HYDROGEOLOGY OF AL-JAZIRA AREA

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ABSTRACT

The Iraqi Jazira Area is generally a flat terrain of less rugged topography with scattered hills. It is dissected by shallow wadis with presence of numerous salt marshes. The drainage is either internal into the marshes, swamps and sabkhas, or originating at the slope of the main structures. The recharge sources of the groundwater in the Jazira Area are mainly direct infiltration and/ or run off, from the intermittent wadis in form of percolation in shallow aquifers. The main water bearing formations in the area are Fat'ha and Injana formations in addition to Quaternary sediments. The groundwater discharge areas occur along Tharthar Lake and Sabkhas.

The regional trend of the groundwater movement in the Jazira Area is generally from north towards south, southeast and southwest. However, locally, the flow of the groundwater takes different directions depending on geological setting, topographic and structural features. The depth of the groundwater reaches some tens of meters in the northern parts, while it is near the surface or as seepage within the discharge areas, along Tharthar Valley and Tharthar Lake and at low lands of salt marshes.

Salinity of the groundwater in the Jazira Area increases, generally from the recharge areas, in the northern parts towards the discharge areas. The quality of the groundwater is mainly sulphatic with chloride and bicarbonate water types in some areas. According to the hydrogeological interpretations, the promising zones of good water qualities and quantities are fixed in Injana Formation, within the northern parts of the Jazira Area near the recharge areas.

هيدروجيولوجـــية منطقة الجزيرة

حاتم خضير الجبوري و نصير حسن البصراوي

المستخلص

تشكل منطقة الجزيرة في الغالب مسطحا متموجا الى منبسط أو قليل التموج مع وجود تلال متناثرة. ان نظام التصريف ضمن المنطقة يكون داخلي، وغالبية المياه السطحية تتغلغل تحت السطح خلال الطبقات النفاذة أو من خلال الشقوق والتكهفات. كافة الوديان الموجودة في المنطقة تكون موسمية وتشكل بعض التجمعات المائية المتمثلة بالممالح (السباخ). تكون تغذية المياه الجوفية عن طريق الأمطار الساقطة بصورة مباشرة ومن مياه الوديان الموسمية، حيث تتسرب المياه الى الخزانات الجوفية القريبة من السطح.

تتمثل الخزانات الجوفية الرئيسية العليا في منطقة الجزيرة بتكويني الفتحة وإنجانة، بالإضافة الى ترسبات العصر الرباعي. إن مناطق التغذية تمتد الى الأجزاء الشمالية والشمالية الشرقية ضمن منطقة أقدام التلال حيث توجد السلاسل الجبلية. بينما مناطق التصريف تقع على إمتداد وادي وبحيرة الثرثار والمناطق المنخفضة المتمثلة بالممالح.

الاتجاه العام لحركة المياه الجوفية في المنطقة يكون من الشمال باتجاه الجنوب والجنوب الشرقي والجنوب الغربي، مع وجود انحرافات موقعية نتيجة الطبيعة الجيولوجية والطوبوغرافية والتركيبية للمنطقة. يقل مستوى المياه الجوفية عن سطح الأرض باتجاه مناطق التصريف، وهو يتراوح مابين عشرات الأمتار تحت سطح الأرض ضمن مناطق التغذية في الأجزاء الشمالية الى القريب من السطح أو النضوح ضمن مناطق التصريف وعلى امتداد وادي وبحيرة الثرثار والمناطق المنخفضة المتمثلة بالممالح.

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تزداد ملوحة المياه الجوفية في المنطقة بصورة عامة من مناطق التغذية باتجاه مناطق التصريف، حيث تتواجد المياه العذبة وقليلة الملوحة ضمن المناطق القريبة من مصادر التغذية في الأجزاء الشمالية بينما تزداد ملوحة المياه عند مناطق التصريف. إن المناطق الواعدة تتركز في الأجزاء الشمالية (ضمن تكوين إنجانة) القريبة من مصادر التغذية للمياه الجوفية.

INTRODUCTION

The Jazira Area is located in the central northwestern part of Iraq. It is bounded by Tharthar Valley and Lake in the east, Makhoul and Sinjar mountains in the north and northeast, Euphrates River and Haditha Lake in the south and southeast and Iraqi – Syrian border in the west (Figs.1and 2). From the tectonic point of view, it lies within the Unstable Shelf (Fouad, 2009). The region is characterized by a relatively low relief, which increases northwards into rugged mountainous area of Sinjar mountain and its surroundings, which all belong to the Foothills Zone. The Jazira Area generally, is of a flat terrain with less rugged topography and scattered isolated hills. Shallow wadis dissect it with the presence of numerous sabkhas (salt marsh) and karstic features. The drainage is either internal mainly into the marshes, swamps and sabkhas, or originating at the slope of the main structures and discharges into Tharthar Lake, Euphrates River and Haditha Lake.

The Jazira Area is characterized by semi arid climate, hot and dry summer and cold winter, with low to intermediate rainfall from south to north, respectively. According to the meteorological information supplied by the Iraqi Organization for Meteorological Information (2000) for the years 1981 – 2000 the annual mean rainfall is around 250 mm, annual relative humidity is about 45%, annual evaporation is about 2800 mm and annual mean temperature is 21^{o} C.

The exposed formations in the Jazira Area belong to Miocene age represented by Euphrates Formation (Early Miocene), which is exposed as a narrow strip along Haditha Lake and Euphrates River, Fat'ha Formation (Middle Miocene), which is exposed mainly in the southern and middle parts of the area and Injana Formation (Late Miocene), which is exposed mainly in the northern parts of the area, in addition to Quaternary sediments (Sissakian, 2000).

The available hydrogeological information is restricted to the northern and middle parts of the Jazira Area, where drilled wells are present. There is a shortage in hydrogeological information at the southern parts of the area, due to lack of drilled hydrogeological wells. The available hydrogeological information in these parts is from hand-dug wells only. The involved hydrogeological information is mainly achieved during the end of the years 1970's and the beginning of the 1980.

For water supply purposes in the Jazira Area, appreciable numbers of wells have been drilled with hydrogeological investigations and evaluation of groundwater resources, these are concentrated mainly in its northern parts, by foreign companies and national organizations (Parsons, 1955a and b; Ingra, 1964; Institute for Applied Research on Natural Resources, 1974; State Organization for Groundwater, 1982; Araim, 1984 and 1990; Al-Dabbaj and Al-Khashab, 2004; Al-Jiburi, 2004a and b, 2007a, b and c and Krasny *et al.*, 2006). The evaluation of the hydrogeological conditions depends mainly on the data provided from the Hydrogeological Data Base, including hydrogeological and hydrochemical investigations. The aforementioned studies can reflect the conditions of the groundwater aquifer system in terms of the groundwater flow direction, salinity and chemical types of water, in addition to other interesting basic information of hydrochemical parameters of aquifers and/ or groundwater bearing formations. From the available hydrogeological and hydrochemical information, it is possible to predict and enclose regions of good quality water for detail investigations or of suitable uses for different purposes.

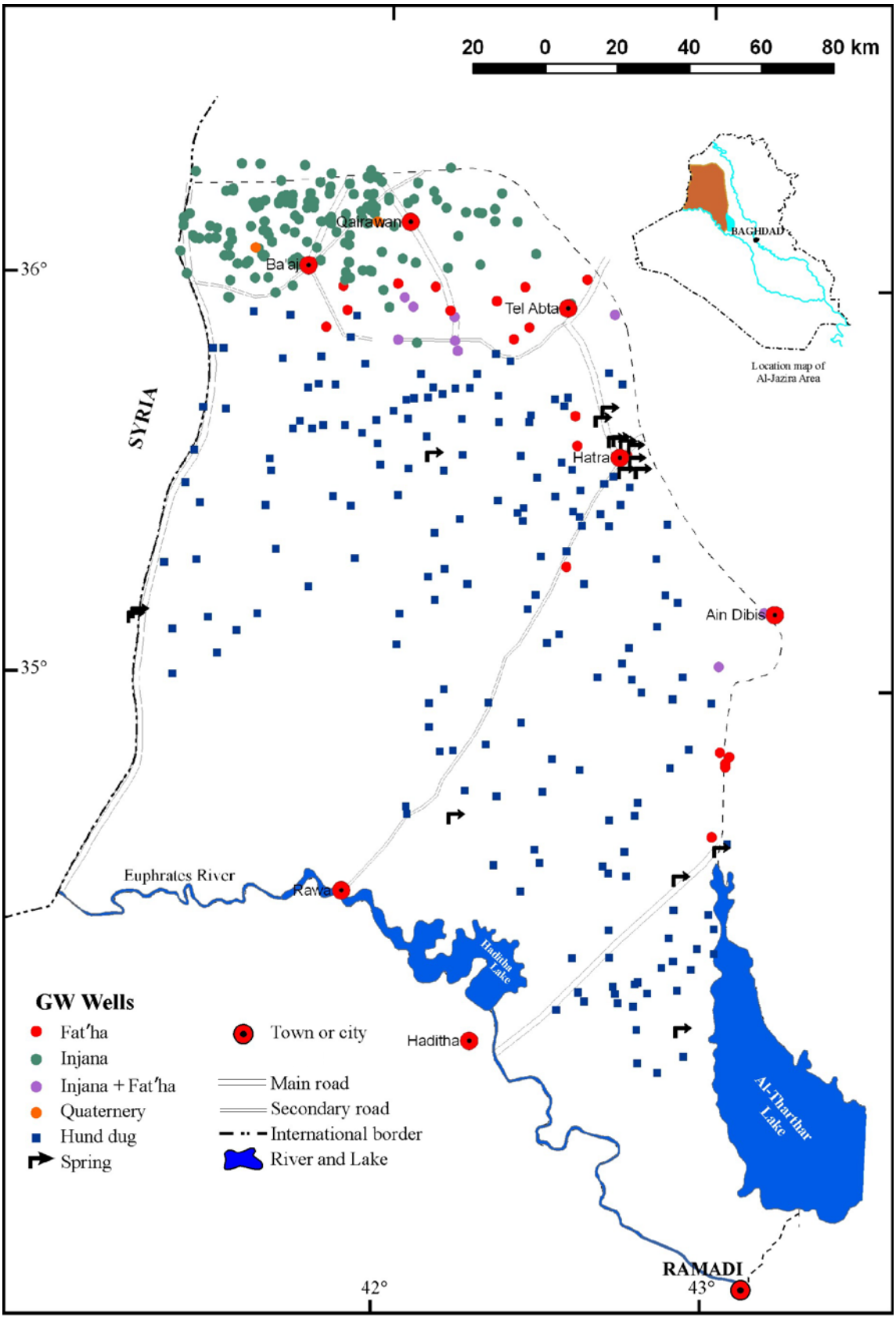

Fig.1: Location map of the available wells and springs in the Iraqi Jazira Area, within the main upper aquifers

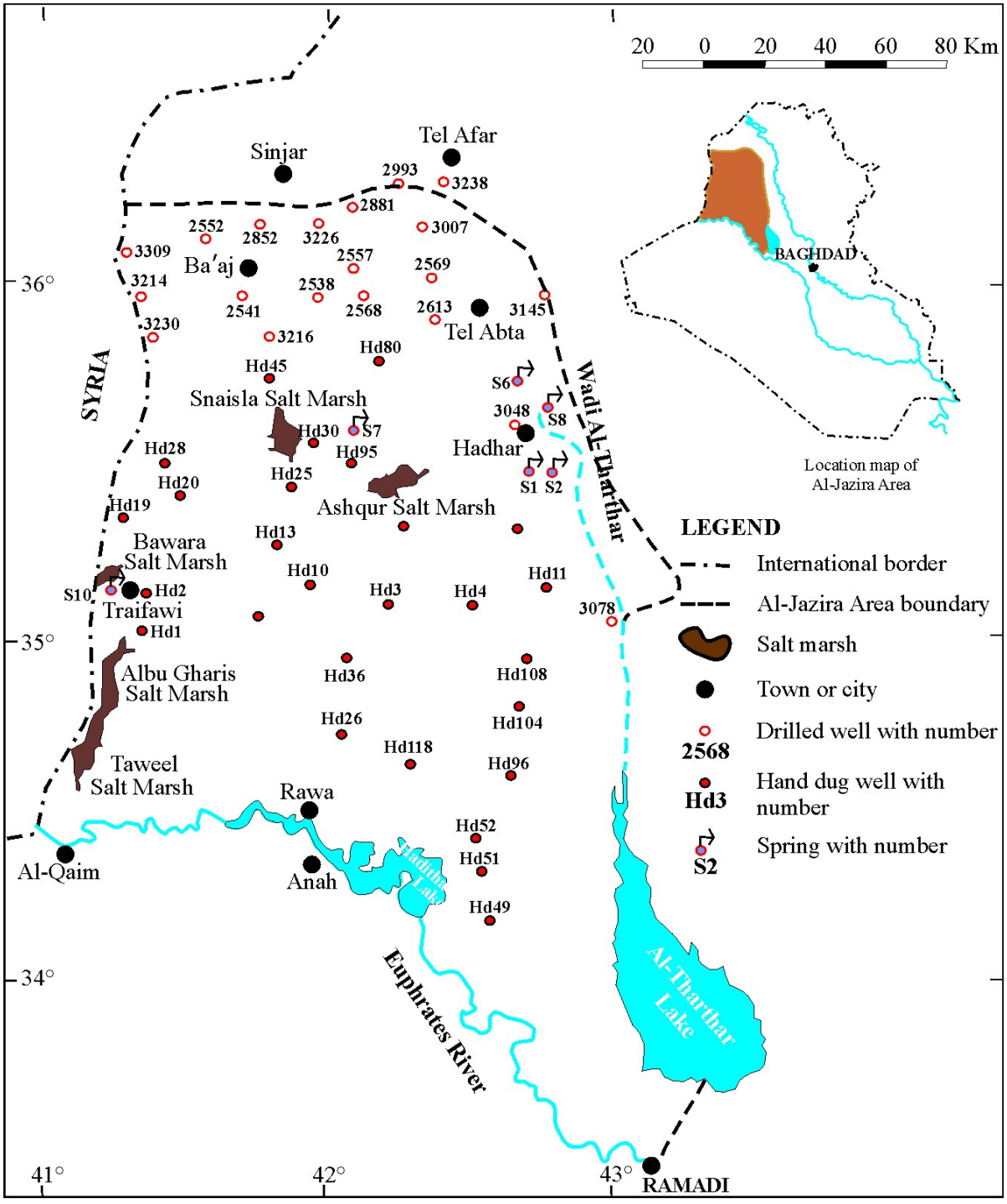

Fig.2: Location map of the Iraqi Jazira Area with location of some selected drilled, hand dug wells and springs (Modified after Al-Jiburi, 2004 a and b)

The aim of this study is to reveal the hydrogeological conditions of the upper main aquifers in the Iraqi Jazira Area, including nature of the aquifers, their extents, the groundwater level, its flow direction, recharge and discharge regions, and type and salinity. This is in order to indicate the promising areas with sufficient amount of water of suitable quality, which is very important for the development of the involved area.

GROUNDWATER AQUIFERS

The groundwater-bearing formations in the Iraqi Jazira Area and their hydrogeological and hydrochemical characteristics are reviewed. According to the hydrogeological investigations carried out in the area; the main upper aquifers are represented by Fat'ha and Injana formations.

■ Groundwater Aquifer in Fat'ha Formation

Cyclic nature characterizes the rocks of Fat'ha Formation; each cycle consists of claystone or marl, limestone and gypsum in a regular order. It is exposed widely in the Iraqi Jazira Area, mainly in the central and southern parts (about two thirds of the Jazira Area) (Fig.3) (Araim, 1984).

The pumping tests of the drilled wells in Fat'ha Formation (Table 1) showed that the transmissivity ranges between (2 – 246) m^2/day, permeability ranges between (0.1 – 6.3) m/day, well discharge ranges between (276 – 1555) m^3/day and static water level ranges between (3 – 49) m below ground surface. Because Fat'ha Formation is rich in gypsum beds, therefore, the water is essentially of poor quality (due to high solubility of the gypsum) and therefore it is considered as a source for chemical contaminants to the groundwater in the area, mainly in form of calcium sulphate. On the other hand, this formation stores good quantity of water through its cavities, fractures, sinkholes and solution channels. Therefore, where this formation is exposed, particularly where it is far away from the recharge area, then the involved area suffers from poor quality of groundwater, not the quantity. The exposure area is characterized by the presence of many salt marshes (sabkhas) that consequently form an additional source for salinity of the groundwater. The total dissolved solids range between (5320 – 19900) mg/l with main sulphatic water type and in the hand dug wells range between (410 – 38487) mg/l (Table 2) (Al-Jiburi, 2004 a and b, 2007 a, b and c).

▪ Groundwater Aquifer in Injana Formation

Injana Formation is composed of cyclic alternation of sandstones, siltstones and claystones. It is exposed widely throughout the Iraqi Jazira Area, mainly at its northern parts. Sandstone beds can serve as a good groundwater reservoir, while the siltstones and claystones serve as the confining or impermeable beds. The thickness of this formation decreases gradually from the mountainous area towards the central parts of the area.

The pumping tests of drilled wells in Injana Formation (Table 1) showed that the transmissivity ranges between (2 – 1274) m^2/day, permeability ranges between (0.1 – 20) m/day, well discharge ranges between (11 – 3960) m^3/day and static water level ranges between (– 0.6) m above ground surface to (67) m below ground surface. The total dissolved solids range between (450 – 25353) mg/l, with main sulphatic water type, also bicarbonate and chloride water types are present of minor extent (Fig.4). The total dissolved solids in hand dug wells range between (1189 – 7812) mg/l (Table 2) (Al-Jiburi, 2004 a and b). Injana Formation is considered the most important aquifer in the Jazira Area, due to the presence of good quality of groundwater, and accordingly it is proposed to represent the promising zones in the area, especially in the northern parts adjacent to the Foothill Zone.

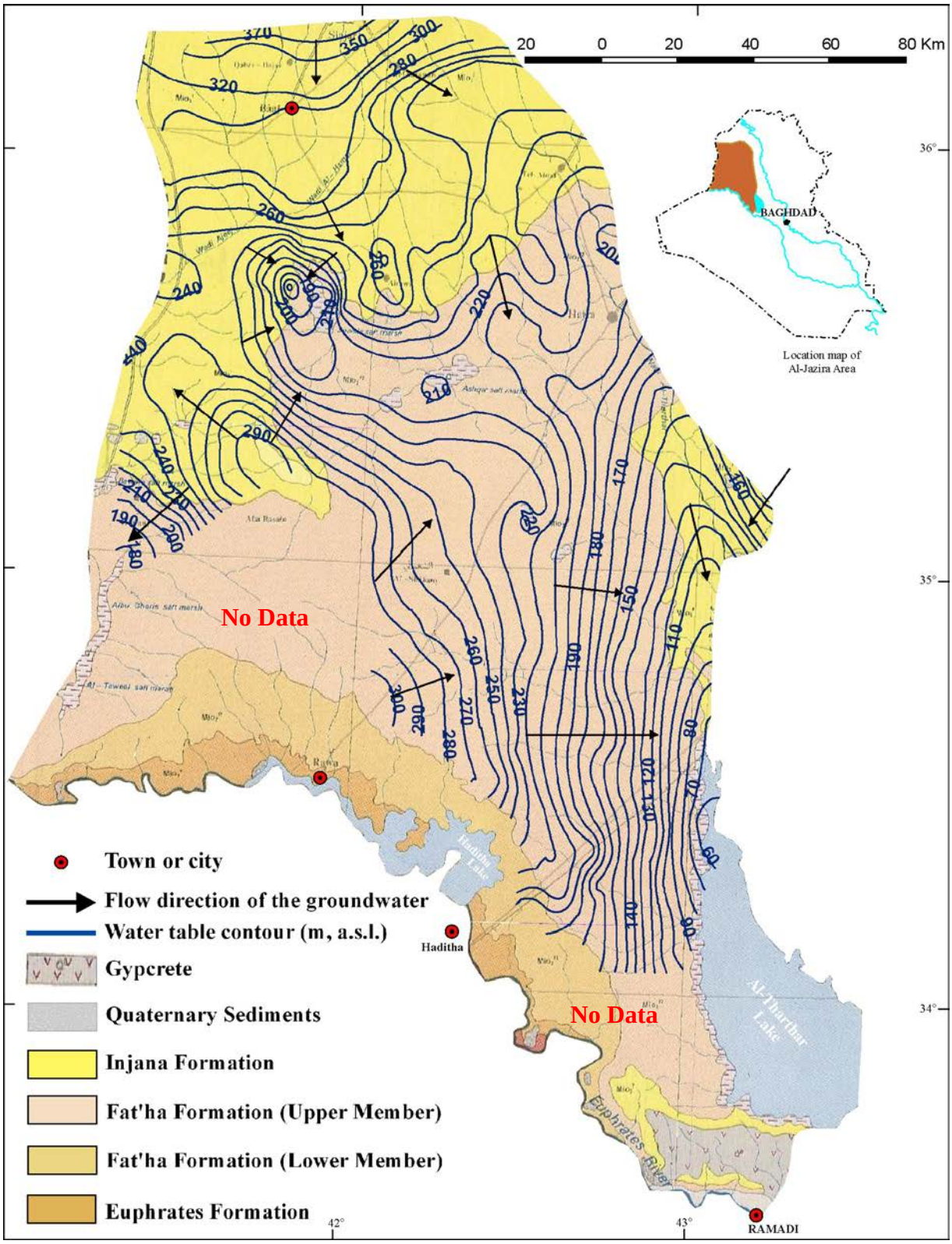

Fig.3: Hydrogeological and geological map of the Iraqi Jazira Area, with the first groundwater level and direction of flow
(modified after Sissakian, 2000 and Al-Jiburi, 2004a and b)

Table 1: Hydrogeological parameters and hydrochemistry of selected wells in the Jazira Area

Well No.	Lat.	Long.	Aquifer	Elev. a.s.l. (m)	Total Depth (m)	S.W.L. b.g.l. (m)	Discharge (m^3/day)	K (m/day)	T (m^2/day)	Salinity (mg/l)	Type of water
2507	36° 17'	41° 32'	I	450	181.0	27.0	118	0.2	17.0	2320	Ca-Sulphate
2525	36° 09'	41° 43'	I	352	68.6	15.6	864	1.4	77.0	525	Ca-Bicarbonate
2537	35° 59'	41° 51'	F	295	213.0	10.3	117	0.5	33.0	5320	Ca-Sulphate
2538	35° 59'	41° 59'	I	290	69.0	12.3	322	1.0	195.0	7800	Mg-Sulphate
2541	35° 59'	41° 42'	I	295	75.0	19.8	82	0.4	18.0	3914	Na-Sulphate
2547	36° 04'	42° 06'	I	270	107.0	10.7	501	7.6	355.0	13478	Na-Chloride
2548	36° 03'	41° 47'	I	302	182.0	16.8	1296	0.3	36.0	1700	Ca-Sulphate
2552	36° 13'	41° 29'	I	405	91.5	37.2	87	0.6	23.0	1200	Ca-Sulphate
2556	36° 00'	42° 01'	F	300	152.0	7.9	189	0.2	35	8786	Ca-Sulphate
2557	36° 04'	42° 03'	I	300	152.0	24.4	466	0.2	13.0	2565	Na-Sulphate
2558	36° 00'	42° 08'	F	285	71.7	24.4	466	0.2	13.0	9074	Ca-Sulphate
2563	36° 03'	42° 11'	I	260	106.0	14.3	93	0.4	37.0	7800	Ca-Sulphate
2568	35° 58'	42° 20'	F	258	92.0	15.5	240	6.3	227.0	6500	Na-Sulphate
2604	36º 10'	41° 51'	I	348	252.0	24.0	1125	0.4	58.0	560	Ca-Bicarbonate
2607	36º 05'	41° 59'	I	323	180.0	21.0	916	0.3	39.0	1014	Na-Sulphate
2613	35º 58'	42° 33'	I	220	61.0	18.3	156	2.1	12.1	3400	Ca-Sulphate
2644	36º 10'	41° 57'	Qt	348	26.0	8.0	104	-	-	5627	Na-Sulphate
2661	36º 07'	41° 35'	Qt	324	37.0	3.0	239	2.1	38.0	2800	Ca-Sulphate
2673	36º 08'	41° 55'	I	337	55.0	6.0	259	-	-	587	Ca-Bicarbonate
2676	36º 18'	42° 13'	I	337	56.0	4.0	486	0.6	14.0	2899	Ca-Sulphate
2680	36º 19'	42° 00'	I	460	72.0	5.0	214	1.3	23.0	1715	Ca-Sulphate
2693	36º 04'	41° 16'	I	323	82.0	27.5	553	1.3	71.0	3160	Ca-Sulphate
2695	36º 12'	41° 40'	I	375	71.0	29.6	579	3.2	90.0	1130	Ca-Sulphate
2701	36º 17'	41° 36'	I	450	110.0	11.2	173	0.6	29.0	319	Ca-Bicarbonate
2704	36º 12'	42° 00'	I	340	145.0	8.4	691	0.5	68.0	1762	Na-Chloride
2770	36º 13'	41° 55'	I	375	56.0	9.5	838	4.5	95.0	950	Ca-Sulphate
2773	36º 16'	41° 49'	I	418	70.0	16.0	1296	3.5	172	700	Ca-Sulphate
2808	36º 14'	42° 10'	I	302	120.0	16.0	778	2.5	68.0	1260	Ca-Sulphate
2848	36º 09'	41° 58'	Qt	338	24.0	8.0	415	6.7	91.0	2890	Ca-Sulphate
2852	36º 15'	41° 47'	I	393	101.5	12.0	225	0.2	10.0	398	Ca-Bicarbonate
2853	36° 09'	41° 55'	I	337	111.0	12.0	968	1.5	110.0	2400	Ca-Sulphate
2863	36° 07'	41° 50'	I	337	120.0	9.0	968	1.3	52.0	902	Na-Sulphate
2898	36° 11'	41° 46'	I	362	187.0	26.0	518	0.4	31.0	700	Ca-Sulphate
2928	36° 16'	42° 06'	I	350	130.0	15.0	648	0.3	32.0	810	Ca-Sulphate
2990	36° 17'	42° 11'	I	336	150.0	9.0	429	0.2	22.0	1750	Ca-Sulphate
2994	36° 09'	41° 52'	I	345	106.0	10.0	583	0.3	19.0	490	Ca-Bicarbonate
3011	35° 51'	42° 05'	I	278	60.0	6.0	164	0.2	5.0	2520	Ca-Sulphate
3013	36° 16'	41° 17'	I	499	264.0	22.9	583	-	-	1400	Ca-Sulphate
3062	36° 10'	42° 24'	F	255	353.6	-	-	-	-	19900	Ca-Sulphate
3078	35° 04'	43° 02'	I+F	130	105.0	6.7	65	-	-	4200	Ca-Sulphate
3176	36° 03'	44° 44'	I	321	150.0	15.0	717	0.2	28.0	1920	Ca-Sulphate
3190	36° 09'	41° 22'	I	367	201.0	42.0	660	0.4	52.0	444	Na-Bicarbonate
3209	35° 56'	42° 00'	I	291	60.0	22.0	173	0.5	15.0	4810	Na-Sulphate
3214	36° 00'	41° 22'	I	318	81.0	16.0	778	1.2	68.0	3923	Ca-Sulphate
3217	35° 57'	41° 30'	I+F	305	114.0	16.0	356	0.1	10.0	4181	Na-Sulphate
3220	35° 58'	41° 40'	I	291	54.0	6.0	356	0.7	14.0	7271	Mg-Sulphate
3226	36° 15'	41° 58'	I	392	136.0	19.0	713	0.7	69.0	4800	Mg-Sulphate
3230	35° 15'	41° 22'	I+F	331	140.0	35.0	365	0.2	11.0	5230	Na-Sulphate
3242	36° 11'	42° 16'	I	289	54.0	4.5	778	3.5	123.0	4498	Mg-Sulphate
3243	36º 19'	42º 22'	I	314	120.0	3.0	778	0.9	30.0	3002	Ca-Sulphate
3267	36º 11'	41º 56'	I	355	220.0	6.0	-	-	-	25355	Na-Chloride
3276	36º 21'	42º 21'	I	332	100.0	4.0	778	0.8	58.0	1750	Na-Sulphate
3309	36º 05'	44º 16'	I	365	165.0	64.0	-	-	-	3364	Ca-Sulphate
3329	36º 12'	42º 03'	I	320	205.0	18.0	132	0.1	3.0	1290	Ca-Sulphate

S.W.L. = Static water level K= Permeability T= Transmissibility

F: aquifer in Fat'ha Formation I: aquifer in Injana Formation Qt: aquifer in Quaternary Sediments

- **Groundwater Aquifer in Quaternary Sediments**

Quaternary sediments within the Iraqi Jazira Area, as a whole, represent a thin mantle with small thickness of one to few meters and attain more than 30 m near the mountainous areas, in the northern parts of the area, covering the older formations unconformably (Araim, 1984). These sediments consist of rock fragments, silty and/ or gypseous soils, mainly in the central and southern parts of the area. In the northern parts, near the mountainous area, these sediments are composed of loam, pebbles and sand. Due to their small thicknesses and limited areal extent, they form, consequently, lenticular and discontinuous aquifers mainly in the form of perched water-table aquifers, or somewhere they may form an unconfined aquifer together with the underlying saturated strata of the older formation. Quaternary sediments are rich in soluble materials, therefore in areas where these sediments are derived from Fat'ha Formation, especially in the central and southern parts of the Jazira Area, the salinity of the groundwater increases. The groundwater yield from these sediments is mainly through hand dug wells, there are limited numbers of drilled wells for yielding water from these sediments.

The pumping tests of drilled wells in Quaternary sediments (Table 1) showed that the transmissivity ranges between (5 – 257) m^2/day, permeability ranges between (0.2 – 24.7) m/day, well discharge ranges between (26 – 660) m^3/day and static water level ranges between (0.3 – 28) m below ground surface. The total dissolved solids range between (526 – 2627) mg/l, with main sulphatic water type (Al-Jiburi, 2007a, b and c). The total dissolved solids in the hand dug wells in the southern parts of the area range between (2235 – 8400) mg/l (Fig.4) (Al-Dabbaj and Al-Khashab, 2004).

- **Groundwater Aquifer in the Euphrates Formation**

There is a lack of hydrogeological information about Euphrates Formation, which is exposed at the extreme southern parts of the Jazira Area, along the eastern bank of the Euphrates River (Fig.3). This formation may receive a considerable recharge from the Euphrates River, but on the other hand, it may be contaminated by water passing through overlying Fat'ha Formation (Araim, 1984). In the Khleissia-1 oil well, which is located at the central part of the Jazira Area brine water appeared within the Euphrates Formation at depth interval (700 – 760) m (Al-Rawi, 1968 and Araim, 1984).

- **Springs**

The Jazira Area is characterized by the presence of water table springs, which occur in the wadis of the area. These water table springs are, generally, of limited yield. There are about 25 springs with discharge varies from less than one l/sec to 10 l/sec, averaging 3 l/sec (Krasny *et al.*, 2006). The water of these springs, is generally highly mineralized, within salt marshes the salinity is more than 20000 mg/l, but generally the salinity is within the range of (2500 – 6600) mg/l (Al-Jiburi, 2004 a and b) (Table 3). These springs are characteristic of areas where the Fat'ha Formation is exposed or is near to the surface and represents the outcrops of perched water table in the permeable strata of Fat'ha Formation. They also yield from alluvium where it is underlain by impermeable bed rock and erosion has cut down to the water table (Dennis and Hantush, 1953 and Araim, 1984).

Springs within the Jazira Area occur especially along wadi courses or along the borders of the deep depressions that receive the internal drainage (Figs.1 and 2). They are perennial or intermittent; they appear or originate principally at the intersection of the water table with the ground surface. Springs located in larger and well-defined drainage systems are generally perennial with a relatively large flow. While those in less defined drainage systems have a relatively small yield and vary from intermittent to perennial.

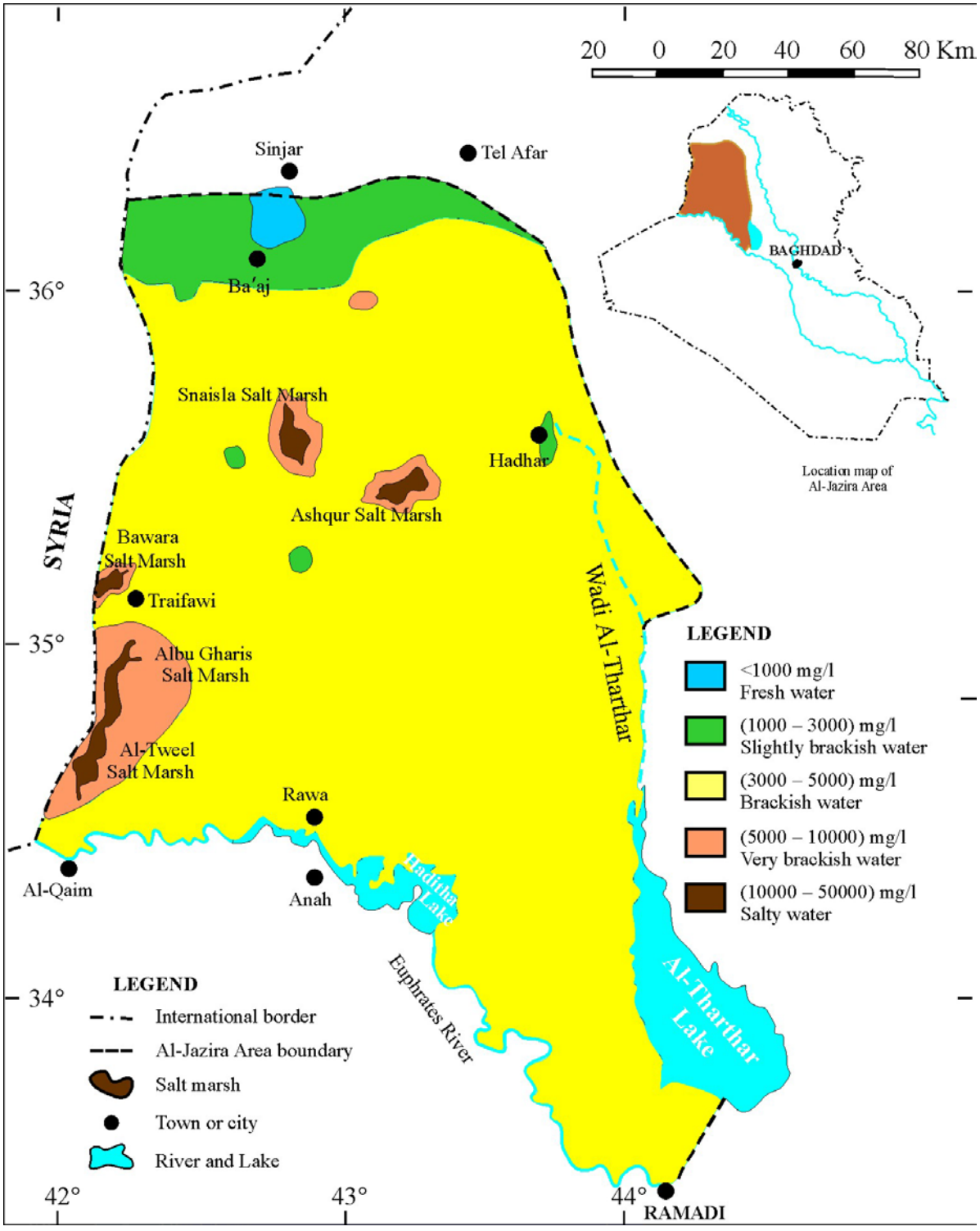

Fig.4: Hydrochemical map of the Jazira Area showing the salinity of the groundwater (Modified after Al-Jiburi, 2004a and b)

Table (2): Water level and salinity of representative hand dug wells in the Iraqi Jazira Area (after Al-Jiburi, 2004a and b)

Hand Dug Well No.	S.W.L m (b.g.l.)	TDS (mg/l)	Aquifer
HD 1	1.2	4520	Quaternary sediments
HD 2	1.5	3000	Quaternary sediments
HD 3	10.3	2475	Quaternary sediments
HD 5	6.2	2238	Quaternary sediments
HD 6	6.0	8900	Quaternary sediments
HD 7	5.8	4899	Quaternary sediments
HD 8	4.6	3361	Quaternary sediments
HD 10	3.7	5863	Quaternary sediments
HD 11	7.5	3544	Quaternary sediments
HD 13	8.9	4502	Quaternary sediments
HD 15	12.2	2973	Quaternary sediments
HD 19	9.7	2757	Quaternary sediments
HD 20	2.4	2165	Quaternary sediments
HD 22	5.6	2772	Quaternary sediments
HD 23	8.4	3071	Quaternary sediments
HD 24	12.4	3307	Quaternary sediments
HD 25	2.1	4160	Quaternary sediments
HD 28	1.2	3613	Quaternary sediments
HD 29	1.5	6396	Fat'ha Formation
HD 30	3.1	3980	Fat'ha Formation
HD 31	1.5	7500	Fat'ha Formation
HD 35	3.4	4400	Fat'ha Formation
HD 37	1.5	4960	Fat'ha Formation
HD 39	3.2	4775	Fat'ha Formation
HD 41	2.3	4850	Fat'ha Formation
HD 43	2.7	3500	Fat'ha Formation
HD 45	5.2	3746	Fat'ha Formation
HD 50	4.6	3510	Quaternary sediments
HD 51	3.7	7839	Fat'ha Formation
HD 56	3.4	4060	Fat'ha Formation
HD 63	1.5	7500	Fat'ha Formation
HD 73	2.4	4400	Quaternary sediments
HD 78	3.4	4900	Quaternary sediments
HD 88	3.1	4440	Fat'ha Formation
HD 93	1.5	3520	Fat'ha Formation
HD 95	1.2	3950	Fat'ha Formation
HD 96	3.1	3200	Fat'ha Formation
HD 99	1.5	3800	Fat'ha Formation
HD 102	1.8	5430	Injana Formation
HD 110	1.2	5085	Fat'ha Formation
HD 114	1.2	3820	Quaternary sediments
HD 115	4.6	2775	Injana Formation
HD 116	1.8	3200	Quaternary sediments
HD 118	2.1	5000	Fat'ha Formation

S.W.L.: Static water level (meter below ground level)

Table (3) Salinity of some representative water table springs in Iraqi Jazira Area (after Al-Jiburi, 2004a and b)

Spring No.	Location	Salinity (mg/l)
S 1	Wadi Tharthar	2960
S2	Wadi Tharthar	2900
S3	Wadi Tharthar	2625
S4	North of AL-Hadhar	3544
S5	North of AL-Hadhar	6565
S6	Wadi Tharthar	4500
S7	Northwest Ashqar salt marsh	6008
S8	Wadi Tharthar Northeast of Al-Hadhar	2523
S9	Wadi Tharthar Northeast of Al-Hadhar	2424
S10	Bawara salt marsh	23155
S11	Bawara salt marsh	22350

GROUNDWATER MOVEMENTS

The groundwater occurrence and movement are largely controlled by geological setting of water bearing strata. Anticlinal structures in the border of the Jazira Area are rather tectonically complicated, where minor faulting and folding exist, that would influence the groundwater movement from place to another. Under such conditions, a hydraulic continuity most likely exists between aquifers of different geologic formations. In the Jazira Area, some hidden sub-surface structures exist, and act as barrier boundaries (Araim, 1984). Additionally, the karst phenomena are common in the Jazira Area and perhaps the undulations in Fat'ha Formation play the same role, which control the groundwater movement and flow direction. The anticlinal chains, which represent the northern and northeastern boundary of the area form a structural water divide.

The groundwater level contour map (Fig.3) shows that the direction of the groundwater movement throughout the entire Jazira Area is variable from place to another. In the northern parts, the general trend of the groundwater movement is towards the south and takes different directions, where it becomes closer to the central parts. In the central parts, where there are extensive topographic depressions (salt marshes) or sabkhas, the flow lines appear in all direction towards the depressions. In the southeastern parts, the general trend is towards Tharthar Valley and Tharthar Lake and toward Euphrates River and Haditha Lake, while in the western and southwestern sides there is a structural control of the groundwater movement. The Tayarat structure forms water divide that makes the flow direction towards south – southeast and west – northwest towards Bawara, Albu Gharis and Taweel Salt Marshes in the Iraqi – Syrian borders.

DISCUSSION

The Jazira Area is characterized by low relief, and generally a flat terrain of less rugged topography with scattered isolated hills. Throughout the area, a large undulated area exists that are dissected by a relatively shallow wadis, karst features and salt marshes. It is also characterized by internal drainage into salt marshes. Most of the Jazira Area is covered by Fat'ha and Injana formations. The Quaternary sediments form a thin mantle throughout the area covering unconformably the older formations. There are no permanent streams in the

area. All wadis of the Jazira Area are insequent, except wadi Tharthar that is subsequent. Along Wadi Tharthar Valley, there are numerous seepages where the water table intersects the ground surface forming marshes and shallow pools. Many shallow depressions exist in the area in the form of intermittent lakes, which are inundated by water during rainy seasons, then dry up during summer, leaving extensive salt deposits. The major portion of the groundwater recharge is derived from direct penetration of rainfall and percolation of run-off as a seepage loss from the intermittent streams and from springs-fed streams near the recharge area of foothill regions.

Injana and Fat'ha formations are considered as the main upper aquifers within the Jazira Area. The sandstone of Injana Formation serves as a good groundwater aquifer with different water qualities that range between fresh and brackish water with different chemical water types like sulphate, bicarbonate and chloride. Fat'ha Formation stores good quantity of water through its cavities, joints, sinkholes and solution channels, but the water is of poor quality.

Clastic rocks are characterized by granular porosity the permeability mainly depends on grain forms and sorting; it is very high in loose sediments and low in cemented sediments, especially in Quaternary sediments and Injana Formation that reveal high well discharges. While in carbonate and evaporite rocks, fissures, fractures and cavities are the most factors affecting the permeability as in Fat'ha Formation. Therefore, the increase of cavities, fractures and fissures causes an increase of water discharge from wells in these rocks.

Catchment areas extend into the adjacent regions of the Jazira Area in the northern and northeastern boundaries, which belong to the Foothill Zone. Discharge areas of groundwater occupy the central and southern parts of the Jazira Area, represented by low lands of salt marshes and along Tharthar Valley and Tharthar Lake, and also into Euphrates River and Haditha Lake (Fig.3).

The groundwater level ranges from several tens of meters below ground surface; mainly in the northern parts, to near the surface or seepage flow in the central and southern parts. The regional direction of the groundwater movement in all involved aquifers is generally towards south, southeast and southwest following the discharge areas along Tharthar Valley and Tharthar Lake and low land of salt marshes in the area. Locally, the direction of the groundwater flow follows different directions throughout the region, depending on the geological setting of the groundwater bearing formations and structural and topographic situation (Fig.3).

Hydrochemistry of the groundwater within the Iraqi Jazira Area varies vertically and laterally, salinity of water increases with depth where the Fat'ha Formation is the main aquifer and towards discharge areas due to evaporation (Fig.4).

There are three main factors affecting the chemical composition of the groundwater: (1) recharge and discharge conditions, (2) speed of flow and (3) lithological characteristics of water-bearing formations (beds), in addition to leakage of deep oil water in regions of highly tectonic disturbances (Al-Jiburi and Al-Basrawi, 2007). Chloridic water type is mainly due to direct effect of oil water and the presence of halite rocks at depth in the area. The bicarbonate water type reveals a recharge source of fresh water. In general, salinity of the groundwater ranges from fresh water within the northern parts of recharge areas to high salinity water within discharge areas.

CONCLUSIONS

- The main water bearing formations in the Iraqi Jazira Area are represented by Fat'ha and Injana formations in addition to Quaternary sediments.
- The recharge sources of the groundwater in the Jazira Area are mainly direct infiltration and/or run off from the intermittent wadis in form of percolation in shallow aquifers.
- The presence of hydraulic continuity between aquifers is assumed to some extent, depending on the piezometric relations of the water-bearing layers, throughout the area.
- The groundwater discharge areas occur along Tharthar Valley and Tharthar Lake and low land of salt marshes in the area, in addition to Euphrates River and Haditha Lake.
- The regional trend of the groundwater movement in all aquifers is generally from north towards south, southeast and southwest. But, locally, the flow of the groundwater may take different directions depending on the geological setting, and topographic and structural features.
- The depth of the groundwater reaches some tens of meters in the northern parts, while it is near the surface or as seepage within the discharge areas along Tharthar Valley and Tharthar Lake, and at low lands of salt marshes.
- Salinity of the groundwater increases generally from fresh water at the recharge areas in the northern parts of the Jazira Area, towards the discharge areas and become high saline water. The quality of the groundwater is mainly sulphatic, with chloride and bicarbonate water types in some parts.
- The hydraulic and chemistry of aquifers are closely linked to stratigraphic, lithologic, structural and topographic features of the water bearing formations within the Jazira Area.
- According to the hydrogeological interpretations, the promising zones of good water qualities and quantities are restricted in the Injana Formation, within the northern parts of the Iraqi Jazira Area, near the recharge areas.

RECOMMENDATIONS

The followings are recommended:

1. Monitoring of the groundwater level in selected and representative wells within the Iraqi Jazira Area in order to provide new data, which is necessary for executing groundwater regime and to detect any variations in the groundwater level.
2. Continuous collection and analyses of groundwater samples from representative wells within the area, based on monthly or seasonal periods to predict any change in chemical composition and water types.
3. Drilling of new deep and observation wells in selected areas, especially in the central and southern parts, where no wells are available, to provide new information in order to evaluate the hydrogeological and hydrochemical conditions, within the involved areas more precisely and to predict or find more promising areas with good quality and quantity of water.
4. Establishment of gauging stations on wadi basins, in order to record wadi run-off, which will aid in evaluation of the groundwater resources.
5. Installation of hydro-meteorological stations, aiming to provide continuous observations of the hydro-meteorological parameters, which will aid also in the evaluation of the groundwater resources.
6. Re-surveying and checking of previously fixed springs in the area, determining their water discharges and hydrochemical composition, and to detect the effect of drought conditions on the discharge of these springs.

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