HYDROGEOLOGY OF THE WESTERN PART OF THE IRAQI WESTERN DESERT

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ABSTRACT

The western part of the Iraqi Western Desert is covered by carbonates, clastics and marl. The main aquifers in the region are within Suffi, Ga'ara, Mulussa, Muhaiwir, Ms'ad, Tayarat, Digma and Akashat formations. However, Nahr Umr, Rutbah and Ratga formations were either not recognized or not announced yet in the involved areas. Ga'ara aquifer is considered the most important one, on a regional scale due to its wide extent and large content of water. Most aquifers are recharged from rainfall and runoff of the intermittent wadis in form of leakage losses through permeable strata, fractures, fissures, joints and cavities into shallow aquifers. It is assumed that a hydraulic connection between aquifers exists 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.

The available updated hydrogeological information in the Hydrogeological Data Base indicates the presence of a water divide within the studied area, to the west of Rutbah town, with a general North – South trend. This water divide causes the groundwater to flow into opposite directions along its trend; accordingly, the general direction of the groundwater within the eastern part is towards east and northeast mainly, following the discharge zone along the right bank of the Euphrates River. While, at the western part of the studied area, the direction of the groundwater flow is towards the west; beyond the Iraqi borders. Locally, different directions of flow occur throughout the region, depending on the geological setting of water-bearing horizons and the nature of structure and topography. All the available previous studies have not mentioned the presence of this water divide within this part of the Western Desert, and always have, generally suggested that the direction of the groundwater flow is towards the east and northeast.

Salinity of the groundwater increases with depth and also towards discharge zones in general, but it ranges mainly from fresh to slightly brackish within the studied area. Water type varies and includes bicarbonate, chloridic and sulphatic water.

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هيدروجيولوجية الجزء الغربي من الصحراء الغربية العراقية

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المستخلص

تغطي الجزء الغربي من الصحراء الغربية العراقية الصخور الجيرية والفتاتية والطفل. إن الخزانات الجوفية الرئيسية في المنطقة تكون ضمن التكوينات الجيولوجية التالية: صوفي، گعرة، ملوصي، محيور، مسعد، طيارات، دگمة وعكاشات. ويعتبر الخزان الجوفي في تكوين گعرة الأكثر أهمية على النطاق الإقليمي ضمن المنطقة، وذلك لامتداده وكثرة المياه التي يحتويه. تكون تغذية غالبية الخزانات الجوفية المائية ضمن المنطقة من مياه الأمطار والوديان الموسمية المنتشرة في المنطقة، حيث تتسرب المياه وتتغلغل خلال الطبقات النفاذة وعن طريق الشقوق والتكسرات والتكهفات إلى الطبقات 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 المياه الجوفية والضغط البيزومتري لهذه المياه ضمن الطبقات الحاملة لها وعلى الطبيعة الصخارية لتلك الطبقات وامتداداتها وميلها.

أوضحت المعلومات الهيدروجيولوجية المتوفرة ضمن قاعدة البيانات الهيدروجيولوجية المحدثة وجود مقسم مائي ضمن منطقة الدراسة يقع الى الغرب من مدينة الرطبة وبامتداد شمال – جنوب، على العموم. يؤدي هذا المقسم المائي الى ان يكون اتجاه حركة المياه الجوفية باتجاهين متعاكسين على طول امتداده، عليه فان اتجاه حركة المياه الجوفية ضمن الجزء الشرقي يكون باتجاه الشرق والشمال الشرقي، نحو منطقة التصريف على امتداد الضفة اليمنى لنهر الفرات. بينما في الجزء الغربي، يكون اتجاه حركة المياه الجوفية نحو الغرب خارج الحدود العراقية. هنالك اتجاهات موقعية أخرى قد تختلف عن الاتجاه العام، اعتمادا على الموقع الجيولوجي للتكوينات الحاملة للمياه والطبيعة التركيبية والطبوغرافية. لم تشر الدراسات السابقة كافة، الى وجود مثل هذا المقسم المائي ضمن هذه المنطقة من الصحراء الغربية، بل تشير دائما الى أن اتجاه حركة المياه الجوفية يكون عموما باتجاه الشرق والشمال الشرقي.

إن ملوحة المياه الجوفية تزداد مع العمق وباتجاه مناطق التصريف على العموم، ولكنها تتراوح في الغالب ما بين المياه العذبة وضعيفة الملوحة وذات نوعية مختلفة تشمل المياه البيكاربونايتية والكلوريدية والكبريتاتية.

INTRODUCTION

The groundwater plays an important role in human living and land development in many areas of Iraq, particularly those, which are remote from fresh surface water supplies, like perennial rivers and streams, or those of rugged topography to use surface water. The studied area is considered a good example of these areas in Iraq. Many tens of wells have been drilled and several studies were carried out by several governmental organizations and foreign firms aiming to supply water for domestic, municipal, agricultural and industrial purposes within the Iraqi Western Desert, among them are: Parsons (1955); Ingra (1964); GEOSURV (1976); Idrotechneco (1977); Consortium (1978 and 1981); Araim (1990); Al-Basrawi (1996); Al-Furat Co. (2000); Al-Jiburi and Al-Basrawi (2002a, b and c); Al-Dabbaj and Al-Khashab (2002a and b); Al-Ghazi (2004); Jassim and Goff (2006); Al-Jiburi and Al-Basrawi (2007).

The evaluation of hydrogeological conditions in the studied area depends mainly on the available previous hydrogeological studies; including hydrogeological and hydrochemical investigations. 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 water bearing formations. From the available hydrogeological and hydrochemical information, it is possible to predict and enclose regions of good water quality for detailed investigations or of suitable use for different purposes.

- **Aim**

The main aim of this study is to indicate the hydrogeological conditions of the groundwater in the western part of the Iraqi Western Desert, according to the available updated Hydrogeological Data Base, 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.

- **Previous Studies**

All the previous studies indicate that, the direction of the groundwater flow in the Iraqi Western Desert is mainly from the west and southwest towards east and northeast. The available information in this study indicates a presence of a water divide; this water divide causes opposite flow directions of the groundwater along its trend, within the western part of the Iraqi Western Desert. This water divide is well represented on the new Hydrogeological Map of Iraq (Al-Basrawi and Al-Jiburi, 2013). Therefore, it is an important thing for the present study to deduce this information to be available for different scientific knowledge and Hydrogeological investigations in the future.

- **Location**

The studied area represents the western part of the Iraqi Western Desert. It lies to the west of the longitude $40^{o}\,30^{'}$, which extends westwards into Syria, Jordan and Saudi Arabia (Fig.1).

- **Materials Used**

In order to update the hydrogeological information within the studied area, different data are provided from the following sources:

- Hydrogeological and hydrochemical information from the updated Hydrogeological Data Base and other available hydrogeological references in Iraq.
- The available hydrogeological studies and maps of different scales that have been previously carried out.
- Geological and topographical information and maps of the studied area.
- Meteorological information.
- Application of GIS techniques.

- **General Geological Setting**

The studied area belongs to the Inner Platform of the Arabian Platform (Fouad, 2012). Topographically, the area is characterized by a gradual increase in elevation from east to west, as a part of the Western Desert. The drainage is mainly easterly and northeasterly, except the valleys west of the longitude 39° which they run towards NW or N, and all valleys are intermittent. Large valleys, such as Hauran dissects the area and discharge into the Euphrates River, far away to the east, while many of these valleys did not have apparent connection with the river. The studied area is covered by carbonate and clastic rocks with subordinate marl and phosphorite. Ga'ara Formation is considered the oldest exposed formation in the area.

- **Climate**

The climate of the studied area, as a part of the Iraqi Western Desert, is continental and subtropical, characterized by dry and hot summer, and cold and low rainfall winter, which can be ascribed to the geographical position and other factors affecting the studied area. General characteristics on the climate of the studied area have been reflected from the data recorded at Rutbah meteorological station, which represents the main station with available data, during

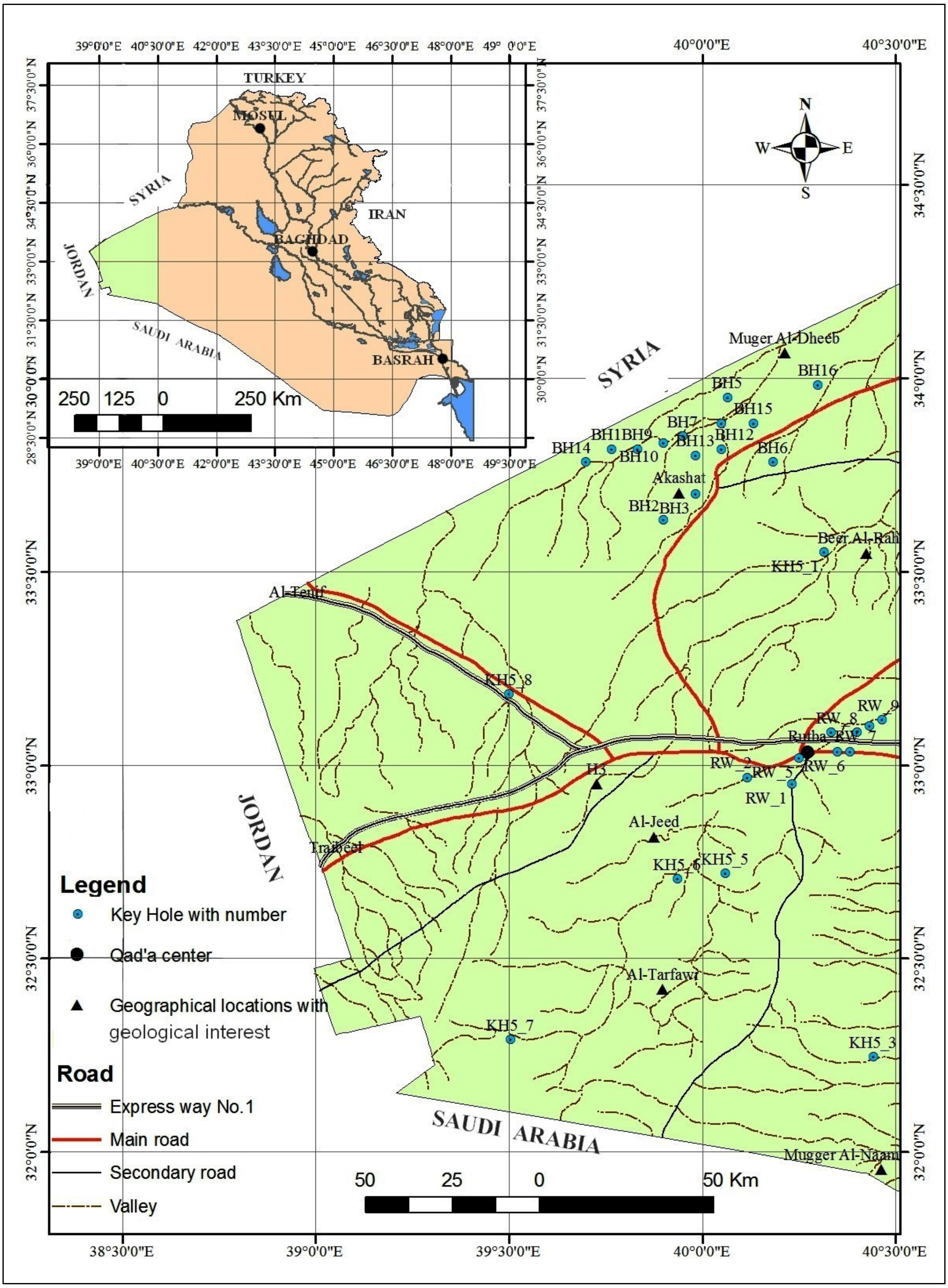

Fig.1: Location map of the studied area, with selected water wells

the period (1970 – 2008). The annual mean rainfall is around 119 mm, annual relative humidity is about 45%, annual evaporation is about 2990 mm, annual mean temperature is 19.6 °C, and annual wind speed is 3.1 m/sec.

AQUIFERS OF THE STUDIED AREA

The aquifers within the groundwater bearing formations in the studied area and their hydrogeological and hydrochemical characteristics are reviewed, from the youngest to the oldest; according to the hydrogeological investigations carried out in the area, these are mentioned hereinafter.

▪ Akashat Aquifer

The Akashat aquifer represents the upper aquifer within the northern parts of the studied area along the Iraqi – Syrian borders. This aquifer is indicated during drilling of hydrogeological wells within Blocks 6 and 5 (GEOSURV, 1976 and Consortium, 1981). The Akashat Formation is penetrated totally or partially during drilling of the wells within the map area. The available information is presented in Table (1).

Table 1: Information of the drilled wells which penetrated Akashat Formation (GEOSURV, 1976 and Consortium, 1981)

Well No.	Depth (m)	Thickness (m)	Penetration
KH5/8	56.5 – 180	123.5	Total
BH14	28 – 83.5	55.5	Partial
BH10	41 – 91	50.0	Total
BH7	40 – 74	34.0	Total
BH12	23 – 66.5	43.5	Total
BH5	67 – 162.5	95.5	Total
BH3	12 – 16.5	4.5	Total
BH6	7.5 – 69.5	62.0	Total
BH1	48 – 113	65.0	Total
BH9	30.5 – 80	49.5	Partial
BH11	41 – 112	71.0	Total
BH13	5 – 42	37.0	Total
BH15	114 – 182	67.0	Total
BH16	246 – 330	84.0	Total

The drilled thickness of the formation in these wells ranges between (4.5 – 123.5) m. It is reduced towards the south and reaches 4.5 m in the well BH3, and it disappears within the middle parts of the studied area, then it appears at the southwestern part of Akashat vicinity; as in the deep well KH5/8 with total drilled thickness of about 123 m. The Akashat aquifer is concentrated at the northern parts of the studied area only. There is no water within Akashat Formation in the deep well KH5/8, because the formation is located above the regional ground water level at this well. Pumping test executed in the well BH5 within the depth interval between (119.5 – 145.5) m, showed that the well discharge was low in this well. Also, pumping test was carried out in the well BH9 within the depth interval (30.5 – 90) m, which indicated a low discharge of the well. In the wells BH10 and BH11, pumping tests were carried out within the depth intervals (24.2 – 72.9) m and (59 – 73) m for both wells, respectively, indicated moderate discharges in these wells. Pumping tests were carried out in the well BH14 for two depth intervals between (33 – 39) m and (52 – 73) m, and also within the well BH15, the results indicated low water discharges in both wells. In the wells BH1 and BH16, pumping tests were carried out with other aquifers, while no pumping tests were carried out in the wells BH7 and BH13, although, they contain water within this aquifer. It is proposed that there is no water within the wells BH12, BH3 and BH6 (GEOSURV, 1976 and Consortium, 1981).

The hydraulic parameters were estimated on the basis of the performed pumping tests in the aforementioned wells within Akashat aquifer reflect that the transmissivity coefficient ranges between (2 – 620) m^2/day, permeability coefficient ranges between (0.1 – 5.2) m/day, discharge ranges between (53 – 475) m^3/day and static water level ranges between (26.6 – 69.7) m; below the ground surface. The total dissolved solids range from (179 – 1072) mg/l and the water type is mainly bicarbonate 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 valleys, where the formation is exposed or through penetration through the upper lying formations. But, the well discharge from this aquifer is mostly low to moderate, due to low content of water, in consequence to local extension and restricted recharge, which is mainly from rainfall (Al-Jiburi and Al-Basrawi, 2007 and 2013).

- **Tayarat and Digma Aquifer**

The Tayarat and Digma formations are exposed in various parts of the studied area. They are composed mainly of limestone, dolomitic and chalky limestone, and are characterized by the presence of fractures, which contain water. The Tayarat, Digma and Akashat formations represent the main upper aquifers along the Iraqi – Syrian borders above the Ga'ara aquifer. Tayarat and Digma formations represent a complex aquifer system with other aquifers in the studied area. The aquifer is concentrated mainly within the northern and northwestern parts of the studied area, according to the available information. There is no water within Tayarat and Digma formations at the southern parts of the studied area, as indicated in the deep well KH5/8 (Consortium, 1981), because the two formations are located above the regional ground water level in this area. The formations are penetrated during drilling of the hydrogeological wells within Block 6 (GEOSURV, 1976). The available information of the wells that penetrated both formations within the studied area is given in Table (2).

Pumping tests were carried out in the wells BH5, BH7 and BH12 within the depth intervals between (272 – 296.5) m, (92 – 135.5) m and (66 – 125) m, respectively, and have reflected low water discharges in these wells. Also, pumping tests were carried out in the wells BH6, BH10 and BH16, while no pumping tests were carried out in the wells BH11, BH13 and BH15, although, they contain water within the two formations. The performed pumping tests of the wells that penetrated the Tayarat and Digma aquifer within the studied area reflect that the transmissivity coefficient ranges between (2.2 – 120) m^2/day, permeability coefficient ranges between (0.2 – 2.6) m/day, discharge of wells ranges between (33 – 272) m^3/day and static water level ranges between (42.3 – 232.7) m; below the ground surface. The total dissolved solids ranges between (485 – 2000) mg/l, with water quality of bicarbonate and sulphatic water; mainly. The performed pumping tests in wells, which discharge from Tayarat Formation in different parts of the Western Desert reflect that the transmissivity coefficient ranges between (202 – 15529) m^2/day, permeability coefficient ranges between (0.2 – 25.6) m/day, discharge of wells ranges between (43 – 2590) m^3/day and static water level ranges between (42.3 – 232.7) m; below the ground surface, with total dissolved solids ranges between (291 – 3330) mg/l, the water type is mainly chloridic and sulphatic with bicarbonate water, rarely (Al-Jiburi and Al-Basrawi, 2007 and 2013). 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.

Table 2: Information of the drilled wells penetrated Tayarat and Digma formations (GEOSURV, 1976 and Consortium, 1981)

Well No.	Depth (m)	Thickness (m)	Penetration
BH1	113 – 275.6	162.6	Partial
BH2	0 – 80	80.0	Total
BH3	16.5 – 57.5	41.0	Total
BH5	162.5 – 325	162.0	Total
BH6	96.5 – 229.5	160.0	Total
BH7	74 – 155.6	81.6	Partial
BH10	91 – 197	106.0	Partial
BH11	112 – 150	38.0	Partial
BH12	66.5 – 216	149.5	Partial
BH13	42 – 131.3	89.3	Partial
BH15	182 – 333	151.0	Total
BH16	330 – 491	161.0	Total
KH5/8	176.6 – 265.5	88.9	Total

- **Ms'ad Aquifer**

The Ms'ad Formation is exposed in different locations of the studied area, and it is totally penetrated during drilling of the deep wells KH5/3, KH5/5, KH5/6, KH5/7 and KH5/8 within the studied area (Table 3). The formation is expected to represent an aquifer within the studied area to the west of the deep wells KH5/7 and KH5/8, towards the Iraqi borders, which did not contain water as in other deep wells, within this formation due to its locations above the regional ground water level. The Ms'ad Formation is composed mainly of limestone and dolomitic limestone. The performed pumping tests of wells considered to discharge from Ms'ad aquifer reflect that, the transmissivity coefficient ranges between (15 – 104) m^2/day, permeability coefficient ranges between (0.2 – 1.1) m/day, discharge of wells ranges between (207 – 648) m^3/day and static water level ranges between (202 – 295.5) m; below the ground surface. The total dissolved solids ranges between (1187 – 4340) mg/l with water quality of sulphatic water type mainly (Al-Jiburi and Al-Basrawi, 2007 and 2013).

Table 3: Information of the drilled wells penetrated Ms'ad Formation (GEOSURV, 1976 and Consortium, 1981)

Well No.	Depth (m)	Thickness (m)	Penetration
KH5/3	150 – 215	65	Total
KH5/5	0 – 52	52	Total
KH5/6	145 – 188	43	Total
KH5/7	150 – 190	40	Total
KH5/8	253 – 325	72	Total

▪ **Muhaiwir Aquifer**

The Muhaiwir Formation is composed mainly of clastic and carbonate rocks. The sandstone represents the lower part of the formation, while the limestone represents its upper part. The formation represents the main upper aquifer within the central part of the studied area. It is encountered only in the deep well KH5/6, while it is not present within the stratigraphic succession in the other deep wells within the studied area. The thickness of the formation in the deep well KH5/6 is 187 m, within the depth interval between (188 – 375) m; below ground surface. The aquifer in this well is located at depth interval between (300 – 330) m below the ground surface. The static water level in this well was 297.6 m; below the ground surface, which reflects that the aquifer is confined. The results of pumping test reflect that the transmissivity coefficient was 632 m^2/day, permeability coefficient was 3.4 m/day, discharge of the well was 1296 m^3/day and storage coefficient was 0.000206.

The hydraulic parameters were estimated on the basis of the performed pumping tests in wells, which discharge from the aquifer within the studied area reflect that, the transmissivity coefficient ranges between (14 – 632) m^2/day, permeability coefficient ranges between (0.1 – 3.4) m/day, discharge of wells ranges between (251 – 1296) m^3/day and static water level ranges between (202 – 306.4) m; below the ground surface. The total dissolved solids ranges between (760 – 3934) mg/l, with chloridic, sulphatic and bicarbonate water type. The available information from other wells, which discharge from this aquifer in other parts within the Western Desert reflect that, transmissivity coefficient ranges between (9 – 1243) m^2/day, permeability coefficient ranges between (0.1 – 9.3) m/day, discharge of wells ranges between (46 – 1296) m^3/day and static water level ranges between (99.6 – 306.4) m; below the ground surface, with salinity ranges between (355 – 5868) mg/l, with chloridic, sulphatic and bicarbonate water type (Al-Jiburi and Al-Basrawi, 2007 and 2013).

▪ **Mulussa Aquifer**

The Mulussa Formation is exposed mainly along the southern rim of the Ga'ara Depression. It is composed mainly of carbonate rocks represented by dolomite and dolomitic limestone. The drilled wells that penetrated Mulussa aquifer are concentrated mainly around Rutbah town. The available information indicate that the Mulussa Formation disappears to the south and west of Rutbah town; in the deep well KH5/8, and it becomes deeper to the east. Detailed study was carried out about the aquifer within the vicinity of Rutbah town (Consortium, 1981). The available information of the wells that penetrated the Mulussa Formation is given in Table (4).

Table 4: Information of the drilled wells which penetrated Mulussa Formation (GEOSURV, 1976 and Consortium, 1981)

Well No.	Depth (m)	Thickness (m)	Penetration
KH5/2	0 – 154	154	Total
KH5/6	410 – 532	122	Total
RW-3	0 – 167	167	Total
RW-5	8 – 120	112	Total
RW-6	35 – 184	149	Partial
RW-7	0 – 123	123	Total
RW-8	0 – 143	143	Total
RW-9	0 – 162	162	Total

It is shown in Table (4) that the thickness of the formation within the vicinity of Rutbah town ranges between (112 – 167) m, the thickness of the formation decreases towards south and west. The available information indicates that the sources of water recharge to the aquifer are mainly rainfall and infiltration from valleys within the studied area. Moreover, the Mulussa aquifer is present at shallow depth within the vicinity of Rutbah town and may represent perched aquifer above Ga'ara Formation, with low to moderate water discharge, but generally with good quality of fresh water and it is used for domestic purposes. Pumping tests were carried out in the well KH5/2 within the depth interval between (98 – 154) m, indicated moderate water discharge from the well, also the pumping test in the well RW-3 within the depth interval between (64 – 154) m reflected moderate water discharge. Pumping tests were carried out in the wells RW-5, RW-6, RW-7, RW-8 and RW-9, reflected low to moderate water discharges from these wells.

The Mulussa Formation represents a perched aquifer in most cases with good water quality, but it represents a deep aquifer, under the Muhaiwir aquifer in the deep well KH5/6, with static water level of 297.85 m; below the ground surface. The static water level of Mulussa aquifer in the well KH5l6 is relatively near the static water level of the Muhaiwir aquifer, which is of 297.6 m; below the ground surface. This may indicate the presence of hydraulic connection between both aquifers, in spite of the presence of Zor Hauran Formation between them, which is characterized by low permeability due to its lithology. The connection may be through weakness zones, such as the presence of fissures, joints and faults. The Mulussa aquifer is located at a depth interval between (440 – 520) m in the deep well KH5/6. The pumping test in this well reflects that, transmissivity coefficient was about 30 m^2/day and the discharge of the well was 864 m^3/day, which is less than the water discharge of the overlying Muhaiwir aquifer.

The performed pumping tests from different wells, which discharge from Mulussa aquifer in the studied area reflect that, the transmissivity coefficient ranges between (0.8 – 81) m^2/day, permeability coefficient ranges between (0.03 – 3) m/day, discharge of wells ranges between (22 – 864) m^3/day and the static water level ranges between (13.1 – 297.85) m; below the ground surface. The total dissolved solids ranges between (250 – 3700) mg/l, with bicarbonate, chloridic and sulphatic water types. The performed pumping tests carried out in wells, which discharge from Mulussa aquifer in other parts within the Western Dessert reflected that, the transmissivity coefficient ranges between (0.8 – 397) m^2/day, permeability coefficient ranges between (0.03 – 4.4) m/day, discharge of wells ranges between (22 – 864) m^3/day and static water level ranges between (2 – 350) m; below the ground surface (Al-Jiburi and Al-Basrawi, 2007 and 2013). The wide range variations in the hydrogeologic parameters reflect the nature and characteristics of the aquifer rocks, which are composed of dolomite and dolomitic limestone with intercalations of marl and claystone. 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, which are represented by direct rainfall and intermittent valleys. The salinity increases generally with depth. Predominant water types are bicarbonate, chloridic and sulphatic. The groundwater of Mulussa aquifer represents the best quality of available water in Rutbah town and surrounding areas.

▪ **Ga'ara Aquifer**

The Ga'ara Formation is exposed only in the Ga'ara Depression within the studied area. It is composed mainly of sandstone with calystone and siltstone. The formation is penetrated by different wells within the studied area, but it is mainly partially penetrated by most of the drilled wells and the maximum total thickness is 720 m in the deep well KH5/1 (Table 5).

It is proposed that there are two aquifer zones within the Ga'ara Formation (Consortium, 1981). The upper zone was penetrated by most of the drilled wells, while both zones were penetrated by the deep wells KH5/1, KH5/2, KH5/3, KH5/5 KH5/6 KH5/7 and KH5/8 within the map area. The available hydrogeological information indicates that the presence of hydraulic connection between both zones within the studied area is very rare. The static water level in the upper zone of Ga'ara aquifer is deeper than the static water level in Mulussa perched aquifer. The hydrogeological information in the deep well KH5/1 reflects no hydraulic connection between both zones, as indicated by different static water levels, also the quality and salinity of the water are different. There is no high difference in static water levels for both zones within the deep well KH5/8, however, there is no hydrochemical analysis for the water of the upper zone, for comparison purpose.

Table 5: Information of the drilled wells which penetrated Ga'ara Formation (GEOSURV, 1976 and Consortium, 1981)

Well No.	Depth (m)	Thickness (m)	Penetration
BH5/8	326.5 – 750	423.5	Total
BH5/1	0 – 720	720	Total
BH5/2	154 – 870	716	Total
BH5/3	385 – 1055	670	Total
BH5/5	92 – 385	293	Total
BH5/6	532 – 560	28	Total
BH5/7	242 – 700	458	Total
RW-3	167 – 400	233	Partial
RW-5	120 – 420	300	Partial
RW-8	143 – 144	1	Partial
RW-9	162 – 167	5	Partial
BH5	325 – 503	178	Partial
BH2	80 – 505	425	Partial
BH3	57.5 – 240	182.5	Partial
BH6	229.5 – 280.1	50.6	Partial
BH15	333 – 362	29	Partial
BH16	491 – 565	74	Partial

The two aquifer zones are also encountered in the deep well KH5/3. No pumping tests were carried out for the upper aquifer in this well, but pouring test was performed in order to determine the hydraulic parameters for the upper layers, due to deep water level, which is 461 m; below the ground surface (Consortium, 1981). The estimated hydraulic parameters of the upper aquifer reflect that, the transmissivity coefficient was about 200 m^2/day, permeability coefficient was 1.3 m/day and the static water level was 461 m; below the ground surface. Pumping test was carried out for the lower aquifer together with the Suffi aquifer within the depth interval between (905 – 1169) m; below the ground surface. The results of the pumping test reflect that, the transmissivity coefficient was 36 m^2/day, permeability coefficient was 0.14 m/day, discharge of the well was 704 m^3/day and salinity of water ranges between (1628 – 1912) mg/l. In the deep wells KH5/5 and KH5/7, the saturated layers reflect the presence of one aquifer within the Ga'ara Formation. The aquifer within the deep well KH5/5 reflects a perched nature, over the underlying Suffi aquifer; due to presence of unsaturated layers separate both aquifers (Consortium, 1981). The results of the pumping tests in the deep wells KH5/5 and KH5/7 reflect that, the transmissivity coefficient was 95 and 170 m^2/day, permeability coefficient was 0.5 and 0.7 m/day, discharge of the wells was 311 and 269 m^3/day and static water level was 253.6 m and 390 m; below the ground surface for both wells KH5/5 and KH5/7, respectively.

Pumping tests were carried out in other wells from Ga'ara aquifer. In the deep well KH5/8; the depth interval between (390 – 400) m, which represents the upper zone was tested and reflected low water discharge with static water level of 318 m; below the ground surface. The lower zone in this well was tested and reflected moderate water discharge with static water level of 309.65 m; below the ground surface and the salinity of ground water in this zone was 1914 mg/l, while no data of water analysis was available from the upper zone; for comparison. Pumping test was carried out in the deep well KH5/1 for the upper zone within the depth interval (180 – 186) m, which reflected low water discharge and with static water level of 180.58 m, below the ground surface, and salinity of water was 514 mg/l. The test of the lower zone in this well within the depth interval between (400 – 730) m reflected good water discharge with static water level of 83.5 m; below the ground surface, while salinity of water was 2200 mg/l. In the deep well KH5/2, the upper zone was tested within the depth interval between (266 – 450) m, and reflected very low water discharge, which may indicate unsaturated condition in this zone. The lower zone was tested within the depth interval between (580 – 635) m, and reflected moderate water discharge with static water level of 335.4 m; below the ground surface, and water salinity was 1120 mg/l. In the well RW-5, the upper zone was tested within the depth interval between (375 – 396) m, and reflected moderate water discharge with static water level of 343 m; below the ground surface and salinity of water was 1744 mg/l. The upper zone in the wells BH5, BH6, BH15 and BH16 was tested with other aquifers, while no test was carried out in the wells BH2 and BH3 because they did not contain water. The performed pumping tests carried out in wells, which discharge from Ga'ara aquifer within the studied area, reflected that the transmissivity coefficient in the upper zone ranges between (0.5 – 620) m^2/day and in the lower zone between (10 – 250) m^2/day, permeability coefficient in the upper zone ranges between (0.1 – 13.9) m/day and in the lower zone between (8.9 – 19) m/day, discharge of water ranges between (48 – 540) m^3/day and (226 – 2872) m^3/day in the upper and lower zones, respectively. The static water level ranges between (29.8 – 461) m and (83.5 – 379.5) m; below the ground surface in the upper and lower zones, respectively. Generally, the transmissivity of the lower water zone in Ga'ara Formation seems to be more uniform than that of the upper zone. The total dissolved solids (salinity) in upper zone ranges between (318 – 2279) mg/l, while in the lower zone is mostly higher and ranges between (1120 – 2208) mg/l (Al-Jiburi and Al-Basrawi, 2007 and 2013).

The recharge within the upper water zone is mainly from rainfall and runoff from intermittent streams, either directly or through the overlying rocks. Various chemical types of water occur, as chloridic, sulphatic and bicarbonate water. The main factors involved in the water mineralization and chemical type are lithologic composition of rocks, conditions of downward water leakage to the groundwater bearing beds of Ga'ara Formation, in addition to possible upward leakage due to hydrostatic pressure of deep and confined water.

▪ **Suffi Aquifer**

The Suffi Formation is not exposed on the surface but it is penetrated during drilling of deep wells within the studied area (This formation is locally named and not announced officially), as a part of the hydrogeological investigations of Block 5 (Consortium, 1981). The formation is composed mainly of sandstone with claystone and carbonate beds. It represents with the Ga'ara Formation the most important groundwater resources within the studied area, due to their wide extension and contain large amount of water. The formation is partially penetrated by the drilled deep wells KH5/1, KH5/2, KH5/3, KH5/5, KH5/6, KH5/7 and KH5/8, as shown in Table (6).

Table 6: Information of the drilled wells which penetrated Suffi Formation (GEOSURV, 1976 and Consortium, 1981)

Well No.	Depth (m)	Thickness (m)	Penetration
KH5/1	720 – 1600	880	Partial
KH5/2	870 – 950	80	Partial
KH5/3	1055 – 1200	145	Partial
KH5/5	385 – 850	465	Partial
KH5/6	560 – 1250	690	Partial
KH5/7	700 – 750	50	Partial
KH5/8	750 – 802.5	52.5	Partial

The available hydrogeological information in the deep well KH5/1 reflects the presence of two groundwater zones within the Suffi Formation. Only, the upper zone was penetrated by the deep wells KH5/2 and KH5/8. Pumping tests were carried out for the upper and lower zones in the deep well KH5/1. The test for the upper zone was carried out within the depth interval between (770 – 858) m, but not good isolation was performed with Ga'ara aquifer; therefore, there is mixing of water from both aquifers. Accordingly the test is not successful and is obscure.

The test of the lower zone was carried out within the depth interval between (855 – 1350) m. It reflected water discharge of 535 m^3/day and a transmissivity coefficient of 37 m^2/day, with static water level of 57.8 m; below the ground surface. No pumping test was carried out for the upper zone in the deep wells KH5/2 and KH5/8. There is no hydrochemical analysis of groundwater samples from the upper zone, but there is one analysis of groundwater sample from the lower zone within the deep well KH5/1, which reflects salinity of 8316 mg/l, with chloridic water type in the lower part of Suffi Formation.

Pumping test was carried out in the deep well KH5/3 for both Suffi aquifer and the lower zone of Ga'ara aquifer within the depth interval between (905 – 1169) m; below the ground surface, the results reflect that, the transmissivity coefficient is 36 m^2/day, permeability coefficient is 0.14 m/day, discharge of the well is 704 m^3/day, draw down is 24.4 m and the ground water level is 317.6 m; below the ground surface. Another pumping test was carried out in the deep well KH5/5 for the Suffi aquifer; separately within the depth interval between (500 – 750) m; below the ground surface, the results reflect that, the transmissivity coefficient was 350 m^2/day, discharge of the well was 1000 m^3/ay and the static water level was 302 m; below the ground surface. No pumping test was carried out for the other deep wells KH5/6 and KH5/7 (Al-Jiburi and Al-Basrawi, 2007). The hydrochemical analysis of water sample from the deep well KH 5/5 shows salinity of 2332 mg/l with Na-Chloride 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 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 be extended 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 was determined. It seems that the water bearing beds of both formations are in a relatively close hydrodynamic interconnection, at 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, 2007 and 2013).

The hydrogeological parameters within the carbonate and clastic aquifers reflect the hydraulic characteristics of these aquifers within the carbonate and clastic formations. High values of transmissivity coefficient indicate the presence of canals and cavities within the rocks of the formations, which represent good passages, for the ground water. The variation in the transmissivity values reflects the geological and structural properties, in addition to karstification and the presence of fractures, joints, fissures and faults; the same holds good with respect to permeability coefficient, since they are both related directly. Therefore, well discharge varies according to variation in permeability and transmissivity, as these values are high, then well discharge will be high also (Al-Jiburi, 2002, Al-Jiburi and Al-Basrawi, 2007, 2009 and 2013).

The main source of recharge to the aquifers within the studied area is the direct rainfall and/ or infiltration losses from surface water run-off valleys. Significant recharge over the area occurs through many sinkholes, depressions and highly permeable valley beds. High permeability is a result of good circulation of water which is increased by concentrated infiltration. The main ground water discharge zone of the aquifers to the east of the water divide is located east outside the border of the studied area along the Euphrates River and it follows the regional fault zone. Along this zone the fractures are enlarged by solution due to good permeability of rocks and morphology of the area to allow upward discharge of water. An amount of water is issued by springs. The discharge zones of the groundwater to the west of the water divide is toward the west mainly outside the Iraqi borders.

DISCUSSION

The present study, according to the available updated hydrogeological information in the studied area reflects the hydrogeological characteristics of the studied area. The main character in the studied area is the presence of a water divide to the west of Rutbah town. This water divide causes the regional direction of the groundwater movement to flow in opposite directions, east and west, as indicated in this study (Fig.2) in contrast with all previous hydrogeological studies. All the previous hydrogeological studies and investigations revealed that the direction of the groundwater flow, within the Iraqi Western Desert, is generally towards east and northeast, following the discharge zones along the right bank of the Euphrates River.

The presence and extension of this water divide within this part of the Iraqi Western Desert may reflect the effect of Hail-Rutbah Arch. The result in this study is highly comparable to the assumption proposed by Henson (1951) with respect to the extension of Hail Arch and distribution of basins within the structural pattern of the basement in Iraq and the adjacent Arab countries (Fig.3).

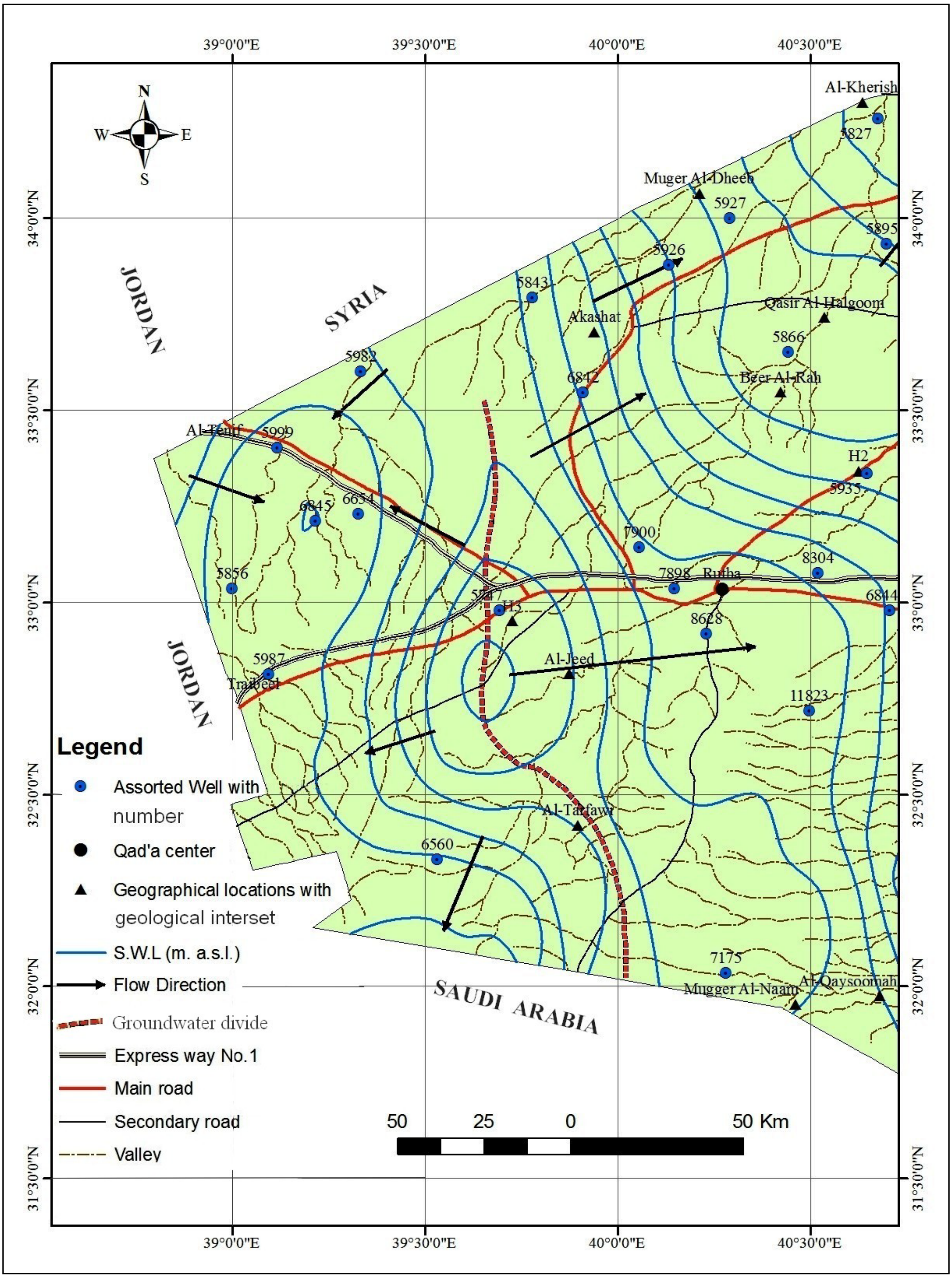

Fig.2: Hydrogeological map shows the static water level and direction of the groundwater flow

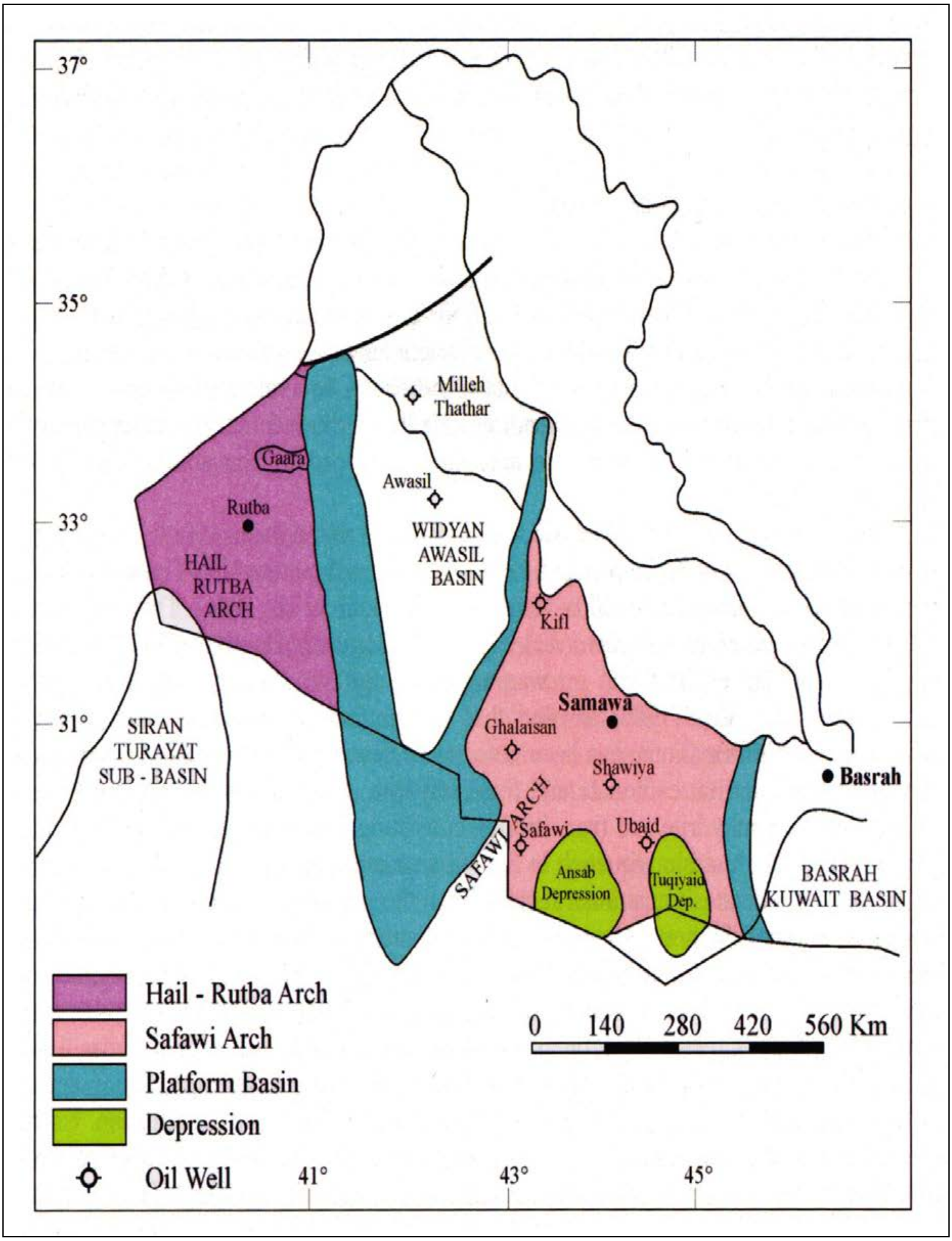

Fig.3: Extension of Hail Arch and distribution of basins within the structural pattern of the basement in Iraq (after Henson, 1951 and Ma'ala, 2009)

The present study can add new information about the hydrogeological characteristics of the Iraqi Western Desert in general, and its western part in particular. Accordingly, more detailed hydrogeological investigations are recommended with respect to the border areas, in order to get more hydrogeological information and characteristics of the joint aquifers with the adjacent countries.

The lithology of an area plays an important role in determining the hydrogeological and hydrochemical characteristics of the groundwater. The lithology of the water bearing formations within the studied area is variable. There are two main types of rocks: clastics and carbonate rocks. Generally, the clastic rocks are characterized by granular porosity.

The permeability depends mainly on grain size and the cementing materials. It is high in loose and low cemented sediments, and may reveal high water discharges of wells. In carbonate rocks, the presence of fissures, fractures and cavities are considered the most important factors affecting the permeability, but angular porosity has no clear effect on permeability. Accordingly, the increase of cavities, fractures and fissures causes increase of water discharge from wells, in carbonate rocks. The presence of muddy materials within these cavities and fractures causes reduction of water from wells. Salinity and quality of the groundwater are also highly affected by the lithology of the water bearing formations.

The main source of water recharge within the studied area is rainfall, as well as, run off in the intermittent valleys, in form of infiltration losses into shallow aquifers. Catchment areas may extend into the adjacent countries; also percolation through valley beds is a most important recharge. Many shallow valleys may disappear within the studied area completely into valley sediments and/ or in playas, which are of karst origin. Flood water of other valleys is lost on percolation either completely or partly.

The zones of discharges are located into two different directions, far away from the water divide, which is located to the west of Rutbah town, in a mainly North – South trend. So that the discharge zone of the eastern part of the studied area is continuing to the east and considered as the main discharge zone of the Western Desert along the right bank of the Euphrates River. While the discharge zone of the western part is located to the west within the borders of the adjacent countries.

Hydrochemistry of the groundwater within the studied area varies vertically and laterally. Generally, salinity of the groundwater increases with depth and towards discharge zones. There are three main factors affecting the chemical composition of the 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 studied area. This is attributed to the direct recharge of fresh water, but its quality is influenced by the lithology of the rocks. The bicarbonate water type reveals the source of recharge of fresh water. Generally, salinity of the groundwater ranges from fresh water to slightly brackish with the presence of chloridic, sulphatic and bicarbonate water types, as indicated in this study (Fig.4).

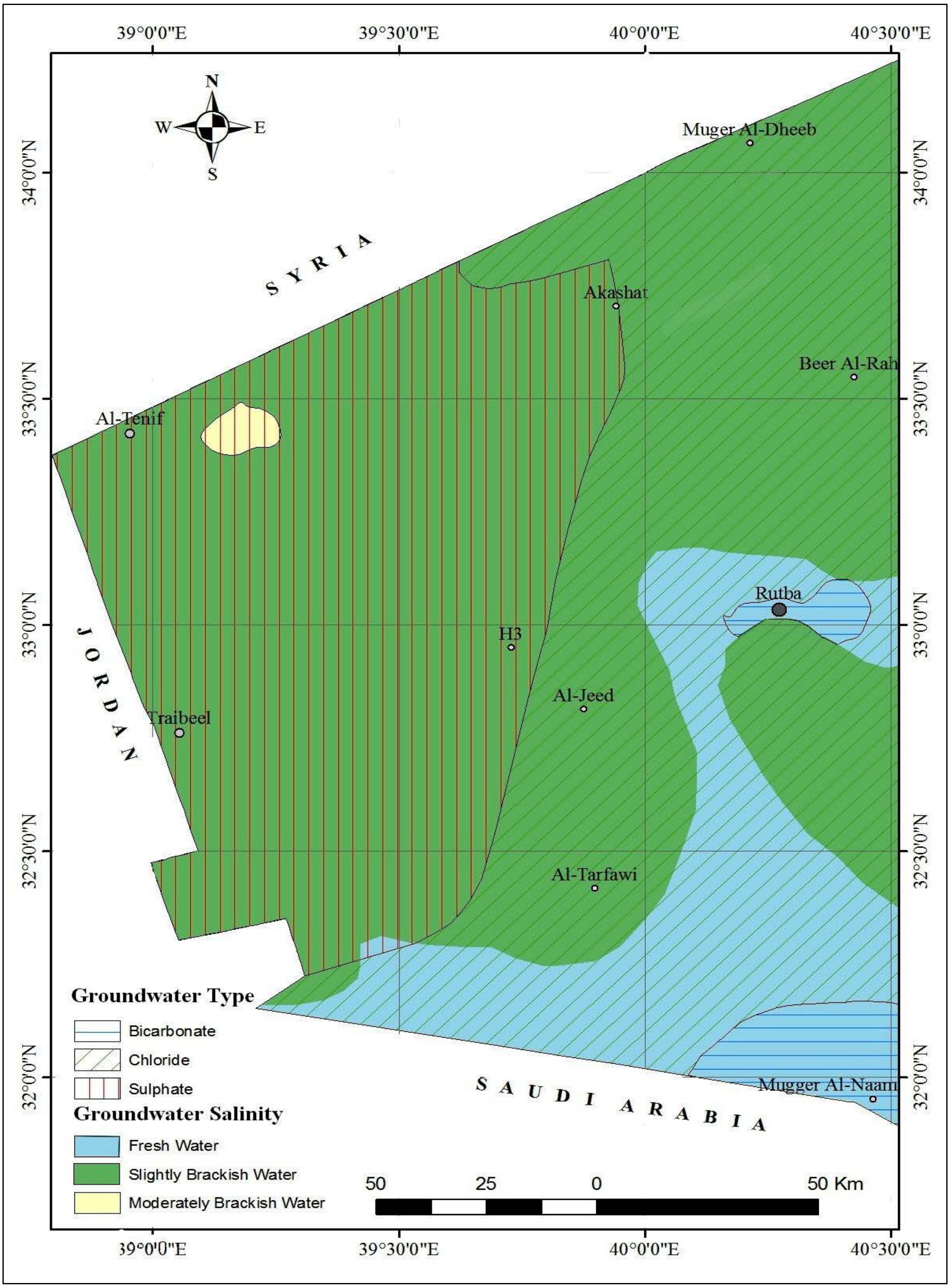

Fig.4: Hydrogeological map shows the salinity and type of the groundwater (mg/l)

The hydrogeological investigations and studies in the Iraqi Western Desert (GEOSURV, 1976, Idrotechneco, 1977 and Consortium, 1978 and 1981, Al-Jiburi and Al-Basrawi, 2007 and 2013) 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 and between Ga'ara and Suffi aquifers. These investigations and studies also revealed the presence of complex and mixed aquifers with unique hydraulic system of wide range hydraulic continuity including different aquifers of different formations (Akashat, Digma, Tayarat, Ms'ad and Rutbah formations). It can be assumed that Ga'ara and Suffi formations represent an aquifer system on regional scale within the studied area, while Akashat, Digma and Tayarat formations represent another aquifer system within the northern part of the area.

CONCLUSIONS

- The available updated hydrogeological information in the studied area revealed the presence of water divide to the west of the Rutbah town, mainly with North – South trend. This water divide causes the groundwater to flow into opposite directions of its trend. The results of this study add new information on the hydrogeological characteristics of the Western Desert in general and its western part in particular.
- The main water bearing formations underlying the studied area from the youngest to the oldest are represented by: Akashat, Digma, Tayarat, Ms'ad, Muhaiwir, Mulussa, Ga'ara and Suffi. Other formations, however, are not considered as yield aquifers either due to their locations above the regional groundwater level, or lithologic and structural properties or due to local extension. Ga'ara aquifer is considered the most important one, on regional scale, due to its wide extent and high content of water.
- The recharge sources of the groundwater in the studied area are mainly direct infiltration from rainfall and/ or runoff from the intermittent valleys in form of percolation into the shallow aquifers.
- A hydraulic continuity is assumed 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 discharge zones of the groundwater occur in the area on both sides of the water divide. In the eastern part of the studied area the discharge zone is far away to the east, along the right bank of the Euphrates River. In the western part of the studied area the discharge zone is located mainly outside the Iraqi borders.
- The regional trend of the groundwater movement is generally towards east and northeast with respect to the eastern part of the studied area, i.e., following the discharge zone of the Western Desert along the right bank of the Euphrates River. While, it is towards the west with respect to the western part of the studied area.
- The aquifers within the studied area 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 (inter granular) porosity.
- Salinity of the groundwater in the studied area ranges mainly between (<1000 – 3000) mg/l. The quality of the groundwater varies from bicarbonate, chloridic and sulphatic water type.

- The hydraulic conditions and chemistry of the aquifers are closely linked to the stratigraphic, lithologic, structural and topographic features of the water – bearing formations within the studied area.

RECOMMENDATIONS

From this study the following can be recommended:

1. More detailed hydrogeological investigations are need, with respect to the border areas in order to provide suitable hydrogeological information and characteristics of the joint aquifers with the adjacent countries.
2. Monitoring or continuous observations of groundwater level in selected and representative wells within the studied area in order to provide new data, which are necessary for executing groundwater regime and to detect any variations that may occur in water level.
3. Continuous collections and analyses of groundwater samples from representative wells within the studied area, based on monthly or seasonal bases as available aid to predict any change in chemical composition and water types.
4. Drilling new deep and observation wells in selected areas on both sides of the water divide, 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 of good water quality.
5. Construction of small dames on the main valleys within the studied area to provide water for recharging groundwater aquifers through outcrops of formations within valley basins, the stored water also can be used for municipal and irrigation purposes in the region.
6. Establishment of gauging stations on valley basins, in order to record valley runoff, which will aid in evaluation of the groundwater resources.
7. Installation of hydrometeorological stations, aiming to provide continuous observations of the hydrometeorological parameters, which will aid also in evaluation of the groundwater resources.
8. Preventing heavy pumping in zones with potentially sufficient groundwater resources, within the studied area. Heavy pumping could deteriorate gradually the groundwater quality and extract volumes of less mineralized groundwater.
9. Preventing the products of urbanization and industrialization, which have caused serious environmental impacts, by contaminating the groundwater.
10. More developed management for water resources, irrigational and agricultural techniques must be applied to avoid deterioration of water quality and soils, in accordance with more developed countries.

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