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Hydrogeological System of Injana Formation in Salahaddin Governorate/ Iraq

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Abstract

Injana Formation is the most extended geological formation in Salahaddin Governorate/ Iraq. About 10% of the studied area is covered by the outcrops of the formation as a recharge area. The formation is a subsurface within the unsaturated zone in 5% of the total studied area, while it exists within the saturated zone in about 85%; it is a major confined groundwater aquifer. Therefore, the hydrogeological system of the layers needs to be re-evaluated to describe the successions of aquifers and confining layers and their relation with each other.

The lithology, depths, water table, saturated thickness, hydraulic characteristics of the aquifers, and the lateral and vertical variations of these characteristics were adopted to classify the hydrogeological system. The lithological composition is mainly composed of alternating successions of claystone, siltstone and sandstone with some differentiation within the studied area.

The Quaternary and, occasionally, the Mukdadiya Formations are dry or of secondary aquifer, except in limited areas of the governorate. Injana Formation represents the major upper aquifer in the area, especially in the western bank of Tigris River. The outcrops of the formation are adjacent to Makhul and Hamrin anticlines; while Al-Tharthar valley represents a recharge area for the groundwater. In the remaining parts of the studied area, the formation represents the main deeper of a confined to semi-confined groundwater aquifer.

The general direction of the groundwater movement in this hydrogeological system is towards the discharge area represented by Tigris River and Tharthar Lake, which is compatible with the topographic slope. The formation is classified as a multi-layer aquifer hydrogeological system.

Keywords: Hydrogeological system; Injana Formation; Salahaddin Governorate, Iraq

النظام الهيدروجيولوجي لتكوين إنجانة في محافظة صلاح الدين/ العراق

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الخلاصة:

تكوين إنجانة هو اكثر التكوينات الجيولوجية انتشارا في محافظة صلاح الدين / العراق، حوالي (10٪) من المساحة المدروسة التي تغطيها منكشفات التكوين تمثل منطقة تغذية. التكوين يتواجد تحت السطح ضمن

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المنطقة غير المشبعة في (5٪) من إجمالي المساحة المدروسة، في حين يتواجد ضمن المنطقة المشبعة في حوالي (85٪) في المنطقة المدروسة، اذ يمثل الخزان الجوفي المحصور الرئيسي للمياه الجوفية. لذلك، يجب إعادة تقييم النظام الهيدروجيولوجي لوصف تعاقب الطبقات الخازنة للمياه الجوفية والطبقات الحاصرة غير النفاذة وعلاقتها ببعضها البعض.

تم اعتماد الوصف الصخري، أعماق، مناسيب المياه الجوفية، السمك المشبع، الخصائص الهيدروليكية للطبقات الخازنة للمياه الجوفية، التباين الأفقي والرأسي لهذه الخصائص ، لتصنيف النظام الهيدروجيولوجي. يتكون التكوين لثولوجيا بشكل أساسي من تعاقب الحجر الطيني والحجر السلتي والحجر الرملي مع بعض التغايرات من مكان الى اخر داخل المنطقة المدروسة.

ترسبات العصر الرباعي، وأحيانًا ترسبات تكوين المقدادية تمثل اما طبقة جافة أو خزان ثانوي للمياه الجوفية فوق خزان انجانة، باستثناء مناطق محدودة من المحافظة. يمثل تكوين إنجانة خزان المياه الجوفية العلوي الرئيس في المنطقة، خاصة في الجهة الغربية لنهر دجلة. تمثل منكشفات التكوين المتاخمة لطيتي مكحول وحمرين المحدبتين، ووادي الثرثار كمنطقة تغذية للمياه الجوفية. في معظم المنطقة المدروسة، يمثل التكوين الخزان الجوفي الأعمق الرئيس المحصور او شبه المحصور للمياه الجوفية.

الاتجاه العام لحركة المياه الجوفية في هذا النظام الهيدروجيولوجي هو نحو منطقة التصريف المتمثلة بنهر دجلة وبحيرة الثرثار، ويتوافق هذا الاتجاه مع اتجاه الانحدار الطبوغرافي. تم تصنيف النظام الهيدروجيولوجي للتكوين على أنه خزان جوفي متعدد الطبقات للمياه الجوفية.

Introduction

Salahaddin governorate is located in the north of central Iraq, 175 km north of Baghdad governorate on the two banks of the Tigris River, between the UTM coordinates of 269966-496883 E and 3722989-3951057 N. The governorate includes the towns Tikrit, Sharqat, Baiji, Samarra, Balad, Dujail, Dor, Alam, and Toz. The western parts (west Makhul and Hamrin) of the governorate lie within the stable shelf zone, while its eastern part (east Makhul and Hamrin) lie within the unstable shelf [1].

The geological formations of Fatha, Mukdadiya and Bai Hassan represent the well-known secondary groundwater aquifers within Salahaddin area, as well as the Quaternary deposits, while the deposits of the Injana Formation layers are the main aquifer in the western parts of the Tigris River in the governorate. Mukdadiya Formation layers represent the secondary upper groundwater aquifer in the area between the Hamrin mountain range to the north and east and the Tigris River to the west (Figure-1). Al-Basrawi and Al-Muslih [2] reported that the groundwater aquifers in the area are confined and unconfined, in addition to the presence of perched aquifers that can be invested by hand dug wells in the governorate.

Injana Formation (Upper Miocene) is the largest extensive geological formation in the governorate of Salahaddin. It is outcropped in about 10%), which plays a role of recharge area, and it represents the main groundwater aquifer in 85% of the total area of the governorate. It is mainly consisted of a sequence of sandstone, siltstone and claystone layers. The maximum thickness of Injana Formation in the area of study is about 550 m.

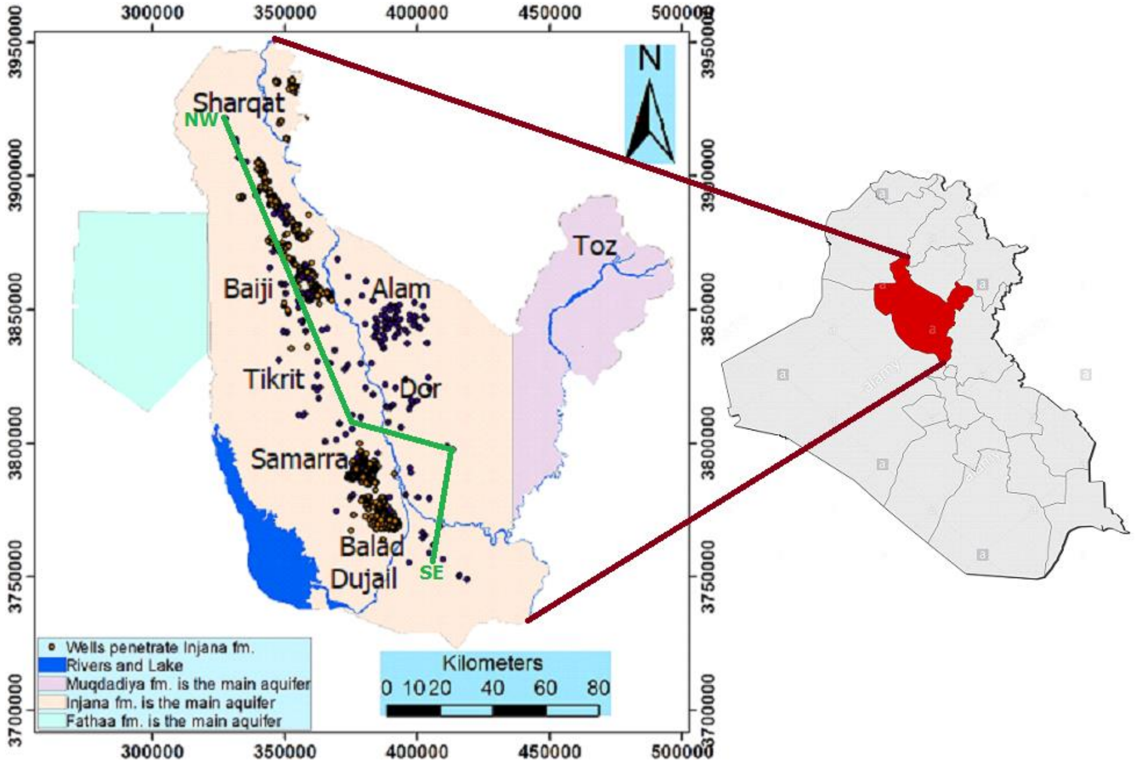

Figure 1-Location map of the studied area (the section NW-SE is shown in Figure 2).

This formation is a clastic alternation of sequence fluvial cycles in lenticels, which pass to each other medium to coarse sandstone, siltstone and claystone, and deposited in fluvial- tidal environment [3,4].

The sandstone of Injana Formation is composed primarily of rock fragments (sedimentary, igneous and metamorphic), quartz (monocrystalline and polycrystalline) and feldspars (orthoclase, microcline and plagioclase). The matrix is subordinate and the cement is mostly carbonate [5].

The claystone beds in the Injana Formation are reddish brown, brownish, conchoidally fractured, calcareous, occasionally silty and containing lenses of siltstone and sandstone. Thickness of individual beds is in the range of 5-20 m, while the sandstone beds are reddish brown, grey, thin bedded to massive and the thickness range of individual beds is 0.5-15 m. Few lenses of limestone and marly limestone occur at different levels in the lower part, and they are greenish and fossiliferous [4].

The transmissivity and hydraulic conductivity are the main significant hydrogeological data required for managing groundwater resources; transmissivity describes the general ability of an aquifer to transmit water over the entire saturated thickness, while hydraulic conductivity measures this ability by unit area [6]. Hydraulic conductivity is defined as the quantity of water moved through the porous media within the time unit under the effect of hydraulic gradient in one unit through one area unit measured vertically on flow direction (length unit/time unit) [7].

The layers of geological formation can be classified, as related to their hydrogeological properties, to aquifers or confining layers. An aquifer is water bearing geologic formation or stratum capable of transmitting water through its pores at a significant rate for economic extraction by wells [8]. It has sufficient permeability and thickness to transmit groundwater within its layers [9].

As for the confining layers, the aquitard is a partially permeable formation or layer(s) though which only seepage is possible and thus the yield is insignificant compared with aquifers, while the aquiclude is a formation which is essentially impermeable to the flow of water [10]. There is a recent trend toward the use of the terms aquifer and aquitard, while neglecting the term aquiclude [11].

Based on the data taken from the theological description archive of the wells drilled in the area within Injana formation, the sandstone, siltstone, sandy silt and silty sand water-bearing layers are considered as aquifers of groundwater, while the clayey layers is considered as aquitard confining layers.

Most of the wells drilling works in Salahaddin Governorate are conducted to invest the groundwater from the Injana aquifer for irrigation purposes. In most cases, the drilling is random, without an accurate prior geological database, leading to the failure of many wells, with additional costs and efforts. This study will be a useful database that benefits the decision maker of groundwater sector in the governorate to choose suitable places and conditions of drilling.

The objective of the present study is to describe the lithology, hydrogeologic and hydraulic conditions, extensions, depth, thickness, and groundwater origin in the study area. We also estimate the recharge and discharge areas and the general direction of groundwater movement in Injana water bearing layers within Salahaddin governorate.

Materials and Methodology

The archived data from the General Commission of Groundwater/ Ministry of Water Resources and the General Establishment of Geological Survey and Mining were used to extract the lithological description and hydraulic properties of the hydrogeological system of Injana Formation. The data of 2322 wells were used to derive the water table of the aquifer, followe4d by the flow directions and depth to groundwater in the studied area. The field and laboratory descriptions of the lithological sequences from 165 wells, based on the data of Table-1 within Salahaddin governorate, were studied to conclude the extensions, thicknesses of clay beds, produced thickness, lateral variations, and geometrical properties of the water bearing layers. The pumping test data were used to analyze and estimate the transmissivity, hydraulic conductivity, and maximum drawdown of the aquifers.

Results and Discussion

Aquifer System

Depending on the section that is derived from the lithological description made on the layers of Injana Formation in the study area, (Figure-2) demonstrates the dominance of clayey sand, sand, and sandy clay sequences, which always represent the groundwater bearing layers. Clay plays the major role of the confining layers (aquitards), while gravel, clayey gravel, gravely clay and sandy gravel layers are mostly dry layers above the groundwater table.

It is evident that the groundwater aquifer within the layers of Injana Formation is generally a confined aquifer, except for one case where it could be a semi- confined aquifer due to the existence of aquitards of clay which produce a multi-layer aquifer.

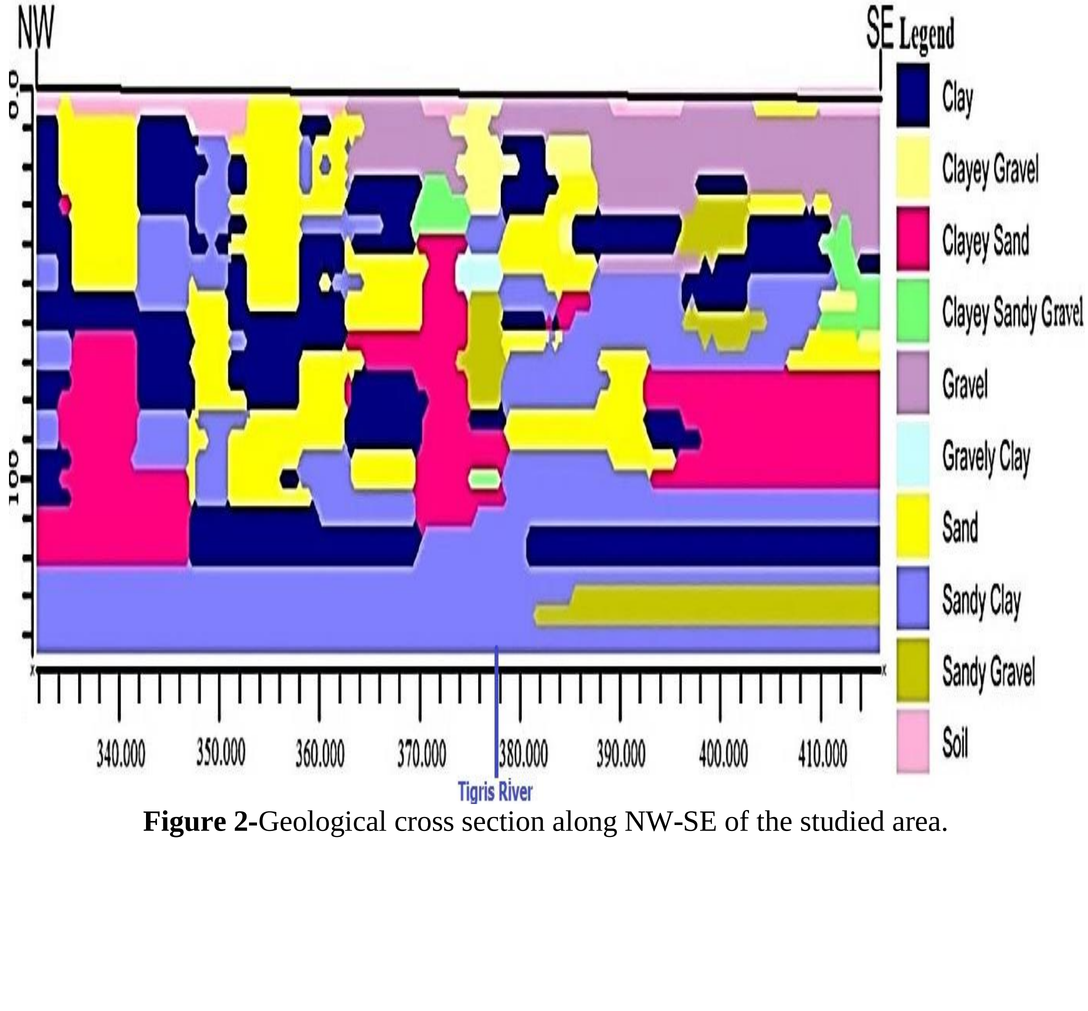

Figure 2-Geological cross section along NW-SE of the studied area.

Table 1-The hydraulic data of selected 40 wells within Salahaddin governorate

X East	Y North	Surf. elev. m.a.s.l	Well depth m	Dep. to Water m	S_w m	Pump. Rate l/sec	Piezo. L. or W.T. m.a.s.l		Clay Thick M	Produ. Thick m	T m^2/ day	K m/ day
							Pizo.L	W.T				
402103	3851179	144	132	45.2	41.14	3.5		98.8	5	81.8	8.82	0.11
393744	3846322	117	102	57.13	27.63	3.5		59.87	7	37.87	13.13	0.35
392016	3851130	127	96	40.2	42.95	3.5	86.8		16	55.8	8.45	0.15
384094	3839645	102	90	32.68	31.52	4		69.32	0	57.32	13.16	0.23
373915	3852871	118	108	10.75	55.77	4	107.3		6	91.25	7.44	0.08
387849	3843080	110	108	52. 2	32.15	3		57.8	7	48.8	9.67	0.2
389988	3851437	124	108	37.25	49.4	3	86.75		9	67.75	6.3	0.09
389383	3843718	110	102	23.15	63.21	3	86.85		11	78.85	4.92	0.06
397210	3846014	117	114	46.35	38.81	3		70.65	0	63.65	8.01	0.13
400329	3843361	110	108	29.14	49.21	4	80.86		12	78.86	8.43	0.11
387406	3835333	102	84	32.45	32.67	5		69.55	0	51.55	15.87	0.31
387827	3838846	103	90	33.2	35.15	4		69.8	5	51.8	11.8	0.23
396226	3837192	95	90	52.38	30.87	4		42.62	5	32.62	13.43	0.41
389135	3846761	117	114	34.36	59.85	2.5	82.64		34	45.64	4.33	0.09
387741	3845083	112	108	37.12	43.23	2.5		74.88	0	70.88	6	0.08
384224	3846726	110	90	27.85	21.95	6.5		82.15	6	56.15	30.7	0.55
374076	3862202	139	108	38.35	21.25	6		100.7	0	69.65	29.27	0.42
384799	3841478	106	81	32.75	25.43	6		73.25	10	38.25	24.46	0.64
383644	3839865	106	90	30.25	12.5	7		75.75	0	59.75	58.06	0.97
391025	3850549	124	84	38.15	26.05	5	85.85		22	39.85	19.9	0.5
332517	3906751	196	108	10.35	36.85	5	185.7		31	66.65	14.07	0.21
335652	3905306	204	108	8.5	44.64	5		195.5	9	90.5	11.61	0.13
398679	3843826	111	84	39.2	7.3	7		71.8	0	44.8	99.42	2.22
382786	3829962	85	66	9	15.75	6	76		24	33	39.5	1.2
397368	3790732	79	72	14.6	5.3	8		64.4	0	57.4	156.5	2.73
389574	3779661	72	90	28.3	17.3	8		43.7	0	61.7	47.94	0.78
369521	3774378	85	96	28.6	28.65	5.5		56.4	0	67.4	19.9	0.3
395777	3780483	56	72	13.2	11.02	7		42.8	0	58.8	65.86	1.12
374966	3779961	82	90	12.3	33.9	5	69.7		16	61.7	15.29	0.25
397762	3789110	76	78	18.3	6.9	8		57.7	0	59.7	120.21	2.01
348866	3887641	182	90	17.2	59.65	4		164.8	0	72.8	6.95	0.1
348270	3885802	169	114	24.35	61.11	4	144.7		10	79.65	6.79	0.09
351021	3882764	162	114	12.2	83	2.5	149.8		26	75.8	3.12	0.04
350752	3888700	202	96	20.38	42.77	5		181.6	0	75.62	12.12	0.16
357844	3866865	145	96	15.35	73.11	2.5	129.7		23	57.65	3.55	0.06
356713	3856041	151	117	31.75	31.05	6		119.3	0	85.25	20.03	0.24
359524	3861582	128	102	18.35	38.95	5.5	109.7		28	55.65	14.64	0.26
356612	3861941	144	102	30.12	39.06	5		113.9	4	67.88	13.27	0.2
348855	3859440	148	108	22.3	45.85	5		125.7	0	85.7	11.31	0.13
350350	3859203	152	102	8.35	80.11	4		143.7	0	93.65	5.18	0.06

Piezometric levels, flow direction and depth to groundwater

The annual recharge of groundwater aquifer, its hydraulic characteristic, groundwater exploitation, and natural groundwater flow are the main factors affecting the groundwater piezometric levels.

In general, the groundwater table in Injana aquifers in Salahaddin governorate, depending of the data of 2322 wells, is highest in the north. The elevation reaches 200 meters a.s.l. and gradually decreases to the south, reaching 115-150 meters a.s.l. within the boundaries of Baiji area. The decrease continues southward and eastward in the center of the governorate and the area adjacent to the Hamrin anticline east of Al-Alam area, as well as the strip adjacent to Al-Tharthar Lake in the southwest of the governorate where the elevation ranges between 80-115 meters a.s.l.. To the south of the central Salahaddin governorate, adjacent to Tigris River in Samarra and Balad areas, the levels are as low as possible (40-80 meters a.s.l.). These differences may be due to several reasons, including the topography of the area, recharge, natural discharge or exploitation of groundwater (Figure-3).

In the far east of the governorate, in Doz area, the unconfined aquifer of Quaternary deposits and Mukdadiya formation, while Injana Formation is a confined deep aquifer. The investment of groundwater is limited to the upper aquifer and does not reach the formation under study. In the far west of Salahaddin, west and northwest of Al-Siniyyah, Injana Formation is completely absent under the effect of erosion. The main aquifer in the area is represented by Fatha Formation which is out of our interest in the present study.

The levels of groundwater mainly control the direction of groundwater flow, which moves in Injana aquifer in the north of the governorate to the south where the center of governorate is located. An exception is the belt between Makhul and Tigris River, where the groundwater flows towards the river which represents the final discharge area of the groundwater in the governorate. In the center and south of the governorate, the groundwater in this multi-layer aquifer flows towards both banks of Tigris River which represents the discharge area of the aquifer.

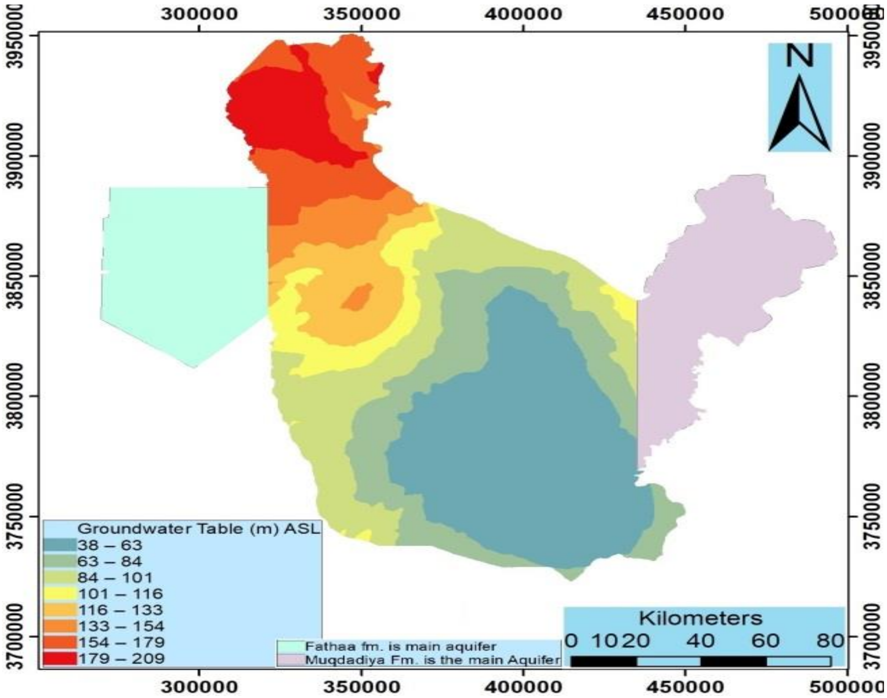

Figure 3-Spatial variation of groundwater table in meters (a.s.l.) in Salahaddin governorate.

Depth of groundwater is a key determinant of the possibilities of exploitation and extraction because it relates to the costs of drilling, wells casing, and pumping equipment, which control the types of wells and drilling techniques.

The data of 165 wells mentioned in (Table-1) were used to map the spatial distribution of the depths to groundwater in Salahaddin governorate. The depth falls in the center of the north of the area until it reaches 3 meters (Figure-4), but it increases toward the east and west of this part of the governorate until it reaches about 20 meters, which is a relatively low depth. This situation is repeated in the extreme central south of the governorate in Balad town, as the depth reaches 3 meters near Tigris and begins to increase to the east and west.

In the east of the area, specifically east and northeast of Al-Alam area, the depths are the largest possible in the studied area (40-80 meters).

In the central and southwest of the governorate, adjacent to the eastern bank of the Tharathar, the depths range between 25-35 meters). The depths of the groundwater are within the contact between Quaternary deposits and Injana Formation which represents the main aquifer. These differences in the depths may be due to several reasons, including the topography of the region, recharge, natural discharge or exploitation of groundwater.

Saturated thickness of Injana aquifer

All the wells in the study area were drilled for exploitation purposes. There are no standard experimental deep wells to be used in the lithological description. Thus, the saturated thickness calculated in these wells, in fact, represents the productive thicknesses that contributes to the supply of groundwater to the wells, which is actually less than the true saturated thicknesses.

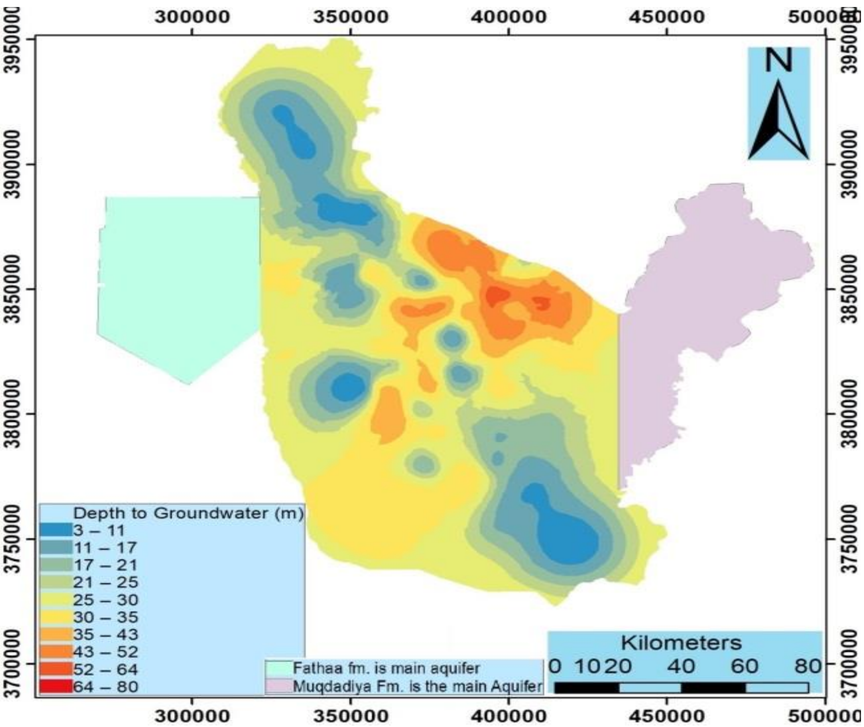

Figure 4-Spatial variation of depth to groundwater in meters (from ground surface) in Salahaddin governorate.

The thickness of Injana saturated produced beds in each well (produced thickness), was calculated between the ground level and the bottom of the well, after the removal of the impermeable clay layers described in the wells. The total thickness of Injana clay layers varied from a well to another, as in the map below which describes clay layers thicknesses (Figure-5).

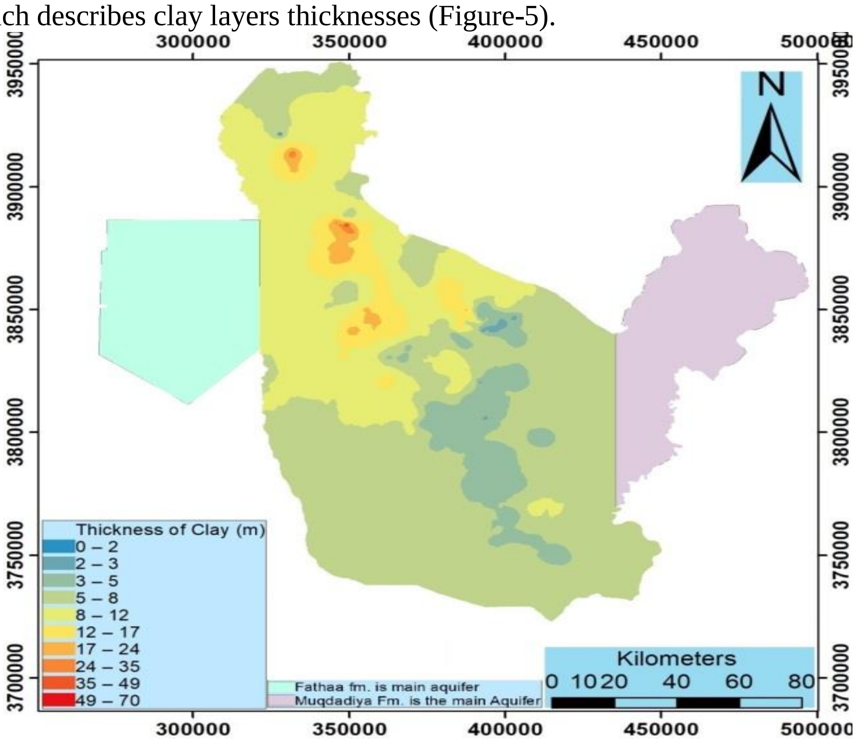

Figure 5-Spatial variation of clay layers thicknesses (m) in the upper part of Injana groundwater aquifer.

Accordingly, the produced thicknesses in the wells drilled within Injana aquifer (after the removal of clay layers) ranged between 50-60 meters throughout the studied area. However, these thicknesses increased in the west of Tigris River in the center of the area, reaching 70 meters (Figure-6), while it was reduced at the east of the river to about 40 meters, due to the presence of the unsaturated layers of Quaternary sediments or Mukdadiya Formation, or both, above the layers of Injana Formation.

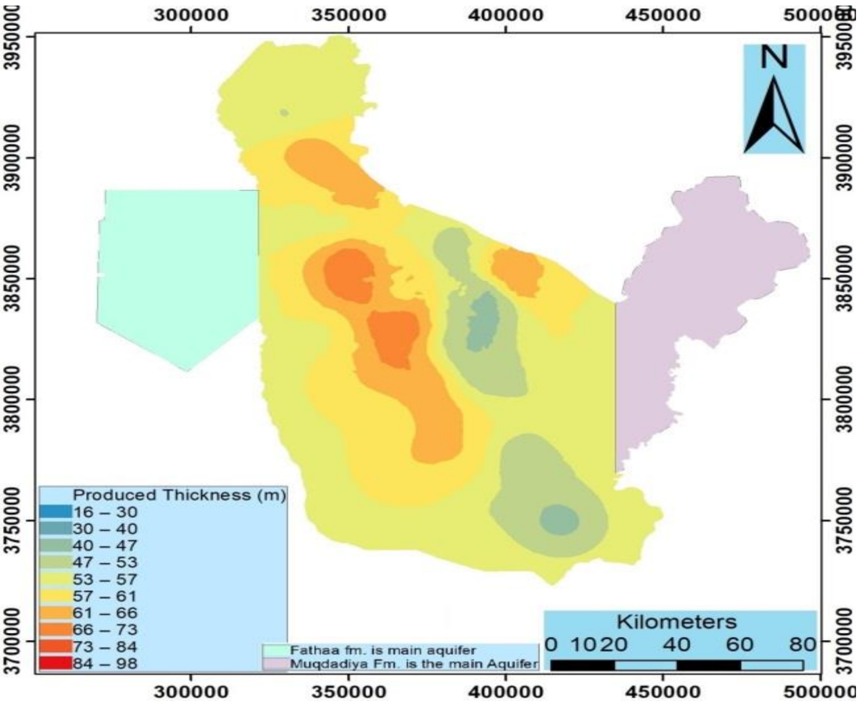

Figure 6-Spatial variation of produced thicknesses (m) of Injana groundwater aquifer in Salahaddin governorate.

Transmissivity and Hydraulic Conductivity

Data of experimental tests of 165 boreholes were adopted to calculate the transmissivity according to the formula described by Raghunath [8], in terms of well productivity (Q), S_w and the drop of water level achieved during the pumping period until reaching the stability of the water table (Table 1).

$$T=(1.2*Q/1000)*S_w \quad \text{.....(1)}$$

where:

Q=Well productivity (l/sec)

S_w= The difference between the level of the stable water and the level of moving water (m)

T= Transmissivity in m^2/sec which was converted later to m^2/day.

The spatial distribution of transmissivity values (T) of the wells in the study area are presented in (Fig. 7) which illustrates low transmissivity within the northern part of the area toward the north and west of Baiji and to the west of Sharqat, ranging between 2-20 m^2/day. Then it increases within the southwest (west of Tigris River) where it ranges 20-40 m^2/day. On the other hand, the transmissivity value is increased significantly in the southeastern part of the area (east of Tigris River) to reach more than 40-700 m^2/day.

The hydraulic conductivity can be calculated by dividing the value of T on the thickness of saturated bed (b).

$$K = T / b \quad \text{.....(2)}$$

where:

T= Transmissivity factor (m^2/day)

K= Hydraulic conductivity (m/day)

b= Saturated thickness (m)

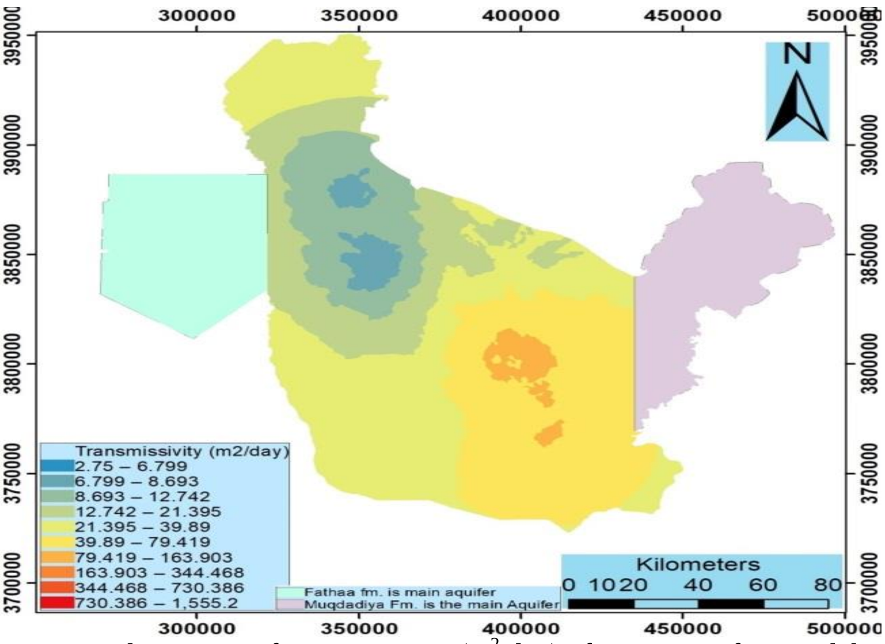

Figure 7-Spatial variation of transmissivity (m^2/day) of Injana aquifer in Salahaddin.

Because the drilled boreholes do not penetrate the whole saturated thickness within Injana Formation, they have replaced the productive thickness which represents the thickness located between the water table and the bottom of the borehole, after excluding the thickness values of the clay. Then, hydraulic conductivity was calculated and the spatial distribution was represented (Figure-8). The spatial distribution of hydraulic conductivity was very similar to that of transmissivity, being low in the west of Sharqat and west to north west of Baiji (0.03-0.17 m/day), then increasing in the south west of the governorate, i.e. west of Tigris River (0.17-0.58 m/day). On the other hand, it increased significantly in the east of Tigris River (0.58-6 m/day , despite that the produced thickness (as referred by Fig. 6) in the east is less than that in the west of the river. The reason is the high transmissivity which characterizes Injana layers in the east of Tigris River due to the increasing and coarsening of sand within Injana Formation.

The ranges of hydraulic conductivity are within the limits of siltstone and fine grained sandstone reported previously [12]. These sediments are the main component of Injana aquifer.

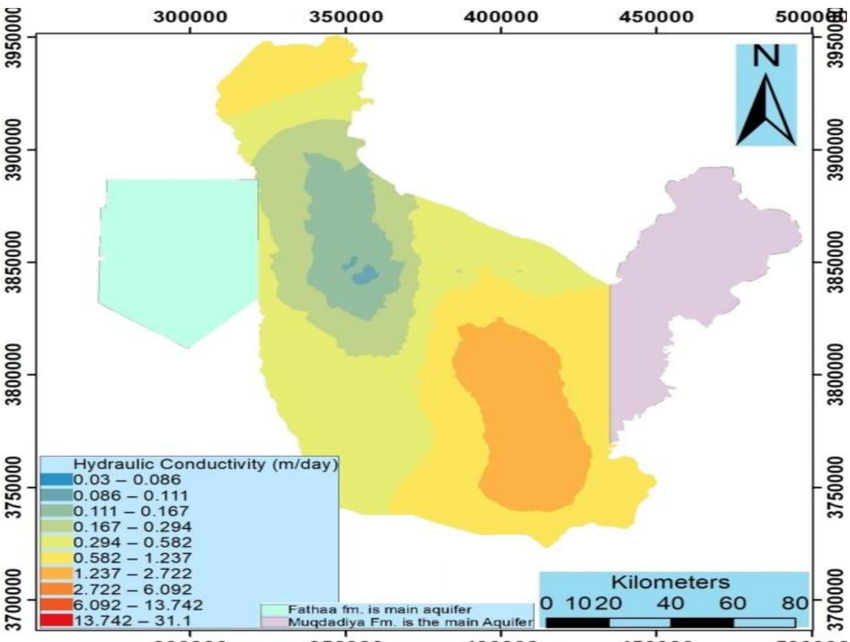

Figure 8-Spatial variation of Hydraulic Conductivity (m/day) of Injana aquifer in Salahaddin.

Pumping rate and drawdown

The response of drawdown to the pumping rate gives an idea about the hydraulic characteristics, especially the specific capacity of the aquifer [13], if it is usual to install pumping equipment proportional to the capability of the well. From this point of view, an equipment of high pumping rate is installed where the high hydraulic properties exist. However, the drawdown below the static water is proportionally low, while the opposite occurs in the aquifers of low hydraulic properties, where the drawdown is high despite the low pumping rate.

This is exactly what happened in the study area, where in the northern part of the study area, west of Sharqat as well as west and northwest of Baiji, the hydraulic characteristics, including transmissivity and hydraulic conductivity, seemed to be low. Thus, in spite of the low pumping rate (3-4.5 liters / sec) (Figure-9), it was found that the total drawdown of water table is high (Figure-10). This interprets the low hydraulic characteristics, that reveal low specific capacity, and thus the aquifer is considered as confined.

In the south-west of the region (west of the Tigris), where the hydraulic characteristics are relatively high, a relative increase in the pumping rate was observed (4.3-6.3 l/sec), followed by a relative decrease in the drawdown (16-29 meters). In the southeast part of the governorate (east of the Tigris River), where Injana aquifer has higher hydraulic characteristics than the other parts of the study area, the pumping rate was also higher (6.3-9.7 l/sec) and the rate of drawdown is lower (5-11 meters), below the static water.

From this point of view, the last part of the study area is more promising and encouraging for the investment of groundwater, because of the encouraging pumping rates and low drawdown, which indicates that the depletion will be low.

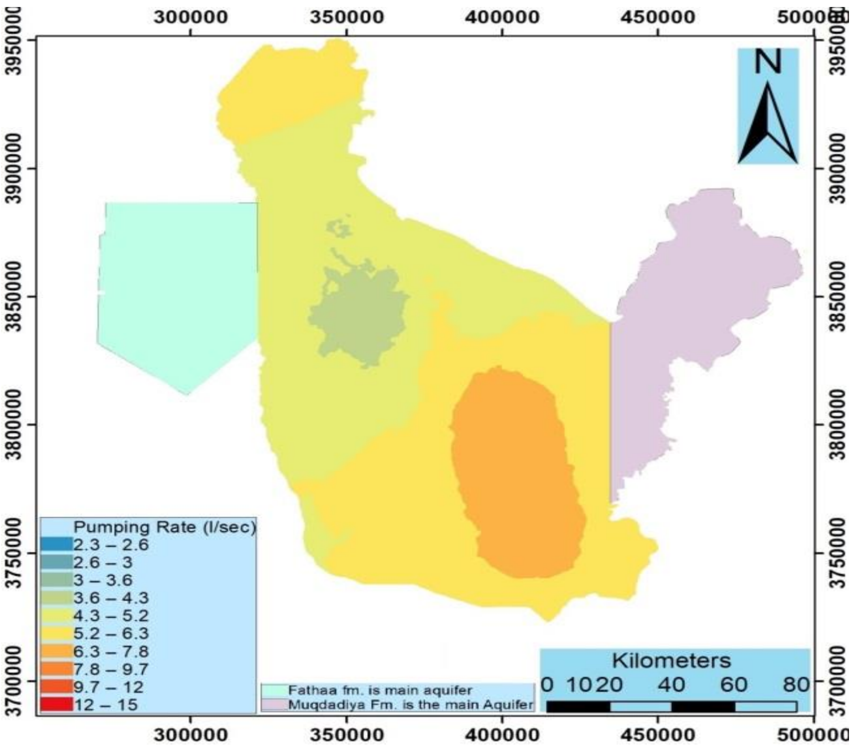

Figure 9-Spatial variation of pumping rate (l/sec) of the wells pumped from Injana aquifer in Salahaddin governorate.

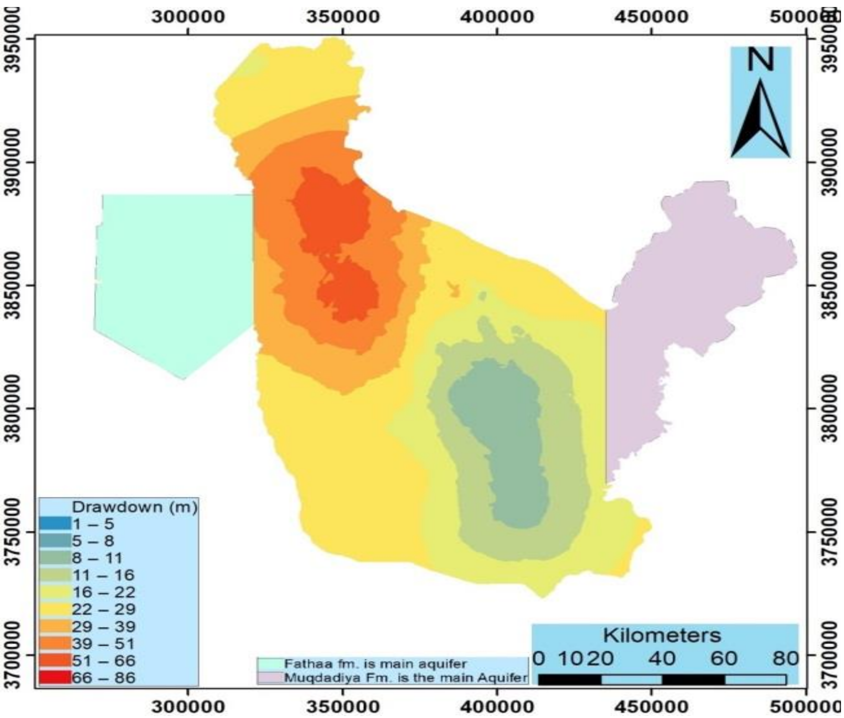

Figure 10-Spatial variation of drawdown S_w (m) of the wells pumped from Injana aquifer in Salahaddin governorate.

Conclusion

The aquifer within Injana Formation is generally a confined, except for some cases where it could be semi- confined due to the existence of aquitard layers of clay which lead to a multi-layer aquifer. The Piezometric level in Injana multi-layer aquifer is highest in the north of the area. It gradually decreases to the south and east, in the center of the governorate, and adjacent to Hamrin anticline, as well as near the strip adjacent to Al-Tharthar Lake and Tigris River.

Groundwater flows within the aquifer from the north of the governorate to the south. While, in the center and south of the governorate, it flows towards both banks of Tigris River which represents the discharge area of the aquifer. The depths to groundwater fall in the center of the north of the governorate, but increase towards the east and west of this part, with relatively low depths. This situation is repeated in the extreme central south in Balad near Tigris River and begins to increase east and west. In the east of the area, specifically east and northeast of Al-Alam, the depths are the deepest in the studied area. The spatial distribution of transmissivity appears to be low within the northern part the area towards north and west Baiji and to the west of Sharqat, then it increases within the southwest of the governorate (west of Tigris River). On the other hand, the transmissivity is increased significantly in the southeastern part of the governorate, where the spatial distribution of hydraulic conductivity seemed similar to that of transmissivity. In the northern part of the study area, west of Sharqat and west and northwest of Baiji, the low pumping rate and high drawdown indicated the low storativity and confining conditions, while in the southwest and southeast of the region (west and east of the Tigris), there was a relative increase in the pumping rate that accompanied with a relative decrease in the drawdown. Thus, the southeast part of the governorate (east of the Tigris River) is more promising and encouraging for drilling and investment of groundwater, which indicates that the depletion will be low.

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