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Groundwater situation before production and after production stoppage in Al-Mishraq Sulfur field-1, northern Iraq

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Abstract

This study dealt with the reality of groundwater before Sulfur production in the Al-Mishraq field-1 and after production stopped in the field, by measuring the groundwater table for (44) wells in 2021, and comparing it to the groundwater table measured by the Polish company Centrozap in 1971, the groundwater table was a range between (187.71-205.8)m in 1971, but in 2021 it ranged was between (188.51-196.55)m.

Maps of the groundwater movement and water table were created using these data. It turned out that there was little change in the direction of groundwater flow; in both cases, the flow is from the west and northwest towards the east with a slight slope toward the southeast and the Tigris River. As for hydraulic properties, it was analyzed in (29) wells, depending on pumping test data from the reports of Al-Mishraq, It was noted that the values of Transmissivity ranged between (1557.5-24.4) m^2/day before production and (5020.6-39.4) m^2/day after production, As for hydraulic conductivity, it ranged between (0.26-14.68) m/day before production, and after production, it was between (0.4-48.9) m/day.

Keywords: Al-Mishraq; hydraulic properties; Sulfur field-1; overburden layers; Productive layers**.**

واقع المياه الجوفية قبل الانتاج وبعد توقف الانتاج في حقل كبريت المشراق-1، شمالي العراق

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قسم علوم الارض التطبيقية، كلية العلوم، جامعة تكريت، تكريت، العراق

الخلاصة:

تناولت هذه الدراسة واقع المياه الجوفية قبل انتاج الكبريت في حقل المشراق-1 وبعد توقف الانتاج في نفس الحقل، وذلك من خلال قياس مناسيب المياه الجوفية في(44) بئر في عام 2021، ومقارنتها بمناسيب المياه الجوفية المقاسة من قبل شركة سنتروزاب البولونية عام 1971، تراوحت مناسيب المياه الجوفية بين (205.8-187.71)م في عام 1971، اما في عام 2021 فتراوحت بين (196.55- 188.51)م.

اعتمادا على هذه البيانات رسمت خرائط لحركة ومستويات المياه الجوفية وتبين ان اتجاه الحركة لم يتغير كثيرا، ففي كلتا الحالتين يكون اتجاه حركة المياه الجوفية من الغرب والشمال الغربي باتجاه الشرق مع الانحدار قليلا باتجاه الجنوب الشرقي اي باتجاه نهر دجلة. اما الخواص الهيدروليكية فقد تم تحليلها في (29) بئرا اعتمادا بيانات الضخ الاختباري من تقارير الشركة العامة لكبريت المشراق، لوحظ ان قيم الناقلية المائية (T) تراوحت

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بين (1557.5– 24.4) م^2/يوم قبل الانتاج وبين (5020.6– 39.4) م^2/يوم بعد الانتاج، اما التوصيلية الهيدروليكية (K) فقد تراوحت بين **(0.26–14.68)** م/يوم قبل الانتاج اما بعد الانتاج فكانت بين **(0.4– 48.9)** م/يوم.

1. Introduction

The groundwater aquifers in the Fatha formation are considered important aquifers and contain deposits of sulfur, which is extracted by the Farash method .[1]

Groundwater is considered one of the main factors controlling Sulfur extraction, as it posed a very great danger in the Sulfur extraction process because its levels are above the level of the producing layers, in addition to the flow of Sulfur towards the Tigris River when Sulfur is melted and transformed into a liquid forming Sulfur cones in the mid of the river reach opposite the Al-Mishraq Sulfur field-1, during production, as in Figure (1), to address the problems arising from the investment of Sulfur ore in the region and its impact on groundwater, the reality of groundwater in that region must be studied.

The current study aims to assess the reality of groundwater, determine the direction of groundwater movement and its natural discharge, and the hydraulic properties of groundwater aquifers before production and after production stops in the Mishraq field.

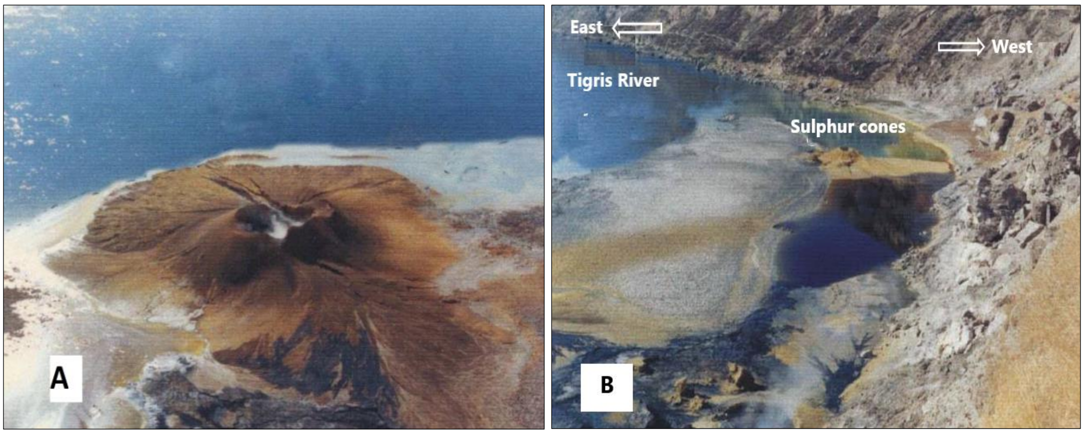


Figure 1: A. molten sulfur leakage in the Tigris River **B**-Sulfur cones in the Tigris River as a result.[2]

2- Study area description

Al-Mishraq field, one of three fields where sulfur extraction occurred, is situated in northern Iraq, approximately 45 km southeast of Mosul, between longitudes (″59 ′17 43) and (″24 ′20 43) east, and latitudes (″55 ′00 36) and (″04 ′05 36) north. The field's area is roughly 17 km^2, as shown in Figure 2.

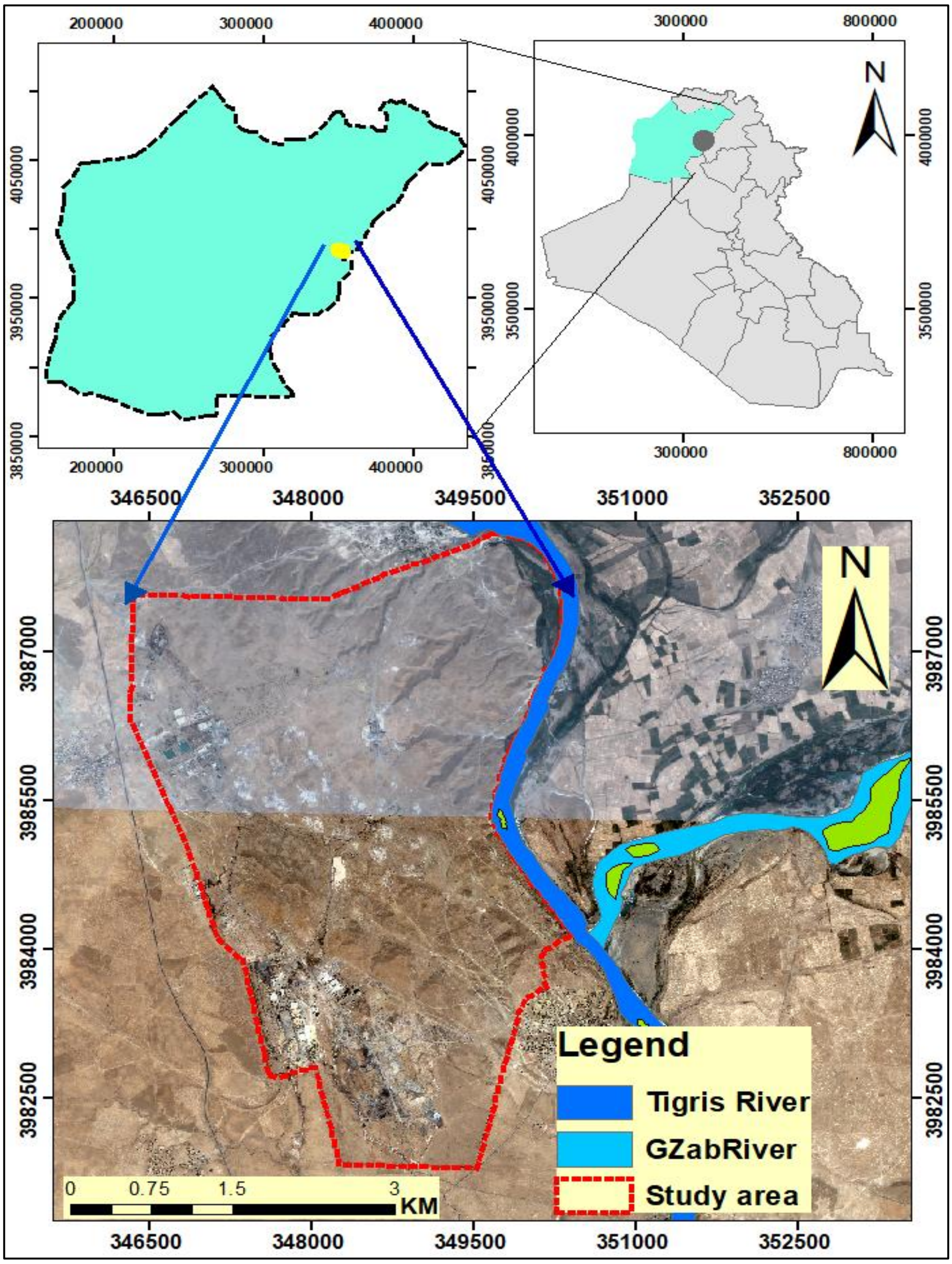


Figure 2: Location map of the study area

Tectonically, the area of the study is located within the foothill zone of the unstable shelf, and due to its location at the intersection of the Tigris fault zone with the Hadhra-Bakhme fault system, Al-Mishraq zone is distinguished in its structural and sedimentary nature (Figure 3), [3], It is the Anticline Mishraq fold whose direction is northwest-southeast is one of the sums of the contiguous folds whose direction is similar to that of the Mishraq fold [4], As well as the presence of several normal and strike-slip faults in two main directions, the first Northeast-Southwest perpendicular to the main fold axis, and the second northwest-southeast, as well as the presence of many thrust faults. In general, it can be said that some of these faults are oriented parallel to the axis of the main fold and others parallel to the direction of the Hadhra-Bakhme fault [5].

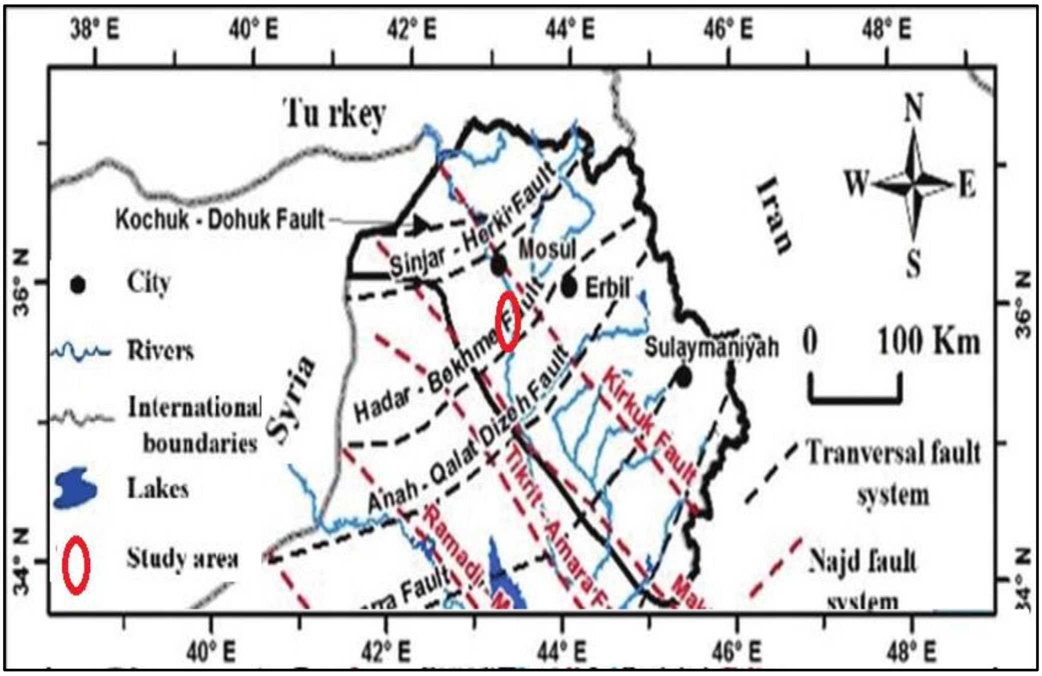


Figure 3: The tectonic map of Iraq from [4], showing the location of the study area concerning the Hadhra-Bakhme fault

The rocks exposed in the study area are all rocks of sedimentary origin, as they are represented in the formations of the Fatha, Injana, and Quaternary sediments (Figure 4).

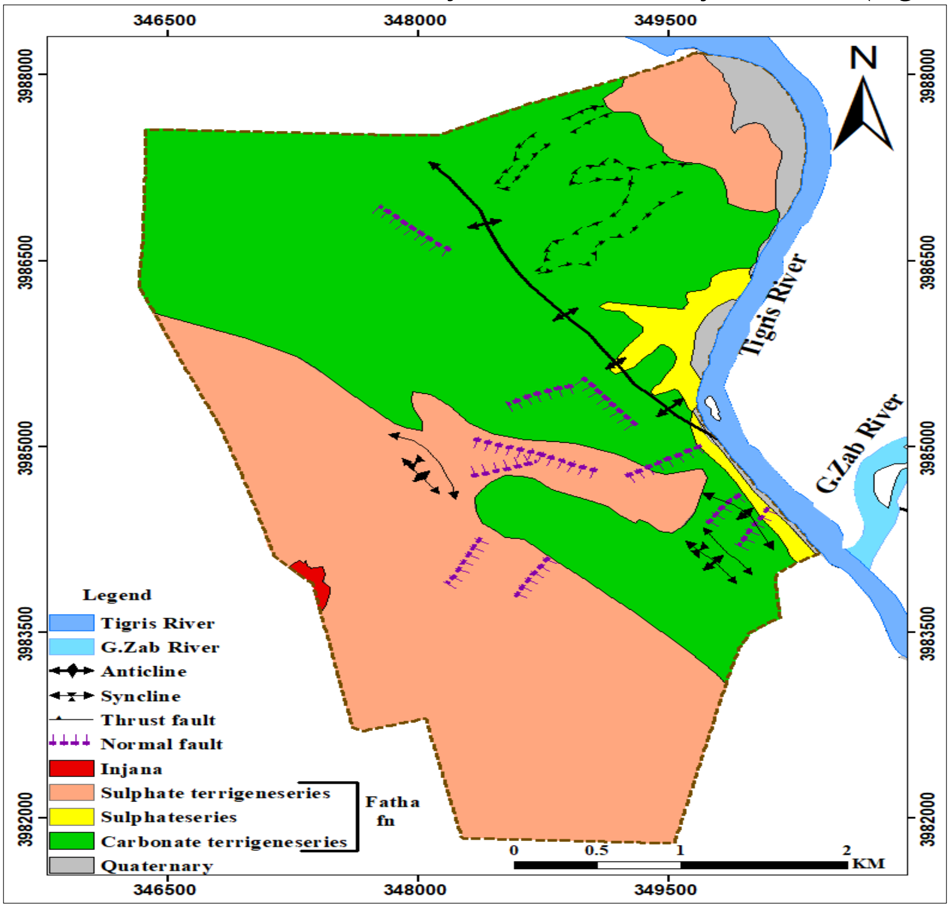


Figure 4: Geological map of the study area [1]

The information on the stratigraphic sequence was obtained through the wells that were drilled by [1], as they penetrated the Euphrates formation. The age of this formation dates back to the Lower Miocene, consists of light to dark limestone that contains: Bituminous and fossils in some of its upper parts, As well as containing marly limestone, dark to light colored marl, and this corresponds to the lithological description of the same formation in Najaf Governorate [6], [7]. There is no significant heterogeneity in the lithology formation between the upper part of the formation and the lower part of the Fatha formation above it. The surface separating them has been determined by microfossils and some types of well-logs.

While of the Injana formation (Upper Miocene). It unfolds in a narrow space, especially along the southwestern edge of the region, and consists of layers of clay, marl, and sandstone [8], [9].

The majority of the study area is covered by the Miocene Fatha formation, which is one of the most significant deposits in the area due to the presence of sulfur deposits formed as a result of the transformation and mineralization of layers of gypsum and anhydrite. The formation also appears in wells that have been drilled in the area and may be covered with Quaternary-age sediments [4].

This formation consists of successive layers of gypsum, limestone, marl, mudstone, and silt [1]. As for the sedimentary environment of this formation, it is a shallow marine environment [10], [11], and its rocks are characterized by weak resistance to erosion processes, which leads to form the erosional geomorphological forms such as karst and caves [12].

The Fatha formation in the study area was divided according to [13] into four sections from the bottom, namely:

1. Productive deposits series
2. Sulfate series
3. Carbonate – terrigenous series
4. Sulfate – terrigenous series

While the Quaternary Sediments cover some narrow areas in the region and consist of gravel and sand of various sizes with clay lenses[3], the thickness of these sediments reaches (25) m in some places.

3- Methodology

1- The lithological sections of the wells available in the study area were drilled by [1], the information of which was obtained from the Mishraq Sulfur State Company, which completely penetrates the Fatha formation.

2- The reality of the groundwater before the production of Sulfur in the Al-Mishraq field was studied based on the data taken from the Mishraq Sulfur State Company, for the study carried out by Centrozab Company in 1971, which numbered (68) wells. After production stopped in the field, the researcher measured the depths of the groundwater in (44) wells in 2021 using the Groundwater depth detector. To ensure that the direction of water movement at any point is perpendicular to the equipotential lines, the spaces confined between the equipotential lines and the flow lines must be as close to squares as possible. The groundwater level map was drawn, which represents a contour map of lines equal to the height of the groundwater level from the surface of the sea (Equipotential Lines), for both cases, before production and after production stopped. The results of the experimental pumping were used for the production layers for (29) wells before producing Sulfur, The same wells were also used after the production process stopped. To obtain the hydraulic properties of the aquifers [14]. Due to the importance of the productive layers aquifer in the production process and its impact on the drainage and consumption of industrial water in the production of Sulfur, which requires the study of hydraulic properties.

4- Results and discussion

4-1 The main aquifers in the study area

Through the study of the lithological sections of the available wells in the study area excavated by the Polish company Centrozap, whose information was obtained from the Mishraq Sulfur State Company, and through previous studies, the aquifer carrying groundwater was identified and represented by the deposits of the Fatha formation, represents the main aquifer of the study area, and due to the lack of continuity in the rocky layers between the parts of the formation and the lack of similarity in groundwater levels. The deposition of Al-Mishraq was counted as a complex multiple aquifer, and it consists of three main aquifer**s** separated by confining layers, these three aquifers consist of some secondary aquifers [15]Which:

4-1-1 Overburden layers aquifer

This aquifer consists of five secondary aquifers carrying groundwater representing the Quaternary in a narrow strip adjacent to the Tigris River, the Sulfate terrigenous series, upper part Carbonate terrigenous series, the Lower part Carbonate terrigenous series and the middle part of the sulfate series [1]. Most of these aquifers are characterized by being discontinuous and poor flowing, as the water recharged for these aquifers places from the northwest side of the sedimentation area and along the direction of the main folds [15].
And because the depths of groundwater that were measured in the wells range between (51-81)m, this aquifer is considered a dry aquifer, or it may contain Perched aquifers.

4-1-2 Productive layers aquifer

This aquifer is the largest groundwater aquifer in the Al-Mishraq region, as it extends on both sides of the Tigris River, which includes the three sulfur layers of the lower part of the Fatah formation. The aquifer of productive layers of the Euphrates formation's upper part contains a marl layer, and the lower part of the overburden layers contains thick layers of gypsum and clay that serve as an aquitard for the aquifer from the bottom and the top [14]. As for the hydraulic aspect, the aquifer occupies a large area and the movement of groundwater is from all sides, as the natural discharge of this water is towards the Tigris River due to the hydraulic connection with the river as a result of the erosion of the covering layers near the river and the presence of faults in the river area [16]. The Productive layers aquifer is characterized as confined and continuous, as well as there is a hydraulic connection for this aquifer with the river in addition to the stable flow, as was proven during the pumping test operations. In general, the water is located within layers of sulfur cavernous limestone, and the average thickness of the water in the reservoir of productive layers based on the information available from hydrogeological wells is about (100 m) approximately [16]. This aquifer was divided into three secondary aquifers according to [1]and separating the three productive layers of limestone with little porosity as well as the layers of compacted mudstone, which are the first productive layer, the second productive layer, and the third productive layer).

4-1-3 Euphrates aquifer

It is located at the top of the Euphrates formation and consists of a single layer of fossiliferous limestone with high secondary porosity. As shown in the stratigraphic sections of the two wells No. (XIX-11, XVIII-4) shown in Figures (6 and 7), as well as the cross-sectional stratigraphic section of the Southwest-Northeast shown in Figure 8.

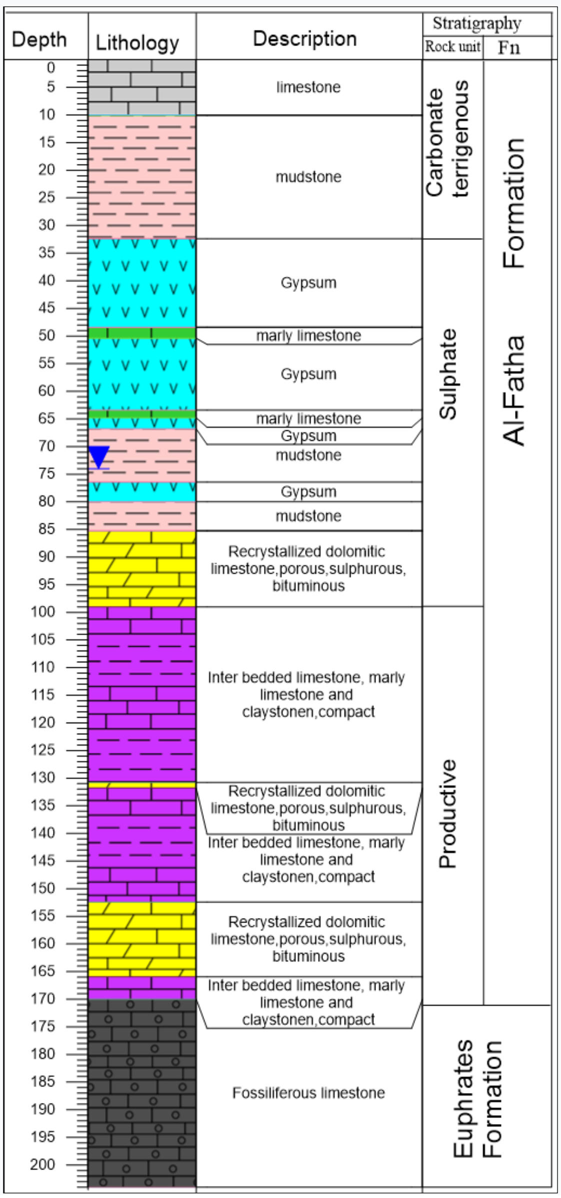


Figure 6: The level of the groundwater relative to the productive layers represented by Dolomitic limestone containing sulphur in the cavities, borehole (XIX-11) in Mishraq-1 [1]

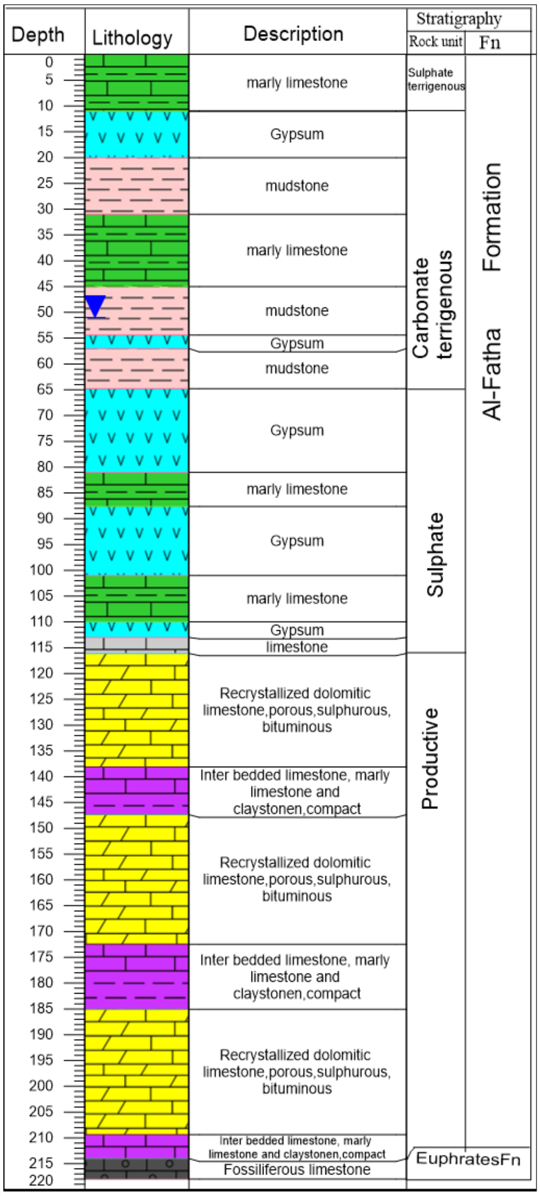


Figure 7: The level of the groundwater relative to the productive layers represented by Dolomitic limestone containing sulphur in the cavities borehole(XVIII-4) in Mishraq-1 [1]

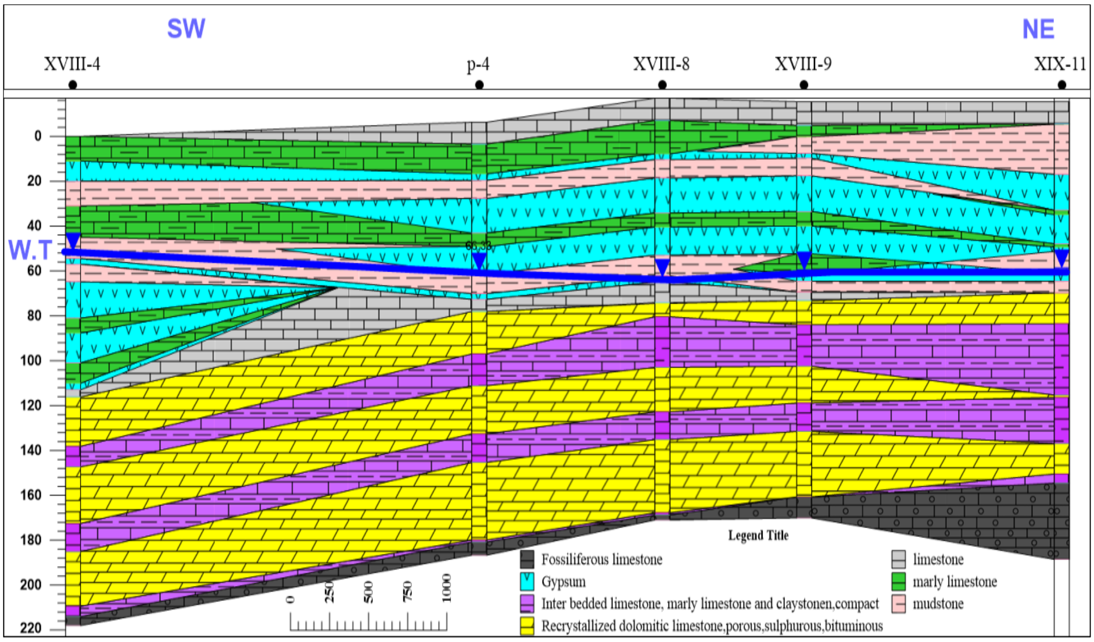


Figure 8: Lithological cross-section Southwest-Northeast in Mishraq 1-, shows the level of the groundwater relative to the productive layers [1].

4-2 Groundwater flow

The depths of the groundwater before production ranged between 83.25-35.6 m, while after production stopped, it ranged between 81-47.37 m, Where it was found that the groundwater before production and after the cessation of production is deep in the axis of the fold and decreases in depth as we move away from the axis of the fold, as in Figures 9 and 10. Watertable is ranged between 205.8-187.71 m in 1971, that is, before production. In 2021, after stopping production, it ranged between 196.19-187.67m, as shown in Table (1).

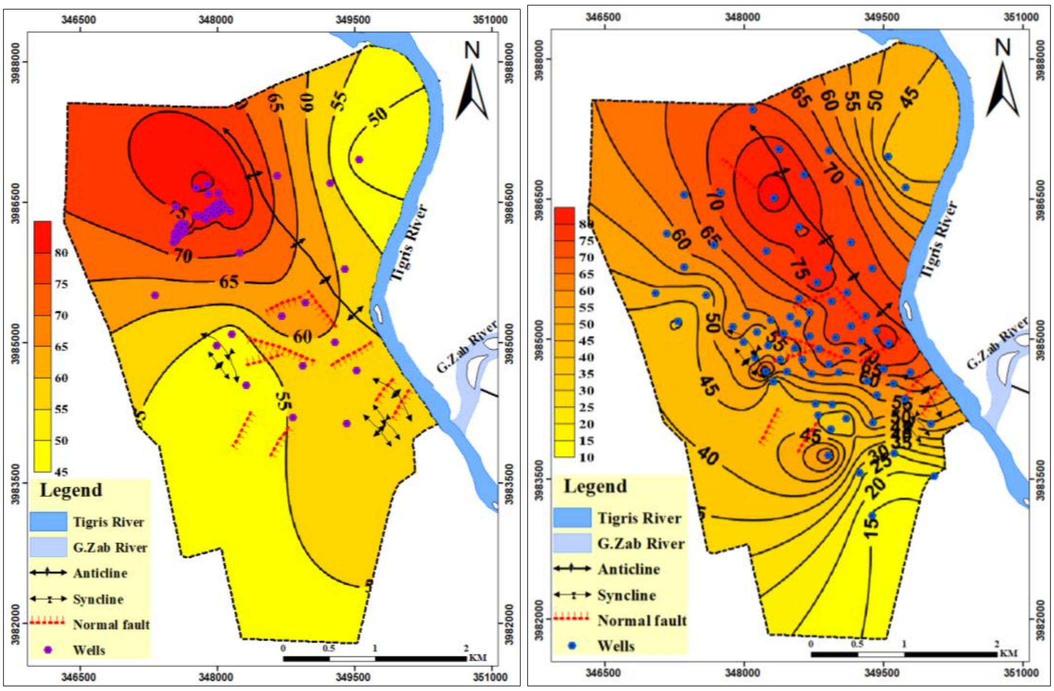


Table 1: Depths and levels of groundwater In the study area

Before production (1971)[14].						After production stoppage (2021)					
no-BH	Elev.(m)	East	North	Dep.(m)	W.T	no-BH	East	North	Elev.(m)	Dep.(m)	W.T
P-1	251.18	348288	3985210	59.60	191.58	C-473	347550	3986098	263.85	72.87	190.98
P-2	256.30	348427	3985064	62.40	193.9	C-479	347570	3986139	264.39	72.93	191.46
P_3	252.97	348495	3985244	61.90	191.07	C-470	347518	3986075	263.14	72.32	190.82
P-4	256.81	348594	3985435	66.51	190.3	C-474	347534	3986132	264.48	74.63	189.85
P-5	256.60	348706	3985284	64.60	192	C-478	347535	3986172	265.43	74.53	190.9
viii-8	249.24	350015	3984096	50.10	199.14	C-484	347573	3986168	265.27	73.15	192.12
x-6	249.29	349385	3984112	49.74	199.55	C-487	347574	3986196	265.53	73.21	192.32
x-8	253.75	349733	3984364	56.90	196.85	C-488	347607	3986163	265.08	73.15	191.93
xi-4	239.00	348938	3984040	35.60	203.4	C-489	347611	3986202	265.99	75.23	190.76
xi-5	238.49	349103	3984155	36.00	202.49	C-490	347575	3986239	265.07	73.28	191.79
xi-7	255.10	349434	3984404	56.40	198.7	C-492	347610	3986236	265.54	74.56	190.98
xi-8	256.07	349615	3984525	59.80	196.27	C-493	347649	3986194	266.28	76.12	190.16
xi-9	263.11	349790	3984648	67.95	195.16	C-494	347608	3986277	265.13	73.66	191.47
xii-4	242.88	348803	3984185	40.20	202.68	C-495	347648	3986270	265	73.78	191.22
xii-5	244.57	348954	3984300	44.60	199.97	CN-1A	347903	3986597	273.85	79.6	194.25
xii-7	255.18	349330	3984556	58.45	196.73	CN-2A	347772	3986656	276.59	80.92	195.67
xii-8	263.91	349502	3984682	69.05	194.86	CN-3A	347892	3986694	277.01	80.94	196.07
xiii-4	246.38	348772	3984312	44.00	202.38	CN-4A	348009	3986601	274.8	79.95	194.85
xiii-6	260.24	349023	3984644	60.34	199.9	CU-1	347797	3986367	269.01	77.52	191.49
xiii-9	269.24	349557	3984960	76.20	193.04	CU-2	348042	3986505	270.84	79.26	191.58
xiv-5	262.17	348729	3984633	59.80	202.37	CU-3	348138	3986407	269.51	81	188.51
xiv-6	263.03	348913	3984734	67.00	196.03	O-5	347549	3986455	270.24	75.17	194.47
xiv-7	261.51	349101	3984878	67.10	194.41	O-8	347322	3985507	256	59.81	196.19
x-3	261.20	348909	3983760	61.20	200	P-5	348706	3985290	251.12	60.8	190.32
xiv-8	260.92	349264	3984983	71.50	189.42	S-535	347834	3986340	269.04	77.98	191.76
xiv-9	267.82	349425	3985095	75.25	192.57	S-531	347768	3986356	266.53	75.16	191.37
xv-4	255.44	348462	3984654	57.20	198.24	S-534	347880	3986372	269.84	78.81	191.03
xv-3	244.6	34831	398454	40.60	204.0	S-542	34788	39863	266.6	75.79	190.88

	8	5	5		8		2	20	7		
xv-5	256.62	348628	3984787	61.30	195.32	XV-3	348315	3984545	244	48.6	195.4
xv-6	260.99	348809	3984898	66.50	194.49	XVII I-3	347997	3984973	246	50.5	195.5
xv-7	264.42	348985	3985024	72.30	192.12	Z-502	347896	3986398	269.42	78.98	190.44
xv-8	266.12	349151	3985141	74.20	191.92	Z-503	347920	3986430	269.38	78.44	190.94
xv-9	264.14	349308	3985254	72.60	191.54	Z-504	347962	3986459	269.47	78.88	190.59
xvi-4	249.55	348392	3984786	51.80	197.75	Z-505	347997	3986487	270.55	79.8	190.75
xvi-6	261.50	348706	3985032	67.55	193.95	Z-509	347997	3986442	269.76	79.98	189.78
xvii-3	249.08	348116	3984805	49.40	199.68	Z-510	347968	3986412	268.28	78.33	189.95
xvii4	248.17	348260	3984932	51.19	196.98	Z-511	347931	3986396	268.39	78.93	189.46
xvi-5	251.76	348549	3984910	57.00	194.76	Z-515	347967	3986363	266.55	74.88	191.67
xvii-9	260.72	349108	3985501	72.50	188.22	Z-516	348003	3986393	266.1	75.12	190.98
xvii-8	263.72	348943	3985410	71.45	192.27	Z-517	348040	3986418	269.11	77.97	191.14
xvii-11	262.87	349378	3985764	71.30	191.57	Z-518	348086	3986447	270.02	79.86	190.16
xviii-3	254.18	347997	3984973	53.50	200.68	m	348161	3985093	245.66	50.77	194.89
xviii-4	250.48	348141	3985080	51.00	199.48	xxi-15	349555	3986957	243.92	47.37	196.55
xviii-8	267.51	348782	3985614	79.80	187.71	X-6	349415	3984135	249.29	59.13	190.16
xviii-9	265.93	348910	3985768	75.00	190.93						
xix-3	259.17	347880	3985135	59.80	199.37						
xix-4	255.70	348025	3985254	59.45	196.25						
xix-11	265.97	349155	3986039	74.00	191.97						
xix-15	247.57	349739	3986629	46.90	200.67						
xxi-1	244.47	347291	3985197	39.19	205.28						
xxi-3	249.93	347590	3985477	46.45	203.48						
xxi-7	266.12	348236	3985948	73.40	192.72						
xxi-9	271.73	348588	3986204	74.60	197.13						
xxi-13	263.83	349232	3986688	67.30	196.53						
xxi-15	243.92	349555	3986957	42.20	201.72						
xxiii-1	253.87	347049	3985497	48.80	205.07						
xxiii-3	261.75	347356	3985772	57.85	203.9						

xxiii-5	266.18	347678	3986015	64.80	201.38
xxiii-9	280.66	348327	3986515	83.25	197.41
xxiii-11	273.52	348652	3986767	75.80	197.72
xxiii-13	263.66	348915	3987027	66.10	197.56
xxv-3	263.43	347167	3986133	58.30	205.13
xxv-7	273.80	347752	3986572	71.85	201.95
xxv-11	282.16	348376	3987042	77.20	204.96
xxvii-5	268.94	347355	3986552	63.79	205.15
xxvii-11	276.80	348094	3987465	71.00	205.8
xvi-3	272.40	348239	3984657	72.60	199.8
xvii-6	254.77	348578	3985171	62.80	191.97

The decrease in levels after stopping production is attributed to two reasons, the first is climatic, and the second may be due to the increase in hydraulic properties due to the production of Sulfur, which leads to an increase in effective porosity, which led to an increase in natural drainage towards the Tigris River and thus lower levels. To know the direction of groundwater movement and its natural discharge in the study area, a Groundwater Level Map was drawn, which represents a contour map of Equipotential lines to the height of the groundwater level above sea level, meaning that Equipotential Lines, for both cases, before and after production. Production stops so that the direction of water movement at any point is perpendicular to the Equipotential lines. Taking into account that the areas between Equipotential Lines and the lines of flow are in the form of squares as much as possible[17]. From the observation of Figures (11 and 12), it was found that the direction of movement did not change much before production and after production stopped. In both instances, groundwater is moving in an eastward direction with a slight slope toward the southeast, indicating that the drainage area is east of the study area, which is represented by the Tigris River.

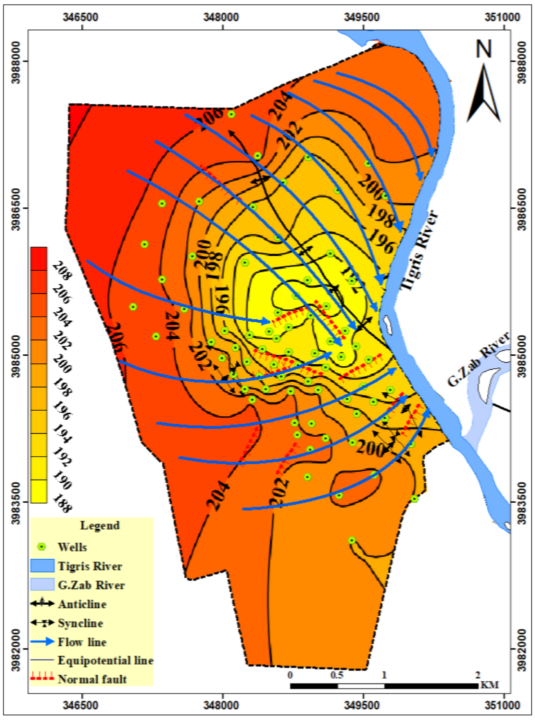


Figure 11: Groundwater movement map in Al-Mishraq Sulfur field-1 before production[14]

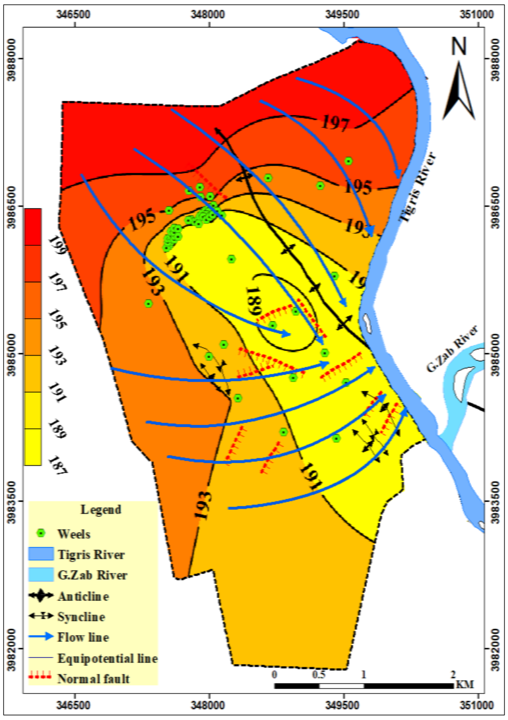


Figure 12: Groundwater movement map in Al-Mishraq Sulfur field-1 after production

The first layer contains less hydraulic pressure than the second and third layers, which helps in the rise of water from it to the first layer [14].It is in hydraulic contact with the river near the XV-9 well, as well as at the fault areas that represent the sites for the passage of groundwater to the drainage area.

4-3 Hydraulic Properties of the Aquifers

1- The values of Transmissivity (T) ranged between 1557.5-24.4 m^2/day before production, and between 5020.6-39.4 m^2/day after production stopped, while the hydraulic conductivity (K) ranged between 0.26-14.68 m/day before production. But after production stopped, it was between 0.4-48.9 m/day [14], as shown in Table 2.

Table 2: Hydraulic properties of wells that have undergone the pumping test [14]

no-wells	east	north	Before production(1971)		After production(2003)	
			K (m/day)	**T(m^2/day)**	**K (m/day)**	**T(m^2/day)**
B.H.-34	350409.3	3982652	0.9	93.1	1.5	150.2
B.H.-35	348874.7	3985545	2.66	272.7	4.4	440
p-1	349212.3	3984340	1.23	127.31	2.1	205.4
p-2	348308.5	3985223	1.41	128.1	2.1	206.7
p-3	348448.2	3985079	1.47	159.6	2.6	257.5
p-4	348515.2	3985259	3.9	422.3	6.8	681.3
VIII-4	348611.8	3985451	6	660	10.6	1064.9
VIII-8	349278.8	3983595	0.26	24.4	0.4	39.4
XII-8	350044.6	3984125	10.52	1082.5	17.5	1746.5
XIII-1	349526.1	3984706	3.69	415.1	5.7	642.5
XIII-6	348225.1	3984042	2.89	303.5	48.9	4889.5

XIX-11	349047.6	3984664	0.33	29.8	0.5	46.5
XIX-15	349167	3986059	2.28	212.3	3.4	342
XIX-3	349745.7	3986654	0.71	72	1.2	116.2
XV-3	347900.7	3985145	1.12	116.9	1.9	188.6
XV-5	348341.6	3984559	0.58	62.4	1	100.7
XV-7	348652	3984803	3.01	316.7	5.1	511
XV-9	349006.3	3985043	14.68	1557.5	25	2503.2
XVII-3	349327.3	3985276	1.51	154	2.5	254.8
XVII-8	348140.1	3984817	9.9	1026.1	48.4	5020.6
XVII-9	348961.4	3985429	1.9	223.5	5.4	558
XVIII-3	349125.6	3985521	1.51	154	2.5	254
XVIII-8	348025.2	3984984	0.7	73.5	1.2	118.6
XVIII-9	348798	3985631	1.5	151.1	2.4	243.8
XXI-3	348925.2	3985787	1.29	135.6	2.2	217.8
XXI-7	347608.2	3985484	0.593	58.4	0.9	94.2
XXIII-13	348249.8	3985960	1.15	116	1.9	187.2
XXIII-5	348918.8	3987045	0.96	103	1.7	166.2
XXIII-9	347691.4	3986023	1.83	172.3	2.8	279.6

Through this information, Transmissivity (T) and hydraulic conductivity (K) data were drawn before and after production stopped in Al-Mishraq field-1, as shown in Figures (13) and (14), as it was found that the increase in hydraulic properties after stopping production The production is regular, the reason may be due to the effect of these characteristics on the production processes, increase the porosity and homogeneously create new gaps. The reason may be due to the effect of these properties on the production processes, increasing the porosity and homogeneously creating a new hole. The results also showed that the relationship is direct as the hydraulic properties values increase at one frequency after production, and this was confirmed by finding the correlation coefficient (R^2). where the strength of the relationship between them indicates the closer this coefficient is to one, as shown in Figures (15) and (16), but there is a high increase in the hydraulic properties in wells (XIII-6) and (XVII-8), the reason may be due to the occurrence of these two wells within the high leakage zone.

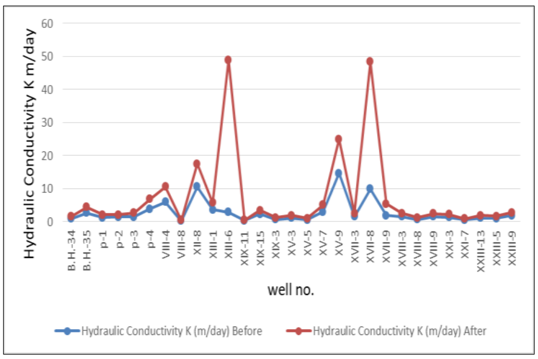


Figure 14: shows the relationship between hydraulic conductivity (K) before and after production stops, in Al-Mishraq field-1, for the data of wells subject to experimental pumping.

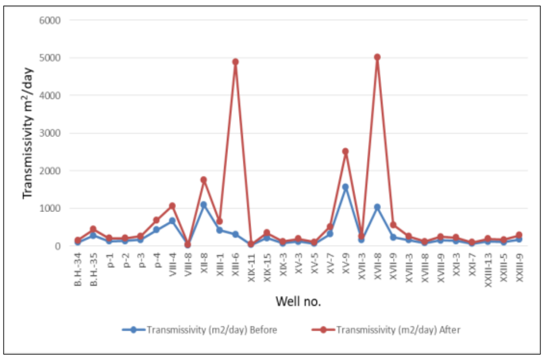
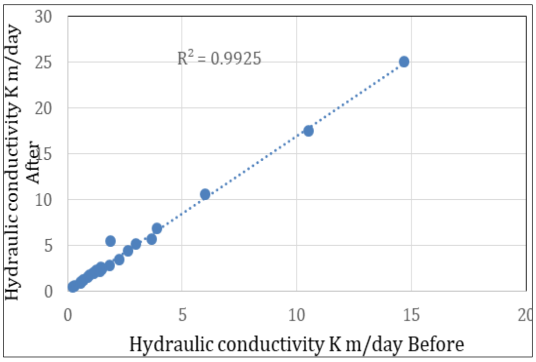


Figure 13: shows the relationship between the Transmissivity (T) before and after production stops, in Al-Mishraq field-1, for the data of wells subject to experimental pumping



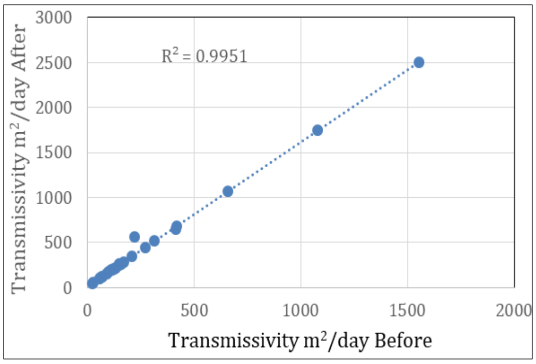


Figure 15: shows the relationship between Transmissivity (T) before and after production stops, in Al-Mishraq field-1

Figure 16: shows the relationship between hydraulic conductivity (K) before and after the production stop, in Al-Mishraq field-1

2- We note that the values of Transmissivity and hydraulic conductivity before production increase east of the study area near the Tigris River and decrease towards the north and northwest of the study area as in the figures (17, 18), The reason for the increase in these characteristics may be due to their influence on the tectonic activity resulting from the influence of the Hadhra - Bakhme fault, which causes the formation of faults and joints parallel to this main fault, which intersect with the joints resulting from the formation of folds and parallel to the axis of the main Mishraq fold, the point of intersection of both systems is considered the main leakage point. The hydraulic properties after production also increase linearly as shown in the figures (19, 20), it is due to the establishment of production sites (production stations) on and around the center of this increase, where large quantities of hot technological water were injected for the underground Sulfur smelting process in the second and third production layers, and that the withdrawal of this molten Sulfur has caused voids to occur There are many large cavities within the productive layers and the enclosing layers between them, where the effective porosity doubled, which was reflected on the hydrogeological behavior of the three secondary Aquifers, which led to an increase in the hydraulic properties of Transmissivity and hydraulic conductivity.

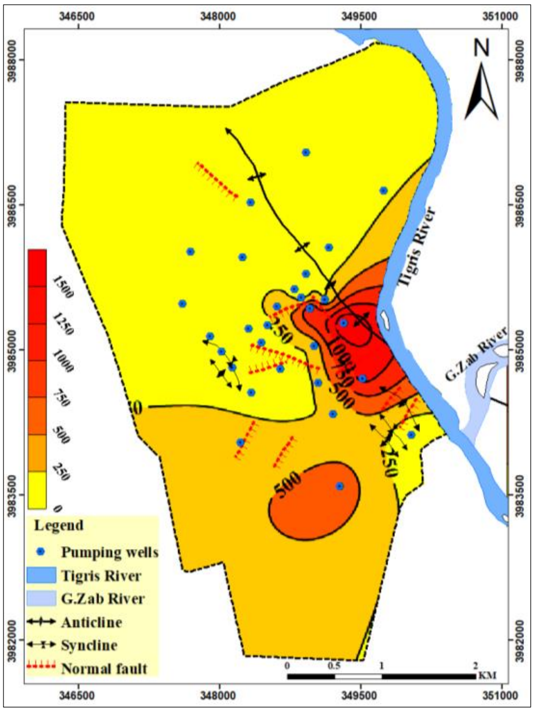


Figure 17: A map representing the distribution of Transmissivity (T) in the wells of the study area before production [14]

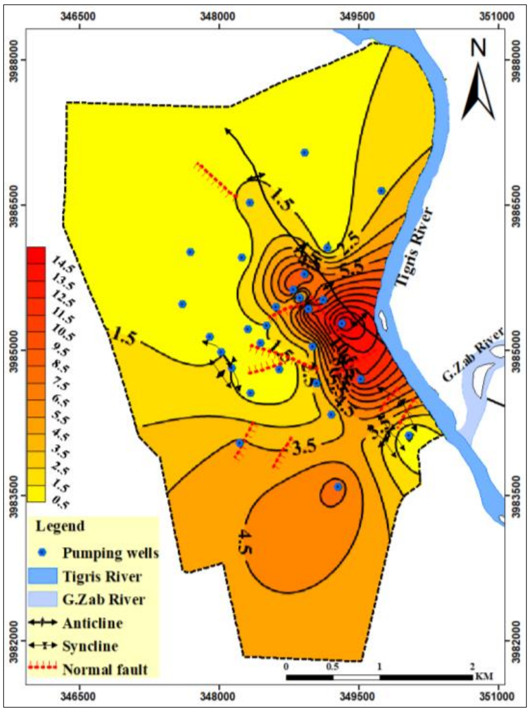


Figure 18: A map representing the distribution of hydraulic conductivity (K) in the wells of the study area before production [14]

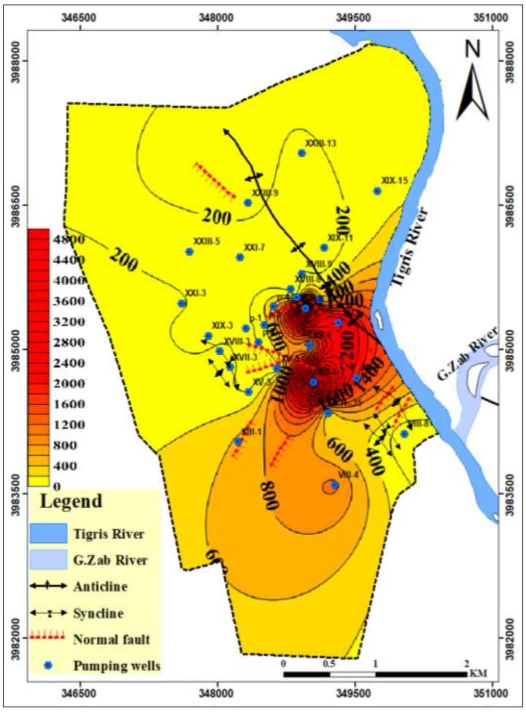


Figure 19: A map representing the distribution of Transmissivity (T) in the wells of the study area after production [14]

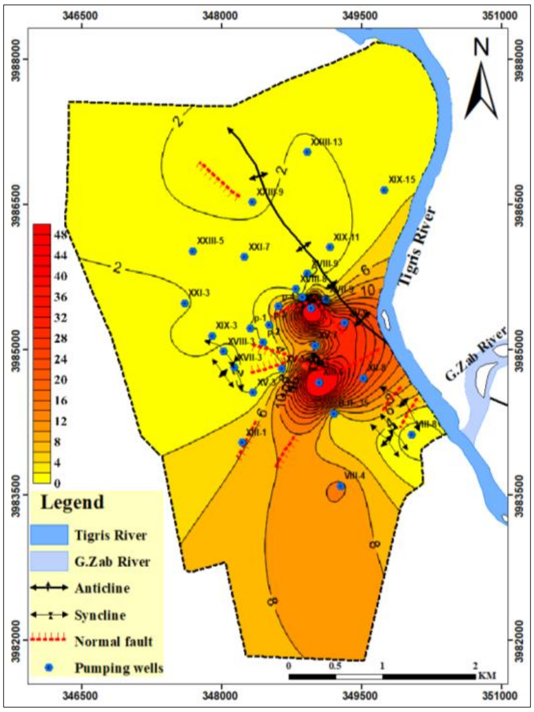


Figure 20: A map representing the distribution of hydraulic conductivity (K) in the wells of the study area after production[14]

Conclusions

Through the study of the cross-section of some wells in the study area, two main aquifers were identified, from the bottom, the Euphrates formation aquifer, and the Productive layers aquifer within the fatha formation. As for the overburden layers aquifer, is dry or may contain Perched aquifers.

1. The general direction of groundwater movement before production and after production stops is from the west and northwest to the east with a slight slope toward the southeast, meaning that the recharge area is north and northwest of the region. As for the drainage area, it is located to the east of the area, represented by the Tigris River, due to the presence of hydraulic contact with the river near the XV-9 well, in addition to the fault areas that represent sites for the passage of groundwater to the drainage area.

2.t was found that there are two main foci of hydraulic conductivity and Transmissivity near the Tigris River. The reason for the increase in these characteristics may be due to their impact on the tectonic activity resulting from the influence of the Hadhra-Bakhme fault. The increase in the hydraulic properties after production is due to the establishment of production sites (production stations) on and around the center of this increase. Where large quantities of hot technological water were injected for the underground smelting process of Sulfur in the second and third productive layers, and the withdrawal of this molten Sulfur has caused the occurrence of many large voids and cavities inside the productive layers and the enclosing layers between them, where the effective porosity doubled, which was reflected on the hydrogeological behavior of the aquifers The three secondary waters, which led to an increase in the hydraulic properties of Transmissivity and hydraulic conductivity

2. The hydraulic properties increase at these faults located in the middle and east of the study area, while the hydraulic properties decrease toward the west and northwest. This is because the faults in the study area play a significant role in the water movement of the aquifer of the productive layers and are thought of as natural channels for the movement of water towards the east, that is, to the Tigris River. This is due to a decrease in the reduction of gypsum and anhydrite to calcareous sulfur-containing rocks, as the reduction process causes these rocks to shrink in size, increasing their permeability and conductivity. Furthermore, the non-reduced gypsum rocks have low initial porosity, which is reflected in their permeability and conductivity, as well as the lack of faults in the study area's west and northwest.

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