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HYDROGEOLOGY

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ABSTRACT

The regional topography of the Iraqi Western Desert is characterized by gradual increase in elevation from east to west with some exceptions. In general, the drainage is towards east and northeast. All wadis in the region are intermittent. Generally, the Western Desert is covered by carbonates, clastic and marl. The dip of the strata is almost gentle and towards northeast and east directions, in the western parts is westwards.

The main aquifers in the region are within Suffi, Ga`ara, Mulussa, Ubaid, Muhaiwir, Rutbah, Ms`ad, Hartha, Tayarat, Umm Er Radhuma, Akashat, Dammam, Ratga, Euphrates, Injana formations and Quaternary deposits. Ga`ara aquifer is considered as the most important one, on a regional scale, due to its wide extent and high content of water. Most aquifers are recharged from rainfall and runoff of the intermittent wadis in form of leakage losses into permeable strata and through fractures, fissures, joints and cavities, especially into shallow aquifers. It is assumed the presence of a hydraulic connection between aquifers to some extent. Leakage of water is either downwards or upwards, depending on piezometric relation of aquifers, lithology, structure and extent of water-bearing horizons.

Groundwater discharge zone is located in the area along the right bank of the Euphrates River. Water river discharge is either in form of underground inflow into the Euphrates, Habbaniya and Razzaza lakes, or in form of springs.

The general trend of the groundwater is towards northeast, following the discharge zone along the right bank of the Euphrates River. Locally, different directions of flow may occur through out the region, depending on the geological setting of water-bearing horizons and nature of structure and topography.

Groundwater level varies from about 300 m below ground surface, in the western parts to artesian or near ground surface, in recharge zones along Euphrates River. Salinity of water increases with depth and also towards discharge zones. It ranges from fresh in the western parts to very high salinity in discharge areas. Water type also varies from bicarbonate or mixed to mainly chloridic or sulphatic in the discharge zones.

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حاتم خضير الجبوري و نصير حسن البصراوي

المستخلص

تمتاز طوبوغرافية الصحراء الغربية بارتفاعها التدريجي باتجاه الغرب ويكون نظام التصريف فيها باتجاه الشرق والشمال الشرقي على وجه العموم، وكافة الوديان الموجودة في المنطقة هي موسمية. تغطي منطقة الصحراء الغربية الصخور الجيرية والفتاتية والطفل، والتي يكون ميل طبقاتها باتجاه الشرق والشمال الشرقي بصورة عامة وباتجاه الغرب في الطرف الغربي.

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الخزانات الجوفية الرئيسية ضمن منطقة الصحراء الغربية تكون ضمن التكوينات الجيولوجية التالية: صوفي، كعرة، ملوصي، عبيد، محيور، رطبة مسعد، هارثة، طيارات، أم رضومة، عكاشات، دمام، رطگـة، فرات وإنجانة وترسبات العصر الرباعي. ويعتبر الخزان الجوفي في تكوين كعرة الأكثر أهمية على النطاق الإقليمي للمنطقة وخاصة ضمن أجزائها الغربية وذلك لامتداده وكثرة المياه التي يحتويها. غالبية الخزانات الجوفية المائية ضمن المنطقة تكون تغذيتها من مياه الأمطار والوديان الموسمية المنتشرة في المنطقة حيث تتسرب المياه وتتغلغل خلال الطبقات النفاذة وعن طريق الشقوق والتكسرات والتكهفات إلى الطبقة الحاملة للمياه. هنالك اتصال هيدروليكي بين الخزانات المائية ضمن عموم المنطقة، أي إن هنالك نضوح أو تسرب للمياه الجوفية من خزان جوفي إلى آخر اعتمادا على مستوى وضغط المياه البيزومتري ضمن الطبقات الحاملة للمياه وعلى الطبيعة الصخارية لتلك الطبقات وامتداداتها وميلها.

تقع منطقة التصريف للمياه الجوفية على امتداد الضفة اليمنى لنهر الفرات، حيث إن التصريف إما أن يكون على هيئة جريان جوفي يصب في نهر الفرات وبحيرتي الحبانية والرزازة أو على هيئة ينابيع أو عيون مائية. الاتجاه العام لحركة المياه الجوفية يكون باتجاه الشمال الشرقي والشرق باتجاه منطقة التصريف على امتداد الضفة اليمنى لنهر الفرات. هنالك اتجاهات موقعية قد تختلف عن الاتجاه العام اعتمادا على الموقع الجيولوجي للتكوينات الحاملة للمياه والطبيعة التركيبية والطوبوغرافية.

يتراوح مستوى المياه الجوفية في الأجزاء الغربية ما بين 300 متر تحت سطح الأرض وبعض الأحيان متدفق ذاتيا أو قريبة من سطح الأرض ضمن مناطق التصريف المحاذية لنهر الفرات. ملوحة المياه تزداد مع العمق وباتجاه منطقة التصريف وهي تتراوح بين العذبة في الأجزاء الغربية إلى عالية الملوحة ضمن مناطق التصريف، وهي ذات نوعية بيكاربوناتية أو مختلطة ضمن الأجزاء الغربية تتحول إلى كلوريدية أو كبريتاتية ضمن مناطق التصريف.

INTRODUCTION

The groundwater plays an important role in human living and land development in many parts of Iraq, particularly those, which are remote from fresh surface water supplies, like perennial rivers and streams, or those of unsuitable topography to use surface water. The development of groundwater in Iraq by means of hand dug wells began several thousands years ago, while the first governmental well was drilled at Tel Awainat in Rabia area northwest of Iraq in 1934. Since that and till now many thousand wells have been drilled by several governmental organizations and foreign firms aiming to supply water for domestic, municipal, agricultural and industrial purposes (Parsons,1955; Ingra,1964; Anarbaev *et al*, 1976; Idrotechnico,1977; Consortium, 1978 and 1981; Al-Basrawi ,1996; Al-Furat Co., 2000; Al-Ghazzi, 2004 and Jassim and Goff, 2006).

The evaluation of hydrogeological conditions depends mainly on the previous hydrogeological studies carried out by different researchers including hydrogeological and hydrochemical investigation. These studies can reflect the conditions of groundwater aquifer system in terms of groundwater flow direction, salinity and chemical type of water, in addition to other interesting basic information of hydrochemical parameters for 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 use for different purposes.

The main aim of this study is to know the hydrogeological conditions of the groundwater in the Iraqi Western Desert including nature of aquifers, their extents, groundwater level, flow direction, recharge and discharge regions, type and salinity, in order to supply the area with sufficient amount of water of suitable quality, which is very important for development of the area.

The Iraqi Western Desert lies to the west of the Euphrates River, extending west and southwest into Syria, Jordan and Saudi Arabia, and its southeastern boundary with the Iraqi Southern Desert is represented by Wadi Al-Khir (Fig.1).

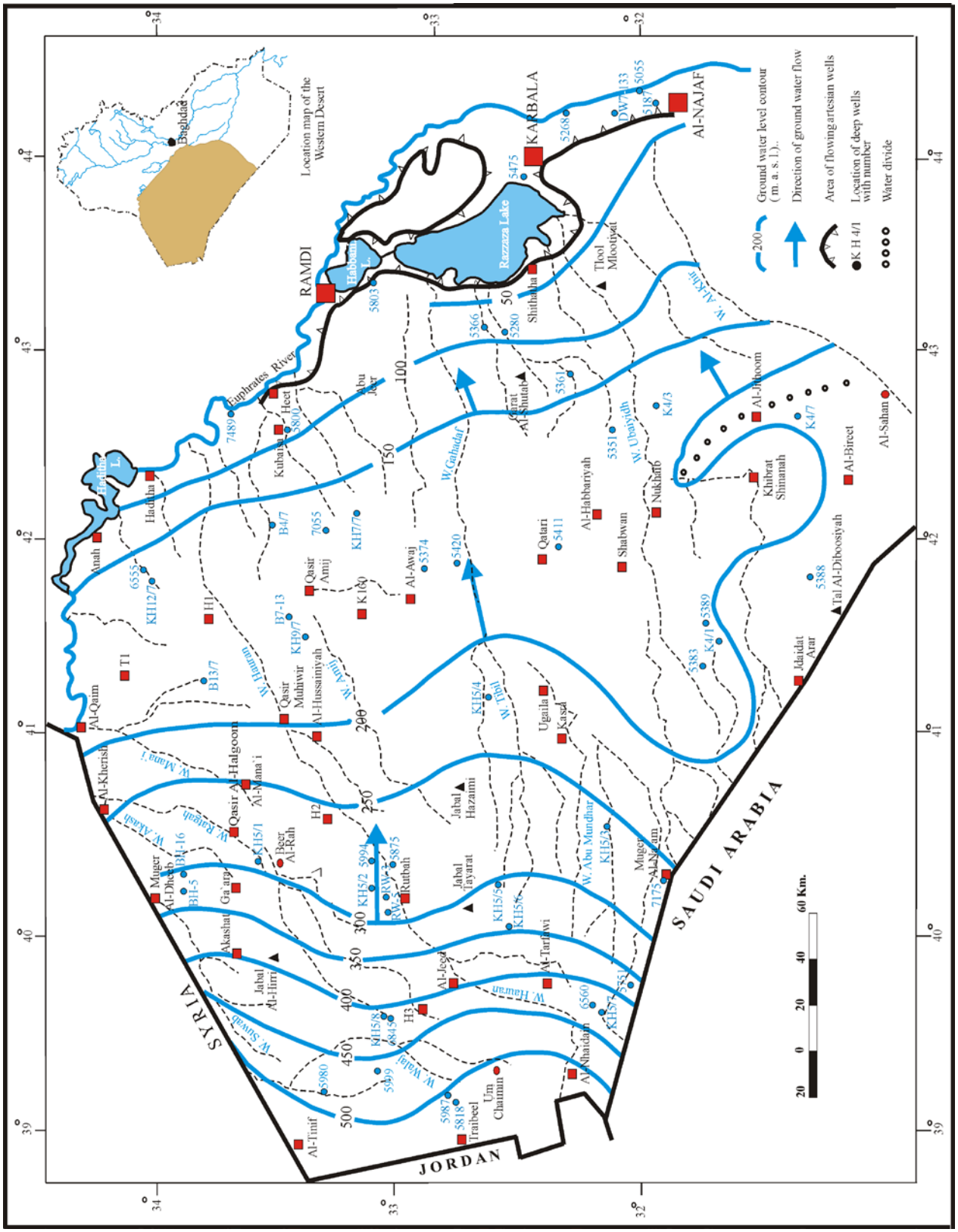

Fig.1: Hydrological map of Iraqi Western Desert shows location of deep wells with static water level and direction of ground water flow (after GEOSURV, int. rep. nos. 2737, 2740, 2776, 2779, 2797, 2798, 2810, 2825 and 2865)

The area belongs to the Stable Shelf of the Arabian platform. Topographically, the area is characterized by a gradual increase in elevation from east to west, in about two meters per kilometer .The drainage is mainly easterly and northeasterly and all wadis are intermittent. Several large wadis, such as Hauran and Ghadaf dissect the area and discharge into the Euphrates River and Razzaza Lake, respectively, while many of these wadis does not have apparent connection with the river. Several depressions exist in the area, and receive water from large wadis.

The climate of Iraqi Western Desert is continental and semi-arid, characterized by dry and hot summer; cold and low rain winter. According to meteorological information supplied by the Iraqi General Institute of Meteorological Information (2000) for the years (1981 – 2000) the annual mean rain fall is around 100 mm, annual relative humidity is about 42%, annual evaporation is about 3200 mm, and annual temperature is 21° C.

The involved area is covered by carbonate and clastic rocks with subordinate marl and phosphorite. Ga`ara Formation is considered the oldest formation exposed in the area. The dip of strata is almost gentle and of northeast direction, in general. Groundwater recharge is mainly from direct rain fall and intermittent stream run off by percolation through fractures, joints, faults, caves and bedding planes, also infiltration through permeable strata.

GROUNDWATER AQUIFERS

The groundwater bearing formations in the Iraqi Western Desert and their hydrogeological and hydrochemical characteristics is reviewed, according to the hydrogeological investigations carried out in the area, the formations from oldest to youngest are:

1- Groundwater Aquifer in Suffi Formation

(This formation is informal unit).

This formation is partially penetrated by drilling all deep wells in the area (Table 1).

Table 1: Penetration and drilled thicknesses in Suffi Formation

Well No.	Depth of penetration (m)	Penetrated thickness (m)	Type of penetration
KH 5/2	870 – 950	80	Partial
KH 5/3	1055 – 1200	145	Partial
KH 5/1	720 – 1600	880	Partial
KH 5/4	475 – 600	125	Partial
KH 5/5	385 – 850	465	Partial
KH 5/6	560 – 1250	690	Partial
KH 5/7	700 – 750	50	Partial
KH 5/8	750 – 802.2	52.5	partial

Suffi Formation is mainly composed of alternation of marl, shale and sandstone of various grain sizes, while calcareous and dolomitic rocks are subordinately present in the lower part (Consortium, 1981). Suffi Formation represents an important groundwater source with the overlying Ga`ara Formation, at the western and northwestern parts of the Iraqi Western Desert. In the well KH 5/1, two zones of groundwater were penetrated through Suffi Formation. The uppermost water bearing strata of this formation were tested at depth interval (770 – 1350) m together with the lowest ones of the Ga`ara Formation. Transmissivity of this part was 100 m^2/day. While the lower zone was tested at depth interval (855 – 1350) m, the transmissivity was 37 m^2/day, discharge of the well was 535 m^3/day, and static water level was 57.8 m below ground surface. The total dissolved solids were 8316 mg/l with

Na-Chloridic water type. Pumping test was executed also in the deep wells KH 5/3 & KH 5/5 and the results are shown in Table (2). While no pumping tests were executed for other wells.

Table 2: Hydrological information of two wells in Suffi Formation

Well No.	Transmissivity (m^2/day)	Discharge (m^3/day)	Static water level (m)below G.S.
KH 5/3	36	704	317.6
KH 5/5	350	1000	302

The hydrochemical analysis of water sample from the deep well KH 5/5 shows salinity of 2332 mg/l with Na-Chloridic water type. This chemical analysis represents water type and salinity of the uppermost part of Suffi aquifer, which is more likely Ga`ara aquifer. While the chemical analysis of a water sample from the deep well KH 5/1 shows 8316 mg/l, which represents the deep water of Suffi Formation (this water may be oil water or may be mixed with deep oil water). Recharge to the Suffi aquifer might somewhere outside the Iraqi borders, and perhaps through downward leakage from the upper aquifers. No clear hydrogeological boundary between Ga`ara and Suffi water bearing zones were determined. It seems that the water bearing beds of both formations are in a relatively close hydrodynamic interconnection, in different localities and water escape may be taken place through low permeable strata depending on hydrostatic pressure of confined water and nature of water bearing beds (Al-Jiburi and Al-Basrawi, 2002a & b; Al-Dabbaj and Al-Khashab,2002a).

2- Groundwater Aquifer in Ga`ara Formation

Ga`ara Formation is composed of thick succession of porous sandstone beds and low permeable shaley beds. However, due to chargeable characteristics of the water bearing beds, interconnection and hypsometric position of the formation as related to the structure, Ga`ara Formation may constitutes more than one separate aquifer. According to the available hydrogeological information about the area perched, unconfined and confined aquifers occur in Ga`ara Formation, which is totally penetrated by different wells (Table 3).

Table 3: Penetration and drilled thicknesses in Ga`ara Formation

Well No.	Depth of penetration(m)	Drilled thickness (m)	Type of penetration
KH 5/1	0 – 720	720	Total
KH 5/2	154 – 870	716	Total
KH 5/3	385 – 1055	670	Total
KH 5/5	92 – 385	293	Total
KH 5/6	532 – 560	28	Total
KH 5/7	242 – 700	458	Total
KH5/8	326 – 750	423	Total
RW-3	167 – 400	233	Partial
RW-5	120 – 425	300	Partial
RW-7	143 – 144	1	Partial
RW-9	162 – 167	5	Partial
BH 2	80 – 505	425	Partial
BH 3	57 – 240	182	Partial
BH 5	325 – 503	178	Partial
BH 6	229.5 – 280.1	50.6	Partial
BH 15	333 – 362	29	Partial
BH 16	491 – 565	74	Partial
KH 4/1	773 – 807	34	Partial

Ga`ara Formation represents the main aquifer at the western and northwestern parts of the Iraqi Western Desert, and may represent deep aquifer in some localities. It is considered as the most extended and important formation in the area due to its high water content. Executed pumping tests in many wells penetrated upper water bearing beds of Ga`ara Formation, which represent mostly unconfined or semi-unconfined aquifers, indicate that the transmissivity coefficient is between (0.5 – 620) m^2/day, permeability coefficient ranges between (0.1 – 13.9) m/day, discharge of wells ranges between (48 – 540) m^3/day and static water level ranges between (29.8 – 461) m below ground surface (Al-Jiburi and Al-Basrawi, 2002a & b; Al-Dabbaj and Al-Khashab, 2002a). With respect to lower water bearing beds, which represent mostly confined aquifer, the transmissivity coefficient ranges between (10 – 250) m^2/day, permeability coefficient ranges between (0.1 – 19) m/day, discharge of wells ranges between (226 – 2872) m^3/day and static water level ranges between (83.5 – 379.5) m, below ground surface. Generally, the transmissivity of the lower water bearing beds in Ga`ara Formation seems to be more uniform than that of the upper beds. The total dissolved solids (salinity) in upper beds ranges between (318 – 2279) mg/l, while in the lower beds is mostly higher and ranges between (1120 – 2208) mg/l. The recharge in the upper water bearing beds is mainly from rainfall and intermittent wadis run off, either directly or through the over lying rocks. Various types of water occur, as Chloridic, Sulphatic and Bicarbonatic water. The main factors involved in the water mineralization and chemical water type are lithologic composition of rocks, conditions of downward water leakage to the groundwater bearing beds of Ga`ara Formation, in addition to upward leakage due to hydrostatic pressure of confined water.

3- Groundwater Aquifer in Mulussa Formation

Mulussa Formation is composed of dolomite, dolomitic limestone, limestone, with intercalations of marl and clay. It is considered as a perched aquifer over the underlying Ga`ara aquifer within the province of Rutbah. Water table can be tapped by drilled and hand dug wells at a depth not more than 15 m, in the central portion of Rutbah Province, mainly around Rutbah town .South and northwards of Rutbah town vicinity, this aquifer disappears (Araim, 1984). East and westwards it gets deeper and the perched water is gradually substituted by confined or unconfined aquifers. The aquifer was penetrated by the deep wells KH 5/6 & KH 5/9. In the well KH 5/6, the aquifer was tapped at depth from (440 – 525) m, the total aquifer thickness is about 85 m. In the well KH 5/9, the aquifer was tapped at depth from (438 – 580) m, the total aquifer thickness is 142 m. Pumping tests results of the wells, which discharge from this aquifer (Hydrogeological Data Base in the State Company of Geological Survey and Mining) show that transmissivity of the aquifer ranges from (0.8 – 397) m^2/day, permeability ranges between (0.03 – 4.4) m/day, well discharge from (22 – 864) m^3/day and static water level ranges between (2 – 350) m below ground surface . The wide range variations in the hydrogeologic parameters reflect the nature and characteristics of the aquifer rocks, which compose of dolomite and dolomitic limestone with intercalations of marl and clay. Due to low discharges of wells it is believed that the aquifer rocks are of low cavities. The total dissolved solids range from (265 – 2943) mg/l. The water of most wells is fresh (less than 1000 mg/l) due to their position near the recharge sources, where are represented by direct rainfall and intermittent wadis. The salinity increases generally with depth. Predominant water types are Bicarbonatic, Chloridic and Sulphatic, respectively. The groundwater of Mulussa aquifer represents the best quality of available water in Rutbah town and surrounding areas (Al-Jiburi and Al-Basrawi, 2002b; Al-Dabbaj and Al-Khashab, 2002a).

4- Groundwater Aquifer in Ubaid Formation

Ubaid Formation is composed mainly of carbonate rocks, at the upper part and clastic deposits at the lower part. Groundwater is found in cavernous rocks of dolomitic limestone. It has been tapped by the deep well KH 5/9 at depth between (180 – 335) m, its thickness attains about 155 m and it may range between (20 – 100) m in other wells (Araim, 1984). Ubaid Formation represents an aquifer in some localities at central western parts of the Iraqi Western Desert. It is not considered as important aquifer due to its low water discharge (Al-Jiburi and Al-Basrawi, 2002b). Pumping tests of previously drilled wells (Hydrogeological Data Base) showed that the transmissivity ranges between (7 – 200) m^2/day, permeability ranges between (0.1 – 4) m/day, well discharge ranges between (39 – 594) m^3/day and static water level ranges between (63 – 293.5) m below ground surface, the aquifer is mainly confined. The total dissolved solids range between (800 – 2139) mg/l, and the water type is mainly Sulphatic with some Chloridic type.

5- Groundwater Aquifer in Muhaiwir Formation

Muhaiwir Formation is composed of massive and well crystalline dolomitic limestone and dolomite with loose sandstones. These rocks are characterized by the presence of cavities and voids, which make the formation as a good water aquifer and is characterized by large water content (Al-Jiburi and Al-Basrawi, 2002a & b; Al-Dabbaj and Al-Khashab, 2002b & c). Muhaiwir Formation is penetrated by many deep wells (Table 4).

Table 4: Penetration and drilled thicknesses in Muhaiwir Formation

Well No.	Depth of penetration (m)	Penetrated thickness (m)	Type of penetration
KH 7/7	714 – 870	156	Partial
KH 9/7	199 – 580	381	Total
KH 12/7	552 – 902	350	Partial
KH 5/6	188 – 375	187	Total

The results of the pumping tests of wells (Hydrogeological Data Base) showed that the transmissivity ranges between (9 – 1243) m^2/day, permeability ranges between (0.1 – 9.3) m/day, well discharge ranges between (46 – 1296) m^3/day and static water level ranges between (99.6 – 306.4) m below ground surface. The total dissolved solids range between (355 – 5868) mg/l with Chloridic, Sulphatic and Bicarbonatic water types, in deep well KH 9/7, two zones of groundwater have been determined fixed and individually tested. The salinity of water in the upper zone, at depth between (225 – 320) m was 580 mg/l, while in the lower zone at depth between (367 – 500) m was 14398 mg/l. The water type in the upper zone was Bicarbonatic while in the lower one was Chloridic. Bicarbonate water type reflects near and direct source of recharge to groundwater, while water of the lower zone probably indicates leakage of deep oil water to the aquifer. Muhaiwir Formation represents an important aquifer in some localities at western and northern parts of the Iraqi Western Desert.

6- Groundwater Aquifer in Rutbah Formation

Rutbah Formation is composed generally from sandstones of fine to medium grained and poorly cemented. Rutbah Formation was penetrated by numerous deep wells (Table 5).

Table 5: Penetration and drilled thicknesses in Rutbah Formation

Well No.	Depth of penetration (m)	Penetrated thickness (m)	Type of penetration
KH 3/7	476.25 – 695	218.75	Total
KH 7/7	0 – 199	199	Total
KH 9/7	357.5 – 552.5	195	Total
KH 12/7	127 – 263	136	Total
B 4/7	0 – 301.6	301.6	Partial
B 13-7	0 – 246	246	Partial
B 7-3	29 – 250	211	Total
B 7-12	437.5 – 534.5	97	Total
KH 4/1	546 – 679	133	Total

The results of pumping tests of many wells (Hydrogeological Data Base) (Table 5) showed that the transmissivity ranges between (2 – 7000) m^2/day, permeability ranges between (0.2 – 19.8) m/day, well discharge ranges between (52 – 2920) m^3/day and static water level ranges between (150.5 – 256) m below ground surface. The total dissolved solids range from less than (1000 – 3000) mg/l, with various water types Chloridic, Sulphatic and Bicarbonatic. Rutbah Formation represents a good aquifer at the central and southern parts of Iraqi Western Desert, due to large water content in accordance with its lithologic nature (Al-Jiburi and Al- Basrawi, 2002c, Al-Dabbaj and Al-Khashab, 2002b & c).

7- Groundwater Aquifer in Ms`ad Formation

Ms`ad Formation is composed mainly of dolomitic limestone with marl and marly limestone. This formation is totally penetrated in many wells (Table 6).

Table 6: Penetration and penetrated thicknesses in Ms`ad Formation

Well No.	Depth of penetration (m)	Penetrated thickness (m)	Type of penetration
KH 5/8	265.5 – 326.5	61	Total
KH 4/1	476 – 546	70	Total
KH 12/1	235 – 357	122.5	Total
B 4/7	99 – 127	28	Total
KH 7/7	377.5 – 476.25	98.25	Total

The Ms`ad Formation does not contain water in the wells KH 5/8, B 4/7 and KH 7/7, because they are located above the regional static level of ground water. The results of the pumping tests of wells (Hydrogeological Data Base) (Table 6) showed that the transmissivity ranges between (15 – 104) m^2/day, permeability ranges between (0.2 – 1.1) m/day, well discharge ranges between (99 – 648) m^3/day and static water level ranges between (198.7 – 295.5) m below ground surface. The water type is usually Sulphatic (Al-Dabbaj and Al-Khashab, 2002b).

8- Groundwater Aquifer in Hartha Formation

Hartha Formation is composed mainly of carbonate and clastic rocks, represented by sandstone. This formation is penetrated by the deep wells KH 4/1, KH 4/3, KH 4/5, KH 4/10, KH 4/7 and 5383. The thickness of the formation in these wells is 311, 426, 370, 407, 394 and

305 m, respectively (Idrotechneco, 1977). Hartha Formation is considered one of the important aquifers within the southwestern parts of the Iraqi Western Desert. The results of the pumping tests of wells (Table 7) showed that the transmissivity ranges between (2 – 588) m^2/day, permeability ranges between (0.1 – 9.2) m/day, well discharge ranges between (198.7 – 2032) m^3/day and static water level ranges between (39.5 – 117.7) m below ground surface. The total dissolved solids range between (1259 – 4060) mg/l with. The water type is mainly Sulphatic and Chloridic. Generally, the variations in the values of transmissivity and permeability are due to variations in rocks, and geologic structure of the area. Secondary porosity in rocks occurs as a result of fractures, fissures in bed rocks and it is more active in areas affected by main structural parameters. In carbonate rocks, secondary porosity increases also with cavities which may occur at surface or in deep within deep aquifers (Al-Jiburi and Al-Basrawi, 2002c & d).

9- Groundwater Aquifer in Tayarat Formation

Tayarat Formation is composed of limestone, clayey limestone, marly dolomitic limestone and dolostone. It is considered as one of the main and most important aquifers within large parts of the Iraqi Western Desert, particularly in Akashat, Rutbah,Ubaidat, Wadi Tabbal and Nukhaib Depression (Al-Jiburi and Al-Basrawi, 2002b, c, d & e; Al-Dabbaj and Al-Khashab, 2002a). The results of the pumping tests of wells (Hydrogeological Data Base) (Table 7) showed that the transmissivity ranges between (202 – 15529) m^2/day, permeability ranges between (0.2 – 25.6) m/day, well discharge ranges between (43 – 2590) m^3/day and static water level ranges between (42.3 – 232.7) m below ground surface. The total dissolved solids range between (291 – 3330) mg/l, the water type is mainly Chloridic and Sulphatic and rarely Bicarbonatic type. The variations in hydraulic parameter values are mainly due to the lithological nature of the aquifer and the presence of cavities, fissures and fractures at different degrees within carbonate rocks of this aquifer.

10- Groundwater Aquifer in Umm Er Radhuma Formation

Umm Er Radhuma Formation is composed mainly of limestone, marly limestone and dolomite with intercalations of evaporates. It is considered as an important aquifer at different localities in the Iraqi Western Desert, particularly at the southern and southeastern parts in Al-Bereet, Nukhaib and Habbariya vicinities. It also forms an important aquifer under Dammam aquifer within the regions west of Nukhaib, Al-Ukhaidir and Rahaliya vicinities (Al-Jiburi and Al-Basrawi, 2002b, c, d & e; Al-Dabbaj and Al-Khashab, 2002a & c). The results of the pumping tests of wells (Table 7) showed that the transmissivity ranges between (2 – 1550) m^2/day, permeability ranges between (0.1 – 21.1) m/day, well discharge ranges between (2 – 3960) m^3/day and static water level ranges from artesian to 170.3 m below ground surface. The total dissolved solids range between (278 – 6640) mg/l, with different water types, mainly Sulphatic and Chloridic, while Bicarbonatic water is less abundant. Bicarbonatic water is mainly found along wadi regions, where water recharge is direct from rainfall and surface run off. In the well 5803 the total dissolved solids was 56832 mg/ l (Table 7), this well is probably located within fault zone (Abu Jir Fault) so that a leakage of deep oil water occurs through this fault to aquifer water causing high salinity (Al-Dabbaj and Al-Khashab, 2002c and Al-Jiburi, 2004). Variations in hydraulic parameters are mainly due to lithologic and structural nature and presence of fractures, fissures, caves and faults, within carbonate rocks.

11- Groundwater Aquifer in Akashat Formation

Akashat Formation is composed mainly of alternation of phosphatic limestone, phosphorite, fossiliferous limestone with detritus materials. This formation is the equivalent of the Umm Er Radhuma Formation in southern parts of Iraq. It represents an aquifer at the northwestern part of the Iraqi Western Desert, particularly within Akashat and Rutbah provinces. The results of pumping tests of wells (Hydrogeological Data Base) (Table 7) showed that the transmissivity ranges between (2 – 620) m^2/day, permeability ranges between (0.1 – 5.2) m/day, well discharge ranges between (53 – 475) m^3/day and static water level ranges between (26.6 – 69.7) m below ground surface. The total dissolved solids range between (179 – 1072) mg/l and the water type is mainly Bicarbonatic with presence of Chloridic water, in some locations. The water in this aquifer is mainly fresh water due to direct recharge from rainfall and surface run off in wadis, where it is outcropping or through penetration through the upper lying formations. But, well discharge from this aquifer is mostly low to intermediate, due to low content of water (Al-Jiburi and Al-Basrawi, 2002b, c, d & e; Al-Dabbaj and Al-Khashab, 2002a & c).

12- Groundwater Aquifer in Dammam Formation

Dammam Formation is composed mainly of dolostone and dolomitic limestone with subordinate marl and chert. It represents the main upper groundwater aquifer at the southeastern parts of the Iraqi Western Desert, particularly within Al-Ukhaidir and Rahaliya localities, and represents the main carbonatic aquifer under clastic deposits of Karbala – Najaf Plateau, west of Euphrates River (Al-Jiburi, 2002b). The results of the pumping tests of wells (Hydrogeological Data Base) (Table 7) showed that the transmissivity ranges between (6 – 5000) m^2/day, permeability ranges between (0.1 – 16) m/day , well discharge ranges between (86 – 5940) m^3/day and static water level ranges from artesian to 80 m below ground surface. The total dissolved solids range between (1000 – 5000) mg/l with main Sulphatic water type.

Ratga Formation, which is the equivalent of Dammam Formation, consists mainly of limestone and chalky limestone. It is exposed in the northwestern parts of the Iraqi Western Desert. This formation does not contain water, in general, because its location is above the regional groundwater level in the exposed area.

13- Groundwater Aquifer in Euphrates Formation

Euphrates Formation is composed mainly of limestone and dolostone contain impermeable clay and marls. Near the surface the limestones are weathered, fractured and karstified, and have enhanced permeability.

This formation represents the upper groundwater aquifer in the regions along and behind Razzaza Lake, Rahaliya area and northern regions along Euphrates River, which represents the discharge regions of groundwater (Al-Jiburi and Al-Basrawi, 2002e). In the northern parts, the formation does not contain water because it is above the regional groundwater level (Al-Dabbaj and Al-Khashab, 2002c).

The pumping tests of wells (Hydrogeological Data Base) (Table 7) showed that the transmissivity ranges between (3 – 1750) m^2/day, permeability ranges between (0.2 – 29.5) m/day, well discharge ranges between (43 – 6600) m^3/day and static water level ranges between artesian to 64 m below ground surface .The total dissolved solids range from (1200 – 30000) mg/l, but mostly range between (2000 – 5000) mg/l, with Sulphatic water type at Shithatha and Rahaliya localities, and Chloridic water in northern parts.

Surface water infiltrates into caverns and fractures and flows towards the Euphrates River or issues at the Euphrates and the Abu Jir Fault along line of springs of variable discharges.

Springs with large yield are Haqlan, Hit, Shithatha and Imam Ahmad Bin Hashim. The Hit spring and some others are highly saline, sulphatic and rich in bitumen, due to mixing of heavy oil and brines from deep confined aquifers. The Haqlan spring originates in basal conglomerate of the Euphrates Formation, they are distributed in an area of about 150 m from the junction of Wadi Haqlan with Euphrates River (elevation about 100 m a.s.l.). The discharge of individual springs is (20 – 100) l/sec. The total discharge is 600 l/sec. The water has H_2S odor. In Shithatha town springs issue at a level of about 90 m a.s.l. The biggest spring of Shithatha is Ain Kabeera with a discharge of about 150 1/sec. The total discharge of Shithatha springs is about 1000 l/sec. Other large springs are Imam Ahmad Bin Hashim 570 l/sec with a salinity of about 2500 mg/l, and Ain Assaf about 500 l/sec. Groundwater also discharges through the alluvial plains, creating swamp-like areas on the right bank of the Euphrates River (Jassim and Goff, 2006).

14- Groundwater Aquifer in Injana Formation

Injana Formation is composed mainly of sandstone, siltstone and claystone. It represents the main aquifer within clastic rocks of Karbala – Najaf Plateau, with thickness reaches 70 m at the central parts. Most wells of shallow depths discharge from this formation. The pumping tests of wells (Hydrogeological Data Base) (Table 7) showed that the transmissivity ranges between (21 – 927) m^2/day, permeability ranges between (0.8 – 40.2) m/day, well discharge ranges between (72 – 720) m^3/day and static water level ranges between close to ground surface to 19.5 m below ground surface. The total dissolved solids range between (2000 – 5000) mg/l with main Sulphatic water type, but Chloridic water is also present. Sources of water recharge are mainly direct rainfall within the plateau, and may be from upward leakage from underlying aquifers within carbonate rocks. Salinity of the water within Injana aquifer does not differ highly from water salinity in the underlying carbonate aquifers such as Dammam Formation, within the plateau (Al-Jiburi, 2002b).

15- Other Possible Aquifers

Other geological formations within the Iraqi Western Desert like Nfayil, Fat`ha, Zahrah, Dibdibba and recent deposits, are not considered as main productive aquifers, although they contain water in some places, particularly during rainfall seasons along wadis and at Karbala – Najaf Plateau, concerning to Dibdibba Formation (Al-Jiburi, 2002b). Fat`ha Formation is considered as deteriorated source for the water due to its gypsum content.

Other formations like Anah, Sheikh Alas, Mauddud, Nahr Umr, Najmah, Amij and Hussainiyat are not considered productive aquifers because their location is above regional ground water level. They may properly represent perched aquifers with good water quality, where available hydrogeological conditions are present. During drilling of deep water wells, the Nahr Umr and Mauddud formations were not encountered because they were considered as Rutbah and Ms`ad formations, respevtively. Therefore, more detailed and new precise hydrogeological information are needed about the aforementioned formations within the Iraqi Western Desert. The source of the ground water in the aforementioned formations is mainly rainfall and surface run off into intermittent wadis during rainfall seasons. This type of aquifer, if present is of limited uses due to low water content. Concerning Zor Horan Formation, it is not considered as a productive aquifer in the Western Desert due to its lithological nature (Al-Jiburi and Al-Basrawi, 2002b).

Table 7: Hydrological parameters and Hydrochemistry of groundwater in selected wells within the Iraqi Western Desert

Well No.	Lat. (N)	Long. (E)	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
7055	33º 16'	42º 14'	EUR	322	254	165	518	0.3	20	2783	Sulphatic
7489	33º 44'	42º 43'	EUPH+IN	-	98	24.5	389	0.3	19	6181	Chloridic
KH 7/7	33º 07'	42º 20'	TAR	282	870	108.9	2208	11	3607	1914	Chloridic
KH 7/7	33º 07'	42º 20'	MH	282	870	105.5	730	1.5	243	5610	Chloridic
KH 12/7	34º 00'	42º 01'	EUR+TAR	276.4	903	99	2208	10.4	4040	2414	Chloridic
KH 12/7	34º 00'	42º 01'	MH	276.4	903	99.6	626.8	0.2	46	5868	Chloridic
B 4/7	33º 37'	42º 01'	RS	316.9	263	155.2	1924	18.6	2533	2590	Chloridic
5803	33º 09'	43º 30'	EUPH+EUR	60	200	17.5	1598	0.3	38	56832	Chloridic
5800	33º 36'	42º 33'	EUPH	150	117	4.5	653	0.6	59	2554	Chloridic
6555	34º 04'	42º 04'	EUR	230	153	77	778	0.4	19	2307	Chloridic
KH 9/7	33º 23'	41º 35'	MH	404.8	619	224.8	943	6.1	575	580	Bicarbonatic
KH 9/7	33º 23'	41º 35'	MH	404.8	619	225.4	1079	9.3	1234	14396	Chloridic
B 7-13	33º 26'	41º 43'	RS	385.7	246	205.3	1027	19.4	514	1980	Chloridic
B 13/7	33º 44'	41º 14'	RS	437.7	302	248.9	534	9	500	1250	Sulphatic
KH 5/9	33º 08'	41º 02'	UB	501.3	580	223.7	219	0.5	41	1700	Sulphatic
KH 5/9	33º 08'	41º 02'	MU	501.3	580	176.1	393	1.9	200	936	Sulphatic
5994	33º 05'	40º 32'	MU	615	251	83	792	0.4	23	907	Sulphatic
BH 5	33º 57'	40º 40'	EUR	497.6	503	69.7	57	0.25	6.4	1072	Chloridic
BH 16	33º 59'	40º 18'	EUR+TAR+GA	411.9	565	85.9	1296	0.2	42.2	2338	Chloridic
RW-3	33º 06'	40º 26'	MU	584.6	400	45.1	285	0.08	2.6	528	Bicarbonatic
RW-5	33º 01'	40º 15'	MU	622.1	420	25.7	39	0.03	0.8	1744	Chloridic

…cont. table 7

KH5/1	33º 33'	40º 19'	Lower GA	495.5	1600	83.5	2877	-	200	2208	Chloridic
KH 5/1	33º 33'	40º 19'	Lower SU	495.5	1600	57.8	533	-	37	8316	Chloridic
KH 5/2	33º 02'	40º 21'	MU	619.3	950	38.5	273	0.09	61	398	Bicarbonatic
KH 5/2	33º 02'	40º 21'	Lower GA	619.3	950	335.4	340	4.4	249	1120	Chloridic
KH 5/8	33º 11'	39º 30'	Upper GA	755.5	803	318	48	-	1	-	-
KH 5/8	33º 11'	39º 30'	Lower GA	755.5	803	309.7	687	-	250	1912	Chloridic
5420	32º 43'	41º 41'	TAY	430	270	232	719	13.1	1000	1878	Chloridic
5374	32º 48'	41º 25'	UB+MH	500	336	252	242	0.4	28	2139	Sulphatic
5875	32º 59'	40º 32'	MU	595	220	70	396	0.1	10	568	Chloridic
KH 5/4	32º 46'	41º 00'	Upper GA	559	600	314	247	0.4	30	1218	Sulphatic
6560	32º 19'	39º 33'	Upper GA	850	572	399	259	1.3	161	1044	Sulphatic
5751	32º 10'	39º 35'	MU	840	121	71	65	0.1	4	3700	Sulphatic
5987	32º 48'	39º 05'	MU	810	450	307	317	0.1	14	2433	Sulphatic
7175	32º 02'	40º 17'	MU	750	160	104	117	0.1	4	250	Bicarbonatic
KH 5/3	32º 15'	40º 27'	Lower GA	750	1200	461	-	1.3	200	1346	Chloridic
KH 5/5	32º 43'	40º 04'	Upper GA	728	852	253.6	311	0.5	95	318	Bicarbonatic
KH 5/7	32º 17'	39º 30'	Lower GA	856	750	390	269	0.7	170	1554	Sulphatic
KH 5/6	32º 42'	39º 56'	MH	807	1250	297.6	1296	3.4	632	2100	Sulphatic
5818	32º 47'	39º 04'	MH	820	385	291	264	0.4	38	2373	Sulphatic
K 4/3	31º 45'	42º 30'	TAR	316.3	913	117	1469	1.3	555	3330	Sulphatic
K 4/3	31º 45'	42º 30'	HAR	316.3	913	117.65	198.7	-	2	4295	Sulphatic
K 4/7	31º 15'	42º 29'	EUR	281.7	700	48.9	2030	0.9	377	1600	Sulphatic
K 4/7	31º 15'	42º 29'	HAR+TAR+EUR	281.7	700	48.9	2032	-	190.1	1788	Sulphatic
K 4/1	31º 45'	41º 29'	HAR	460	810.6	260.6	778	-	High	1259	Chloridic

…cont. table 7

K 4/1	31º 45'	41º 29'	RS	640	810.6	235.5	639	-	High	1000	Chloridic
K 4/1	31º 45'	41º 29'	Upper GA+RS	640	810.6	235.5	540	-	High	1260	Chloridic
5383	31º 50'	41º 23'	HAR	490.4	360	296.4	329	9.2	588	1386	Chloridic
5389	31º 47'	41º 34'	TAR	440.8	293.5	246.3	432	15.3	277	1613	Chloridic
5388	31º 19'	41º 43'	TAR	373.2	226	165	368	2.3	138	1681	Sulphatic
5980	33º 24'	39º 07'	MS	700	352	249	311	0.2	20	2843	Sulphatic
5999	33º 24'	39º 07'	MS	680	350	249	317	0.2	21	4340	Sulphatic
6845	33º 12'	39º 13'	MS	755	398	295.5	324	0.2	15	1187	Sulphatic
5280	32º 36'	43º 24'	EUPH	45	181	6	654	3.8	620	1863	Chloridic
5351	32º 00'	42º 27'	EUR	280.4	125	90.9	162	0.7	22	873	Sulphatic
5361	32º 18'	42º 59'	EUR	199.2	137	103	268	12	420	2454	Sulphatic
5366	32º 45'	43º 23'	EUPH	45	74.5	-0.3	467	2.6	117	1920	Chloridic
5411	32º 18'	42º 03'	TAR	343	538	151.3	2246	11.5	4070	2258	Chloridic
5044	32º 01'	44º 15'	DAM	30	140	12.5	138	0.9	29	6300	Sulphatic
5055	32º 02'	44º 23'	IN	25.1	31	13.7	660	6.5	90	7088	Chloridic
5187	32º 01'	44º 20'	DAM	300	150	6.5	594	1.3	25	3688	Chloridic
5475	32º 37'	43º 57'	DAM	40	155	8	297	0.1	17	5293	Sulphatic
DW7-133	32º 04'	44º 19'	DAM+EUR	-	298	-11.35	691	-	37.8	3710	Chloridic
5268	32º 28'	44º 15'	IN	29	32	-	196	3.9	186	4000	Sulphatic

SU: aquifer in Suffi Formation	RS: aquifer in Rutbah Formation	EUR: aquifer in Umm Er Radhuma Formation
GA: aquifer in Ga`ara Formation	MS: aquifer in Ms`ad Formation	DAM: aquifer in Dammam Formation
MU: aquifer in Mulussa Formation	HAR: aquifer in Hartha Formation	EUPH: aquifer in Euphrates Formation
UB: aquifer in Ubaid Formation	TAR: aquifer in Tayarat Formation	IN: aquifer in Injana Formation
MH: aquifer in Muhaiwir Formation		

DISCUSSION

The lithology of water bearing formations within the Iraqi Western Desert is variable; water is present in two types of rocks: clastics and carbonate rocks. Clastic rocks are characterized by granular porosity, permeability mainly depends on grain size and it is very high in loose and low cemented deposits and reveals high well discharges. While in carbonate rocks, fissures, fractures and cavities are the most factors affecting the permeability, but angular porosity has no clear effect on permeability. Therefore, the increase of cavities, fractures and fissures causes an increase of water discharge from wells, in carbonate rocks. The presence of muddy materials within these cavities and fractures causes reducing in water productivity from wells.

Most of recharge water within the Iraqi Western Desert is from rainfall, as well as, run off in the intermittent wadis, in form of seepage losses into shallow aquifers. Catchment areas extend into the adjacent countries; also percolation through wadi beds is the most important ways of recharge. Many shallow wadis lost their courses within the Iraqi Western Desert discharging completely into wadi deposits and/ or in playas, which are mainly of karst origin. Flood water of large wadis is lost on perculation either completely or partly.

Discharge zone of groundwater occupies the terrain along the Euphrates River, and rather a wide belt of NW – SE direction, connecting depressions of Habbaniya and Razzaza Lakes. The Euphrates River valley represents a discharge zone of aquifers existing along its course. Aquifer discharge is either in form of direct inflow into the river, or in form of springs along valley edge (Kubaisa, Rahaliya and Shithatha areas). The main water paths are connected to the fracture zones. Another possible discharge zones are the Haditha Lake, Habbaniya and Razzaza Depressions, and artificial discharge through flowing wells in Rahaliya – Ukhaidir region.

Hydrogeological investigations in the Iraqi Western Desert (Idrotechneco, 1977 and Consortium, 1977 & 1981) assumed a hydraulic continuity between aquifers to some extent. Leakage, either downwards or upwards from one aquifer to another is assumed, depending on the piezometric relations of water bearing horizons throughout the area. This condition is clearly illustrated between Rutbah and Ga`ara aquifers (Al-Ubaidat region) and between Ga`ara and Suffi aquifers (Wadi Huran and H_1 regions). These investigations also revealed the presence of complex and mixed aquifers with unique hydraulic system of wide range hydraulic continuity including different aquifers of different formations (Umm Er Radhuma, Tayarat, Ms`ad and Rutbah formations) within the eastern parts of the Iraqi Western Desert. There is a hydraulic connection between most aquifers within discharge zones, due to presence of faults and fractures in carbonate rocks.

Groundwater level ranges from more than 300 m below ground surface, in the western parts to artesian flow in discharge zones along Euphrates River, whereas the regional direction of groundwater movement is generally towards east and northeast, following the discharge zones along the right bank of the Euphrates River. Locally, the direction of groundwater flow follows different directions through out the region, depending on the geological setting of the groundwater bearing formations and structural and topographic situation (Fig.1).

Hydrochemistry of groundwater within the Iraqi Western Desert varies vertically and laterally. Salinity of water increases with depth and towards discharge zones. There are three main factors affecting the chemical composition of groundwater: (1) recharge and discharge conditions (2) speed of flow and (3) lithological characteristic of water bearing beds, in addition to leakage of deep oil water in regions of highly tectonic disturbance. Chloridic type of water is mainly due to direct effect of deep oil water. This water is of high salinity, particularly within deep wells. There is deep water of low salinity and of Chloridic type

within the western parts of the Iraqi Western Desert due to direct recharge of fresh water but its quality is influenced by the lithology. The Bicarbonatic water type reveals a recharge source of fresh water. In general, salinity of groundwater ranges from fresh water, within western parts of recharge zones to high salinity water within discharge zones along right bank of Euphrates River (Fig.2) and from Bicarbonate water to Chloridic and Sulphatic water types with in the same direction.

The hydrogeological investigations within the Iraqi Western Desert included many promising sites in different localities (Fig.3). These sites are characterized by available amounts of groundwater with suitable salinity, and include: Wadi Swab (within Akashat region), Wadi Amij, Wadi Tabbal, Ga`ara and Rutbah vicinities, Kasra vicinity, $H_1$ – pumping station and Tel Badran (within Ubaiyidh – Hauran Province), Wadi Al-Khirr area, Wadi Ar`ar area and Wadi Hamir area (within Lussuf – Ubaidat Province). Wadi Al-Khirr promising area is located partly within the Western Desert and mainly within the Southern Desert.

The areas of artesian discharge are located within the discharge zone as a belt along the right side of the Euphrates River which is called zone of springs and extends mainly between Hit – Najaf areas (Fig.1).

CONCLUSIONS

- The main water bearing formations in the Iraqi Western Desert are (from oldest to youngest): Suffi, Ga`ara, Mulussa, Ubaid, Muhaiwir, Rutbah, Ms`ad, Hartha, Tayarat, Umm Er Radhuma, Akashat, Dammam, Euphrates and Injana formations. While other formations are not considered as yield aquifers either due to their locations above regional groundwater level, or lithologic and structural properties or due to local extensions.
- The recharge sources of groundwater in Iraqi Western Desert are mainly direct infiltrations and/ or run off the intermittent wadis in form of percolation into the shallow aquifers. The recharge areas extend outside Iraqi border into Saudi Arabia.
- It is assumed the presence of hydraulic continuity between the aquifers 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.
- The groundwater discharge zone occurs in the area along the right bank of the Euphrates River. The discharge is either in form of underground flow in the Euphrates River and/ or Habbaniya, Razzaza and Haditha Lakes, or in form of springs. Within some places, in this zone, phenomena of self-flowing wells exist that form an artificial discharge of groundwater.
- The regional trend of groundwater movement is generally towards east and northeast (i.e., following the discharge zone along the right bank of the Euphrates River). But, locally, the flow of groundwater takes different directions throughout the region depending on geological setting and topographic and structural features.
- The depth of groundwater reaches more than 300 m, in the western parts (within the recharge zone), while it is near the surface or of artesian nature, in the eastern parts within the discharge zone along the right bank of the Euphrates River.
- The aquifers within the Iraqi Western Desert are of two groups: (a) carbonate aquifers, which are characterized by double porosity (i.e. primary porosity and secondary porosity mainly developed along bedding and fissures system due to karstic phenomena and tectonic disturbances) and (b) clastic aquifers which are characterized by primary (intergranular) porosity.
- Salinity of water increases generally from the recharge areas, in the western parts towards the discharge zone, in the eastern parts along the Euphrates River. The quality of water varies from bicarbonatic (or mixed) to sulphatic and chloridic in some direction.

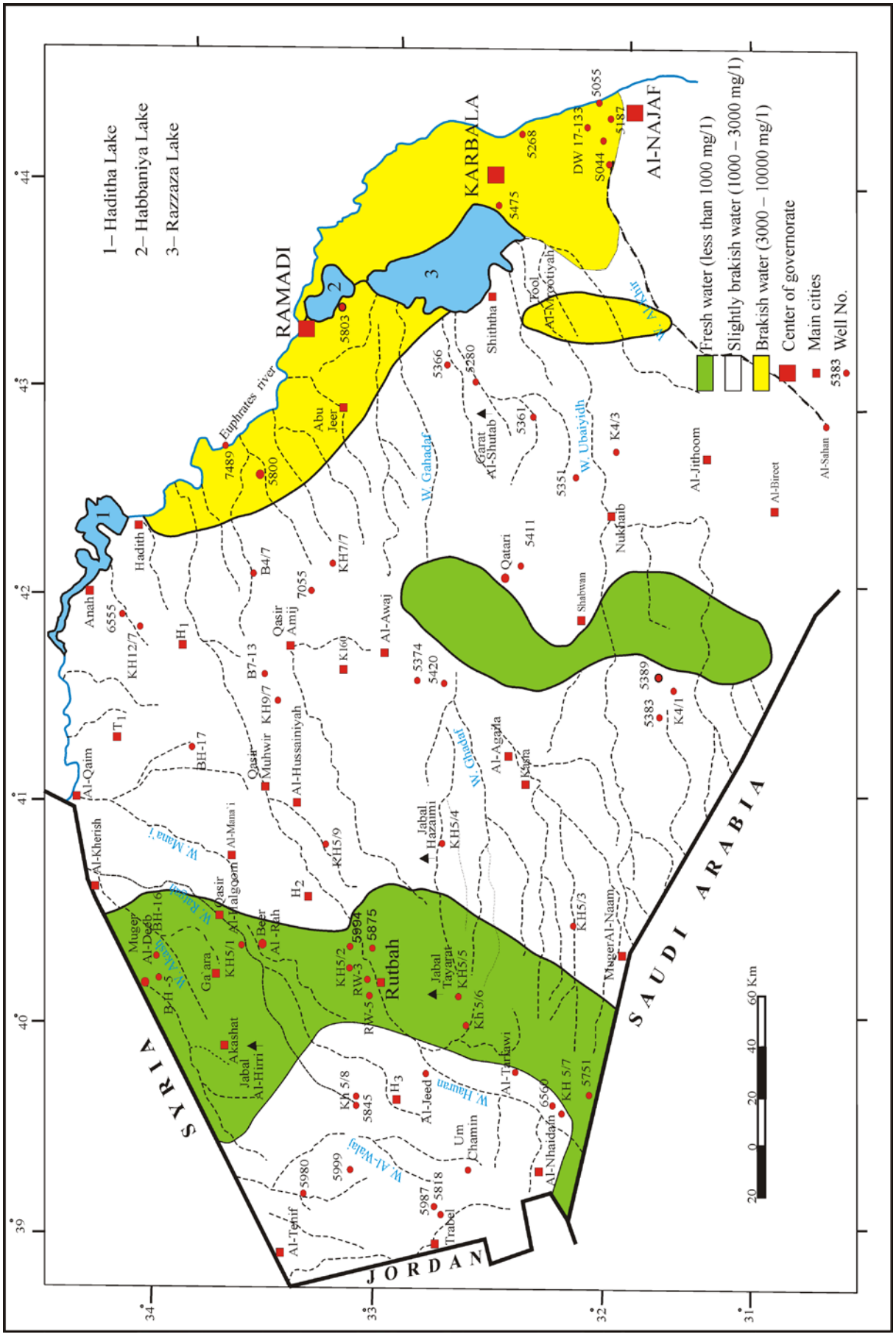

Fig. 2: Hydrochemical map of Iraqi Western Desert shows salinity zone of groundwater (after GEOSURV, int. rep. nos. 2737, 2740, 2776, 2779, 2797, 2798, 2810, 2825, and 2865)

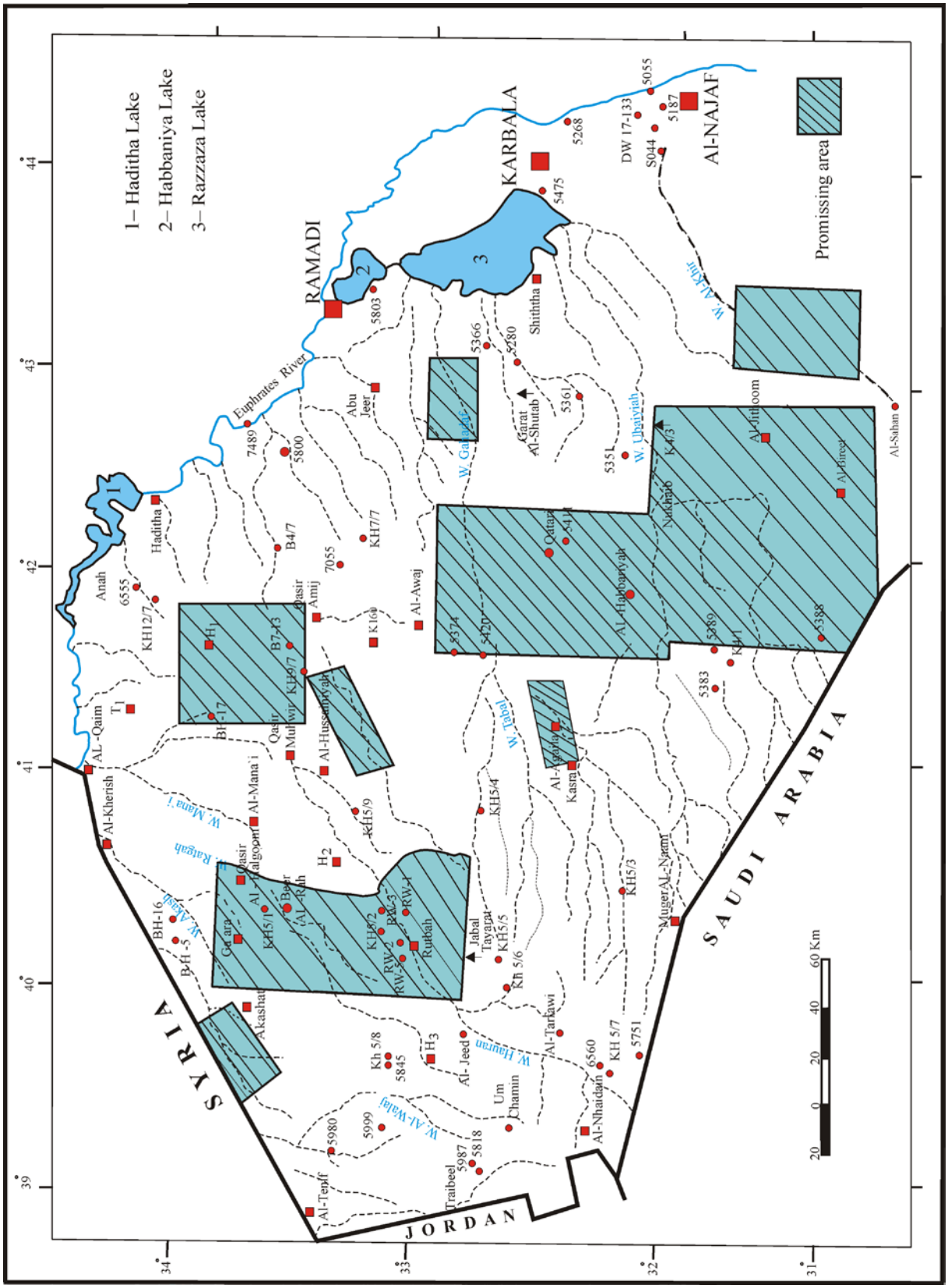

Fig. 3: Groundwater promising areas in Iraqi Western Desert (modified from Araim, 1984)

- The hydraulic and chemistry of the aquifers are closely linked to the stratigraphic, lithologic, structural and topographic features of the water-bearing formations within the Western Desert.
- Artesian zone is located along the right bank of the Euphrates River. It is extended as a narrow belt between Hit and Al-Samawa.
- According to the hydrogeological investigations many promising zones of good water qualities and quantities were fixed at different localities within the Iraqi Western Desert.

RECOMMENDATIONS

The followings are recommended:

1- Monitoring of groundwater level in selected and representative wells within the Iraqi Western Desert in order to provide new data, which are necessary for executing groundwater regime and to detect any variations in ground water level.

2- Continuous collections and analyses of groundwater from representative wells within the Iraqi Western Desert, based on monthly or seasonal bases, to predict any change in chemical composition and water types.

3- Drilling new deep and observation wells in selective areas, and where no wells are available, especially within promising areas, 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 new promising zones.

4- Construction of small dams on the main wadis within the Iraqi Western Desert to provide water for recharging groundwater aquifers through wadi basins, the stored water also can be used for municipal and irrigation purposes within the region.

5- Control of self-flowing wells within the discharge zones along Euphrates River to provide save usage of water, and prevent undesirable losses and environmental pollution within the involved areas.

6- Establishment of gauging stations on wadi basins, in order to record wadi run off, which will aid in evaluation of groundwater resources.

7- Installation of hydro meteorological stations, aiming to provide continuous observations of the hydro meteorological parameters, which will aid, also in evaluation of groundwater resources.

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