للمياه للأغراض المنزلية والزراعية. أجريت هذه الدراسة للتعرف على تواجد وتوزيع المياه الجوفية في الحوض من خلال تحديد ورسم خرائط لهذا المورد المائي الحيوي والمهم. يمكن تحقيق ذلك من خلال استخدام بيانات الاستشعار عن بعد من Sentinel-2B بدقة 10 أمتار للحصول على خرائط استخدام الأراضي / الغطاء الأرضي (LULC) وكثافة الخطوط، بينما تم استخدام DEM (دقة 30 مترًا) لكثافة الصرف (Drainage Density) وتقدير خريطة الانحدار للمنطقة (Slope). فضلا عن ذلك، تم استخدام الخريطة الجيولوجية وبيانات هطول الأمطار (Rainfall). تم استخدام GIS أيضًا لتشغيل النموذج للحصول على خريطة مناطق المياه الجوفية المحتملة (GWPZ). يتم تقييم المياه الجوفية المتاحة على نطاق واسع والتي يمكن الحصول عليها على أنها المورد الأكثر أهمية وحيوية لإمدادات المياه العذبة التي يمكن أن تلبي متطلبات المنطقة للأغراض المنزلية والري. تُستخدم طريقة عملية التسلسل الهرمي التحليلي (AHP)، وهي الطريقة الأكثر استخدامًا لتحليل نماذج قرار المعايير المتعددة لرسم خرائط مناطق المياه الجوفية المحتملة. كثافة الصرف، استخدام الأرض / الغطاء الأرضي، الجيولوجيا، كثافة الخط، هطول الأمطار والمنحدرات هي الطبقات المواضيعية الست التي تم إعدادها إلى منصة نظم المعلومات الجغرافية. تشير النتائج إلى أن ما يقرب من 89٪ من المنطقة المدروسة تقع داخل منطقة ذات إمكانيات عالية أو عالية جدًا من المياه الجوفية. الهدف من هذه الدراسة هو رسم خريطة وتحديد المناطق المحتملة للمياه الجوفية التي ستكون مفيدة لإدارة موارد المياه وتحديد مواقع احتمالية تواجد المياه الجوفية وتوافرها.

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Introduction

Arid and semi-arid regions have limited surface water due to poor rainfall and high evaporation. Therefore, they are experiencing a growing surface water scarcity (Elubid, et al., 2019) and accordingly, groundwater is becoming an important source of fresh water in these regions, and it helps to supply water for different purposes, particularly for domestic and agricultural purposes (Li, et al., 2018a and 2018b). Agricultural activity is considered as one of the most important activities in the region and this what makes the water of greatest importance as it is the main element in irrigation and the sustainability of agriculture.

Iraq is considered a rich country in terms of water resources when compared to other countries in the Middle East. However, due to the expansion of inhabitance, changing of the climate, and decreasing of surface water inflow from riparian countries, these resources are becoming increasingly scarce. In general, Iraq is going through a severe crisis in the availability of water, as future predictions indicate that this shortage will increase steadily during the next three decades. For these reasons, Iraq should carry out a reassessment of its water resources and set up plans for managing these important resources. The area under study is a part of Khazir river basin which is a tributary of Greater Zab River Basin. Aqra plane constitutes the major part of this basin, starting from the left bank of Khazir river while the area or the plane located to the right bank of the river belongs to Mreba and Qasrok territories. The primary source of water, in addition to the water of the Khazir River, is groundwater, especially in the summer and autumn seasons when the stage in rivers drops to its lowest levels.

Groundwater mapping, derived from Geographic Information System (GIS) and remote sensing data, is used to track the availability and distribution of groundwater. The delineation of Groundwater Potential Zones (GWPZs) is the modern approach of groundwater mapping which in turn is relied on remote sensing and GIS. Furthermore, GWPZs are very important and helpful in water resource management particularly when there is an extensive use of this resource especially for domestic and irrigation purposes. In addition, groundwater Potential gives an idea about the quantity of water available in the aquifers. The amount of groundwater available in a given region is referred to as "groundwater potential," and it is determined by a number of hydrologic and hydrogeological parameters (Jha, et al., 2010). Accordingly, this term or expression illustrates the feasibility of the occurrence of groundwater in a specific region from the perspective of hydrogeological investigation.

Groundwater exploration is becoming increasingly important to address different water supply demands from drinking, domestic, industrial, and agricultural sectors, especially in places with a shortage of surface water for human and agricultural use (Elubid, et al., 2019), (Stampolidis, et al., 2005). GWPZ delineation using remote sensing and GIS is an alternative that can produce satisfying results to the traditional methods of groundwater exploration and delineation, such as drilling wells, geological, and geophysical approaches (Fetter 1994).

Data collected by remote sensing is the most essential information sources for problems related to land and water-related issues and their management. Integration of geographic information systems (GIS), remote sensing, and analytical hierarchy process (AHP) enables the identification of groundwater potential zones in an economically and time-efficient manner. The integrated approach takes into account a number of factors, such as rainfall, slope, drainage density, lineaments, Geology, and land use/landcover, in order to reduce uncertainty and human error and thus improve precision. Therefore, remote sensing tends to produce the aforementioned characteristics, which, after processing and analysis, can be used to identify and locate groundwater resources in the study area. Many authors (Chaterjee and Bhattacharya, 1995); (Krishnamurthy and Srinivas, 1995); (Srivasthava and Bhattacharya, 2000); (Sarkar, et al., 2001) emphasized on the relevance of remote sensing data and techniques provided by geographic information systems for building a database that can be utilized to identify potential groundwater occurrence regions.

In dry to semi-arid climates, delineating groundwater potential zones with RS and GIS is also effective (Ganapuram, et al., 2009), (Murthy, 2000), (Leblanc, et al., 2007), (Abdalla, 2012), (Al-abadi and Al-shamma, 2014). (Rahmati, et al., 2015).Delineating groundwater potential zones with RS and GIS is also an effective approach to estimate groundwater potential zones in arid to semi-arid climate zones (Ganapuram, et al., 2009), (Murthy, 2000), (Leblanc, et al., 2007),(Abdalla, 2012),(Al-abadi and Al-shamma, 2014), (Rahmati, et al., 2015). The attribute layer selection is optional, and the feature classes used to identify the groundwater potential zones (GWPZ) varies from one study to another.

The groundwater potential zones were delineated using a mix of Analytical Hierarchy Process (AHP) and GIS methodologies in this study. (Saaty, 1977, 1980, 1990, 1994, 2008) created the analytic hierarchy process (AHP) as a multi-criteria decision-making technique. The technique may be used to simplify difficult judgments by reducing them to a series of pair-wise comparisons and then synthesizing the findings. Furthermore, the AHP tool is an effective method for assessing the consistency of a result, hence decreasing bias in the decision-making process.

The objective of this work is to use RS-GIS and AHP to identify the GWPZs of the Khazir river basin. For this purpose, six thematic layers have been used in the study (geology, rainfall, slope, drainage density, land use/land cover, and lineament density). When it comes to developing sustainable groundwater plans in this region, this study will be a valuable resource for groundwater resource planners and managers.

Study Area

Khazir river basin, (Fig.1), is located in northern Iraq as a part of Duhok Governorate in Kurdistan Region. The study area is a part of Khazir Basin with an area about 1047km^2. The river (Khazir) divides the area into two parts, the left-bank-part is a part of Aqra plain, while the right-bank-part belongs to Shekhan district. The area is surrounded by Aqra Mountains in the north and Maqlob Mountain in the south. From the geographical point of view, the area is located between the two latitudes 36° 29´ 00´´ and 36° 51´ 00´´N and two longitudes, 43° 27´ 00´´and 43° 52´ 00´´E. The maximum elevation is at Aqra Mountain, with an altitude of 1640 m a.s.l., while the lowest altitude is about 300 m a.s.l. at the confluence point between the Khazir and Gomel rivers. The most important geomorphological features of the region are associated with river deposits, which are separated from the most northern part of the area by ridges that are part of the southern limb of the Aqra Anticline. There are also some of the streams that only appear seasonally. The climate of Iraq is mostly continental, sub-tropical and semi-arid. The study area has a semi-arid, Mediterranean climate. Summers are dry and hot, while winters are cold and rainy.

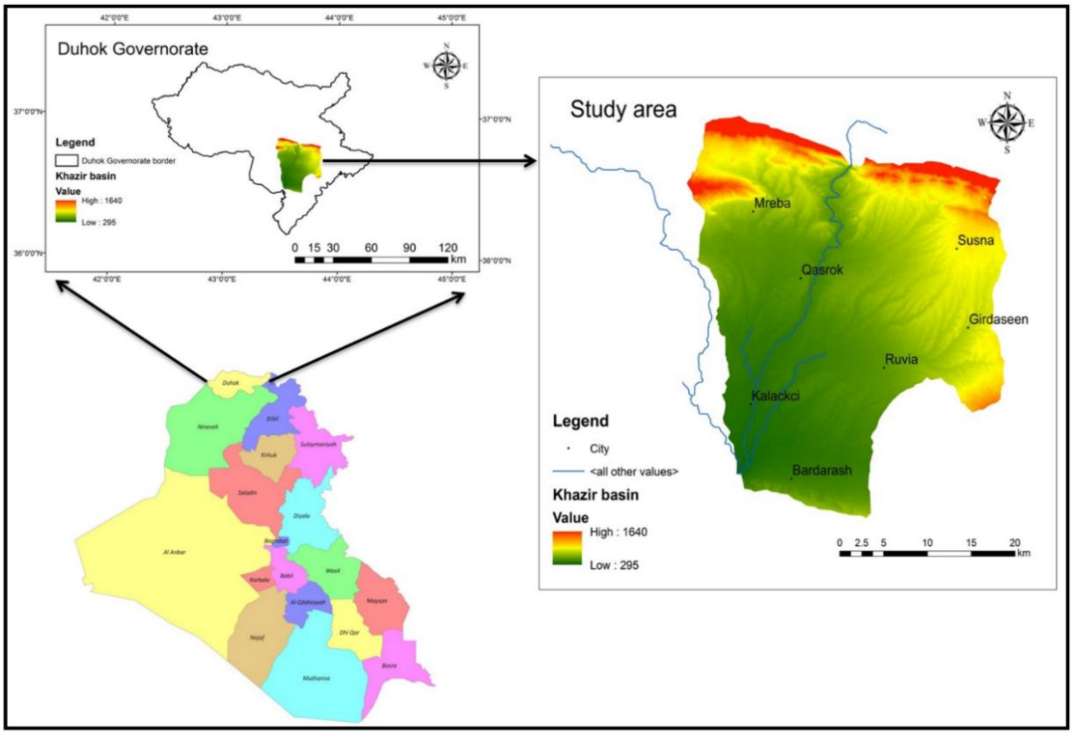

Fig.1. A map illustrating the location of the research area

The Khazir River is the largest tributary of the Greater Zab River. This river is the main tributary of the Tigris. The river drains water from an area of about 2900 km2. The length of Khazir is around 96 kilometers. Prior to its confluence with its tributary, the Gomel River, almost half of the river's length flows within the study area.

On the basis of geographical, stratigraphic, and structural characteristics, Iraq is divided into three primary tectonic zones: the thrust zone in the northern east, the folded zone in the north and northern east, and the unfolded zone in the center and south-west (Bolton, 1958; and Dunnington, 1958). The research area is situated on the southern margins of the folded zone between the Maqloob and Aqra anticlines, which both run almost east-to-west. The northern part of the study area is an orographic region including the geologic formations outcrops Aqra-Bekhme, Qamchuqa Cretaceous and Pilaspi (Middle Eocene) formations. These limestone formations comprise the fractured aquifer system. The rest of the area is agricultural plain made up of Pliocene (Bakhtiari Group) and Quaternary deposits (Figures 2 and 3).

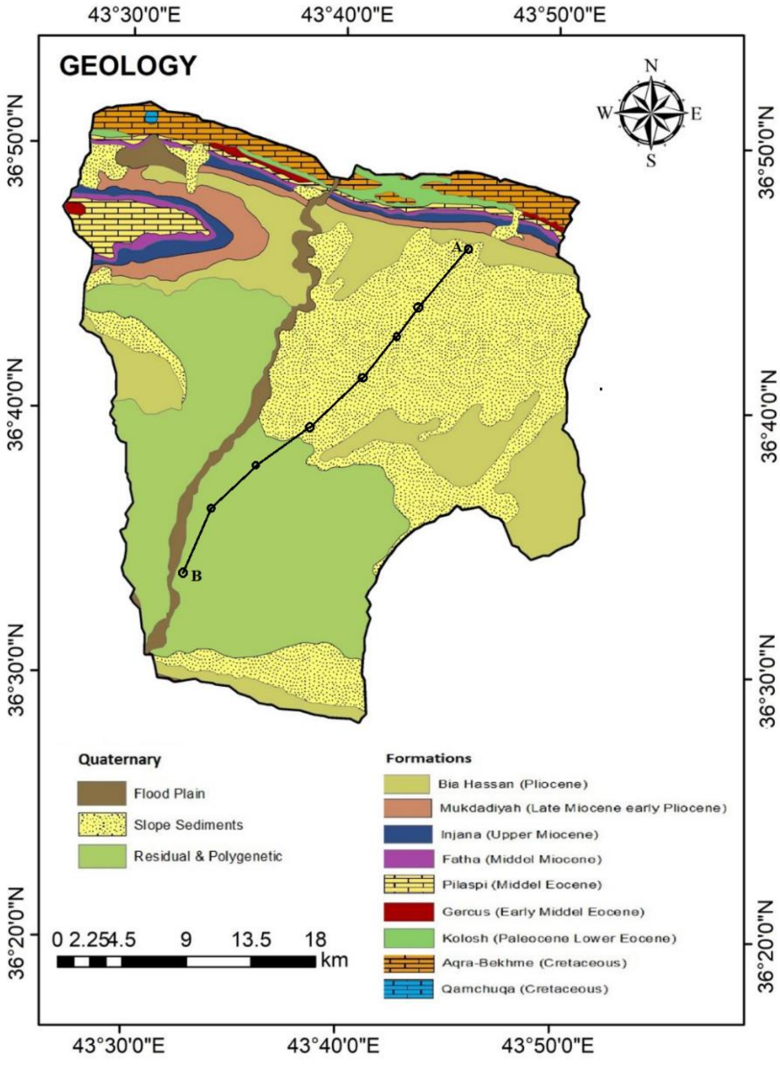

Fig.2. Geological map of the study area

A brief description of the geologic formations outcropping in the study area starting from Qamchuqa formation (> 300 m thick), Early Cretaceous, the oldest formation, comprises organodetrital and detrital and locally argillaceous limestone with some degree of dolomitization (Sissakian, 2013). Aqra Formation (75-315 m), Late Cretaceous, reef limestone complex with massive rudists-shoal facies, and detrital forereef limestone / Marls, marly limestones. Khurmala Formation (10-30 m), Paleocene, lagoonal crystallized limestone, dolomite with interbeds of different clastic rocks. Kolosh Formation (150-400 m), Early Eocene, Shales, sandstones, chert, radiolarite. Gercus, Middle Eocene (150-300 m), Red clastic sandstone and claystone, red and purple shale with gypsum lenses. Basal conglometares exists as well. Pila Spi Formation (75-160 m), Late Eocene, Dolomitic and chalky limestone with chert nodules. Fatha Formation (Lower Fars), Middle Miocene (100-350 m), gypsum and anhydrite interbedded with limestone and marl.

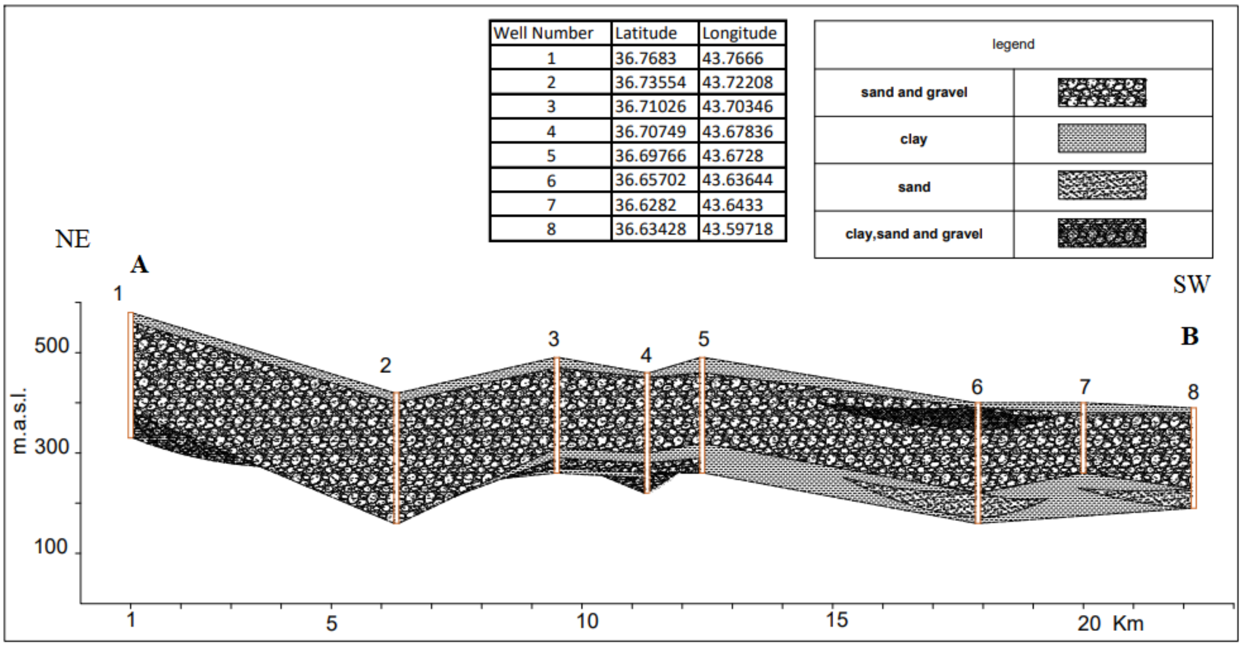

Fig. 3. Geologic cross-section of study area obtained from the productive well logs with their coordinates shown in the figure (well profiles obtained from General Directorate of Groundwater in Duhok)

Injana Formation (Upper Fars), Late Miocene (100-2000 m), the basal unit comprises thin-bedded calcareous sandstone, and red and green mudstone with very thin gypsum bed. Purple Siltstone. Mukdadiyah Formation (Lower Bakhtiari), Early Pliocene (50-660 m), gravely sandstone, sandstone and red mudstone. Sandstones are strongly cross-bedded. Bai Hassan Formation (Upper Bakhtiari), Late Pliocene (300-1000 m), Alternation or compacted conglomerate, brown compacted claystone and grey course sandstone. Older Alluvium, Pleistocene, River's flood plain terraces composed mainly of rock fragments gravel, sand silt and clay. The Bai Hassan (Upper Bakhtiari) unconfined aquifer and the Mukdadiyah (Lower Bakhtiari), confined aquifer is considered to be the two most important aquifers in the area under study. These two aquifers are separated by an impermeable confining bed mostly consists of claystone or silty claystone. Aqra Plain is an unconfined aquifer composed of Pliocene gravel, sand, and silty clay.

The most recent deposits are represented by Quaternary sediments that overlays Bai Hassan formation (Upper Bakhtiari) and include different types of Pleistocene to Holocene sediments. The quaternary sediments comprise River terraces, Moraine Sediments from glacier origin, Calcrete which are rock fragments are mainly of limestone, cemented by clayey and calcareous materials, alluvial fan sediments, Colluvial sediments, Flood plain sediments, valley fill sediments, and Residual sediments represented soil (brown to reddish brown) is calcareous and clayey with different sizes of rock fragment of limestone which increase with depth.

The primary water-bearing sediments range in thickness from 140 to 240 m (Fig. 3). The unconfined aquifer is underlain by a 10 to 100 m confining impermeable clay bed that separates Bia Hassan Formation from Mukdadiyah Formation (Lower Bakhtiari). The later represents the confined aquifer where many artesian flowing wells which are located in the middle and northern portions of the research region.

Materials and Methods

In order to develop potential groundwater zones, the study's principal idea is to integrate six thematic layers of geology (Geo), drainage density (DD), slope (Sl), land use/land cover (LULC), rainfall (Rf), and lineaments density (LD). These layers were then processed using raster calculator analysis under ArcGIS 10.6.1. environment. Through the integration of remotely sensed data (RS), analytical hierarchy process (AHP) and geographic information systems (GIS), the zones of groundwater potentiality have been identified. Field research, field surveys, and satellite imagery downloaded freely from the USGS Earth Explorer website.

Map digitization, field data and digital image processing, all play roles in preparing new thematic layers. To facilitate their use with ArcGIS 10.6.1, all data have been pre-processed and inserted to GCS WGS 1984 UTM zone 38 North. The present investigation was founded on a wide variety of data from various origins. The data sources are briefly listed in (Table 1).

Table 1. List of the data sources

Elements	Data type	Spatial Resolution	Source
Lineament Density Map	Sentinel 2B	10 m	USGS
Land Use / Land Cover Map	Sentinel 2B	10 m	USGS
Drainage Density Map	ASTER DEM	30 m	USGS
Slope Map	ASTER DEM	30 m	USGS
Geology Map	Reference		Jassas, et.al. 2015
Rainfall Map	Rainfall Data	Interpolated on 30 m Resolution	Directorate of Meteorology and Seismology of Duhok Governorate

In this study, the Khazir river basin's GWPZs were delineated using RS and GIS-based Multi Criteria decision making via AHP. (Fig. 4) demonstrates the methodology used in this study.

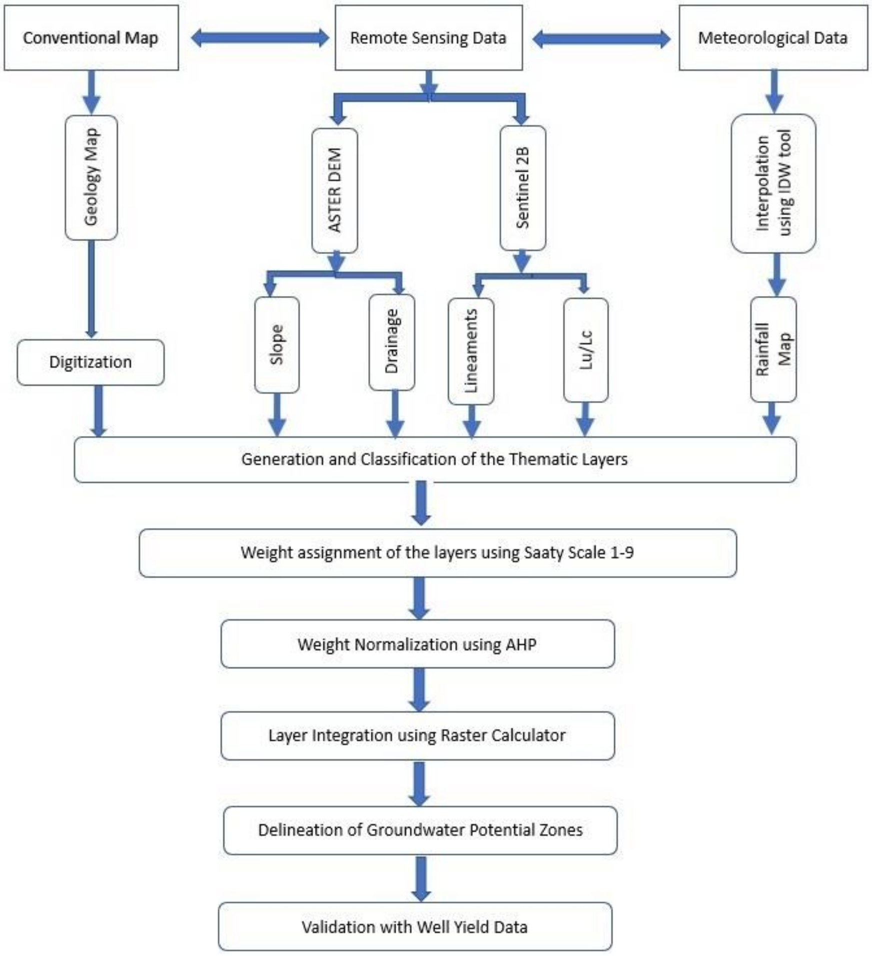

Fig. 4. Flowchart of methodology for delineation of groundwater potential zones (GWPZs).

Analytic Hierarchy Process (AHP)

Multi-criteria decision analysis utilizing AHP is the most prevalent GIS-based method for delineating groundwater potential zones, (Arulbalaji, et al., 2019). The AHP approach generates and integrates thematic layers according to their significance and impacts on groundwater potential.

Six thematic layers have been used for carrying out this study, which have been chosen according to their significance in influencing on groundwater parameters. A pairwise comparison matrix was created depending on (Saaty, 1980, 2005) scale. The significance of one layer's influence on groundwater potentiality in relation to another layer was rated using Saaty's 1–9 scale. A rating of 1 indicates that the two layers have an equal impact, while a rating of 9 indicates that the layer has the greatest impact when compared to another layer (Table 2).

Field experience and in-depth knowledge are both taken into account when deciding the value to assign to each thematic layer on the Saaty scale.

Table 2. The relevance of the parameters on a scale from one to nine (Saaty,1980)

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

In order to assist the determination of the parameters' relative priority and ranks, an AHP-based pairwise comparison matrix was built (Table 3). Each pair of layers was given priorities using a one-to-nine-point scale. For instance, geology has a greater impact on groundwater potentiality than slope, and was thus assigned a value of 3.

Table 3. Pairwise comparison matrix for AHP-based GWP zonation

	Geo	Sl	Rf	LULC	DD	LD	Normalized Principal Eigenvector
Geo	1	3	5	3	4	4	40.55%
Sl	1/3	1	3	4	3	3	24.26%
Rf	1/5	1/3	1	2	2	2	11.84%
LULC	1/3	1/4	1/2	1	2	2	9.87%
DD	1/4	1/3	1/2	1/2	1	1	6.74%
LD	1/4	1/3	1/2	1/2	1	1	6.74%
Total	2.37	5.25	10.5	11	13	13	100.00%

Utilizing the principal eigenvalue and consistency index, the AHP incorporates the concept of uncertainty into decision-making (Saaty, 2004). In other words, in order for a pairwise matrix to be consistent, λ-max needs to be equal to or larger than the number of layers that are being investigated, which in this case is six layers; otherwise, it is necessary to build a new matrix.

The consistency index was computed using the primary eigenvalue of a 6*6 matrix, which was determined to be 6.316 (Table 4).

In case the consistency ratio (CR) is 10 percent or below, then the weights that have been given are deemed consistent; otherwise, these weights need to be reassessed so that inconsistency may be reduced as much as possible (Saaty,1990). Using Equation (1),

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

Saaty introduces a consistency scale that may be interpreted as both a deviation and a degree of consistency; he calls it the Consistency Index (CI). where λ max represents the greatest eigenvalue of the pairwise comparison matrix and n represents the total number of categories or attributes.

The CI in this study is:

$$CI = (6.316 – 6)/6\text{-}1 = 0.0632 \quad (2)$$

Table 4. Computation of the principal eigenvalue (λ max)

Parameters	(Column-1)	(Column -2)	λmax (1) x (2)
Geo	2.37	0.4055	0.961
Sl	5.25	0.2426	1.274
Rf	10.50	0.1184	1.243
LULC	11.00	0.0987	1.086
DD	13.00	0.0674	0.876
LD	13.00	0.0674	0.876
Sum (λmax)			6.316

The determination of CR is calculated using the following equation:

$$CR = \frac{CI}{RI} \quad (3)$$

The order of the matrix, which is displayed in (Table 5) for different n values, determines the value of RI, where RI is the random index. The RI value for the six parameters in the current research is determined that equals 1.24.

Consequently, CR is:

$$CR = 0.0632/1.24 = 0.051 = 5.1\,\% \quad (4)$$

where a CR of 5.1 percent (less than 10 percent) is considered acceptable to carry out the Raster calculator analysis so that the weighted parameters for mapping the ground-water potential zones can be integrated.

Table 5. The ratio index, abbreviated as RI, for a variety of n scores (Saaty,1980).

N	3	4	5	6	7	8	9	10
RI	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Determination of Groundwater Potential Index

The GWPI of the area under study was determined by using the following formula (Malczewski, 1999):

$$GWPI = \sum_{w=1}^{m} \sum_{j=1}^{n} (W_j \times X_i) \quad (5)$$

Wj is the normalized weight of j parameter, Xi is the weight of class i, m is the number of parameters, and n is the number of classes inside a particular parameter. By using the overlay tool supported by spatial analyst within GIS, groundwater potential map was generated

$$GWPZ = Geo_w Geo_r + Sl_w Sl_r + Rf_w Rf_r + LULC_w LULC_r + DD_w DD_r + LD_w LD_r \quad (6)$$

Geo, Sl, Rf, LULC, LD, DD stand for geology, slope, rainfall, land use/cover, Lineament density and drainage density, respectively. The symbol 'w' reflects a thematic layer's weight (column 4 in Table 6), while 'r' expresses subclasses' ratings (rank) in each layer (column 3 in Table 6).

Table 6. Assigned rank and weight of thematic layers

Thematic layers	Class	Assigned Rank	Parameter weight
Geology	Flood Plain	8	40.55
	Residual & Polygenetic	7	
	Slope Sediment	8	
	Aqra-Bekhme (Cretaceous)	3	
	Bai Hassan (Pliocene)	9	
	Fatha (Middle Miocene)	2	
	Gercus (Early Middle Eocene)	1	
	Injana (Upper Miocene)	3	
	Kolosh (Paleocene Lower Eocene)	2	
	Mukdadiyah (Late Miocene early Pliocene)	6	
	Pilaspi (Middle Eocene)	6	
	Qamchuqa (Cretaceous)	1	
Slope (Degree)	0-5	9	24.26
	5-10	8	
	10-20	5	
	20-30	4	
	>30	2	
Rainfall (mm/yr)	< 400 - 475	3	11.84
	475 - 550	4	
	550 - 625	5	
	625 - 700	7	
	700 - 820	8	
LU-LC	Scrub forest	4	9.87
	Vegetation	7	
	Agriculture	7	
	Water body	8	
	Built_up area	2	
	Alluvial deposite	6	
	Pasture	7	
	Bare land	2	
Drainage density (km/km2)	Very low	6	6.74
	Low	5	
	Moderate	3	
	High	2	
	Very high	1	
Lineament density (km/km2)	0 - 0.5	2	6.74
	0.5-1	3	
	1-1.5	4	
	1.5-2	5	
	2-2.5	6	

Factors Influencing Groundwater Recharge Zones / preparation of thematic layers

Slope (Sl)

Slope of the landscape has its direct influence on the velocity of surface runoff and hence on the time of concentration of the catchment and consequently on the groundwater recharge. Therefore, areas with gentle slopes reduces the surface runoff and, as a result, raises the infiltration rate, hence increasing the likelihood of groundwater recharge. While area with a steep slope gradient performs high runoff and therefore a comparatively low GWP.

Using Spatial Analyst Tools > Surface > Slope in ArcGIS 10.6.1, using data from ASTER DEM and a grid with a cell size of 30 meters, a slope map of the region was created in degrees.

Drainage Density (DD)

Drainage density is the ratio of stream lengths to drainage basin area. The potential for groundwater is inversely related to the density of drainage systems., therefore low Drainage density (Dd) means more opportunity of rainfall to be soaked in the ground via infiltration process and hence more replenishment of groundwater, while high Dd causes more water to be ran on the surface and accordingly less opportunity for water to be infiltrated into the ground and consequently less groundwater recharge. By utilizing Spatial Analyst Tools, then Density and Line Density in ArcGIS 10.6.1, we were able to determine the drainage density of the research region.

Lineament Density (LD)

Any linear structures that may be identified as lines in satellite imaging are considered as Lineaments. Lineaments can be found in a variety of environments. From a geological perspective these are often faults, joints, or the borders between stratigraphic units. Other elements that may contribute to the formation of lineaments include the presence of roadways and rail roads, contrast-emphasized intersections between natural or man-made geographic features (such as fence lines), agricultural boundaries between cultivated and uncultivated lands, and indistinct "false alarms" brought on by unknown contributing factors.

Hydrogeologists place a premium on these features because they define underground water flow routes. Since the presence of lineaments typically indicates a permeable zone, their density might provide an indirect indication of groundwater potential. Groundwater potential zones should be located in areas with a high lineament density (Haridas, et al., 1998).

Using the (sentinel 2B) band 8 of the oct2021 (Thematic Mapper and Operational Land Imager) satellite imagery with PCI Geomatica Software, a lineaments map of the Khazir river basin was generated. In PCI Geomatics, the "Enhancements" tool was used to add the image and improve its quality. Then, Tools is selected > Algorithm Librarian > Line: Lineament Extraction. After that, the generated map was uploaded to ArcGIS. The lineament map was edited under the GIS environment and all false lineaments were omitted such as roads, boundaries between agricultural land, then the lineament density map or layer was created by selecting the tools Spatial Analyst tools > Density> Line Density. The final vector map of lineaments was then converted to Raster map.

Land use/Land cover (LULC)

Surface runoff and the amount of moisture contained in the soil are both significantly impacted by land use and land cover. The absence of permeable surfaces in built-up areas often brings about in a limited rate of water penetration into the ground. In contrast, agricultural fields and forests both allow for more water penetration because the vegetative cover has the ability to both store water and make it easier for infiltration. According to the findings of the reference (Etikala, et al.,2019), surface waters, lakes or streams, have the highest rate of infiltration capacity, followed by forested areas, agricultural areas, populated areas, and industrial or quarry sites respectively.

Satellite data from Sentinel_2B with acquisition date 21 oct.2021 and resolution 10m were gathered. Using the GIS tool capabilities, the images were color composited via the bands 3, 4, and 8 as RGB colors. The study area in the image was then extracted by mask “extraction by Mask” under ArcGIS 10.6.1 environment. The final map was reprojected to UTM then using image classification the LULC was classified via supervised classification in ArcGIS10.6.1. In this classification, polygons were picked, digitized, and arranged in "Area of Interest" layer to produce the signature files. That is to say, a signature was made by drawing many polygons around a certain land use type, classifying it into a specific category. The same method was then applied to the remaining land use types, resulting in a number of distinct classes that accurately reflect the various forms of land use existing in the area under study.

(Assigning per pixel signatures)>>>maximum likelihood classification>>> LULC Maps.

Due to its limited spatial resolution, the satellite image may not be able to capture all of the things in the picture. However, this constraint was lessened with the use of Google Earth imagery and data from field studies (on 15.11.2021 field trip) to enable better interpretations of land use.

Rainfall (Rf)

Surface runoff and infiltration rates are strongly influenced by rainfall as a key component of the hydrological cycle. High infiltration rates contribute to groundwater recharge, which is dependent on the intensity and duration of rain. The Meteorological directorate of Duhok provided the average annual rainfall data from 15 rain gages outside and inside the study area from 2000 to 2021. After that, an inverse distance weighted (IDW) spatial interpolation was used to the data in order to generate a map depicting the distribution of rainfall. Following that, produce a rainfall map for the research area using the Spatial Analyst Tools, then Extraction and finally Extract by Mask menu option.

Geology (Geo)

The aquifers that hold groundwater are determined by the geology of the area. The availability and recharging of groundwater are strongly influenced by regional geological factors such as the permeability and porosity of different rock types. While some studies have ignored the lithology parameter in GWP zoning and instead they focused on the drainage properties and the density of lineaments as criteria to determine whether the porosity is primary or secondary in nature, the idea given by (Yeh, et al.,2016) was followed and incorporated the lithology into our analysis to reduce the variability in estimating these two parameters.

The geology of the study area was obtained from the geological map given in a published article by (Jassas, et al., 2015). First, two maps were obtained, one was for Quaternary deposits and the second was for geological formations. These two maps were then merged by ArcGIS to produce the whole geological map. Then geological map as polygons was converted into a raster map.

Result and Discussion

Many factors affect water infiltration into the soil, but the slope of the terrain is one of the most important. In general, infiltration rate decreases with increasing slope angle, therefore will affect the amount of water to be recharged into the groundwater. The Khazir river basin has a slope gradient that varies from 0 to less than 89, depending on the location. There are five different categories of slope that have been assigned to the entire region, 0 - 5˚, 5˚ - 10˚, 10˚ - 20˚, 20˚ - 30˚, and 30˚ - 89˚. The slope map of the area under study is shown in (Fig. 5a).

The fact that 57% of the watershed is classified as having a slope angle between 0 and 5 degrees indicates that the area under consideration possesses an excellent potential for a high infiltration rate. In a similar manner, 30% of the areas have a slope between five and ten degrees, which results in substantial runoff and is regarded as having a good infiltration rate. This indicates that 87% of the land, in total, constitutes the bulk of the area, therefore almost the whole area is highly potential to infiltration rate. The areas that have a slope between 10 and 20 degrees are classified as having a moderate infiltration rate since they cover 8% of the total area and create relatively substantial runoff. Whereas Slopes between 20 and 30 degrees and between 30 and 89 degrees are deemed to have an exceptionally low infiltration rate (only 4 and 2 percent, respectively), resulting in an excessive runoff and inadequate infiltration.

Sustainable water resource management requires understanding how LULC affects groundwater recharge and surface runoff (Owuor, et al., 2016). precise and trustworthy information regarding the existing and future LULC will help manage resources (Murmu, et al., 2019; (Singh, et al., 2018). The rate at which water moves from the unsaturated to the saturated zone is affected by both land use and land cover. Groundwater recharge, evaporation, and surface runoff are all influenced by the LuLc ratio, so any modification in that ratio will have consequences. Scrub Forest, Vegetation, Water body, Built-Up area, Agriculture, Bare land, Pasture, and Alluvial deposit are the eight different classes that make up the LULC for the study area, which can be seen in (Fig.5b).

The area that is utilized for agriculture and vegetation is very well suited for the process of recharging groundwater. The presence of vegetation cover reduces the amount of runoff and hence enhances infiltration. The land that is utilized for grazing and scrub forest might be classified as land that is only moderately suited for the recharging of groundwater. The built-up region and the bare terrain are both considered to be the least appropriate areas for the recharging of groundwater. The precipitation has a propensity to soak into the ground in agricultural and forested areas, while it has a tendency to flow immediately over residential areas and bare land as surface runoff.

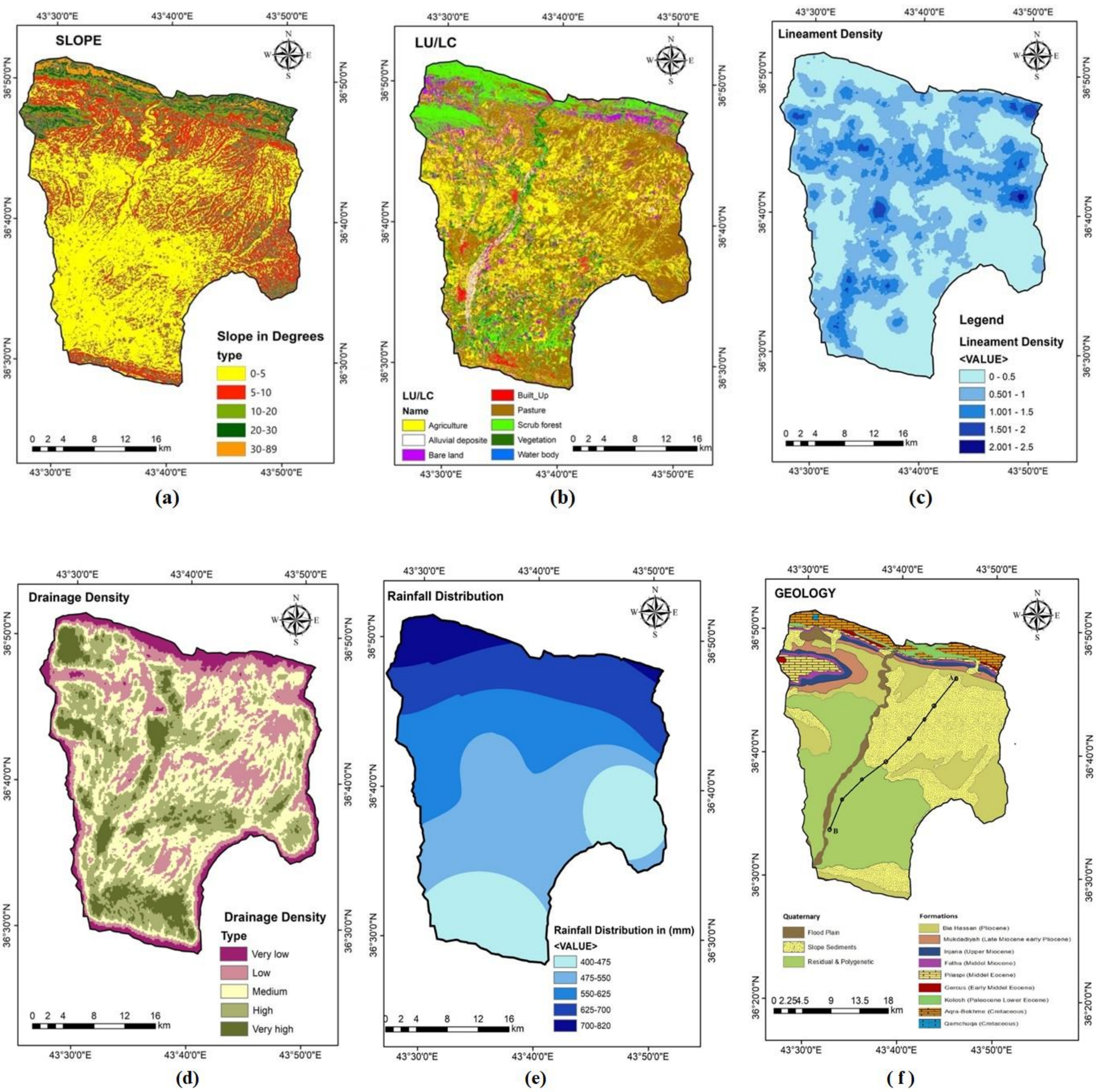

Fig.5. Thematic layers of, (a)Slope, (b) LuLc, (c) lineaments density, (d) drainage density, (e) Rainfall, (f) Geology.

It is estimated that around 38 percent of the overall area is made up of pasture land, while about 28 percent of the territory is used for agricultural purposes and is cultivated. 17 percent of the land is made up of scrub forest, 8 percent is made up of bare terrain, and just 4 percent is covered by vegetation. The remaining minute portion, which is just five percent, is made up of built-up land, water bodies, and alluvial deposits. The possibility for groundwater recharge was taken into account while assigning the weights or ranks to the various factors. For the purpose of groundwater delineation, a high weight was given to the vegetation, agricultural land, pasture land, alluvial deposit, and waterbody; on the other hand, a low weight was given to built-up land, bare land, and scrub forest.

The existence of groundwater resources as well as their movement are greatly influenced by the lineaments and the junctions between them. Lineaments have the potential to act as a conduit for the flow of groundwater, which may result in an increase in secondary porosity. A high lineament density indicates that there is adequate groundwater potential in an area, and the existence of lineaments is a sign that the zone is permeable (Magesh, et al.,2012), (Fashae, et al., 2014).

The study area has a lineament density that ranges from 0 to 2.5 kilometers per square kilometer (Fig.5c). The region's lineament was sectioned out into the following five classes: between 0 and 0.5 kilometers per square kilometer, between 0.5 and 1 kilometer per square kilometer, between 1.5 and 2 kilometers per square kilometer, and between 2 and 2.5 kilometers per square kilometer. Northeastern portions of the basin are often characterized by dense lineaments. The general pattern of the lineaments in the area that was researched reveals an obvious reduction in density as one travels to the southwest of the investigated region.

As far as lineament density is concerned, it is high in the North and north-east of the study area, whereas it decreases in the middle and south. This is because the geology of the area in the north and north-east consists of fractured Pilaspi formation and other older fractured and highly jointed formations such as Aqra formation. In the southern portion of the region, where the density of lineaments is lower, this element will play a smaller role in recharging groundwater than the other ones.

The regions that have a greater lineament density are considered to be favorable for the development of groundwater; hence, the zone that has a high lineament density was classified as having a high groundwater potential and given a higher weightage value.

Drainage density is one of the key parameters that govern surface runoff which in turn has a role in identifying groundwater potentiality (Rajasekhar, et al.,2019), (Bhunia,2020). In addition, the drainage map is useful because regional drainage characteristics provide details about the hydraulic conductivity of rocks and give an overall picture of groundwater supply (Fashae, et al., 2014). Figure 6 illustrates the drainage pattern of the study area. It provides information about the area's morphometry and geomorphological properties.

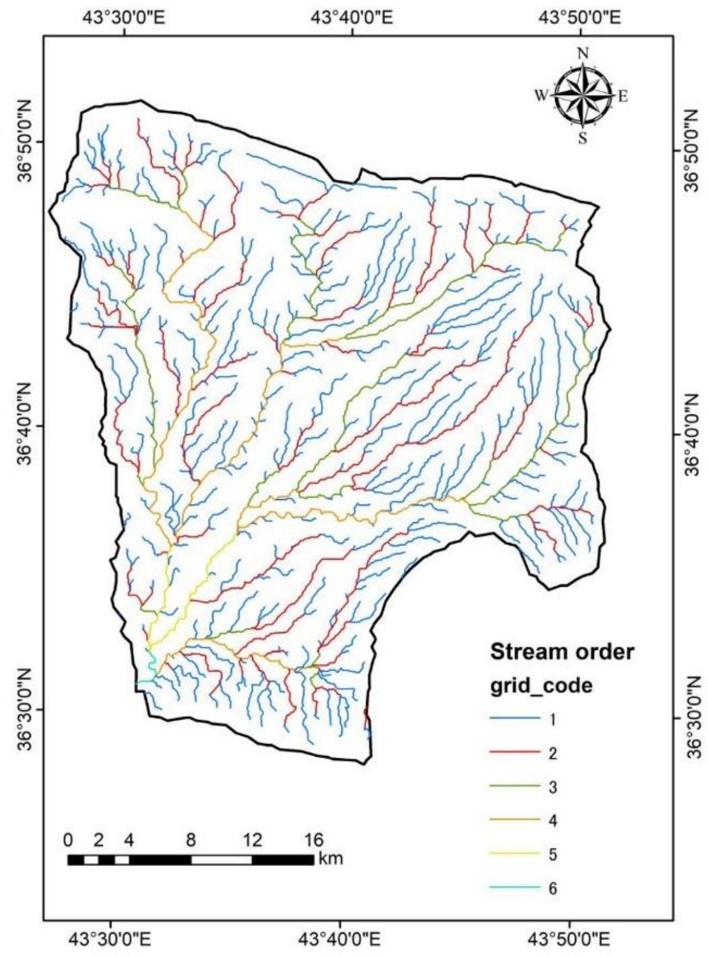

Fig. 6. Streams direction of the study area

The density of drainage in a basin can be used to infer information about the basin's topography, climate, erosion resistance, and rock permeability (Singhal and Gupta, 1999). Therefore, the highest drainage density area experiences the greatest amount of surface runoff and the least amount of groundwater recharge. Therefore, the density is high in the region where many streams come together. There are many streams that run north to south in the study region and join at lower elevation close to the outlet point (Fig.6). In brief, in contrast to a weakly drained basin, which has a delayed hydrologic reaction when rainfall occurs, a drainage basin with a high density indicates a highly segmented drainage system.

To classify the drainage density, the research area has been divided into five categories: very low, low, medium, high, and very high which cover 84, 225 355, 296 and 95 square kilometers respectively (Fig.5d). Because of its correlation with surface runoff and permeability, low density is given more weight than high density when assessing the potential groundwater zone. The drainage density area percent for very low, low and moderate are the predominant classes that gives an indication of more surface recharge and consequently high groundwater potentiality.

Rainfall is an important contributor to the replenishment of groundwater; for this reason, it is regarded as a significant input in the process of determining groundwater potential zones (Adiat, et al., 2014). (Shekar and Pandey, 2014). The amount of water that will be refilled into the aquifer system is partially determined by the amount of rainfall that occurs. The highest possible infiltration rate in a particular location is more likely to occur when the maximum rainfall rate occurs.

In the northwestern region of the area under study, the annual precipitation ranges from around 625 to 820 millimeters, whereas the annual precipitation ranges from approximately 400 to 625 millimeters in the eastern part. The reported rainfall in the southern section ranges from about 400 to 550 millimeters per year, whereas the recorded rainfall in the northeastern part ranges from about 625 to 820 millimeters per year. As a result of the orographic effect, the regions that are higher in elevation experienced greater amounts of precipitation compared to the low land altitude parts. The amount of precipitation also decreases in the direction of the south, which is toward lower elevations. The average annual precipitation of the catchment is 715 mm. The annual precipitation in the area under study ranges from 400 to 820 millimeters and is divided into the following five categories: 400-475 millimeters, 475-550 millimeters, 550-625 millimeters, 625-700 millimeters, and 700->820 millimeters (Fig.5e). The category that receives the least amount of precipitation takes a low weight since its contribution to groundwater potential is poor. The class that has experienced a greater amount of precipitation obtains a greater weight.

Because of differences in porosity and permeability across different geological formations, the local geology is crucial to the penetration of surface water into an aquifer system.

The geology of the study area (Fig.5f) is divided into nine types of rocks formations and three types of Quaternary deposits named Cretaceous Qamchuqa and Aqra-Bekhme formations which cover about 4.1% of the total area, Paleocene Lower Eocene Kolosh formation covers 1% of the area, Middle Eocene Gercus and Pilaspi formations which cover approximately 3.4% of the total area, Miocene Fatha (Lower Fars) and Injana formations (Upper Fars) cover 4% of the area. All these formations were deposited in a marine environment and mainly consist of limestone except for the Injana (Upper Fars) formation, which was deposited in a shallow marine to continental environment and consists of claystone, siltstone and sandstone. As Quaternary deposits, Flood plain, Slope sediments and Residual & Polygenetic which cover 3%,35% and 41% of the total area respectively. The Mukdadiyah formation (Late Miocene) represents a confined aquifer, and the Bia Hassan formation (Pliocene) regarded as an unconfined aquifer, are the two formations that are considered to be the most significant in terms of hydrogeology. Both formations cover approximately 5% and 18% of the area, respectively. These two formations were deposited under a continental environment and are composed of clastic materials for the most part (conglomerate, sandstone, siltstone and claystone).

Groundwater potential zone

Using the raster calculator tool in the ArcGIS program, the systematic AHP analysis on weighted components was able to build a groundwater potential zones map. This was accomplished by integrating all of the thematic maps, including Geology, Rainfall, Drainage density, Lineament, LULC, and Slope. The equal interval approach is used as the basis for the classification of the groundwater potential zone. The groundwater potential zone of the area under study was divided into four distinct zones: Very high, High, Moderate, and Low.

At the first glance looking at (Fig.7), it is clear that the majority of the area is high and very highly groundwater potential zone which covers about 89% of the total area under study (Fig.8). This can be interpreted to the facts that these zones, geologically, belong to the highly permeable Bai Hasan Formation outcrops, the slope sediments of high permeability and Residual & polygenetic deposits. In addition, the Slope of the watershed is among other parameters that has its outstanding or distinctive impact on the groundwater potentiality. It is obvious that the areas with low slope gradients corresponds to those zones of high or very high potential zones. The effect of LULC on groundwater potentiality is conspicuous because each class has a different degree of influence on GWPZ and hence different potentiality of groundwater. For instance, the agricultural and pasture areas make about 66% of the total area where the GWP is high or very high. The groundwater potentiality is influenced by the drainage density as well. As it is clear from the drainage density map, the low and medium classes of the drainage density are allocated in areas of high and very high zones of groundwater potential, this reflects the fact that low drainage density means high soil or sediment permeability and accordingly high infiltration rate. Moreover, lineaments have a significant impact on the potential of groundwater. Since it is presumed that places with a greater lineament density are more suitable to the development of groundwater, the zone was classified as having a high groundwater potential and given a higher weightage score.

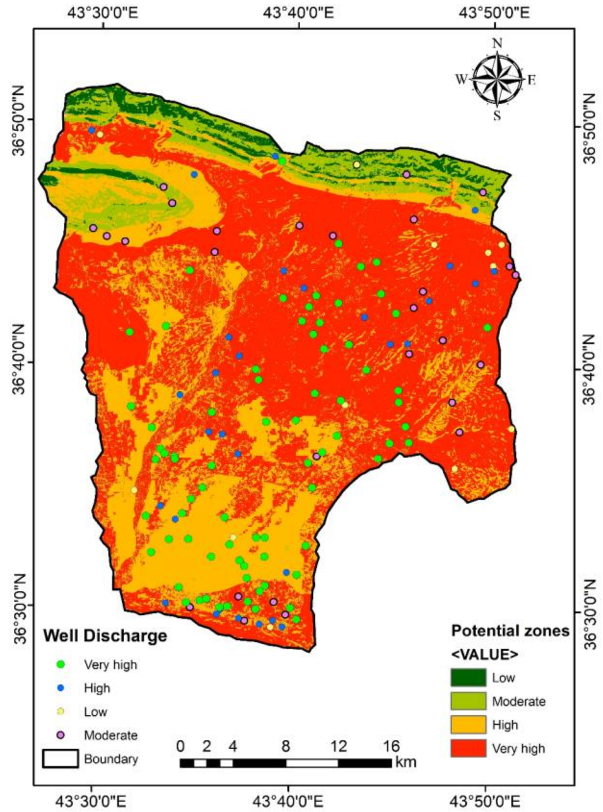

Fig. 7. Groundwater potential zones (GWPZs) of the study area and Well yield categories used for validation.

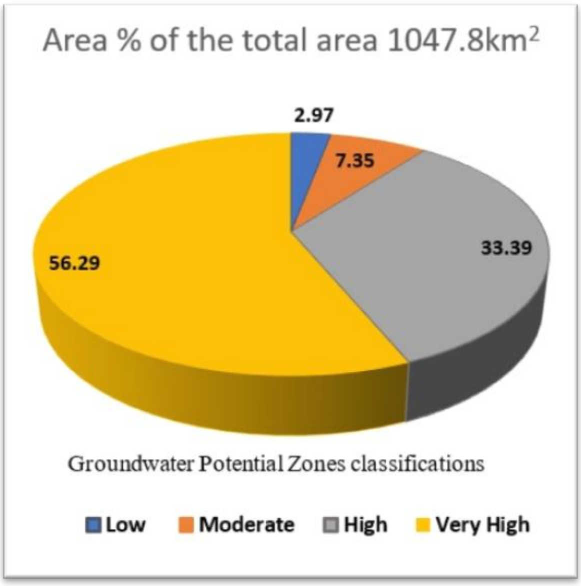

Fig. 8. Groundwater Potential Zones with their corresponding covering area percent

4.2 Result Validation

Using the wells' currently available abstraction rates, the delineated groundwater potential map was checked for accuracy. As can be observed from (Fig. 7), 31 of the 68 wells with very high pumping rate (24–16 l/s) lie inside the zone of high GWP, whereas 37 of the very high yielding wells fall within the zone of very high potentiality (Table 7). There are a total of 31 high productive wells, with 1, 13, and 17 wells designated for the moderate, high, and very high potential zones, respectively. The total number of moderately productive wells is 31. Six wells are located in the moderate potential zone, 8 in high potential zone and 17 in very high potential zone. The number of low-productive wells is 9, none of them is located in low potential zone, one in moderate potential zone while the rest (8 well) are in the zone of very high potential.

Table 7. Groundwater Potential Zones versus Well abstraction classes used for validation

				Yield class			
Potential Zones	Area	Area %	Total No. wells	V.High (24-16 l/s)	High (15.9 – 9.5 l/s)	Moderate (9.4 – 3.6 l/s)	Low (< 3.5 l/s)
Low	31.114	2.97	0	0	0	0	0
Moderate	77.03	7.35	8	0	1	6	1
High	349.878	33.39	52	31	13	8	0
Very High	589.75	56.29	79	37	17	17	8
Total	1047.772	100	139	68	31	31	9

Conclusion

The results of this study show that remote sensing, GIS, and AHP methods can be used in delineating GWPZs in the Khazir basin. Compared to conventional methods, this study reduced both time and money spent on assessing the groundwater resources of the basin.

Using geology, rainfall, slope, LULC, drainage density, and lineaments as the six thematic layers, this work aimed to construct a spatial model for delineating groundwater potentiality. Four groundwater potential zones are shown on a map that was created by integrating these thematic layers using the spatial analyst extension of ArcGIS software and AHP, with verification using available discharge (Yield) rates of boreholes. The area covered by this study is around 1047.8 km^2, the very high groundwater potential zone (589.7 km^2) is prevalent, while the high groundwater potential zone covers an area of about 347.9 km^2. Zone considered moderate is 77 km^2, while zone considered low is 31.1 km^2 in size.

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