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GROUNDWATER POTENTIAL ZONES DELINEATION USING AHP AND GIS TECHNIQUES, FOR THE AL-AJEEJ DRAINAGE BASIN, NORTHWEST IRAQ

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ABSTRACT

The climate variability severely affects the factors influencing groundwater recharge. The unreliable seasonal and poor quantities of the surface water resources tend to increase the decline in the groundwater levels. Therefore, it is necessary to delineate the groundwater potential availability (GWP), which can be used to augment the groundwater source.

The analytical hierarchy process (AHP) technique, as a popular method, is applied to determine the importance of groundwater influencing factors. To integrate the groundwater influencing spatial dataset, all the geospatial datasets preparation was carried out in the Geographic Information system (GIS) environment.

The Al-Ajeej drainage basin was chosen in this research to delineate the groundwater potential zones, where the groundwater serves as the main source for domestic and agricultural uses more than the seasonal surface water. Seven thematic layers of the influencing factors, such as rainfall, lithology, geomorphology, elevation, lineament density, slope, and drainage density, have been selected to assess groundwater potential zones (GWPZ) for the Al-Ajeej drainage basin.

Three GWPZ have been concluded, comprising “**Good**”, “**Moderate**” and “**Poor**”. The **Good** GWPZ is developed in the northern and southeastern parts; the **Moderate** GWPZ is distributed in the north and southwestern parts, while the **Poor** GWPZ is significant on the southern slopes of Sinjar Mountain and a small area in the most western part.

تحديد نطاقات المياه الجوفية المحتملة باستخدام تقنيات المعالجة الهرمية (AHP) ونظم المعلومات الجغرافية (GIS) لحوض العجيج المائي، شمال غرب العراق

لؤي داود يوسف

المستخلص

التعيرات المناخية تؤثر بشدة على العوامل المؤثرة في تغذية المياه الجوفية. التغيرات الموسمية غير المتوقعة والكميات القليلة من مصادر المياه السطحية تعمل على زيادة النقص في مناسيب المياه الجوفية. وعليه يكون من الضروري تحديد أنطقة المياه الجوفية المحتملة (GWP) التي قد تستخدم لزيادة مصادر المياه الجوفية. ان عملية المعالجة الهرمية (AHP)، كاسلوب شائع، يستخدم لتحديد اهمية العوامل المؤثرة في المياه الجوفية، ومن اجل تكامل البيانات المكانية المؤثرة في المياه الجوفية، تم تنفيذ المعالجات اللازمة للبيانات الجيومكانية في بيئة نظم المعلومات الجغرافية (GIS).

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تم اختيار حوض العجيج للتصريف المائي لأنجاز هذه الدراسة، حيث تمثل المياه الجوفية المصدر الرئيس للاستخدام المنزلي وللإغراض الزراعية والتي تعد اكثر من المياه السطحية الموسمية. استخدمت سبعة طبقات كعوامل مؤثرة في تحديد انطقة المياه الجوفية، مثل الساقط المطري، الصخارية، الظواهرالجيومورفولوجية، الارتفاعات، كثافة الظواهر الخطية، الأنحدارات وكثافة الوديان. تم استنتاج ثلاثة انطقة للمياه الجوفية المحتملة في منطقة الدراسة، تتضمن أنطقة المياه الجوفية **"الجيدة" و"المتوسطة" و"الفقيرة"**. يتواجد نطاق المياه الجوفية **"الجيدة"** في الأجزاء الشمالية والجنوبية الشرقية من الحوض، وتتوزع الانطقة **"المتوسطة"** في الأجزاء الشمالية والجنوبية الغربية، في حين ان النطاقات **"الفقيرة"** بالمياه الجوفية تتواجد على المنحدرات الجنوبية لجبل سنجار اضافة الى مساحة صغيرة عند أقصى الجزء الغربي.

INTRODUCTION

Groundwater availability in an area is mainly depending on the climate, geology, hydrology, ecology, physiography, and the interaction between them (Arkoprovo *et al*., 2012). Rainfall is highly seasonal in dry and semi-arid regions, as it is the only source of fresh water. Groundwater is one of the most precious natural resources in such areas, for a variety of purposes including agricultural, drinking, other socio-economic, and cultural activities. Determining groundwater potential zones (GWPZ) is critical for water resource conservation and management in arid regions (Das *et al*., 2017).

Because field observation of groundwater availability and potentiality is costly and time-consuming, the integration of remote sensing (RS) and geographic information system (GIS) provides a more accurate result and allows researchers to investigate the role of various geological, geomorphic, and climatic factors in groundwater availability (Das *et al*., 1997; and Kaliraj *et al.*, 2014). RS data are used in GIS software to extract structural and surface features and other parameters to identify potential groundwater zones (Ramasamy and Anbazhagan, 1997). There are a variety of methods applied for this purpose such as frequency ratio, weights of evidence, and the Analytical Hierarchy Process (AHP).

In the current work, the AHP was chosen as an effective tool for a problem involving multi-criteria decision analysis (Saaty 2008; Hossein *et al*., 2016; Gupta *et al*., 2018; and Agarwal *et al.*, 2019). This method emphasizes the importance of an integrated RS, GIS, and AHP model for implementing an efficient and low-cost approach to determining GWPZ in the Al-Ajeej area of mountainous terrain that is much more complex in terms of precipitation, lithology, geomorphology, slope, drainage density, and other factors, as well as the method's applicability to other regions with similar characteristics.

The current study aims to identify and delineate the GWPZ by integrating various thematic layers. This method is used for the Al-Ajeej drainage basin, which is facing a shortage in water supply, because it depends on rainfall and intermittent surface water only as a source for groundwater recharge, in addition to its arid and semi-arid climate conditions. The resulted GWPZ map can be used to delineate and decide the locations for drilling and dug wells for domestic and irrigation purposes (Ibrahim-Bathis and Ahmed, 2016).

The Al-Ajeej drainage basin is located in the NW of Iraq, near the Iraqi – Syrian borders within Nainawa Governorate. It is within the Al-Jazira Province, South of Sinjar Mountain, and is defined by the following coordinates; Longitudes 41º 10' – 42º 00' E and Latitudes 35º20' – 36º 25' N, as shown in Fig. (1).

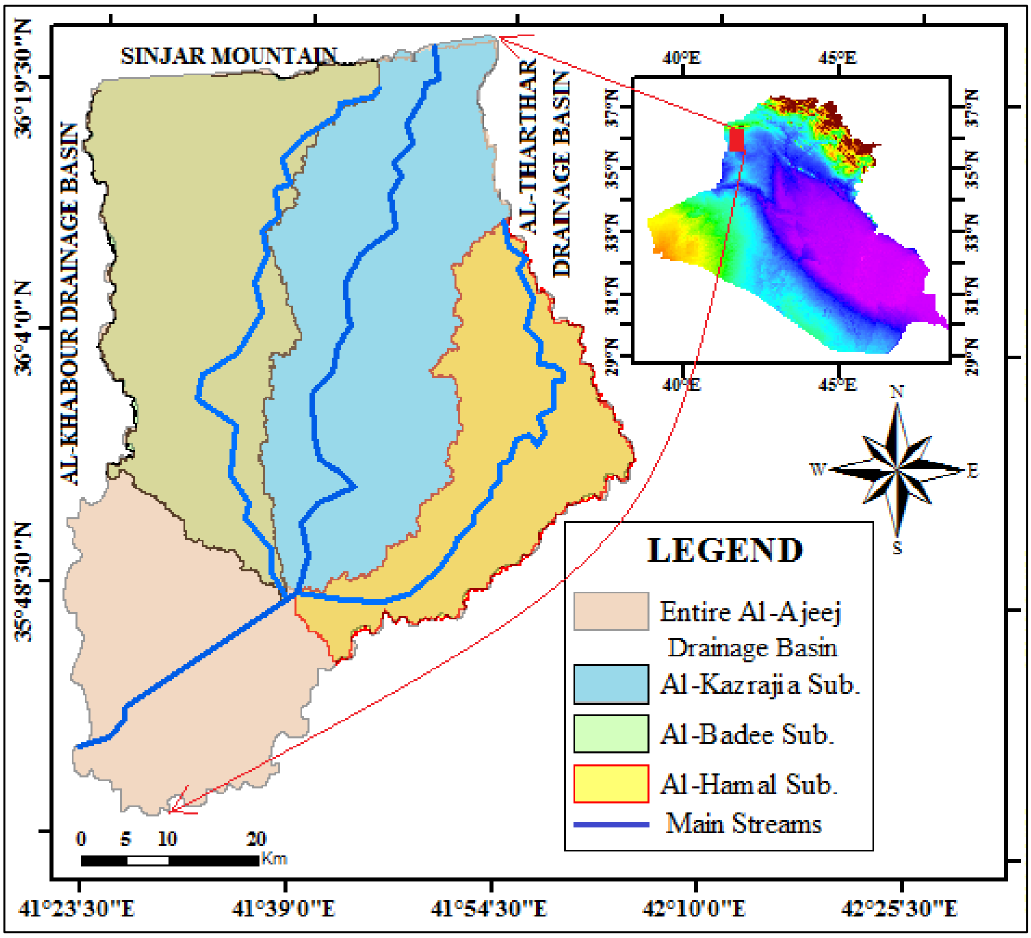

Fig.1: The location map shows the Al-Ajeej drainage basin and its subbasins

The Al-Ajeej drainage basin is bounded by two main drainage basins; Al-Tharthar to the east and Al-Khabour to the west. The Al-Ajeej drainage basin has a catchment area of 3805.6 Km², a perimeter equal to 819.8 Km, a length of about 91.8 Km, and elevations between 200 to more than 1340 m above sea level (Yousif, 2019).

This basin has three subbasins constituting the northern and southeastern parts, while the rest southwestern part constitutes the complementary part. The northern parts are occupied by the Al-Badee and Al-Khazrajiya subbasins, and the southeastern part is occupied by the Al-Hamal subbasin. The main trunks of these three subbasins are joined together, south of Al-Ba'aj city, to form the main trunk of the Al-Ajeej valley (see Fig.1), which runs in the complementary southwestern part of the basin. The main branches, which drain from the southern slopes of Sinjar Mountain, have different trends. The tributaries of; the Al-Badee subbasin, flow NNW – SSE direction; the Al-Khazrajia subbasin, flows N – S trend, while the tributaries of; the Al-Hammal subbasin and the southwestern parts of the Al-Ajeej basin, flow NE – SW direction (Al-Taiee and Rasheed, 2011).

▪ Previous Works

There are many geological and hydrological studies were conducted for the area south of Sinjar Mountain and surrounding it since the beginning of the 1970s of the last century. The hydrological studies were applied to study the hydrological and water supply management to solve the problem of the water shortage in Iraq. This study will focus only on studies that included the study area, which was conducted during the last decade, which are;

- Al-Taiee and Rasheed (2011) analyzed the engineering characteristics of the Al-Ajeej basin, to predict the possibility of surface runoff harvesting, using Watershed Modeling System (WMS).
- Zakaria *et al.* (2012) studied rainwater harvesting in the eastern Sinjar Mountain area. They applied Rain Water Harvesting (RWH) to provide a new source for water, to discover the capability of the area for rainwater harvesting.
- Al-Ansari *et al.* (2013) studied the water harvesting and reservoir optimization in selected areas of south Sinjar Mountain. They applied WMS and linear programming (LP) optimization techniques to maximize the irrigated area, for solving large-scale water supply problems.
- Sissakian *et al*. (2015) reported on the origin and the evolution of Wadi Al-Ajeej. They showed that the estimated age of abandoning Wadi Al-Ajeej to its original course is most probably during the Late Pleistocene.
- Yousif (2019) used the Digital Elevation Model (DEM; 30 m resolution) of Iraq to extract and analyze the morphometric characteristics of the Wadi Al-Ajeej drainage basin, using the GIS technique.
- Yousif (2021) estimated the possibility of active tectonics of the Al-Ajeej drainage basin, using the GIS technique, by analyzing six morpho-tectonic parameters to classify the results according to the Relative Active Tectonics (Iat).

GEOLOGICAL SETTING

Geomorphologically, the main landforms developed in the studied area are briefly described according to Ma'ala (2009), which is directly involved with the studied area.

- Two units of structural – denudational origin are developed as a plateau and dissected slopes.
- Four units of denudational origin are developed as pediments, badlands, erosional plains, mesas, and buttes.
- Two units of solution origin are developed as sinkholes and salt marshes.
- Four units of fluvial origin are developed as river terraces, infilled valleys, alluvial fans, and depression fill sediments.
- Forms of aeolian sediments are developed as sand dunes and nabkhas.

Stratigraphically, the Injana Formation of the Late Miocene age is the only exposed rock formation in the southwestern parts of the Al-Ajeej drainage basin. It is exposed in the base of the main Al-Ajeej valley and consists predominantly of red, brown, and gray claystone, siltstone, and sandstone (Ma'ala, 1976 in Ma'ala and Al-Kubaysi, 2009).

Different types of Quaternary sediments covered un-conformably the outcrops of the Injana Formation with variable thicknesses ranging from a few centimeters up to 10 m. Three main genetic types of Quaternary sediments were differentiated; these are:

1- Alluvial sediments such as river terraces, alluvial fans, and sheet runoff sediments.
2- Slope sediments are developed in the southwestern area of the basin. The thickness ranges from (0.5 – 1.5) m.
3- Residual soil of sandy silty soil covers the majority of the northern part of the area, with variable thicknesses (0.5 – 3 m).

Tectonically, the studied area is located within Al-Jazira Subzone, of the Mesopotamia Foredeep, which is a part of the Outer Platform (Unstable Shelf) of the Arabian Plate (Fouad, 2012). It is dominated by a network of subsurface extensional structures. These structures are mainly ENE – WSW, and NW – SE trending grabens and normal faults (Fouad, 1997; and 1998; and Nasir, 2001).

- **The climate of the Area**

The Al-Ajeej basin is characterized by an arid to semi-arid climate with cold winter with little rainfall and humidity and hot summer with high-temperature differences between night and day (Al-Qassab *et al*., 1987). The rainfall quantities are restricted from October till May with snowfalls in the Sinjar Mountain in the north. The average monthly rainfall in Sinjar and Al-Ba'aj hydrological stations for the period (1991 – 2001) are shown in Table (1). According to the meteorological information supplied by the Iraqi Organization for Meteorological Information (I.O.M., 2000) for the years (1980 – 2000), the annual mean rainfall is around 250 mm, annual mean relative humidity is about 45%, evaporation is about 1800 mm, and annual mean temperature is 21 °C.

Table 1: Average monthly rainfall in Sinjar and Al-Ba'aj hydrological stations for the period (1991 – 2001) after (Al-Taiee and Rasheed, 2011)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual (mm)
Sinjar	67.6	63.4	64.7	45.3	23.1	0.72	0.0	0.0	o.5	12.2	37.1	67.6	382
Ba'aj	57.8	44.5	47.6	24.0	21.1	2.5	0	0	0.24	10.8	37.9	37.9	311

MATERIALS AND METHODS

To get the groundwater potential zones, in the Al-Ajeej drainage basin, digital cartographic and statistical methods have been used and applied in three steps; **1)** generation of the geospatial database, **2)** generation of the weight for groundwater prospecting factors and associated features, **3)** validation the results. ArcGIS 10.4 software has been used to generate the geospatial data, while the generation of weight for groundwater influencing factors and associated features have been calculated by the AHP method in Microsoft Excel software 2010. The final output map has been generated in ArcGIS with the help of raster calculator tools for all thematic layers.

The generation of thematic layers involves digital image processing and the digitization of conventional and present maps (Jhariya *et al*., 2016 and Kumar *et al*., 2014). To extract GWPZ in the Al-Ajeej basin, seven factors have been considered, viz rainfall, geology, geomorphology, elevations, lineament density, slope, and drainage density. These factors are thought to be the most effective in influencing groundwater production and storage, and they provide a good base for locating effective GWPZ (Jhariya *et al*., 2016; Rahmati *et al*., 2015). The flow chart of the current work is shown in Fig. (2).

The seven thematic maps were assigned weights computed by the AHP and the normalized weights for these layers were obtained by satisfying the consistency index (CI) and the consistency ratio (CR) value of the constructed pair-wise matrix. Thus, the created matrix should be consistent if its CR value is < 0.1 (Saaty, 2004). The layers were subjected to weighted overlay analysis after assigning the determined weights. Based on the index value derived using Eq. (1), the GWPZ was classified into three classes; Poor, Moderate, and Good

(Saaty, 2004; Agarwal *et al.*, 2013; Kumar *et al.*, 2014; Rahmati *et al.*, 2015; and Razandi *et al.*, 2015).

GWPZ = Rfr x Rfw + Ltr x Ltw + Gmr x Gmw + Evr x Evw + Ldr x Ldw + Spr x Spw + Ddr x Ddw ……………………………………………… Eq. (1)

Where GWPZ is groundwater potential zones, Rf is rainfall, Lt is lithology, Gm is geomorphology, Ev is elevation, Ld is lineament density, Sp is the slope, and Dd is drainage density. The suffixes r and w represent the rank and weight of each layer.

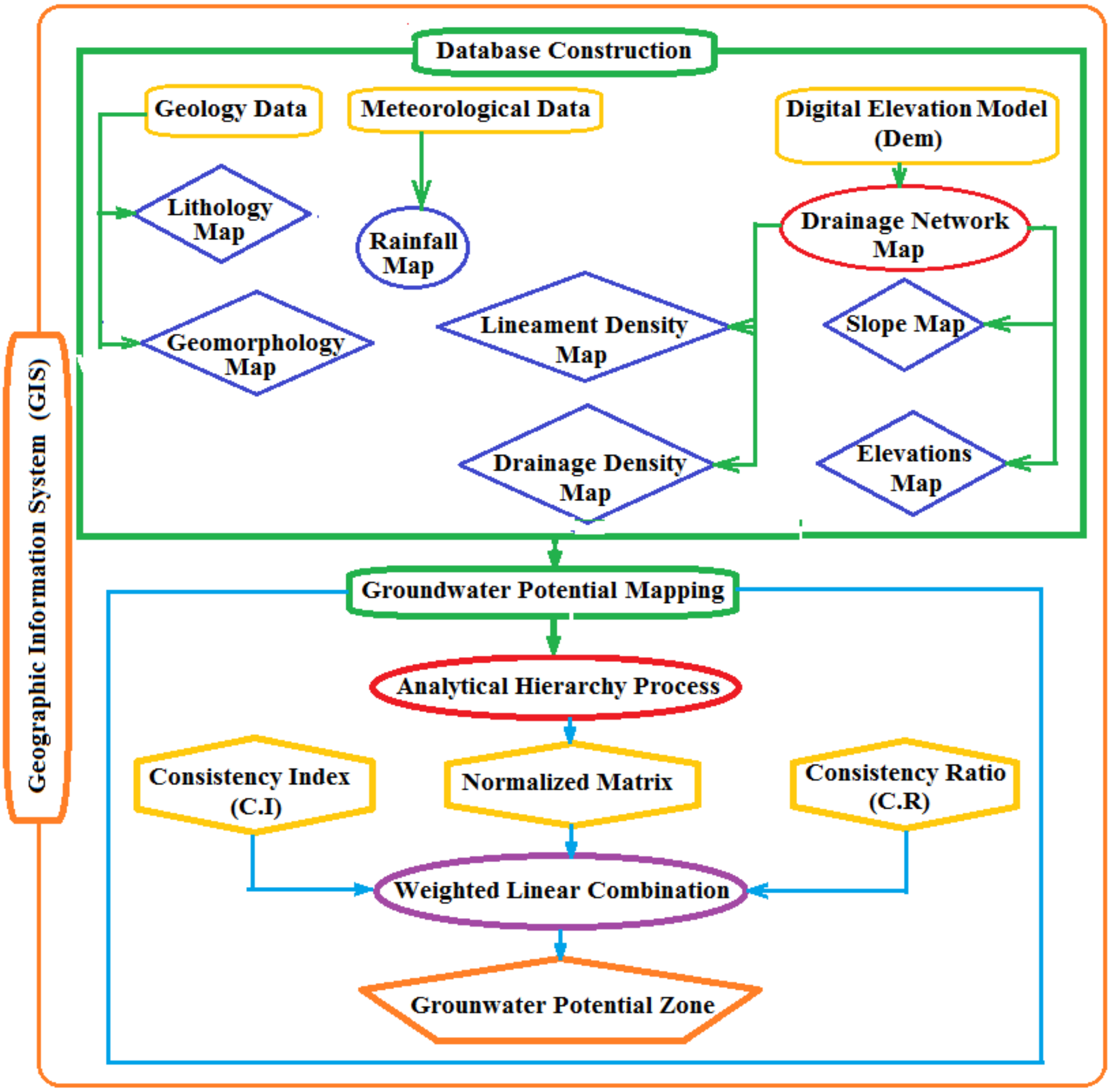

Fig.2: Flowchart for the identification method of the GWPZ in the Al-Ajeej basin

For multi-parameter assessment, the AHP method is extremely useful (Saaty, 1980). AHP is a structural mathematical method for decision-making that involves creating an eigenvalue pairwise comparison matrix utilizing experts' knowledge to calculate the rank and weights (Saaty and Vargas, 2012). It is based on the construction of a pairwise matrix in which the weights of each parameter were computed using the Saaty (2008) scale, taking into account the relative importance of all other parameters, as shown in Table (2).

Table 2: The relative importance of parameters according to scale of Saaty (1980)

Importance intensity	Definition	Description
1	Equal importance	Two activities contribute equally to the other
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or Strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	Activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, and 8	Intermediate values between two adjacent judgments	When compromise is needed

RESULTS

A pair-wise matrix was constructed having seven criteria arranged in rows and columns by developing the influencing factor as a structured hierarchy for the selected seven influencing parameters.

The basic procedure for rating a set of criteria is;

- Developing pair-wise comparison matrix of each criterion;
- Normalize the matrix;
- Average the value of each row to get the corresponding rating to evaluate different potential decisions.

The resulted criteria comparison matrix of this work is demonstrated in Table (3);

Table 3: Criteria comparison matrix for the AHP process for the Al-Ajeej basin

Matrix	R.f	L.t	E.v	G.m	L.d	S.p	D.d	Normalized Eigen Vector
R.f	1	3	4	5	6	7	8	39.15 = 39%
L.t	1/3	1	3	4	5	6	7	24.65 = 25%
E.v	1/4	1/3	1	2	3	5	6	13.46 = 14%
G.m	1/5	1/4	1/2	1	3	5	5	10.24 = 10%
L.d	1/6	1/5	1/3	1/3	1	3	5	6.28 = 6%
S.p	1/7	1/6	1/5	1/5	1/3	1	4	3.81 = 4%
D.d	1/8	1/7	1/6	1/5	1/5	1/4	1	2.23 = 2%
Sum	2.218	5.093	9.20	12.733	18.533	27.25	36	100 %

R.f = Rainfall, L.t = Lithology, E.v = Elevation, G.m = Geomorphology, L.d = Lineament density, S.p = Slope, and D.d = Drainage density

The basic rating procedure is;

- First add up all the values in each column.
- Note, that the values in each column add up to 1.0
- Average the value of each row to get the corresponding rating (criteria weight) as shown in Table (4).
- Each value of the row average multiply by 100 to get the criteria weighted average (mean)

Table 4: Normalized comparison matrix

Factor	R.f	L.t	E.v	G.m	L.d	S.p	D.d	Criteria Weight	C.W. mean	C.W/ C.W.mean
R.f	0.451	0.589	0.435	0.393	0.324	0.257	0.222	2.671 / 7	0.382	7.013
L.t	0.15	0.196	0.326	0.314	0.269	0.220	0.194	1.669 / 7	0.238	7.013
E.v	0.113	0.065	0.109	0.157	0.162	0.183	0.167	0.947 / 7	0.135	7.015
G.m	0.091	0.049	0.0543	0.0786	0.162	0.183	0.139	0.756 /7	0.108	7.0
L.d	0.075	0.039	0.0362	0.0261	0.0539	0.11	0.139	0.479 / 7	0.068	7.044
S.p	0.064	0.033	0.0214	0.0156	0.0179	0.037	0.111	0.3001 / 7	0.043	6.98
D.d	0.056	0.029	0.0181	0.0157	0.0108	0.009	0.028	0.166 / 7	0.024	6.92
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0			
λ_{max}										**7.044**

Note: The differences in the values of the weighted criteria mean column are due to abbreviating long decimal numbers.

RANK AND WEIGHTS DETERMINATION USING AHP

To determine the rank and weights by considering an eigenvalue pairwise comparison matrix, the expert's knowledge is used. The factors that influence the results were arranged into a structural hierarchy, and a pairwise matrix was constructed and filled up by assigning a rank based on relative importance using the Saaty (1980) scale (see Table 2). To determine the CI and CR a computation is made using Eqs. 2 and 3. The created matrix was checked if the CR is less than 0.1 (CR < 0.1) and then the obtained criteria weights were used for analysis.

The main eigenvalue and the CI in the AHP reflect the idea of judgmental uncertainty (Saaty, 2004). Saaty used equation (2) to calculate the CI, which is a measure of consistency as deviation or degree of consistency.

$$CI = (\lambda_{max} - n) / (n - 1) \ldots\ldots\ldots\ldots\ldots\ldots \text{ Eq. (2)}$$

Where the principal eigenvalue (λ_{max}) is the largest eigenvalue of the pair-wise comparison matrix (Table 4) and n is the number of classes.

A principal eigenvalue of 7.044 for a 7x7 matrix was obtained and used for the computation of the CI (Table 4).

Hence, C.I = (7.044 – 7) / (7 – 1) = 0.0073

CR can be calculated from equation (3) to measure the consistency of the pairwise comparison matrix;

$$CR = CI / RI \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eq. (3)}$$

Where RI is the Ratio Index. The value of RI for different n values is given in Table (5):

Table 5: Ratio index (RI) values for different values of N according to Saaty (1990)

The consistency indices of randomly generated reciprocal matrices[54]												
Order of the matrix												
N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
RI value	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

In the current work, RI equals 1.32 for seven factors. Therefore, CR is:
CR = 0.1028 / 1.32 = 0.078
Where, a CR of 0.078 is less than < 0.1, which is acceptable to conduct the weighted overlay analysis to integrate the weighted factors for the GWPZ mapping for the current work.

FACTORS INFLUENCING GROUNDWATER RECHARGE ZONES

The individual layer (criteria) was reclassified and the assignment of ranking is carried out according to the impact of parameters and their respective classes in controlling the potential groundwater recharge over an area. Each parameter and its respective classes are allocated ranks and weights based on their comparative potential contribution (Table 6).

Table 6: AHP ranks and weights of the seven parameters used in this study

Parameter	Type	Rank	Weight	Overall	Parameter	Type	Rank	Weight	Overall
1- Rainfall (*R.f*)	High Medium Low Very Low	4 3 2 1	39	156 117 78 39	**5- Lineament Density (*L.d*)**	Moderate Very Low High Very High Low	3 1 4 5 2	6	18 6 24 30 12
2- Lithology (*L.t*)	Fat'ha Alluvial Sheet runoff Residual Soil Slope sed. Injana River Terraces	4 5 4 2 1 5 3	25	100 125 100 50 25 125 75	**6- Slope (*S.p*)**	Flat Area Gentle Slopes Steep Slopes Very Steep Slopes	4 3 2 1	4	16 12 8 4
3- Elevation (*E.v*)	500-800m 300-500m >800 m <300m	2 3 1 4	14	28 42 14 56	**7- Drainage Density (*D.d*)**	Very Low High Low Very High Moderate	5 2 4 1 3	2	10 4 8 2 6
4- Geo-morphology (*G.m*)	Elevated Region Pediment Badland Sand dunes Ba'aj Plain Alluvial Fan	1 5 2 3 4 5	10	10 50 20 30 40 50					

- **Rainfall Map**

Rainfall (***R.f***) is one of the main indicators of groundwater potential and the major source of recharge. It determines the amount of water that would be available to percolate into the groundwater system (Agarwal *et al.*, 2013). Intensity and duration of rainfall highly have significance on infiltration and runoff volume (Abuzied *et al*., 2015).

Al-Ajeej Valley drainage basin suffers from water shortage, as there are no permanent sources of water, except for monsoon rainwater (Al-Taiee and Rasheed, 2011; and Zakaria, 2012).

The rainfall thematic layer has been created by interpolating the mean annual rainfall values of six rain gauge stations; Mosul, Ba'aj, Rabiah, Sinjar, Telafer, and Tel-Abta in the Al-Ajeej basin and surrounding for the period (1970 – 2017) according to (I.M.O.S., 2017) as shown in Table (7). The rainfall map was grouped into four classes which are; 209 – 230, 230 – 270, 270 – 320, and 320 – 353 mm/year.

It is observed that the northern and the eastern parts receive the largest amount of rainfall, while the western part receives the lowest amount of rainfall (Fig.3a). High rainfall is favorable for high groundwater potential and the higher the rainfall is the more the volume available for percolating the soil (Saranya and Saravanan, 2020). Hence, for regions receiving more rainfall of 320 – 353.6 mm of rain, a higher rating of 152 was given, and for the region with lower rainfall of 200 – 230 mm of rain, a rating of 39 was assigned. As the rainfall has more influence on the potential zone, it has been assigned a large weight of 39.

Table 7: Average annual rainfall values in the studied basin and surrounding for the period (1970 – 2017) according to (I.M.O.S., 2017)

Station	Rainfall	X-Coor.	Y-Coor.	Station	Rainfall	X-Coor.	Y-Coor.
Mosul	352.3	43.09	36.19	**Sinjar**	353.5	41.50	36.19
Ba'aj	215.6	41.44	36.02	**Telafar**	305.4	42.29	36.22
Rabiah	353.9	42.06	36.48	**Tel-Abta**	209.9	42.43	35.55

- **Lithological Map**

The occurrence of groundwater primarily depends on the lithological properties of the geological formations on the area surface (Hachem *et al*., 2015). Lithological (L.t) properties determine porosity and the movement of groundwater (Ayazi *et al*., 2010; Chowdhury *et al*., 2010; and Jhariya *et al*., 2016). The geologic thematic layer of the study area was digitized according to Ma'ala and Al-Kubaysi (2009) and was categorized into seven main groups namely; Al-Fat'ha Formation, Injana Formation, alluvial, rain-wash, residual, slope, and river terraces sediments (Fig.3b).

- **Elevation Map**

The topographical elevation (E.v) is likely to affect the occurrence of groundwater prospects and is regulated by various geomorphological and hydrogeological processes, i.e., geology, meteorological conditions, land degradation, etc. (Pourghasemi *et al*., 2012)

The elevation map of the Al-Ajeej basin has been derived from the DEM (30 m resolution). The DEM of the study area was unfilled and unprocessed, and therefore, it was cleaned up by filling sinks to cover up the local depressions. The elevation map represents the ground surface undulations available for depression storage. The elevation of the study area ranges from 208 to 1352 m above sea level. The thematic map was categorized into four groups, and classified based on the elevations to the areas with elevations; < 300m, 300 – 500 m, 500 – 800 m, and > 800 m, depending on the contour lines' elevations. The higher elevation was found to the north, while the lower elevation was found to the southwest of the map. While assigning the weight to delineate the GWPZ, the high weight potential was assigned for lower elevation areas and low weight for higher elevations according to Patra *et al*. (2018). A high rating of 56 was assigned to regions with elevations of less than 300 m and a lower rating of 14 was assigned to the region with more than 800 m elevations (Fig.4a).

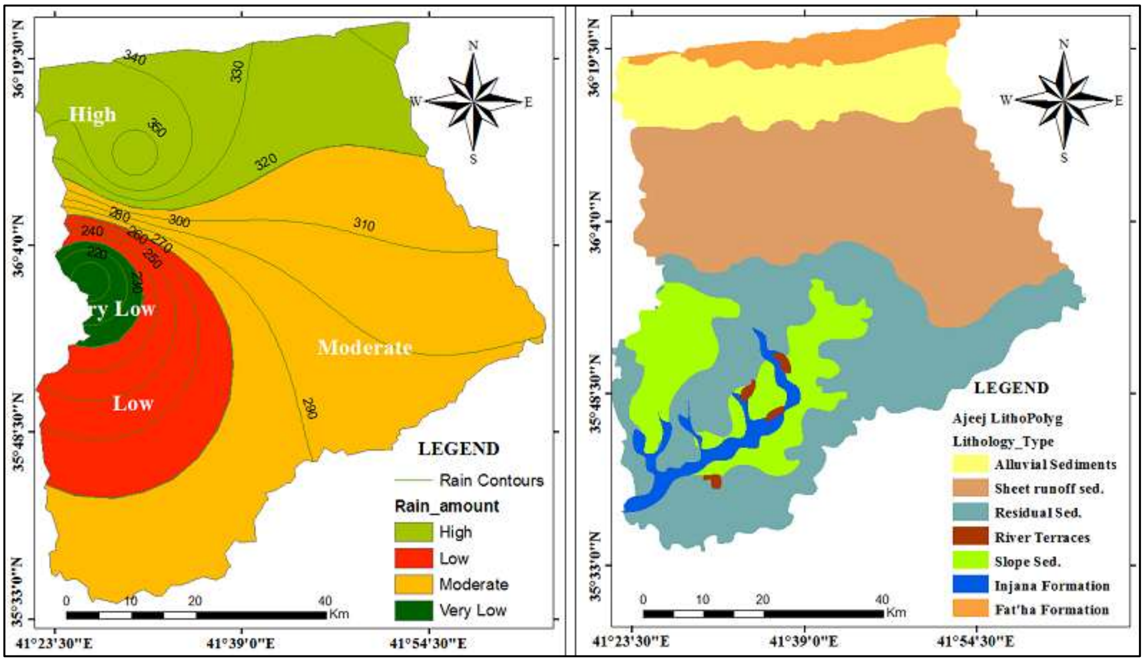

Fig.3: Thematic layers of the; **a)** Rainfall and **(b)** Lithology, maps of the Al-Ajeej basin

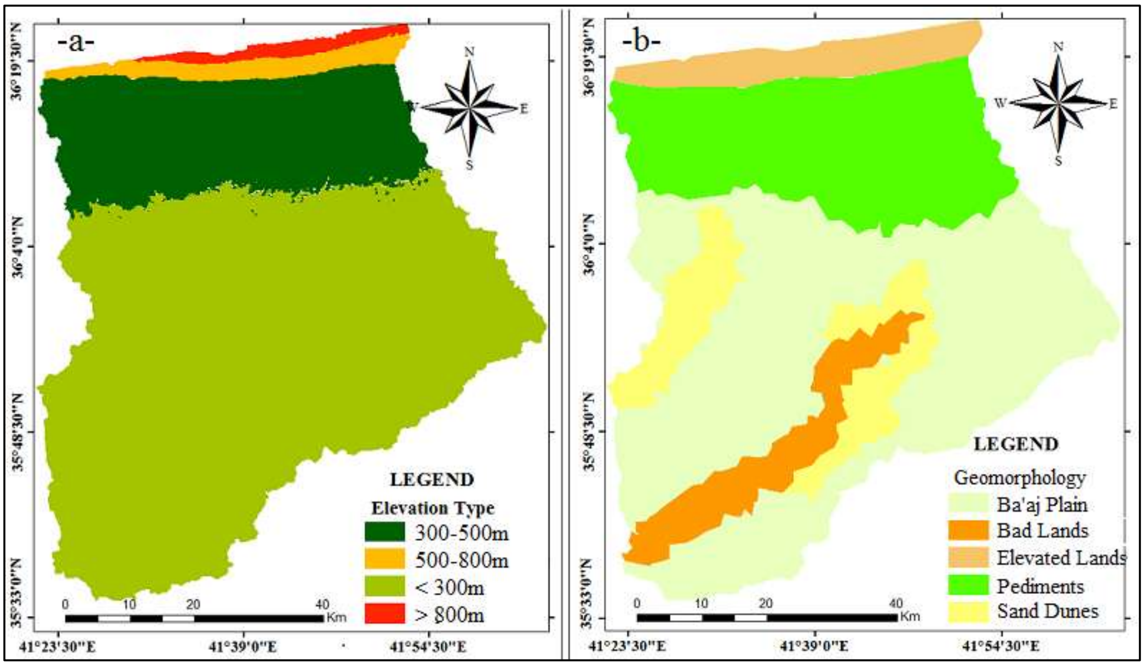

Fig.4: Thematic layers of the; **a)** Elevation and **(b)** Geomorphology, maps of the Al-Ajeej basin

- **Geomorphology Map**

Geomorphology (G.m) is the study of earth surface features, which helps depict inherited processes relating to the GWPZ also structural features (Swain, 2015). The Geomorphology map of the Al-Ajeej basin was digitized according to Ma'ala (2009) and categorized into five classes namely; denudational hills, pediment, Ba'aj plain, sand-dunes, and badlands. About 70% of the total area was found to have pediplain. These are a result of the coalescence of pediments and are relatively flat terrain. The highest rating of 50 has been given to pediment and Ba'aj plain based on its percolation capacity. These geomorphological features form about (2756.5 Km^2) more than 75% of the total area. The lowest rating of 10 was assigned to the denudation hills to the north of the basin, which were found to form less than 7% spread among the total area (Fig.4b).

- **Lineament Density Map**

Lineaments (L.d) are the presence of joints, faults, and fractures that provide a route for percolated water and are also an indirect indicator of a GWPZ (Pinto *et al*., 2017). Lineaments are structurally controlled linear or curvilinear features, which are identified from satellite imagery by their relatively linear alignments. Lineament density was also digitized from the DEM 30 m resolution using ArcGIS software. The lineament density of an area can directly reveal the groundwater potential since the presence of lineaments usually denotes a permeable zone (Sitender, 2010). Studies have shown that groundwater intensity increases with higher lineament density (Yeh *et al*., 2016).

For the study area, the lineament density was categorized into five classes for the convenience of assigning weights as; very low, low, moderate, high, and very high lineament density. The highest rating of 30 was assigned as very high lineament density to regions with 418.2 Km^2 areas. This class has covered almost 11.45% of the total area. The moderate value is 18 which involves (37%) of the basin area that occupies 1352.7 Km^2. Fig. (5a) shows the higher concentrations of lineaments (Very High and High classes) are found along the main three valleys (forming Al-Ajeej main valley) and surrounding areas, while the regions with Very Low lineament density are concentrated at the basin divide, have an aerial coverage of about 6.7% of the total area and a rating of 6 has been assigned.

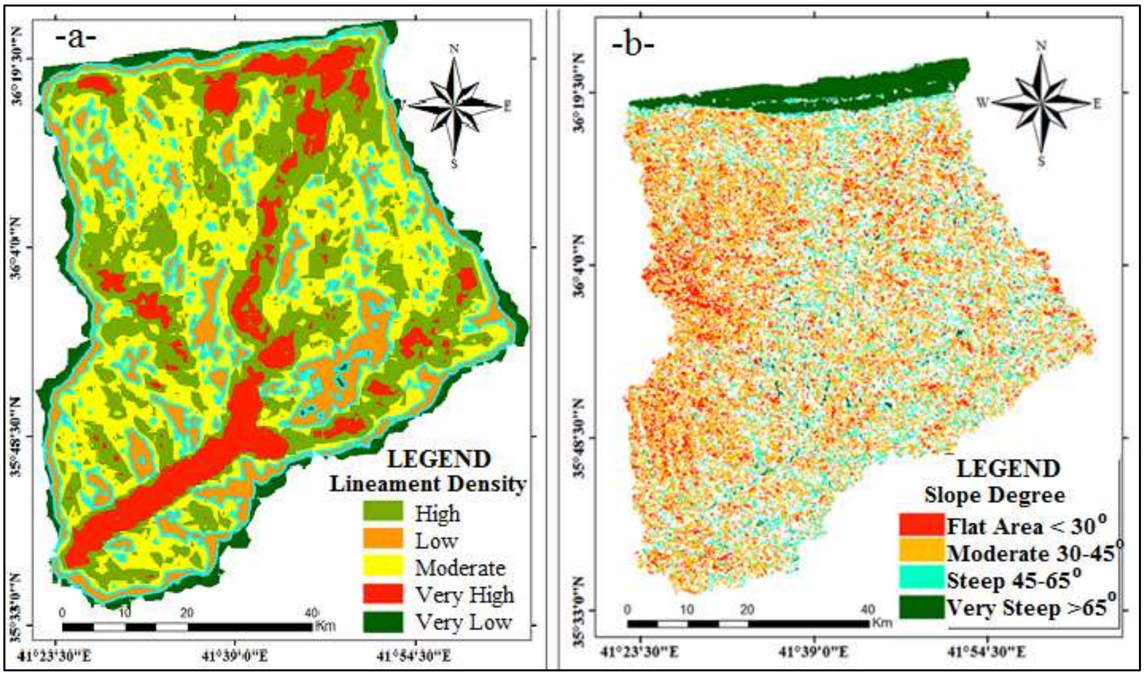

Fig5: Thematic layers of the; **a)** Lineament and **b)** Slope, maps of the studied basin

- **Slope Map**

The slope (S.p) of the region is the factor that affects runoff and infiltration. The steeper the slope is higher the runoff (Gupta *et al*., 2018). The slope map of the study area was classified into four classes depending on the slope angle value. About 24% of the total region were flat terrain having slope angles ranging between 0 and 30° was assigned the highest rating of 16 as it is considered to be the best-suited region for higher infiltration, classes having slope value between 31° and 50° extended to an area of 53% were considered to be moderately suitable for infiltration and were assigned a rank of 12, and for 13% of regions with steeper slope angles ranging 51° – 65°, while the lowest value (4) has been assigned for the very steep (> 65°) slope regions involve 10% of the total area (Fig.5b).

- **Drainage Density Map**

The drainage density (D.d) is a substantial measure of the linear scale of the landform components and an illustration of channel spacing proximity (Horton, 1932). Drainage density measurement is a helpful numerical indicator for landscape dissection and runoff potential (Chorley, 1969). The drainage density is inversely related to permeability, which influences runoff and the quantity of infiltration (Ibrahim-Bathis and Ahmed, 2016). The lower D.d means permeable soil, excellent vegetation cover, and lower relief, while the higher D.d indicates that the opposite is true (Harlin and Wijeyawickrema, 1985).

DEM with 30 x 30 m resolution was used to derive the drainage density map by determining the flow direction and flow accumulation of the region using ArcGIS10.4. The drainage density thematic map was classified as Very Low with an area of 149.5 Km^2, Low with 489.5 Km^2 area, Moderate of 1125.1 Km^2 area, High of 1323.6 km^2 area, and Very High with an area of 588.9 Km^2 (Fig.6). Very Low D.d is given a higher weight of 10, which refers to the good groundwater recharge area, for the studied basin (Table 6). These features are distributed along the main three valleys and surrounding areas, while the very high D.d is given the lowest weightage of 2 refers to the very unfavorable for groundwater recharge.

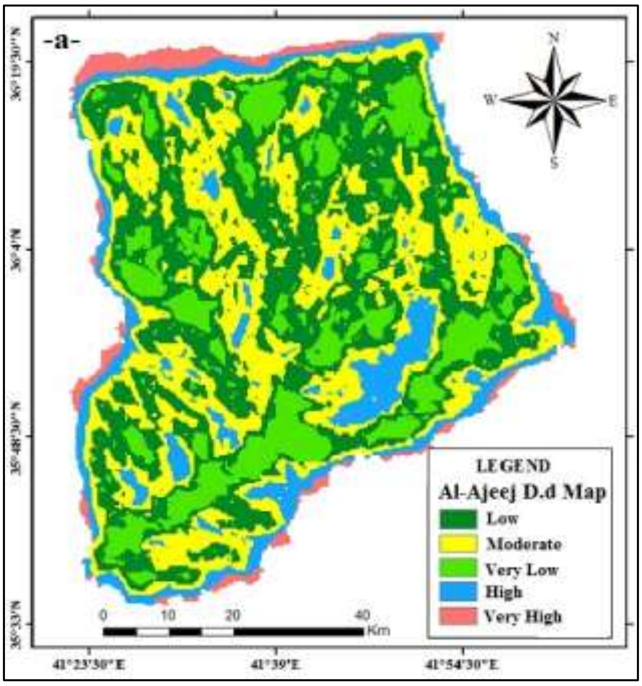

Fig.6: Thematic layers of the drainage density (D.d) factor

GROUNDWATER POTENTIAL ZONE DEVELOPMENT

The seven thematic layers were created in the GIS background, and the appropriated ranks and weights determined by the AHP method were assigned to them for the overlay process. The results obtained were categorized into three classes; "**Poor GWPZ", "Moderate GWPZ"** and **"Good GWPZ"** based on index value calculated using Eq. (1).

Most of the studied area has a flat terrain, which is the most favorable condition for recharge of groundwater. "Good GWPZ" about 38% (703.8 Km^2) of the studied area was more likely to be found in the vicinity of the foothills where alluvial and sheet runoff sediments were found predominantly. The "Moderate GWPZ" about 54.6% (1010 Km^2) of the area is distributed in the central and the southwestern parts due to the residual soil sediments, pediment, and Ba'aj plain geomorphological features, while the "Poor GWPZ", about 7.4% (136.5 Km^2) of the area, are limited at the extremely uppermost northern parts in addition to a small area at the southwestern part of the studied area. The northern part is due to the rigged, very steep slopes and elevated denudational hills of Sinjar Mountain (Fig.7), while the southwestern part is due to the sand dunes, slope sediments, and badlands and the very low annual rainfall amounts.

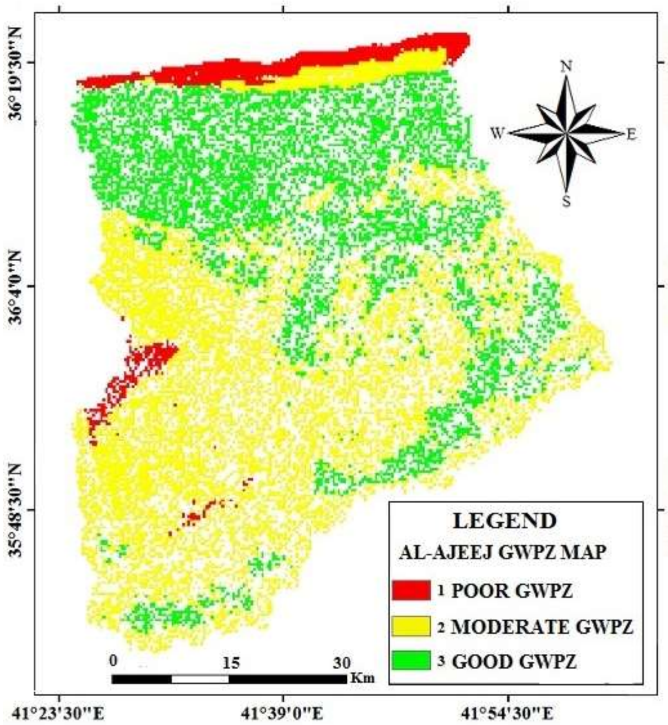

Fig.7: Thematic layers of the groundwater potential zones (GWPZ) map for the Al-Ajeej drainage basin

DISCUSSION

Based on the above methodology and arrangement of pixels, the final output map of GWPZ has been categorized into three classes, "Good", "Moderate" and "Poor" GWPZ through the selection of natural breaks in ArcGIS 10.4 software. The output model of GWPZ reveals that groundwater potential is strongly determined by physical parameters such as; climate, geology, geomorphology, lineament density, slope, drainage density, etc. The groundwater potential map (Fig.7) reflects that the northern parts of the Al-Badee and Al-

Khazrajia subbasins and almost parts of the Al-Hammal subbasin bear high groundwater potential because these regions are characterized by high surface water storage, i.e., a lesser degree of slope, the presence of alternating layers of sand, silt, and clay underlying the presence of loamy texture, which allows penetrating groundwater in these parts. Therefore, all of these factors are favorable for influencing the groundwater availability in this part of the study area. On the other hand, the poor GWPZ are distributed uppermost northern, extremely southwestern parts, and a few along the bottom of the main Al-Ajeej valley (Fig.7). The Poor GWPZ in the northern parts are, due to the presence of very steep slopes, the harder rock of the pre-Quaternary sediments and very high D.d values, although the high annual rainfall amounts.

The southwestern part is Poor GWPZ, due to the sand dunes and very low annual amounts of rainfall, while in the southern part, along the bed of the main Al-Ajeej valley, it may be due to the presence of clayey strata within the Injana Formation that reduces the groundwater recharge.

CONCLUSION

- The application of GIS and analytical hierarchy process (AHP) form an effective and powerful tool for assessing the groundwater potential of arid to semi-arid regions such as Al-Jazira Province Northwest of Iraq, in which the Al-Ajeej drainage basin is developed. The tool is integrated with the AHP to obtain the ranks and weights for the parametric layers. Thus, the application of this integrated tool was used to delineate the groundwater potential zones (GWPZ). The AHP was used to assign a proper weight of individual thematic layers and respective classes for GWPZ.
- The occurrence of groundwater in the region is mainly controlled by the climate, lithology, elevations, and geological lineament and to less extent geomorphology, slope, and drainage density. In addition, this method would be an excellent instrument to plan the location of future artificial groundwater recharge projects.
- The final groundwater potential map of the study area is classified as Good, Moderate, and Poor Zones. The good groundwater potential zone is characteristic of flat alluvial and Al-Ba’aj plains.
- This work is very much practical in the age of resource depletion because this final map will be helpful to the authorities who are engaged in land use planning and water resource management.
- The resulted map is also helpful to the common people as they can identify the effective drilling area and can extract more groundwater resources. So, the final map is practically important as one may confidently rely on it for the successful drilling of boreholes in this region.

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