Iraqi National Journal of Earth Science
www.earth.mosuljournals.com

Investigating Hydraulic Properties of Aquifers in Duhok Governorate, Kurdistan Region, Iraq

Shwan Seeyan [1*]

[1] *Soil and Water Department, Agriculture Engineering Sciences College, University of Salahaddin, Erbil, Iraq.*

Article information

Received: 22- Sep-2024

Revised: 03- Nov-2024

Accepted: 18- Feb -2025

Available online: 01- Oct-2025

Keywords:
Hydraulic Conductivity Specific Yield
Transmissivity
Aquifer properties
Duhok Governorate

Correspondence:
Name: Shwan Seeyan

Email:
shwan.seeyan@su.edu.krd

ABSTRACT

The properties of the aquifer that influence well performance are depth, aerial extent, number of water-bearing formations that the well penetrated through, and the hydraulic properties of the aquifer that allow water to flow through the aquifer must typically be established. The transmissivity and hydraulic conductivity are important factors. Pumping test data were carried out for 40 drilled boreholes (including observation and monitoring wells) at different locations to determine the groundwater flow direction and hydraulic properties of the aquifers in the Duhok area. The depths of the wells range from 70 to 265 m, with an average of 171 m, while well discharge ranged from 3.0 to 17 l/s, with an average of 7.0 l/s. The results of the analysis reveal that the value of hydraulic conductivity varies from 1.25E-6 m/sec to 1.2E-3 m/sec with an average of 1.02E-4 m/sec, and the transmissivity varies from 1.82E-4 to 4.37E-2 m^2/sec with an average of $8.75*10^{-3}$ m^2/sec. Specific yield ranges between 0.11 to 3.29 percent with an average of 1.06 percent. Maps of the Duhok aquifer's piezometric surface, hydraulic conductivity, specific yield, and transmissivity have been created. These can be employed in the area's planning, site selection, and well-drilling procedures.

DOI: 10.33899/earth.2025.153785.1360, ©Authors, 2025, College of Science, University of Mosul.

دراسة الخواص الهيدروليكية لخزانات المياه الجوفية في محافظة دهوك، إقليم كردستان، العراق

شوان سيان [1]*

[2،1] قسم التربة والمياه، كلية علوم الهندسة الزراعية، جامعة صلاح الدين، اربيل، العراق.

معلومات الارشفة

تاريخ الاستلام: 22- سبتمبر - 2024

تاريخ المراجعة: 03- نوفمبر - 2024

تاريخ القبول: 18- فبراير - 2025

تاريخ النشر الالكتروني: 01- اكتوبر - 2025

الكلمات المفتاحية:
التوصيلية الهيدروليكية
العائد النوعي
النفاذية
خصائص الحوض المائي
محافظة دهوك

المراسلة:
الاسم: شوان سيان
Email: shwan.seeyan@su.edu.krd

الملخص

إن خصائص الخزان الجوفي التي تؤثر على أداء البئر هي العمق و الامتداد الجيولوجي وعدد التكوينات الحاملة للمياه التي يخترقها البئر والخصائص الهيدروليكية للخزان الجوفي التي تسمح بتدفق المياه عبر الخزان الجوفي. وتعتبر نفاذية المياه والتوصيل الهيدروليكي من العوامل المهمة. تم إجراء بيانات اختبار الضخ لـ 40 بئرًا محفورًا (بما في ذلك آبار المراقبة والرصد) في مواقع مختلفة لتحديد اتجاه تدفق المياه الجوفية والخصائص الهيدروليكية للخزانات الجوفية في محافظة دهوك. تتراوح أعماق الآبار من 70 إلى 265 مترًا بمتوسط 171 مترًا بينما يتراوح تصريف البئر من 3 إلى 17 لترًا في الثانية بمتوسط 7 لترًا في الثانية. وقد أظهرت نتائج الضخ التجريبي أن قيمة التوصيلية الهيدروليكية تراوحت بين 1.25 اس-6 و 1.2 اس-3 متر/ثانية بمتوسط 1.02 اس-4 متر/ثانية، وتراوحت قيمة النفاذية بين 1.82 اس-4 و 4.37 اس-2 متر/ثانية بمتوسط $8.75*10^{-3}$ متر/ثانية. ويتراوح العائد النوعي بين 0.11 إلى 3.29 في المائة بمتوسط 1.06 في المائة. وقد تم إنشاء خرائط الحوض المائي في دهوك والتوصيل الهيدروليكي والعائد النوعي والنفاذية. ويمكن استخدامها في تخطيط المنطقة واختيار الموقع وإجراءات حفر الآبار.

DOI: 10.33899/earth.2025.153785.1360, ©Authors, 2025, College of Science, University of Mosul.

Introduction

Groundwater is found in permeable saturated geologic formations known as aquifers that provide a well with a sufficient amount of water. Particularly in arid and semi-arid regions with limited access to surface water, the groundwater becomes a significant source of water supply (Wurbs and James, 2010). Because groundwater occurs deeper below the zone of microbial activity and the earth acts as a natural filter, it is deemed potable (Abija et al, 2020). The capacity of a rock or unconsolidated sediment to transfer or pass through water is known as permeability (Garg, 2005). Accurate hydraulic parameter values are fundamental and important data for potential groundwater withdrawal (aquifer yield) and also for sustainable groundwater management (Ali et al, 2022). The amount of groundwater in any given location relies on the originating aquifer's features, its size, and when it discharges (Hamil and Bell, 1986; Amha et al., 2016). Hydraulic conductivity, or the coefficient of permeability, is used to measure it. Another physical concept used to describe the flow of groundwater is transmissivity.

Geological formations with a uniform or tightly packed texture have a high capacity to retain water (porosity), but the low-capacity causes transmit or move material (permeability), whereas those with a higher porosity and higher permeability have enough capacity to yield sizable amounts of groundwater to wells and springs (Salako and Adepelumi 2018). The rate of groundwater flow across an aquifer increases with hydraulic conductivity and hydraulic gradient. Transmissivity and hydraulic conductivity are two of the most crucial hydrogeologic variables required for managing groundwater resources because they indicate an aquifer's general ability to convey water (Robert et al., 2000). The hydraulic properties of an aquifer are critical in determining how much water can be extracted from it and how quickly it can be recharged. These properties are used in modeling groundwater flow to understand how water moves through the subsurface and to design effective groundwater management strategies. Aquifer hydraulic properties can be estimated using different approaches, both in the field and laboratory. Aquifer hydraulic tests may be performed by a pumping test (Tang et al., 2017).

An aquifer test, also known as a pumping test or a well test, is a method used to evaluate the performance of an aquifer, which is a layer of porous rock or sediment that contains water. The purpose of an aquifer test is to determine the characteristics of an aquifer, such as its hydraulic conductivity, transmissivity, storativity, and other parameters that are important for the management of groundwater resources. Understanding groundwater flow and designing groundwater wells (boreholes) to achieve sustainable yields depend greatly on the calculation of aquifer characteristics like hydraulic conductivity and specific yield (Raji et al, 2017).

The results of an aquifer test can be used to determine the sustainable yield of the aquifer, the rate at which water can be withdrawn from the aquifer without causing depletion or degradation of the resource. Aquifer tests are an important tool for water resource managers, hydrogeologists, and engineers who are responsible for managing groundwater resources (Li et al, 2023). They are used to design and optimize well fields, to evaluate the effects of pumping on the aquifer and surrounding environment, and to assess the potential impacts of new development on the groundwater resources in the area.

The specific aim of our research is to develop and determine the hydraulic properties of the aquifer and to investigate the transmissivity, hydraulic conductivity, specific yield, and storativity, as well as the groundwater movements in the Duhok area.

Area description

The study area is located in the north of Iraq between the latitudes (36º 25′ to 37º 25′ N) and longitudes (42º 20′ to 43º 56′ E). Duhok anticline and Zawita anticline are the major geological structures in the area (Fig. 1). According to a previous study of FAO, hydrogeologically, the study area is partially located on four basins, including the Sumel–Duhok basin, Zaxo basin, Mabruk basin, and Aqra–Bardarash basin (Stevanovic and Markovic, 2004).

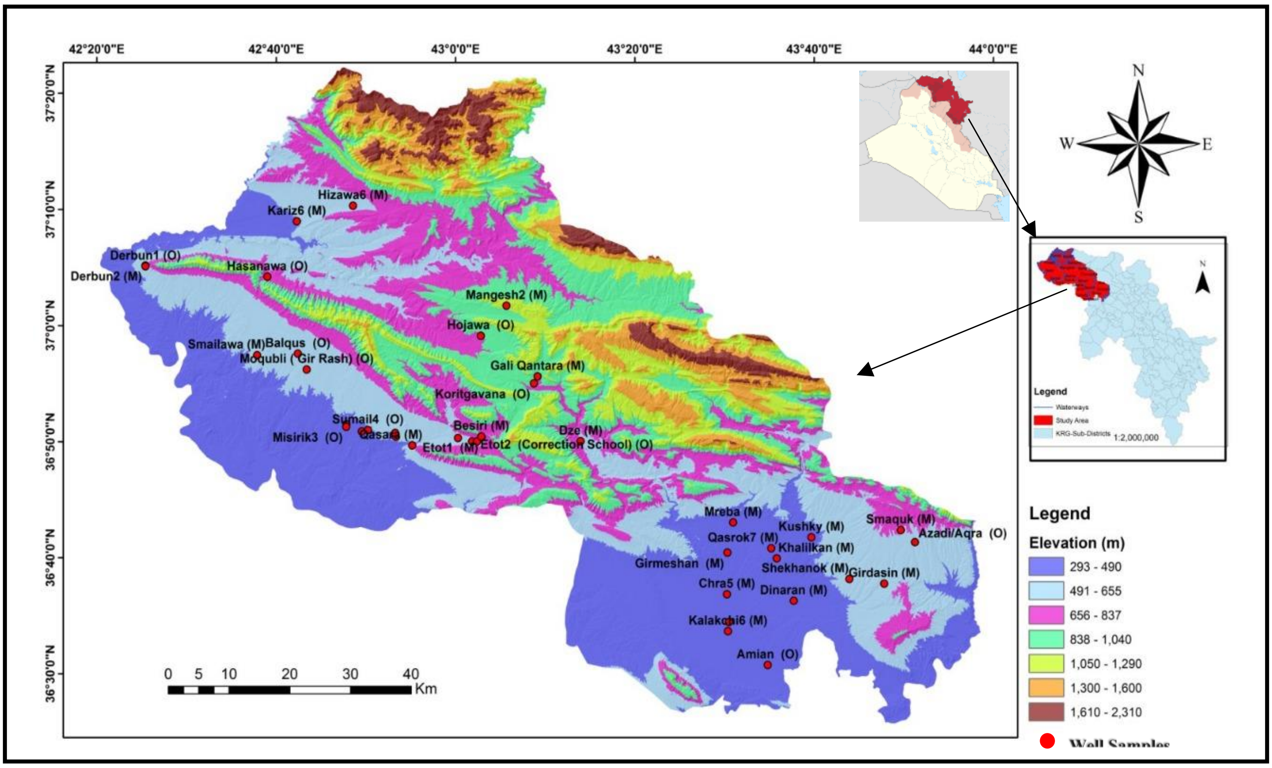

Fig. 1. Digital terrain model showing the study area with well location.

Tectonic and Stratigraphic Setting

Tectonically, the study area is located in the Highly Folded Zone. The main geologic formation of the area is composed of three lithological rock units (Cretaceous, Tertiary, and Quaternary deposits). The geologic formations cropping out in the studied area include Fatha and Injana. Bai Hassan and Muqdadeya formations crop out in the southern and southeastern parts of the study area. While the Pila Spi, Gercus, Avanah, and Shiranish formations are seen to crop out at northern and northwestern parts of the area (Fig. 2), a description of the geological formations is presented below:

Cretaceous Deposits

This type of rock mainly covered the northeastern and southeastern parts of the eastern, western, and some central parts. It is mainly composed of massive limestone and dolomites of the Qamchuqa Formation overlain by well-bedded to massive limestone (marly limestone) of the Aqra-Bekhme Formation. It is further overlain by the Shrianish Formation of marly limestone, gray to yellow-gray in color, and the Tanjeor Formation that consists of blue marl, sandstone, and claystone with conglomerates (Buday and Jassim, 1987).

Tertiary Deposits

These types of rocks are exposed in the southeastern, eastern, and central parts of the area. Most lands are covered by this age and lithology (Buday and Jassim, 1987). The formations having this age are Khurmalla, Avana, Gercus, Pila Spi, Injana, Fatha, Muqdadeya, and Bai Hassan Formations.

Quaternary Deposits

Quaternary deposits cover the rock units in the proposed area; these deposits are not affected by Alpine orogeny and consist of clay, loam, silt, and sand. The stratigraphy of Quaternary deposits is unconformable with the underlying unit (vertically and horizontally), comprising gravels of alternative coarse, medium, and fine grain size (Hamed, 2013). The age of the Quaternary deposits is Pleistocene to Holocene. These deposits were divided after

Sissakian and Yukhana (1978) into river terraces, slope deposits, polygenic deposits, and flood plain deposits.

Geomorphology of the area

The many geomorphological aspects in the area are influenced by structures, the makeup of the sediments, and climate variables. Moreover, to a limited extent, the effects of chemical action, mechanical weathering, and the erosion process are all important. The region is distinguished by its high topography in general.

Mountain ranges, narrow plains, and deep valleys are the most significant geomorphological features in the region. A portion of the planned region is roughly a plain surface, especially around Hujava village, which is surrounded by massive flood deposits and divided by various valleys. The drainage patterns of the valleys are dendritic, parallel, and rectangular types. The dendritic pattern is usually constructed above horizontal rocks or a gentle slope. While the parallel and rectangular patterns appear in a similar lithological area of moderate dip.

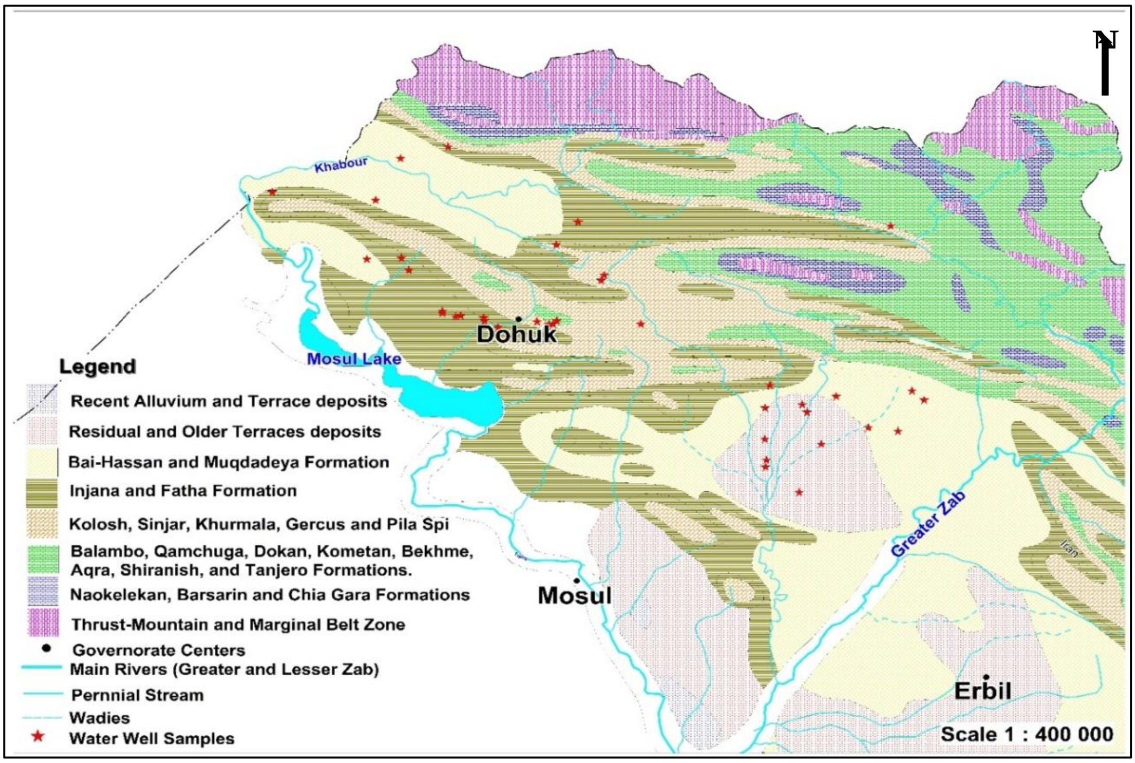

Fig. 2. Geological map of the study area.

Aquifer system in the study area

The main aquifer units in the upper part of the study area (Mountain area) are:

1. *Fissured Aquifers*: In this type, water is mainly stored within cracks and joints of carbonate rock. These cracks are considerably widened by the solution. Pila Spi Formation is a good example of a fissured aquifer.

2. *Karstified Aquifer*: Extensively widened cracks would evolve to form channels and caves, a process called Karstification. Such aquifers are usually formed in massive limestones of less dense fracture than the previous types. The limestones of Aqra- Bekhme, Qamchuqa, and Lower Shiranish formations stand as probable examples of this aquifer type.

3. *Aquiclude aquifer* in the Gercus and Kolosh formations.

Aquifer types in the middle part and the plain area are:

1. *Intergranular Multi-layered Aquifer*: This aquifer is represented by Upper Fars (Injana), Lower Fars (Fatha), and Bakhtiari formation. It is characterized by low production, because it is composed of very heterogeneous lithology (sandstone, siltstone, conglomerate, marl, gypsum, and clay), which contains an insignificant amount of stored water, which is not sufficient for supplying water for big projects.

2. *Unconfined and Confined Aquifer*: In the study area, aquicludes are represented by the Bakhtiari Formation and Recent deposits of high permeability and porosity. In view of existence, many lenses of mud within the aquifer could be considered as a semi-confined aquifer. The main areas of recharge for the unconfined and confined aquifers are located in the Aqrah Mountain area. Ali (2007) classified the conglomerate within the Bakhtiari Formation as a confined aquifer; due to the high degree of compactness of these layers, joints and fractures represent the other aspect of its effective porosity. When the layers start to become more saturated with water, the intergranular pores will be triggered, while the fractures work as an additional effective transmission zone for groundwater movement; accordingly, he claims that the term intergranular is preferable to the fissures of this aquifer because it is more similar to conglomerate lithology.

Hydraulic Parameters

Hydraulic properties refer to the characteristics of water movement through porous materials, such as soil or rock. These properties are important in a variety of fields, including hydrology, geology, environment, and civil engineering. All the hydraulic parameters calculated by the Aquifer test program are:

Hydraulic Conductivity

Hydraulic conductivity refers to the ability of a porous medium, such as soil or rock, to transmit water. It is a measure of the ease with which water can move through the pores or openings in the material. The hydraulic conductivity of a material is usually represented by the symbol "K" and is expressed in units of velocity, such as meters per second or feet per day. Aquifer hydraulic conductivity is the ability of the aquifer to transmit water under the effect of a hydraulic gradient (Ferreira et al., 2005).

The hydraulic conductivity depends on a number of factors, including size, shape, and distribution of the pores or openings in the material, as well as the properties of the water itself. For example, a material with larger pores will typically have a higher hydraulic conductivity than a material with smaller pores. Similarly, the hydraulic conductivity will be affected by the viscosity and temperature of the water. Hydraulic conductivity is an important parameter in many fields, including hydrology, geology, and civil engineering. It is used, for example, in the design of drainage systems, the evaluation of groundwater resources, and the assessment of soil contamination.

Mathematically, the hydraulic conductivity could be defined by the formula below:

$$K = k * (\rho g / \mu) \qquad \text{(Oborie et al., 2018)}$$

Where: K is the hydraulic conductivity (cm/s or m/s), k is the intrinsic permeability, ρg is the density of fluid, and μ is the dynamic viscosity of fluid.

Porosity

Porosity is the fraction of the total volume of a material that is composed of pores (voids). It is a measure of the ability of a material to hold and transmit water. As a measure of the interstices or voids present, porosity is the ratio of the volume of the interstices to the overall volume of a geological formation, rock, or soil. A rock has an inherent porosity known as primary porosity when it is emplaced, which is reduced over time by cementation or compaction processes. This porosity is present when a rock is emplaced by cooling from an igneous melt, induration from loose sediment, or soil formation from weathering of rock materials. However, secondary porosity refers to joints, fissures, fractures, or solution cavities that developed within rocks after they had already been deposited. As a result, primary and secondary porosities add up to total porosity.

Only a specific subset of the pores in a rock would allow for water circulation if all of the pores located within the rock are not connected. Pumice, a glassy volcanic rock (solidified froth), has a high total porosity and contains a lot of entrained gas, which makes it likely that it will float on water. Effective porosity is the portion of a material that permits water movement.

Mathematically, porosity (n) is given by the formula below:

$$\textit{Porosity (n)} = Vp/Vt$$

Where: *Vp* is the pore volume of the rock or soil sample, *Vt* is the total volume (pores and solids).

Transmissivity

Water transmissivity refers to the ability of a material to transmit or allow water to pass through it. It is a measure of the permeability of a substance to water. Water transmissivity is an important property in various fields such as geology, hydrology, and civil engineering, where it is used to determine the flow of water through soil and rock layers.

Water transmissivity is often expressed in terms of hydraulic conductivity, which is the rate at which water can move through a unit cross-sectional area of the material under a unit hydraulic gradient. Hydraulic conductivity is typically measured in units of length per time, such as meters per second or centimeters per hour.

The water transmissivity of a material depends on its porosity, permeability, and other factors such as the particle size distribution, compaction, and saturation of the material. Highly porous and permeable materials tend to have higher water transmissivity than dense and impermeable materials.

It could be mathematically defined as:

$$T = Kb \ (\mathrm{m^2/day}) \qquad \text{(Todd, 1980)}$$

Where: T is the transmissivity, K is the hydraulic conductivity, and b is the saturated thickness of the aquifer.

Results

Groundwater flow direction

Normal groundwater movement or subsurface flow depends on forces acting on the groundwater and is not usually static (Todd, 1980). Measuring the elevation of groundwater at various sites over an aquifer's aerial extent is the most effective way to determine the direction of groundwater migration (Oborie1 and Nwankwoala, 2017).

The groundwater movements and flow direction are measured using 40 wells, including observation and monitoring wells (Table 1). Groundwater flow direction is from the central part of the study area to the southern and western parts of the area (Fig. 3).

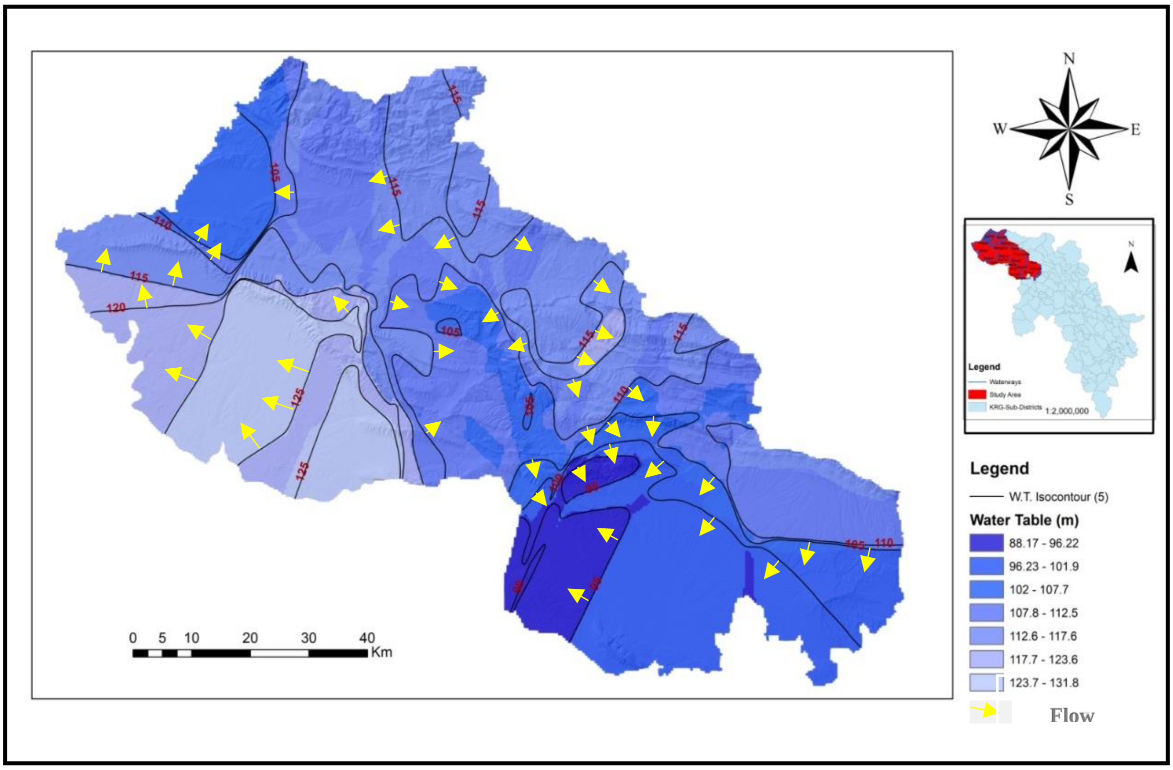

Fig. 3. Groundwater flow direction map of the study area.

Table 1: Observation (O) and Pumping (P) wells in the study area with well depths and discharges (Q) (UTM Coordination system-WGS-84).

SN	Well Name	X	Y	Elevation (m)	Depth (m)	Water Table (m)	Q (l/Sec.)
1	Hizawa-6 (P)	306069	4117423	587	162	102	8.70
2	Kariz-6 (P)	296837	4114933	482	180	137	13.20
3	Hasanawa (O)	291977	4106090	696	180	127	7.10
4	Derbun-2 (P)	271901	4107872	576	110	83	8.30
5	Derbun-1 (O)	271885	4107774	567	120	67	8.30
6	Smailawa (P)	290295	4093607	508	180	114	8.80
7	Balqus (O)	296989	4093838	529	137	84	6.41
8	Moqubli (Gir Rash) (O)	298438	4091312	504	168	102	6.70
9	Misirik-2 (O)	304986	4082579	459	196	143	8.40
10	Misirik-3 (O)	304947	4082193	456	201	160	8.40
11	Sumail-5 (Dor Dawagin) (O)	307519	4081426	464	265	187	7.80
12	Sumail-4 (O)	308524	4081672	463	189	129	8.30
13	Tanahi-1 (P)	313152	4080577	473	186	114	8.00
14	Tanahi-2 (P)	313011	4081196	478	180	130	8.00
15	Qasara (P)	315808	4079225	478	200	140	5.40
16	Baroshky (P)	323352	4080392	555	144	92	8.90
17	Nizarky (P)	325663	4079848	599	110	77	8.20
18	Etot-2 (Correction School) (O)	326485	4079844	595	162	95	8.00
19	Etot-1 (P)	327249	4080554	649	171	106	2.50
20	Besiri (P)	327187	4080643	659	197	130	7.20
21	Koritgavana (O)	335842	4089099	844	182	135	4.00
22	Hojawa (O)	327119	4096693	823	130	97	5.60
23	Mangesh-2 (P)	331326	4101487	1049	200	154	13.70
24	Gali Qantara (P)	336454	4090213	829	150	96	8.50
25	Sheladze (P)	392122	4100639	697	160	106	16.70
26	Dze (P)	343542	4079885	642	120	81	5.80
27	Mreba (P)	368642	4066921	429	200	148	7.90
28	Girmeshan (P)	367709	4062120	406	132	90	7.20
29	Qasrok-7 (P)	374918	4062815	426	175	121	7.20
30	Chra-5 (P)	367636	4055496	363	80	68	4.90
31	Girk Zobash (P)	367979	4051084	350	70	43	3.40
32	Kalakchi6 (P)	367805	4049596	346	108	69	9.70
33	Khalilkan (P)	375847	4061202	443	86	49	9.70
34	Kushky (P)	381526	4064574	455	180	107	4.45
35	Azadi/Aqra (O)	398609	4063797	581	180	117	9.40
36	Smaquk (P)	396255	4065731	648	141	98	4.30
37	Girdasin (P)	393532	4057189	569	190	130	7.50
38	Shekhanok (P)	387774	4057939	541	180	128	3.40
39	Dinaran (P)	378632	4054448	391	224	168	3.40
40	Amian (O)	374337	4044221	355	110	73	4.30

Hydraulic parameters

The results of the hydraulic properties are obtained by the Aquifer Test Program using 26 monitoring wells. During an aquifer test, a well is pumped at a known rate, and the response of the water level in the well and the surrounding aquifer is measured over time. The data collected during the test is then used to calculate the parameters that describe the behavior of the aquifer. The hydraulic conductivity of the Duhok basin ranges from 1.25E-6 to 1.19E-3 m/sec with an average of 1.02E-4 m/sec. Transmissivity ranges from 1.82E-04 to 4.37E-02 m^2/sec with an average of 8.75E-03 m^2/sec. Specific yield ranges from 0.11 to 3.29 with an average of 1.06 (Table 2).

A measure of the hydraulic conductivity is the ease with which water can penetrate rock or soil: High values denote materials that are easily permeable to water, whereas low values denote less permeable materials. Gali Qantara monitoring well in Zawita sub-district has a lower hydraulic conductivity than the other wells due to the inclusion low low-permeable rocks like clay and silty clay. Sand and gravel aquifers have higher hydraulic conductivity than clay or unfractured granite aquifers because of their high porosity and permeability, the higher value is in the Smaquk monitoring well in the Grdasin sub-district. The higher value of transmissivity is in Smaquk because the drawdown in this well is broad and shallow, and the low value of transmissivity is in Gali Qantara monitoring well because it developed deep and narrow cones of depression.

A high value of specific yield is in the Kalilkan monitoring well in the Aqra district, and a low value is in the Etot-1 monitoring well in the Zawita sub-district. Specific yield or drainable porosity levels are influenced by the pore size, shape, distribution, compaction of the subsurface formation, and drainage time. A high specific yield is desirable for water resource management and groundwater extraction purposes. It means that the aquifer has the potential to yield a significant amount of water for various uses, such as drinking water supply, irrigation, or industrial purposes. However, it's important to note that specific yield alone is not the only factor determining the sustainability of groundwater extraction. Other factors such as recharge rates, groundwater recharge areas, and overall aquifer management are also crucial for long-term water resource sustainability.

Hydraulic Parameters Interpolation

Spatial interpolation by means of Kriging is used to plot the distribution of the hydraulic parameters. Kriging assumes that the distance or direction between sample points reflects a spatial correlation, which is used to explain variation in the surface (Seeyan and Merkel, 2015).

Figures (4 to 6) represent the hydraulic parameters distribution in the study area which shows the high hydraulic conductivity in the southwestern part and low value in the south and western parts, the high transmissivity is in the north and eastern parts and low value in the southern part, and the high specific yield in the south and northwestern parts and the low value in the western part.

Table 2: Hydraulic Properties of the Pumping Wells.

Pumping Wells	X	Y	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Specific Yield
Hizawa-6	306069	4117423	8.32	1116	0.786
Kariz-6	296837	4114933	11.72	1972.8	2.907
Derbun-2	271901	4107872	16.27	1598.4	0.815
Smailawa	290295	4093607	0.41	59. 8	0.353
Tanahi-1	313152	4080577	1.67	259.2	0.462
Qasara	315808	4079225	3.41	627.8	0.875
Baroshky	323352	4080392	5.71	800.6	0.392

Nizarky	325663	4079848	2.14	195.8	0.812
Etot-1	327249	4080554	0.24	34.13	0.109
Besiri	327187	4080643	5.50	839.5	1.572
Mangesh-2	331326	4101487	15.26	2548.8	1.306
Gali Qantara	336454	4090213	0.10	15.7	0.229
Sheladze	325663	4079845	1.06	156.9	0.663
Dze	343542	4079885	3.21	381.6	1.203
Mreba	368642	4066921	0.33	59.62	0.54
Girmeshan	367709	4062120	2.46	272.16	1.062
Qasrok-7	374918	4062815	4.56	635	1.827
Chra-5	367636	4055496	1.54	107.14	0.209
Girk Zobash	367979	4051084	1.54	107.14	0.808
Kalakchi6	367805	4049596	1.54	107.14	2.235
Khalilkan	375847	4061202	19.58	1555.2	3.294
Kushky	381526	40645747	3.48	503.9	0.925
Smaquk	396255	4065731	103.53	3772.8	1.08
Girdasin	393532	4057189	1.04	161.3	0.692
Shekhanok	307683	4057938	12.01	1670.4	0.573
Dinaran	378632	4054448	1.54	107.14	1.838
Maximum Value			103.53	3772.8	3.294
Minimum Value			0.1	15.7	0.109

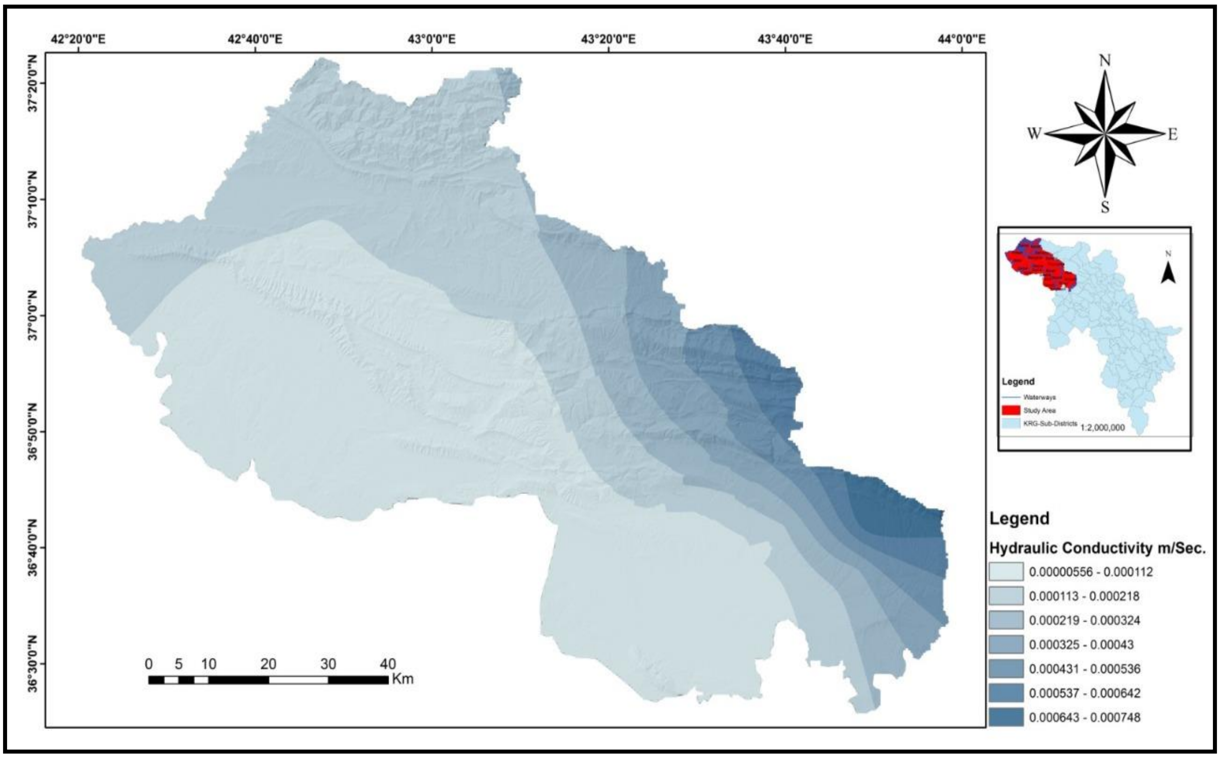

Fig. 4. Hydraulic conductivity distribution map in the study area.

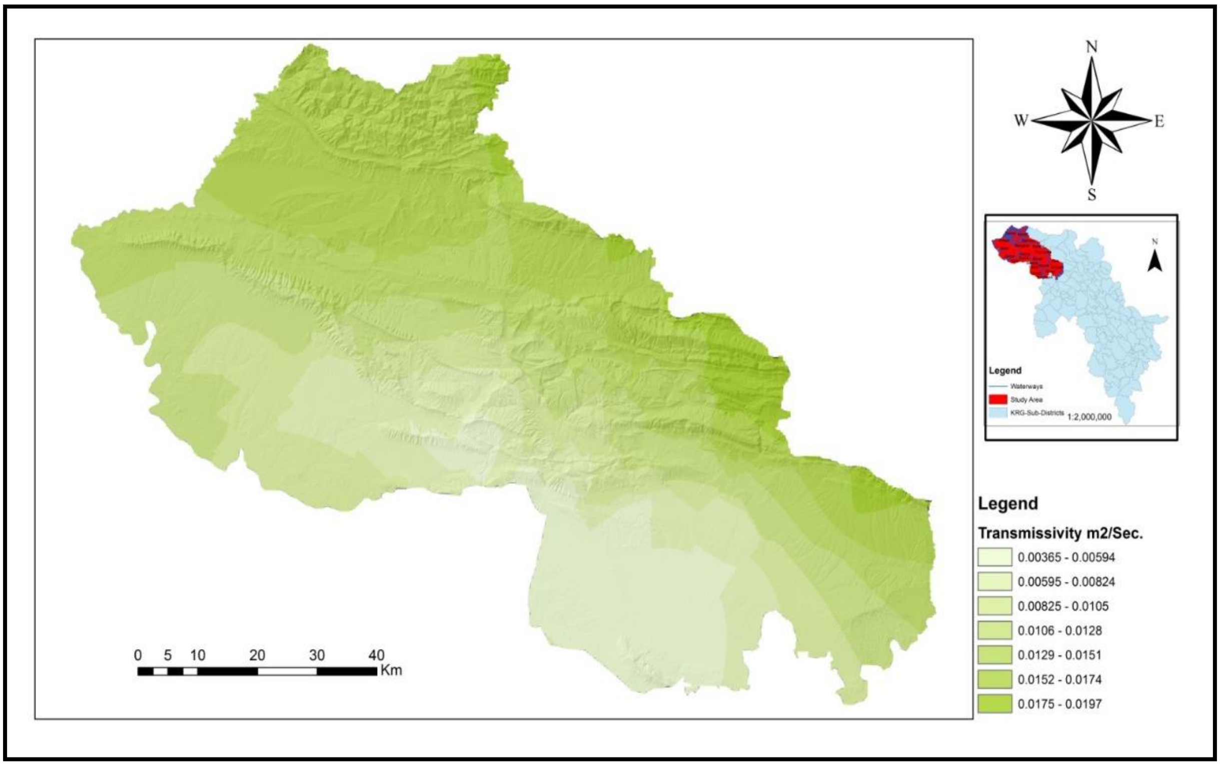

Fig. 5. Transmissivity distribution map in the study area.

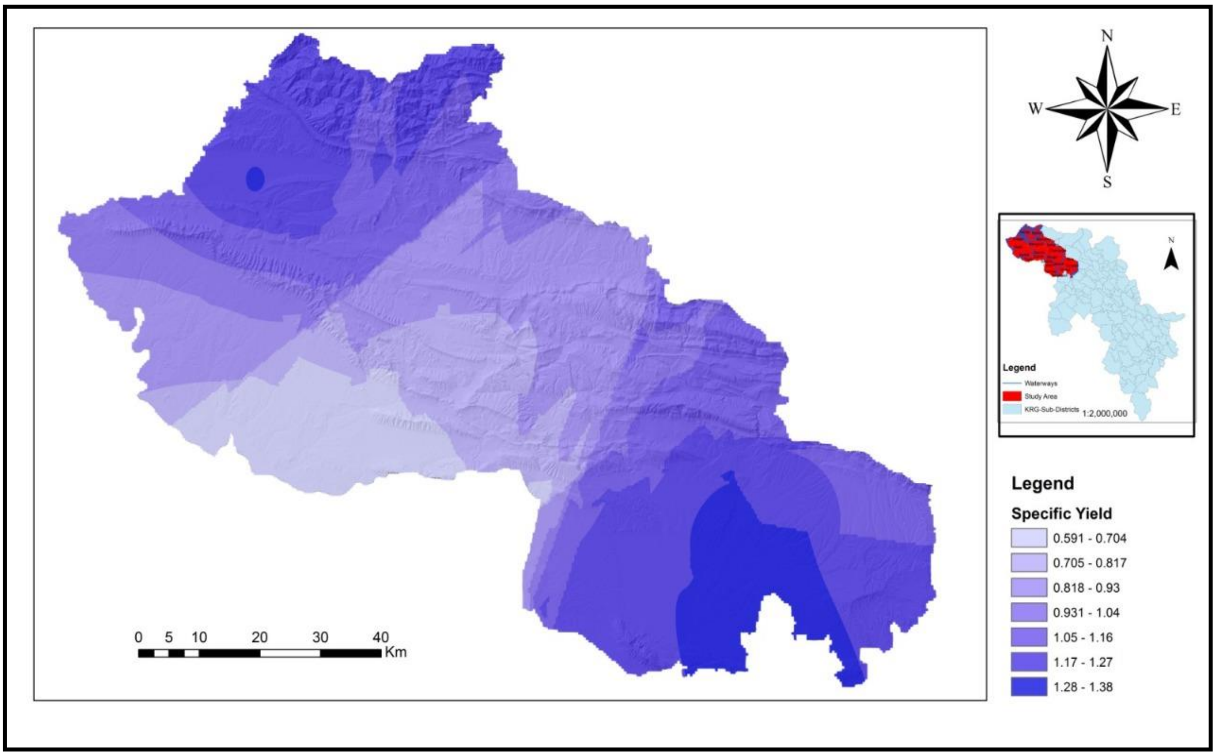

Fig. 6. Specific yield distribution map in the study area.

Discussion and Conclusion

Investigating the hydraulic properties of groundwater aquifers is crucial for understanding and managing water resources. The karstic, fissured-karstic, and porous aquifers are predominant in the Duhok basin. The hydraulic parameters have been determined using the Aquifer Test program for the studied monitoring wells. The higher value of hydraulic conductivity in the study is in the southeastern part, and the lower value is in the center of the basin.

Because of the developing deep and narrow cones of depression in the center of the basin, the transmissivity in this area has high values. The high value of specific yield is in the southeastern part, which indicates that a larger proportion of water can be extracted from the aquifer. This means that the aquifer has a relatively high capacity to store and transmit water. It suggests that the aquifer material is more porous and has a higher degree of interconnected void spaces, such as fractures, allowing water to flow more freely.

Acknowledgements

The author thanks the Ministry of Agriculture and Water Resources in Kurdistan for providing some available information. Also extended thanks are extended to the presidency of Salahaddin University in Erbil City, Kurdistan Region, Iraq, for funding this research.

Conflict of Interest

The author declares no conflict of interest.

References

Abija, F.J., Abam, T.K.S., Teme, S.C. and Eze, C.L., 2020. Ground subsidence and intermountain topographic depressions above a producing oilfield: A link to flood vulnerability in the Niger Delta basin, Nigeria: Journal of Earth Science and Climatic Change, v. 11, 9 P.

Ali S.S., 2007. "Geology and Hydrogeology of Sharazoor - Piramagroon Basin in Sulaimani Area, Northeastern Iraq", Unpublished Ph.D. Thesis, Faculty of Mining and Geology, University of Belgrade, Serbia, 330 P.

Ali M.H., Zaman M.H., Biswas P., Islam M.A., and Karim N.N., 2022. Estimating Hydraulic Conductivity, Transmissibility and Specific Yield of Aquifer in Barind Area, Bangladesh Using Pumping Test. European Journal of Environment and Earth Sciences, Vol. 3. http://dx.doi.org/10.24018/ejgeo.2022.3.4.308.

Amha EA, Anam GS., 2016. Determination of Aquifer Hydraulic Parameters from Pumping Test Data Analysis: A Case Study of Akpabuyo Coastal Plain Sand Aquifers, Cross River State, S-E Nigeria, IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG). 4(1): pp. 1-8. Doi: 10.9790/0990-04110108

Buday, T. and Jassim, S.Z., 1987. The Regional Geology of Iraq (Stratigraphy and Paleogeography). Vol. 2, 352 P.

Ferreira, J.P.L., Chachadi, A.G., Catarina D., and Henriques, M.J., 2005. Assessing aquifer vulnerability to seawater intrusion using GALDIT method: Part 1 Application to the Portuguese Aquifer of Monte Gordo. The Fourth inter-Celtic Colloquium on Hydrology and Management of Water Resources, pp. 1-12. https://www.researchgate.net/publication/287403434

Fidelis A.A., Nse U.E., Abam, T.K.S., and Abimbola I.I., 2020. Assessment of Aquifer Hydraulic Properties, Groundwater Potential and Vulnerability Integrating Geoelectric Methods with SRTM-DEM And LANDSAT-7 ETM Lineament Analysis in Parts of Cross River State, Nigeria. London Journal of Research in Science: Natural and Formal, Volume 19. pp. 35-51. https://www.researchgate.net/publication/344358077

Garg, S.K., 2005. Water Supply Engineering. Khanna Publishers, Delhi, India.

Hamed, M., 2013. Hydrogeology, Hydrochemistry, and Ground Water Flow Modeling of Shaqlawa-Hiran Basin in Erbil Governorate Iraqi Kurdistan Region.

Hamil F. and Bell G., 1986. Groundwater Resources Development. Butterworth's Publications. https://doi.org/10.1016/B978-0-408-01409-0.50004-0

Li, Y., Zhou Z., Zhuang C., and Dou Z., 2023. Estimating Hydraulic Parameters of Aquifers Using Type Curve Analysis of Pumping Tests with Piecewise-Constant Rates. Water, 15(9), 1661; https://doi.org/10.3390/w15091661.

Oborie E. and Nwankwoala H.O., 2017. Determination of Groundwater Flow Direction in Yenagoa, Bayelsa State, Nigeria. Journal of Scientific Achievements, 2 (9): 23-27

Oborie, E, Opigo, A.M., and Nwankwoala, H.O., 2018. Estimation of Aquifer Hydraulic Conductivity and Evaluation of Empirical Formulae Based on Grain Size Analysis and Permeameter Test in Yenagoa, Bayelsa State, Nigeria. International Journal of Innovative Science and Research Technology. 3 (3): pp. 313-321. https://www.researchgate.net/publication/324455022

Raji, S.A., Ijigade, F.O., Adelodun, O., Oyewole, O.A., 2017. Using Aquifer test pro 2016 for estimating Groundwater hydraulic Parameter for Sustainable yield. International Journal of Engineering Trends and Technology (IJETT), V48(2), pp. 85-87. DOI: 10.14445/22315381/IJETT-V48P215.

Robert, E., Mace, R.C., Smyth, L.X., Jinhuo, L., 2000. Transmissivity, Hydraulic Conductivity, and Storativity of the Carrizo-Wilcox Aquifer in Texas. Technical report "University of Texas at Austin, USA". https://www.beg.utexas.edu/files/publications/contract-reports/CR2000-Mace-1.pdf

Salako, A.O. and Adepelumi, A.A., 2018. Aquifer, Classification and Characterization. Chapter in Book "Aquifers - Matrix and Fluids". DOI: 10.5772/intechopen.72692

Stevanovic, Z. and Markovic, M., 2004. Hydrogeology of Northern Iraq. General Hydrogeology and Aquifer Systems. 3rd ed., Rome, Italy.

Seeyan S. and Merkel B., 2015. Determination of Recharge by Means of Isotopes and Water Chemistry in Shaqlawa-Harrir Basin, Kurdistan Region, Iraq. Hydrology Current Research 05(03). DOI: 10.4172/2157-7587.1000179

Sissakian, V.K. and Youkhanna, R., 1978. Report of Regional Geologic Mapping of Erbil – Shaqlawa – Koisanjak – Raider area. D.G.G.S.M.I. Geol. Survey. Dept., Unpublished Report.

Tang Y, Zhou J, Yang P, Yan J, Zhou N., 2017. Hydrogeological Parameters Calculation. In: Groundwater Engineering. Springer Natural Hazards. DOI:10.1007/978-981-10-0669-2_2.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edition, John Wiley and Sons, New York.

Wurbs, R.A. and James, W.P., 2010. Water Resources Engineering. Prentice Hall.