HYDROGEOLOGY

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ABSTRACT

The Southern Desert represents a rolling and/ or undulating plain, which may be a flat or slightly rolling in some parts. The drainage system is internal, with most of the surface water percolating to underground through permeable strata, fractures, fissures and karst cavities. All valleys are intermittent draining either into marshes and sebkhas bordering the Euphrates River or are blind valleys.

The Southern Desert is built up of sedimentary rocks, mostly of carbonate sequences and friable clastics with very gentle dip northeastwards. The main recharge to the groundwater is from direct rain fall, as well as seepage losses from intermittent wadis.

There is a hydraulic connection between the main aquifers within the whole Southern Desert. Aquifers of Hartha, Tayarat, Umm Er Radhuma and Dammam formations represent a complex hydrogeological unit. Dammam aquifer is considered the most important one, on a regional scale due to its extent and content of large amount of water. Aquifers in Dibdibba formation and Quaternary sediments are also important in supplying water for irrigation purposes within the southeastern parts. While the aquifer within Ghar – Euphrates Formation is less important, due to high salinity of water and its local extent.

Generally, groundwater movement is from west and southwest to east and northeast, that is from the recharge areas towards the main discharge zone along Euphrates River, Hor Al-Hammar and Shatt Al-Arab. There are local deviations from the main direction of the movement due to geological, structural and topographical nature of the region. Groundwater level varies from tens of meters from ground surface, in recharge areas to near surface or artizian, in discharge areas. Water salinity increses in general, from recharge areas toward discharge areas. Fresh water of bicarbonate type may represent areas of direct recharge, while the discharge zone is characterized by water of higher salinity and of sulphtic or chloridic type.

الهيدروجيولوجـــي

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المستخلص

تشكل الصحراء الجنوبية مناطق مسطحة ومتعرجة في الغالب الى منبسطة قليلة التعرج. إن نظام التصريف هو من النوع الداخلي ضمن المنطقة وغالبية المياه السطحية تتغلغل تحت السطح خلال الطبقات النفاذة أو من خلال الشقوق والتكهفات. وكافة الوديان الموجودة في المنطقة هي موسمية وقد تشكل بعض التجمعات المائية أو تنتهي الى المستنقعات والأهوار على امتداد نهر الفرات، أو في منخفضات كارستية. تغطي منطقة الصحراء الجنوبية طبقات من الصخور الجيرية والفتاتية وهي ذات ميل قليل باتجاه الشمال الشرقي. يكون تغذية المياه الجوفية عن طريق الأمطار الساقطة بصورة مباشرة ومن مياه الوديان الموسمية، حيث تتسرب المياه الى الخزانات الجوفية القريبة من السطح.

هنالك اتصال هيدروليكي بين الخزانات الجوفية الرئيسية ضمن عموم المنطقة متمثلة بالخزانات الجوفية ضمن تكوينات الهارثة، طيارات، أم الرضومة والدمام، حيث تشكل وحدة هيدروجيولوجية معقدة ومهمة. يمثل تكوين الدمام الخزان الجوفي الإقليمي الأكثر أهمية ضمن المنطقة وذلك لسعة امتداده واحتوائه على كميات كبيرة من المياه.

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وكذلك يعتبر الخزانين الجوفيين ضمن تكوين الدبدبة وترسبات العصر الرباعي من الخزانات الجوفية المهمة في المنطقة ويمكن استغلالهما للأغراض الزراعية. أما بالنسبة للخزان الجوفي ضمن تكوين الغار– الفرات فيعتبر الأقل أهمية وذلك لارتفاع ملوحة مياهه في أغلب الأحيان ومحدودية امتداده.

إن الاتجاه العام لحركة المياه الجوفية هو من الشرق والشمال الشرقي نحو مناطق التصريف، على امتداد الضفة الغربية لنهر الفرات وهور الحمار وشط العرب، مع وجود انحرافات موقعية نتيجة الطبيعة الجيولوجية والتركيبية والطوبوغرافية للمنطقة. يقل مستوى المياه الجوفية عن سطح الأرض باتجاه مناطق التصريف، فهو يتراوح ما بين عشرات الأمتار تحت سطح الأرض ضمن مناطق التغذية في الأجزاء الغربية والجنوبية والجنوبية الغربية الى التدفق الذاتي أو القريب من السطح ضمن مناطق التصريف.

إن ملوحة المياه تزداد بصورة عامة من مناطق التغذية باتجاه مناطق التصريف، حيث تتواجد المياه العذبة ذات النوعية البيكاربوناتية ضمن مناطق التغذية المباشرة، بينما تزداد ملوحتها وتكون ذات نوعية كبريتاتية أو كلوريدية عند مناطق التصريف.

INTRODUCTION

The Southern Desert represents the southern parts of Iraq (Fig.1). It lies to the west of Euphrates River and Shatt Al-Arab and extends to west and south into Saudi Arabia and Kuwait. It is divided from the Western Desert by Wadi Al-Khair. The eastern and, partly, the northern parts are located within the southern part of the Mesopotamian Zone. Whereas, the remaining parts belong to the Salman Zone of the Stable Shelf (Al-Kadhimi *et al*., 1996).

From topographic point of view most of the Southern Desert, especially the external southern and southwestern parts represent rolling plain covered entirely with residual soil with angular fragments of limestone and chert and it is dissected by numerous shallow, basin like depressions and sharp escarpments, along it's southwestern boundary. The drainage pattern is interior, with most of the surface water percolating underground or forming rain pools (playas). The northern and northeastern parts of the Southern Desert are flat to slightly rolling areas, dissected by shallow wadis debouching into marshes and depressions bordering the Euphrates River. The eastern and southeastern parts are slightly rolling, sandy to gravelly, covered mostly by Dibdibba Formation, while considerably covered by Al-Batin Alluvial fan south of Basrah. In these parts, the wadis are very shallow and broad, draining into marshes and sabkha bordering the Euphrates River. Sand dunes exist in a belt of variable width from Samawa, along the northeastern side of the Southern Desert, to Iraqi – Kuwait borders. The Southern Desert is built up of very gently dipping sedimentary strata, composed mostly of carbonate sequences. Clay, sand and evaporite influences are common throughout them. The strata are inclined with very gentle slope towards the Mesopotamian Plain. The regional strike of these strata runs in a northwest – southeast direction being sub-parallel to the Euphrates River. In the south of the region it swings southwards to become in a north – south direction being sub parallel to the Shatt Al-Arab.

The main recharge to the groundwater, in the Southern Desert is from direct rain fall, as well as infiltration from intermittent wadis. The recharge area extends outside the Iraqi territory into Saudi Arabia.

The climate of the region is represented by arid climate. According to the meteorological information of Iraq (General Institute for Iraqi Meteorological Information, 2000) for the period (1971 – 2000) mean annual evaporation was 3400 mm, mean annual rainfall was about 90 mm, mean annual temperature was 24 $^{\circ}$C, mean annual relative humidity was 39%, mean annual dryness factor was 38 and mean annual wind speed was about 4 m/sec.

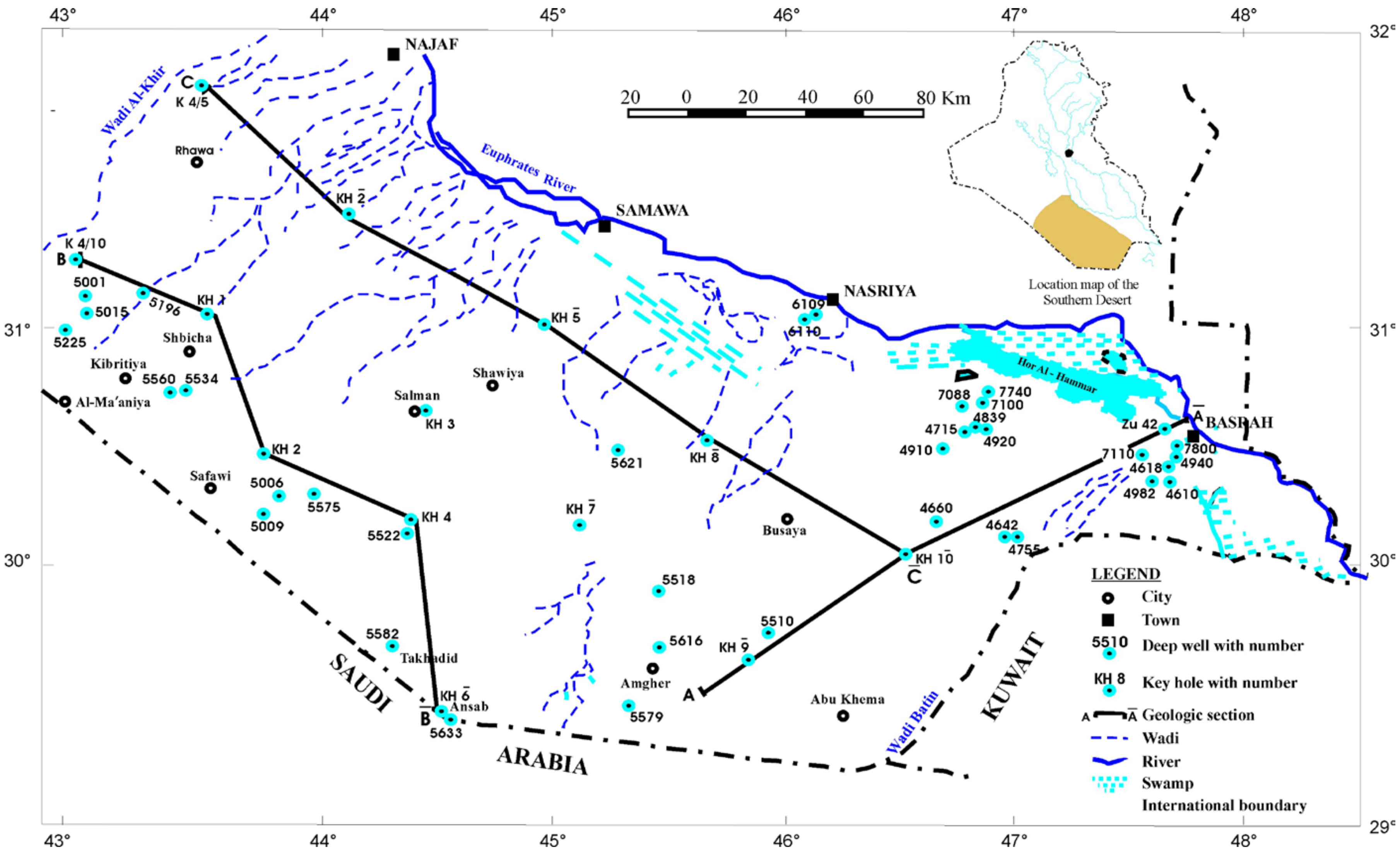

Fig.1: Location map of the Iraqi Southern Desert, shows location of selected wells (modified after Araim, 1984)

The hydrogeological conditions of the Southern Desert were studied by previous investigators as: Parsons (1955); Ingra (1964); Idrotechnico (1977); Krasny (1982) in Jassim and Goff (2006); GEOSURV (1983); Al-Shama'a (1993); Al-Kubaisy (1996) ...etc. The present study depends mainly on the hydrogeological and hydrochemical maps of different scales that are present in GEOSURV library.

The aim of this study is to evaluate the hydrogeological conditions, particularly within the uppermost regional water bearing formations in terms of static water level, groundwater flow direction, salinity and chemical type of water, in addition to other basic interesting information, including recharge and discharge areas, to predict suitability of the groundwater for different utilization and development of the Southern Desert.

GROUNDWATER AQUIFERS

The groundwater bearing formation in the Iraqi Southern Desert and their hydrogeological and hydrochemical characteristics are reviewed, from the oldest to youngest formations according to the hydrogeological investigations carried out in the area (Figs.1 and 2), these are:

▪ Groundwater Aquifer in Hartha Formation

Hartha Formation is composed of limestone, dolomitic limestone, shale and anhydrite with sandstone layers. It is considered as an important aquifer within the northwestern parts of Southern Desert. Hydrogeological investigation designated the presence of groundwater within Hartha Formation (deep wells K 4/5 and K 4/10) (Fig.1) as a part of complex hydrogeological system, with other sharing formations, which represent the main aquifers within the region through hydraulic connections between them (Idrotechnico, 1977). The thickness of the formation in the two deep wells is 370 and 407m, respectively. Pumping tests were carried out in the well K 4/5 for the depth interval (864 – 940) m, which reflects transmissivity coefficient 163.3 m^2/day and well discharge 1097 m^3/day, with static water level 39.5 m below ground surface and total dissolved solids 4061 mg/l, with sulphatic water type. No pumping test was carried out for the Hartha Formation in the well K 4/10 separately, but together with Tayarat Formation (Table 1). In the fourth test which included the lower part (38 m) of Hartha Formation and 31 m of the upper part of Sa'adi Formation, the discharge was very low, so it is not recommended for pumping from this depth interval.

Table 1: Results of pumping test in the deep well K 4/10

Measurement	Test			
	1	2	3	4
Depth (m)	341.5 – 464	341.5 – 648	341.5 – 761	759 – 828
Aquifer	49.5 m (T) 133 m (H)	49.5 m (T) 257 m (H)	49.5 m (T) 370 m (H)	38 m (H) 31 m (S)
S.W.L (m)	103.2	103.3	103.7	104.7
Discharge (m^3/d)	1849	1875	1892	43
Drawdown (m)	0.35	0.1	v. small	>30
Trans. (m^2/d)	1210	v. high	v. high	v. low
TDS (mg/l)	2960	2752	2803	2848
Sharing of aquifer discharge (%)	27 (T) 73 (H)	17 (T) 83 (H)	11 (T) 89 (H)	55 (H) 45 (S)

T: Tayarat Formation H: Hartha Formation S: Sa'adi Formation

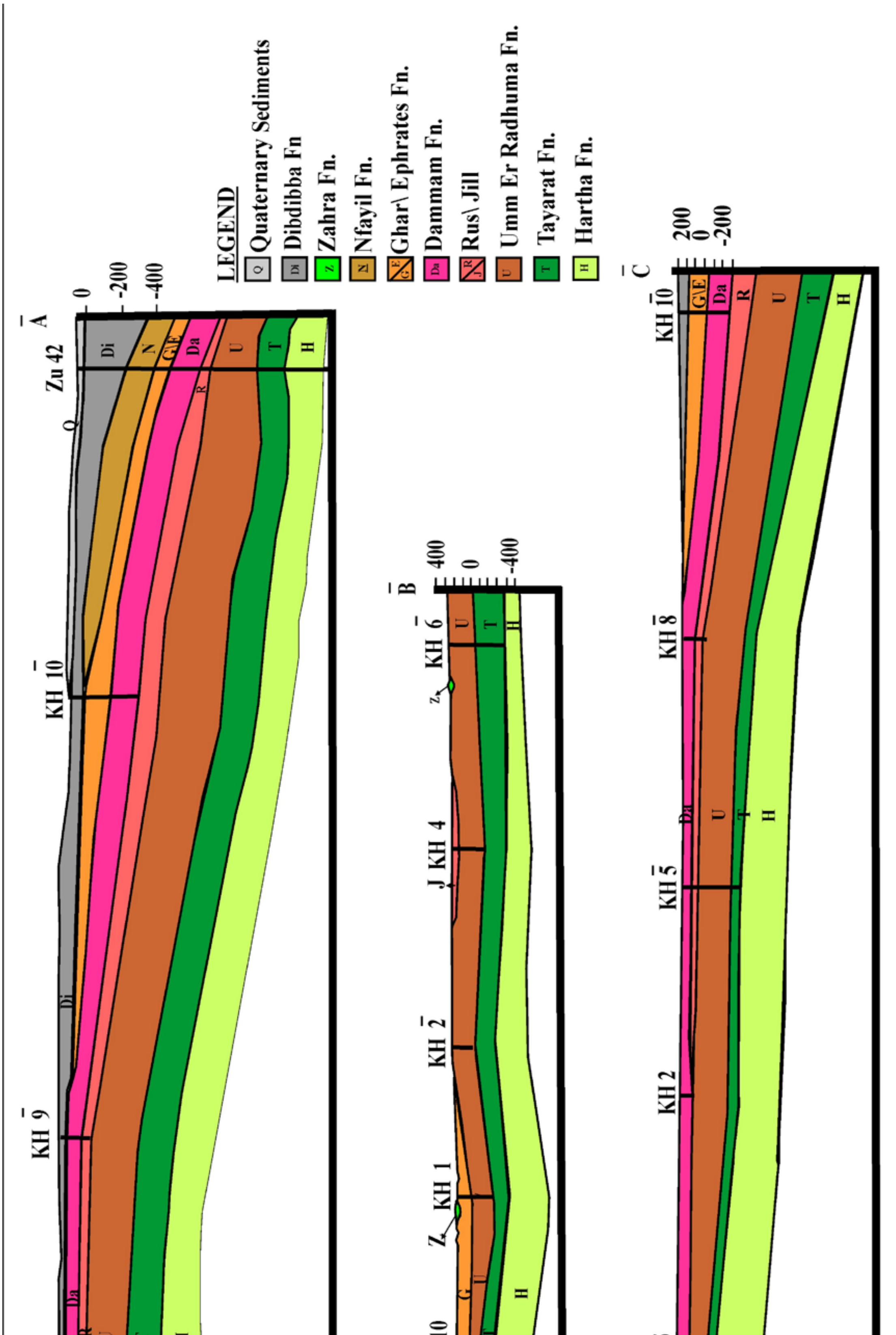

Fig.2: Geological cross section in the Iraqi Southern Desert (modified after Araim, 1984)

If we suppose a homogeneous condition within the aquifer system, so that well discharge is high and similar in all test stages and drawdown is very small, which reflects similar discharges from all parts of Hartha Formation; this may reflect the low effect of the lower part of Tayarat Formation, although it's sharing inflow decreases from 27% to 11%. The similarity in static water level in the three tests indicates a presence of hydraulic connections between aquifers. Also there is similarity in water type and total dissolved solids. The authors believe that these tests reflect the characteristics of Hartha Formation, therefore, there is no importance to the lower part of Tayarat Formation, therefore the transmissivity coefficient within Hartha Formation is very high, due to the presence of fissures, joints and cavities (Al-Jiburi and Al-Basrawi, 2002a and Al-Dabbaj and Al-Khashab, 2002a).

The hydrogeological investigations indicated that there is no groundwater of suitable quantity within the geological formations below Hartha Formation, which are Sa'adi, Tannuma, Al-Khaseeb, Kifil, Rumaila and Ahmadi in the deep well K 4/10 at depth interval (797 – 940) m, except the depth interval (759 – 828) m, which includes the lower part (38 m) of Hartha Formation, and the upper part of Sa'adi Formation (31 m), as mentioned before. The results of these tests reflect very low transmissivity in these parts of the formations with very low well discharge, so that water content is considered not valuable. Accordingly, the aforementioned six geological formations, which are below Hartha Formation, are considered aquiclude. While water bearing formations represent hydrogeological complex aquifer system with hydraulic connection between aquifers and similar water quantity and water salinity. These water-bearing formations are Dammam, Umm Er Radhuma, Tayarat and Hartha (Idrotechnico, 1977).

- **Groundwater Aquifer in Tayarat Formation**

Tayarat Formation is composed of limestone, clayey and dolomitic limestone and dolostone; it is characterized by the presence of cavities and karstification in most areas. This formation is considered one of the most important aquifers in the Southern Desert. It represents a complex hydrogeological unit with Dammam, Umm Er Radhuma and Hartha formations, due to presence of hydraulic connection between these formations (Al-Jiburi and Al-Basrawi, 2002a). The results of pumping tests carried out in many wells provided the following data, by the Hydrogeological Data Base, transmissivity coefficient ranges from (0.5 – 1800) m^2/day, permeability coefficient ranges from (very low – 20.3) m/day, well discharge ranges from (86.4 – 3494) m^3/day and static water level ranges from 176 m below ground surface to artesian flow. Total dissolved solids range from (648 – 5510) mg/l with sulphatic water type. These hydrogeological parameters reflect the hydraulic characteristics of the aquifer within Tayarat Formation. High values of transmissivity coefficient indicate the presence of karstified canals and cavities within the rocks of the formation, which represent good passages for groundwater. The variations in the transmissivity values reflect the geological and structural properties in the area, in addition to karstification phenomenon and the presence of joints, fissures and faults; the same thing holds good with respect to permeability coefficient, since they are related directly. Therefore, well discharge vary according to variations in permeability and transmissivity, as these values are high, well discharge will be high also (Table 2).

▪ **Groundwater Aquifer in Umm Er Radhuma Formation**

Umm Er Radhuma Formation is composed mainly of dolomitic limestone and dolomite, with thin beds of anhydrite. It is characterized by the presence of fractures, fissures and cavities, which aid to be a good water bearing formation within the Southern Desert. Hydrogeological investigation (GEOSURV, 1983) reflected the presence of huge amounts of groundwater within the formation, which represents a part of complex hydrogeologic system with other aquifers within other geological formations lying below and above it (as mentioned before). The recharge area extends widely inside and outside the Iraqi borders within the Saudi Arabia, which represents a good source of recharge.

The result of pumping tests provided by the Hydrogeological Data Base of well discharge from this formation reflect hydrogeological parameters (Table 2) as: transmissivity coefficient ranges from (3 – 2100) m^2/day, permeability coefficient ranges from (0.1 – 21.1) m/day, well discharge ranges from (33 – 3266) m^3/day and static water level ranges from (6.6 – 142.7) m below ground surface. Total dissolved solids range from (167 – 4500) mg/l, with predominant sulphatic water quality and presence of chloridic and some bicarbonatic water types.

Table 2: Hydrogeological parameters and hydrochemistry of selected wells in the Iraqi Southern Desert

Well No.	Lat.	Long.	Aquifer	Elev. a.s.l. (m)	Total Depth (m)	S.W.L.* a.g.l. (m)	Discharge (m^3/day)	K ** (m/day)	T *** (m^2/day)	Salinity (mg/l)	Type of water
5004	30° 30'	43° 53'	UER	400	121	80.0	44	1.2	42	2985	Sulphatic
5006	30° 04'	43° 55'	UER	380	126	68.1	434	4.9	248	2059	Sulphatic
5534	30° 30'	44° 33'	Dam	197	22	6.0	118	20.4	309	3481	Sulphatic
5560	30° 30'	44° 30'	Dam	205	30	7.5	691	30.9	879	7536	Sulphatic
5510	29° 48'	46° 03'	Dam	200	170	136.0	44	2.0	5	6478	Chloridic
5518	29° 47'	45° 37'	Dam	200	106	57.0	588	17.9	878	3159	Sulphatic
5579	29° 25'	45° 20'	Dam	323	200	88.2	396	2.4	227	2382	Sulphatic
5616	29° 47'	45° 37'	Dam	200	120	57.0	660	7.2	446	3686	Sulphatic
5001	30° 53'	43° 05'	Dam+UER	293	147	80.2	337	4.1	266	2862	Sulphatic
5015	30° 49'	43° 05'	UER	321	170	106.5	324	0.3	14	2407	Sulphatic
5196	30° 56'	43° 21'	UER	309	200	76.6	43	-	3	3209	Sulphatic
5225	30° 45'	43° 00'	Tay	308	200	94.0	429	0.4	37	3246	Sulphatic
5573	30° 07'	46° 07'	Dam	130	158	50.0	297	1.0	6	1817	Sulphatic
5621	30º 20'	45° 23'	Dam+UER	170	132	88.0	398	1.6	63	4007	Sulphatic
6109	30º 56'	46° 10'	Ghr/Euph	170	24	5.2	231	4.1	70	60080	Chloridic
6110	30º 55'	46° 09'	Ghr/Euph	170	24	5.4	165	3.2	54	61024	Chloridic
K 4/10	31º 01'	43° 01'	Dam	315	940	104.3	1037	100.0	4750	3612	Sulphatic
K 4/10	31º 01'	43° 01'	Dam+Tay	315	940	103.2	1149	14.0	3800	3522	Sulphatic
K 4/10	31º 01'	43° 01'	Tay+U.Har	315	940	103.2	1849	9.8	1210	2960	Sulphatic
K 4/10	31º 01'	43° 01'	Tay+M.Har	315	940	103.3	1875	-	v. high	2752	Sulphatic
K 4/10	31º 01'	43° 01'	Tay+L.Har	315	940	103.7	1877	-	v. high	2803	Sulphatic
K 4/5	31º 49'	43° 29'	UER	224	970	142.7	1097	0.5	37	3981	Sulphatic
K 4/5	31º 49'	43° 29'	Tay	224	970	137.3	26	-	0.1	3807	Sulphatic
K 4/5	31º 49'	43° 49'	Har	224	970	39.5	1097	-	163	4061	Sulphatic
KH 1	30º 48'	43° 40'	Dam	287	400	60.5	584	-	7	2504	Chloridic
KH 1	30º 48'	43° 40'	UER	287	400	62.6	518	-	23	4290	Sulphatic
KH 2¯	31º 15'	44° 24'	Dam	130	140	60.0	86	-	5	4210	Sulphatic
KH 3	30º 29'	44° 32'	Dam	198	420	6.5	2877	-	1636	3120	Chloridic
KH 3	30º 29'	44° 32'	UER	198	420	6.6	2160	-	1720	2812	Sulphatic
KH 3	30º 29'	44° 32'	Tay	198	420	-5.6	86	-	0.5	2000	Sulphatic
KH 4	29° 58'	44° 31'	Dam	322	419	42.7	501	-	1549	1080	Sulphatic
KH 4	29° 58'	44° 31'	UER	322	419	44.3	950	-	302	2346	Sulphatic
KH 4	29° 58'	44° 31'	Tay	322	419	53.5	700	-	1883	4040	Sulphatic
KH 5¯	30° 55'	45° 02'	Dam	111	605	69.0	2160	-	v. high	4648	Chloridic
KH 5¯	30° 55'	45° 02'	UER	111	605	60.7	518	-	23	8382	Sulphatic
KH 5¯	30° 55'	45° 02'	Tay	111	605	-0.4	136	-	0.5	4630	Sulphatic
KH 6¯	29° 12'	44° 43'	UER	357	590	65.3	302	-	81	1000	Bicarbonate
KH 6¯	29° 12'	44° 43'	UER+Tay	357	590	69.0	700	-	77	1730	Sulphatic
KH 6¯	29° 12'	44° 43'	Tay	357	590	69.0	691	-	-	1981	Sulphatic
KH 7¯	30° 02'	45° 15'	Dam	224	585	52.6	1469-3+	-	625	4228	Chloridic

…cont. table 2

KH 7¯	30° 02'	45° 15'	UER	224	585	38.3	527	-	10	6330	Chloridic
KH 7¯	30° 02	45° 15'	Tay	224	585	-23.0	4147	-	34	4858	Sulphatic
KH 8¯	30° 22'	45° 44'	Dam	133	300	75.5	164	-	3	6510	Sulphatic
KH 9¯	29° 31'	45° 58'	Dam	249	195	113.5	1123	-	171	6120	Sulphatic
KH10¯	29° 58'	45° 55'	Ghr	107	516	92.2	397	-	1250	17818	Chloridic
KH10¯	29° 58'	45° 55'	Ghr+Euph	107	516	82.4	648	-	150	4116	Sulphatic
KH10¯	29° 58'	45° 55'	Euph	107	516	81.6	605	-	113	8058	Chloridic
KH10¯	29° 58'	45° 55'	Dam	107	516	84.3	622	-	1092	49620	Chloridic
5552	29° 58'	44° 32'	Dam	321	40	29.0	65	3.8	10	2732	Sulphatic
5582	29º 30'	44º 30'	UER	350	123	50.0	528	0.6	40	2393	Sulphatic
5633	29º 12'	44º 45'	UER	310	105	66.0	238	0.7	21	167	Bicarbonate
4610	30º 18'	47º 42'	Qt	10	30	9.5	475	14.9	306	6300	Chloridic
4618	30º 22'	47º 44'	Qt	9	24	7.5	654	28.0	462	5600	Chloridic
4642	30º 03'	47º 02'	Dib	88	104	73.0	157	1.7	52	1476	Chloridic
4660	30º 06'	46º 43'	Dib	17	28	9.0	594	7.3	87	8181	Chloridic
4715	30º 29'	46º 52'	Dib	54	61	41.0	132	1.3	23	1063	Chloridic
4755	30º 03'	47º 02'	Dib	88	112	78.0	216	2.1	45	5998	Chloridic
4839	30º 29'	46º 52'	Dib	54	62	40.5	194	1.9	36	2295	Chloridic
4920	30º 29'	46º 52'	Dib	53	60	40.3	363	2.9	44	2760	Chloridic
7088	30º 34'	46º 52'	Dib	-	80	19.8	964	2.3	57	35710	Chloridic
7100	30º 35'	46º 54'	Dib	-	80	17.6	864	4.0	56	33404	Chloridic
7740	30º 36'	46º 56'	Dib	-	36	23.5	792	22.3	223	2067	Chloridic
4910	30º 22'	47º 42'	Qt	10	22	8.2	574	19.0	262	3978	Sulphatic
4940	30º 14'	47º 42'	Qt	18	32	17.0	231	8.0	120	4398	Sulphatic
4982	30º 16'	47º 40'	Qt	16	31	10.8	449	14.3	289	6570	Chloridic
7110	30º 24'	47º 36'	Qt	-	24	10.7	562	9.5	93	7429	Chloridic
7800	30º 26'	47º 42'	Qt	-	24	8.0	660	17.1	248	12570	Chloridic

* Static water level ** Permeability *** Transmissibility

Har: aquifer in Hartha Formation
Tay: aquifer in Tayarat Formation
UER: aquifer in Umm Er Radhuma Formation
Dam: aquifer in Dammam Formation
Euph: aquifer in Euphrates Formation
Ghr: aquifer in Ghar Formation
Dib: aquifer in Dibdibba Formation
Qt: aquifer in Quaternary Sediments

- **Groundwater Aquifer in Dammam Formation**

Dammam Formation is composed of variable carbonate rocks mainly limestone, dolomitic limestone and dolomite, with marl and evaporites. It is characterized by the presence of cavities and karstified canals in addition to fractures, fissures and joints, which cause the formation to have high transmissivity and permeability, in most areas. The hydrogeological investigations in the Southern Desert (GEOSURV, 1983) reflected that Dammam Formation contains huge amounts of groundwater. This aquifer is a part of a complex hydrogeological unit within different formations, on a regional scale, with hydraulic connection between them. Dammam Formation is considered as the main regional groundwater aquifer within the Southern Desert, due to its wide extension and content of huge amounts of groundwater. The results of pumping tests provided by the Hydrogeological Data Base of wells discharge from this formation (Table 2) reflect hydrogeological parameters as: transmissivity coefficient ranges from (3.1 – 4752) m^2/day, permeability coefficient ranges from (0.1 – 100) m/day, well discharge ranges from (26 – 6542) m^3/day and static water level ranges from 170 m below ground surface to artesian flow. Total dissolved solids range from (350 – 8530) mg/l, with predominant sulphatic water type and presence of chloridic and bicarbonatic water types also. The source of the sulphate is attributed to the presence of evaporites within the rocks of the formation and/ or other formations, or gypsiferous soils, which are dissolved by rain water and percolate through permeable strata or through fractures, fissures, joints and cavities within the cap rocks to the groundwater aquifers (Al-Jiburi and Al-Basrawi, 2002b; Al-Dabbaj and Al-Khashab, 2002b and c; Al-Dabbaj *et al*., 2002 and Al-Wa'aily *et al*., 2002). In the discharge area, huge groundwater issues form large springs, locally forming lakes (Sawa Lake and Samawa Salt Lake). The remaining groundwater is confined below the relatively impermeable layers of the Mesopotamian Plain (Krasny, 1982 in Jassim and Goff, 2006).

▪ **Groundwater Aquifer in Ghar – Euphrates Formation**

Ghar Formation is composed of sandstone, pebbly sandstone, limestone and conglomeratic limestone, while Euphrates Formation is composed mainly of limestone, with impermeable clay and marl. Groundwater is present within these two formations, especially at the northeastern parts of the Southern Desert, which represent a discharge area as these formations are exposed. The hydrogeological investigations in the Southern Desert (GEOSURV, 1983) reflect the presence of groundwater within these two formations in the well KH 10¯ with thickness of 206 m at depth interval of (81 – 287) m, while these two formations are not present in the penetrated sequence in well KH 9¯ (Fig.1). The results of pumping tests carried out in many wells provided by the Hydrogeological Data Base of wells discharge from this aquifer reflect hydrgeological parameters as: transmissivity coefficient ranges from (21 – 246) m^2/day, permeability coefficient ranges from (1.3 – 14) m/day, well discharge ranges from (99 – 881) m^3/day and static water level ranges from (2.4 – 16.6) m, below ground surface. Total dissolved solids range from (1966 – 64853) mg/l, with predominance of chloridic water type. This aquifer is not considered as a main and important one, due to its bad water quality in most cases and its limited extension.

▪ **Groundwater Aquifer in Dibdibba Formation**

Dibdibba Formation is composed of pebbly sandstone and sandstone with some claystone, siltstone, and marl associated with secondary gypsum. It is (30 – 260) m thick (Krasny, 1982); it is exposed at the southeastern part of the Southern Desert. This formation contains two water layers, in some places, lower and upper layers. The lower layer is characterized by salinity more than 10000 mg/l in most areas, while the salinity in the upper layer does not exceed 10000 mg/l (Al-Kubaisy, 1996 and Al-Basrawi, 2006). The results of pumping tests provided by the Hydrogeological Data Base of wells discharge from this aquifer (Table 2) reflect hydrogeological parameters as: transmissivity coefficient ranges from (15 – 265) m^2/day, permeability coefficient ranges from (0.3 – 25.1) m/day, well discharge ranges from (86 – 1037) m^3/day and static water level ranges from (18 – 103) m below ground surface. Total dissolved solids range from (4790 – 35710) mg/l with chloridic water type. Variations in hydraulic parameters are mainly due to lithological composition of the formation, which contains claystone of variable thicknesses, extensions and characteristics from one locality to another. Dibdibba Formation may not contain water at western parts of its outcrop areas, as it is indicated by the hydrogeological investigation (GEOSURV, 1983) in the deep well KH 10¯, which penetrates this formation at the depth interval of (0 – 80) m below ground surface, also in the well KH 9¯, which penetrates the formation at the depth interval of (0 – 30) m. No water was found in Dibdibba Formation in these two wells, it is considered as a carrier for water in these two locations, due to its high permeability enables rain fall water to pass through into lower formations that contain water.

■ **Groundwater Aquifer in Quaternary Sediments**

The aquifer within Quaternary sediments is mainly concentrated at the southeastern part of the Southern Desert. Quaternary sediments cover this part with a considerable thickness that makes these sediments suitable to contain water and represent the uppermost main aquifer in the area. These sediments are mainly composed of sand, pebbles, silt and mud or clay in addition to salt, gypcret is also well known within surface sediments of Al-Batin alluvial fan (Krasny, 1982).

Generally, Quaternary sediments are characterized by their inhomogeneous nature vertically and laterally, especially, within the upper parts of these sediments due to the presence of different layers of silt and clay at a depth that may reach to (20 – 25) m (Krasny, 1982). There are hundreds of drilled wells within these sediments to the west of Khor Al-Zubair and Al-Basrah City, especially between Safwan and Zubair Cities (Al-Kubaisy, 1996). The results of pumping tests provided by the Hydrogeological Data Base of wells discharge from these sediments (Table 2) reflect hydrogeological parameters as: transmissivity coefficient ranges from (14 – 964) m^2/day, permeability coefficient ranges from (2.9 – 74) m/day, well discharge ranges from (12 – 1166) m^3/day and static water level ranges from (3.9 – 36) m below ground surface. Total dissolved solids range from (2600 – 22224) mg/l with sulphatic and chloridic water types. Groundwater may be found within Quaternary sediments at different parts in the Southern Desert. The thickness of these sediments and their lithological nature are suitable to contain and store water especially, in valleys, this may happen seasonally or annually depending on wet seasons.

GROUNDWATER MOVEMENT

Generally, groundwater movement in the Southern Desert is from southwest to northeast, towards discharge zone along Euphrates River, Hor Al-Hammar and Shatt Al-Arab. Groundwater either discharges in form of springs or flows underground into Mesopotamian Plain sediments (Fig.3). Locally, deviation from the main groundwater direction may occur due to geological, structural and topographic nature, which effect on the groundwater movement. The source of water recharge is mainly from direct rain fall and infiltration from intermittent wadis within the area and adjacent regions outside Iraqi borders in Saudi Arabia. Recharge area extends outside the Iraqi territory into Saudi Arabia, so underground leakage from groundwater basins in Saudi Arabia, is also possible. Numerous karstic features exist in addition to fractures and fissures within the rocks, which facilitates of surface water transmission to feed the groundwater.

DISCUSSION

The hydrogeological division of rocks depends mainly on the hydrogeological properties of the rocks, their lithological and structural characteristics and grain size distribution of their contents. Porosity of carbonate rocks depends mainly on lithological and structural nature in addition to karstification phenomenon, which is very common within the rocks due to solution. Secondary porosity, in carbonate rocks depends on many factors, the most important are: rock solubility, climatic conditions, presence of acidic solutions, presence of faults, fractures, fissures, joints, cavities within parent rocks, structural and tectonic conditions, geological, geomorphological and topographical nature of the area and movements of ground and surface water. These factors affect carbonate rocks, which contain water and cause to increase their permeability and water movements. In recharge regions, water movement is generally, from above to down, and the quantities of percolated water depend mainly on lithology, permeability of the rocks and presence of fractures, fissures, faults, joints and cavities within these rocks. It also depends on amounts of rain fall and surface run off. While in discharge regions, water movement is upwards within springs zone to the west of Euphrates River at the extreme northeastern part of the Southern Desert, and laterally towards Mesopotamian Plain.

The geological formations, which contain groundwater and can be considered as water bearing formations within the Southern Desert, are Hartha, Tayarat, Umm Er Radhuma, Dammam, Ghar – Euphrates and Dibdibba formations and Quaternary sediments. The geological investigations of geological sections through deep boreholes showed the presence of rather complicated multi-aquifer system with impermeable sediments (mainly marl) being in lenses form, which locally separate the aquifers only.

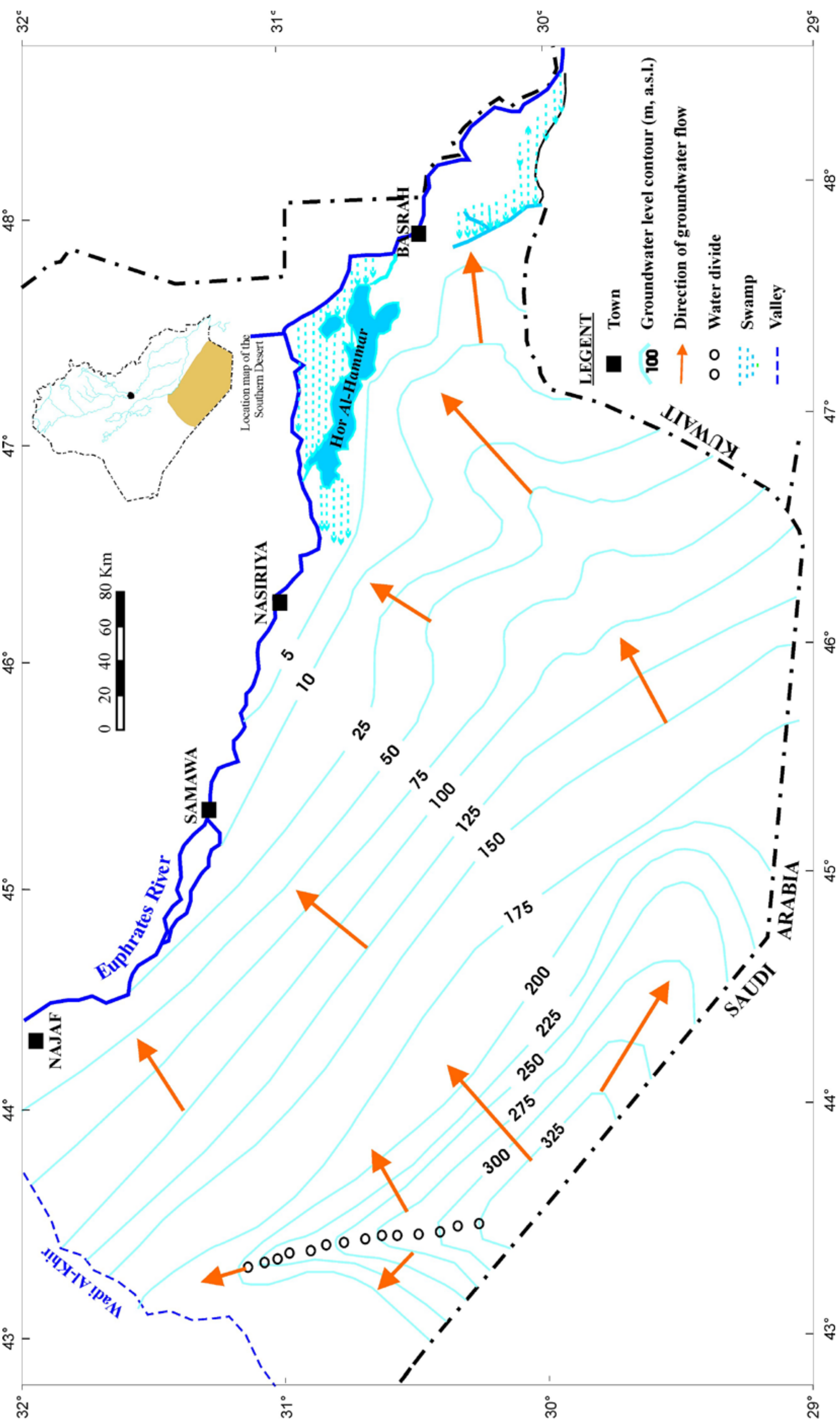

Fig.3: Hydrogeological map of the Iraqi Southern Desert, shows static water level and direction of groundwater flow (after GEOSURV, int. rep. nos. 2701, 2705, 2709, 2737, 2806, 2809, 2911 and 2964)

Therefore, hydraulic continuity through out system is quite probable. Although the hydraulic connections between these aquifers are on regional scale, these aquifers are under high hydraulic pressures, in some locations, within Tayarat, Umm Er Radhuma and Dammam formations. The static water level is above the ground surface, in southwestern area of Samawa City, which reflects phenomenon of self-flowing wells. Generally, Dammam Formation represents the main regional aquifer within the Southern Desert. In addition to the mentioned aquifers, groundwater may be present in a form of perched aquifers, when the conditions are suitable in different formations or Quaternary sediments to store water in such type of aquifers. The hydrogeological investigations revealed the presence of such perched aquifers, especially, along wadi courses. The main recharge to the groundwater is from direct rain fall, as well as infiltration from intermittent wadis. Underground water leakage from adjacent groundwater basin in Saudi Arabia is possible. The regional groundwater flow is from the recharge areas, in the south and southwest outside the Iraqi territory towards the discharge areas along the Euphrates River, Hor Al-Hammar and Shatt Al-Arab. There are local deviations from the general groundwater flow direction due to geological, structural and topographical nature, as the presence of water divides. The water level depth decreases according to the groundwater flow direction in the recharge areas; it reaches more than 200 m. below ground surface, while at the discharge zone the water level becomes of less depth near ground surface or may be self-flowing (artesian) within upper formations.

In the Southern Desert, appreciable amounts of evaporatic rocks were found throughout the investigated lithological sections (Fig.2). The evaporates are predominantly present within Umm Er Radhuma, Rus and Dammam formations. The other formations also contain some evaporatic rocks. The high solubility of these rocks as well as accumulated salt crust in shallow depressions under the influence of evaporation is responsible for high groundwater salinity. The recharge areas of the Southern Desert are characterized by intensive fractures and cavities system, thus rapid circulation of groundwater, as well as high infiltration rate of surface water through fractures and cavities; low salinity of groundwater is expected, locally and at shallow depths. Salinity of the groundwater in the recharge areas is usually less than 1000 mg/l and of bicarbonatic or sulphatic water type. While in the discharge areas bordering the Euphrates River, where long term contact of the water with the host rocks occur and circulation of water is low, therefore the salinity usually attains high values, may be more than 10000 mg/l with sulphatic or chloridic water type, this is attributed to the factors influencing on chemical composition (Fig.4).

The hydrogeological investigation within the Iraqi Southern Desert showed many promising sides in different localities (Fig.4), these locations are characterized by huge amounts of groundwater with suitable salinity; they are Wadi Al-Khir, Shbicha, Ma'aniya, Safawi, Takhadid, Ansab, Amghar and Salman.

CONCLUSIONS

- The main investigated water bearing formations underlying the Iraqi Southern Desert from the oldest are presented by: Hartha, Tayarat, Umm Er Radhuma, Dammam, Ghar – Euphrates and Dibdibba formations in addition to Quaternary sediments.
- The groundwater, in the Southern Desert originates mainly from the atmosphere. Rain fall partly infiltrates through soil and rocks and saturates voids, fissures, cracks, joints and faults. Run-off in wadis and along their courses partly percolates through bedrocks. Leakage from deeper aquifers occurring in the eastern part of the Southern Desert is also important in groundwater replenishment, although it occurs over restricted areas. Therefore, the rain fall form the major component of groundwater replenishment. The recharge areas extend outside Iraqi border into Saudi Arabia.

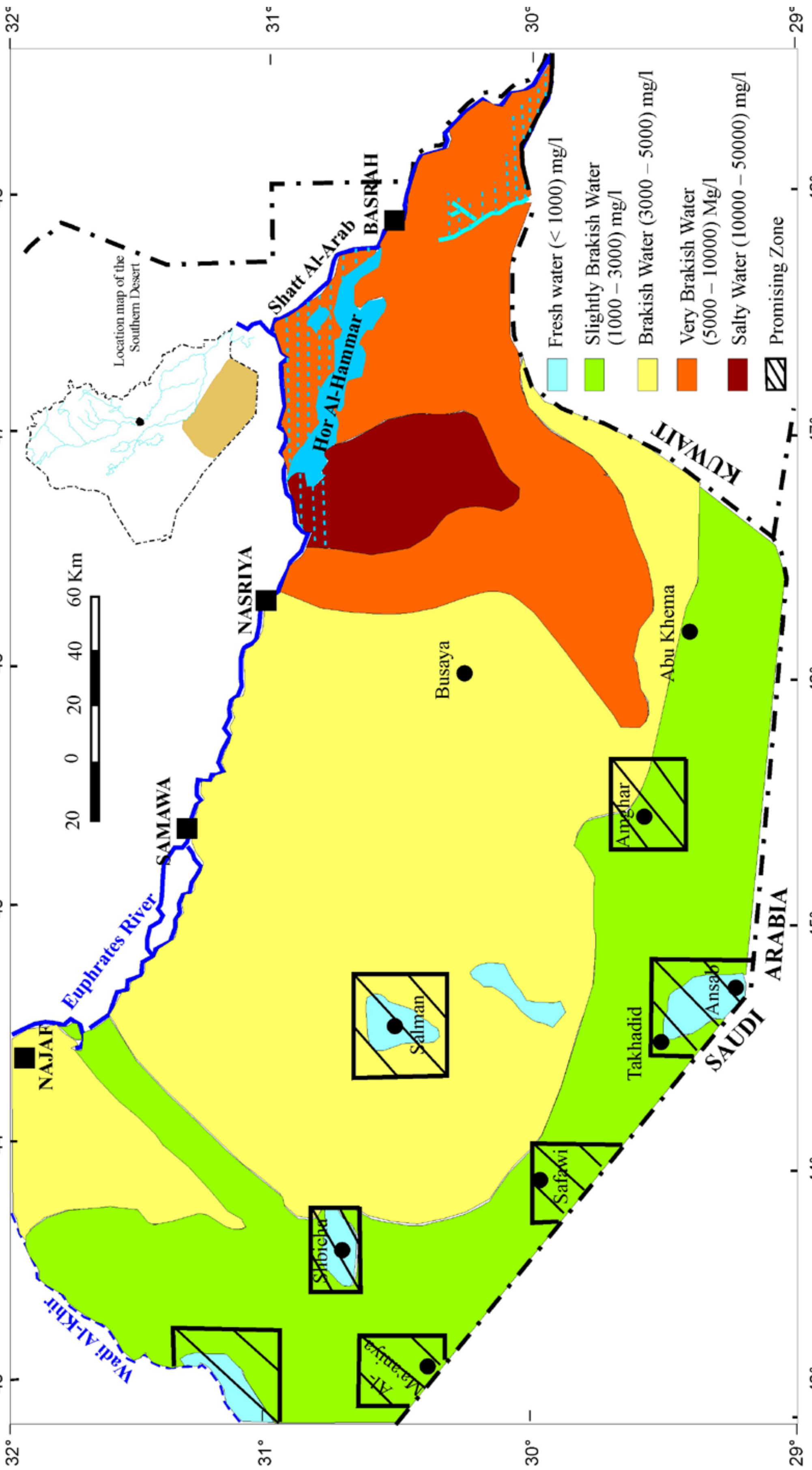

Fig.4: Hydrochemical map of the Iraqi Southern Desert, shows salinity zones of groundwater and promising zones (after GEOSURV, int. rep. nos. 2701, 2705, 2709, 2727, 2737, 2806, 2809, 2911 and 2964)

- A hydraulic continuity was observed between the aquifers of Hartha, Tayarat, Umm Er Radhuma and Dammam formations, to some extent. There is leakage either downward or upward from one aquifer to another, depending on the piezometric relations of the water-bearing layers throughout the region.
- Dammam Formation is considered as the most important regional aquifer in the Iraqi Southern Desert due to its wide extent and content of huge amount of water.
- The regional trend of the groundwater movement is generally towards east and northeast; following the discharge zone along the western bank of the Euphrates River, Hor Al-Hammar and Shatt Al-Arab. But, locally the flow of the groundwater takes different directions throughout the region depending on geological setting, topographic and structural features.
- The groundwater is considered of low salinity in recharge zone at the western parts of the Southern Desert. Salinity of the groundwater ranges mainly between (less than 1000 – 2000) mg/l, with chemical water types of Ca – bicarbonate – sulphate. In discharge areas, salinity of the groundwater is much higher, when long-term contact of water with the host rocks occurs and the groundwater circulation is low, and may attain more than 10000 mg/l, with predominant Ca – Na – sulphate – chloride water types.
- Salinity of the groundwater also increases with depth, with very wide range from fresh water (less than 1000 mg/l) to attain 50000 mg/l. High salinity of the groundwater is usually found at depth and particularly within the isolated structures, where the groundwater circulation is usually low.
- High transmissivity values prevail over the lower ones and support the conclusion that numerous karst canals and cavities serves as a main transmitting medium.
- Deep wells yield water of rather complex chemical composition. There are three main factors affecting chemistry of the groundwater: the manner of recharge and discharge, water velocity and lithology of country rocks. Moreover, upward leakage of oil field water in the area of tectonic disturbances also may influence the water chemistry. Chloridic type of water might be attributed due to direct influence of deep oil waters.
- The aquifers within the Iraqi Southern Desert are of two groups :
  a) Carbonate aquifers, which are characterized by double porosity, i.e. primary and secondary porosities mainly developed along bedding planes and fissures system, caused due to karst phenomenon and tectonic disturbances.
  b) Clastic aquifers, which are characterized by primary (intergranular) porosity.
- The hydraulic and chemistry of the aquifers are closely linked to the stratigraphic, lithologic, structural and topographic features of the water bearing formations.
- According to the data of the hydrogeological investigations, many promising zones of good water qualities and quantities were fixed at different locations within this study in the Southern Desert.

RECOMMENDATIONS

According to this hydrogeological and hydrochemical study of the Iraqi Southern Desert, the following are recommended:

1- Monitoring or continuous observations of groundwater level in selected and representative wells, in order to provide new data, which are necessary for executing groundwater regime and to detect any variations that occur in water level.
2- Continuous collections and analyses of the groundwater samples from representative wells, based on monthly or seasonal bases, as available aid to predict any change in chemical composition and water types.

3- Drilling new deep and observation wells, in selective areas, and where there are no available old wells, especially within promising areas, to provide new information in order to evaluate the hydrogeological and hydrochemical conditions, within involved areas, more precisely and to predict or find more new promising areas.
4- Construction of small dams on main wadis to provide water to recharge the groundwater aquifers through wadi basins, the stored water also can be used for local domestic uses and irrigation purposes within the region.
5- Establishment of gauging stations on wadi basins, in order to record run off, which will aid in evaluation of the groundwater resources.
6- Installation of hydro meteorological stations, aiming to provide continuous observations of the hydro meteorological parameters, which will aid also in evaluation of the groundwater resources.
7- Continuous observation of the groundwater level and analyses of groundwater samples from selected wells in the agricultural areas within Safwan – Al-Zubair regions in order to prevent deterioration and depletion of groundwater in these regions. The possibility of recharging the groundwater artificially might be taken into consideration.

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