Iraqi Bulletin of Geology and Mining *Vol.14, No.2, 2018* *p 121 – 137*

HYDROGEOLOGICAL AND HYDROCHEMICAL SETTINGS OF THE QUATERNARY AND PRE-QUATERNARY AQUIFERS IN THE SOUTHWESTERN PART OF THE MESOPOTAMIA – IRAQ

Naseer H. Albasrawi[1], Hussein A. Jassas[2] and Jamal H. Awad[3]

Received: 01/ 01/ 2018, Accepted: 03/ 05/ 2018
Key words: Aquifer, Water Type, Salinity, Flow Direction, Transmissivity, Mesopotamia, Iraq

ABSTRACT

The spatial variation of the hydrogeological and hydrochemical characteristics of the main upper aquifers in southwestern part of the Mesopotamia is investigated, based on sampling from sixteen groundwater wells of different depths and locations, drilled by Iraq Geological Survey (GEOSURV) during dry season of 2011. Pumping tests were conducted to evaluate the hydrogeological parameters in these wells. The suitability of groundwater for different uses and the hydrochemical evolution of groundwater were evaluated using the field measurement of the physiochemical parameters (pH and EC) and analyzing the groundwater samples for major cations and anions. The hydrochemical and hydrogeological results were compared with previous hydrogeological data in the area and found them compatible. The Quaternary sediments cover most of the study area and represent the main intergranular-type aquifer, whereas the carbonate rocks of the Euphrates Formation (Lower Miocene) and the Dammam Formation (Upper Eocene) represent the main fracture-type aquifers in the southwestern parts of the area. In general, the groundwater quality in the shallow aquifer of the Quaternary sediments is saline to brine water of chloridic type, except for the zones along the rivers and stream where the groundwater is brackish. The groundwater in the fracture aquifer in the southwestern parts is of sulfate type, brackish to highly brackish water. There is a significant spatial variation in the hydrogeological parameters due to the lateral variation in the Quaternary sediments and the variation in the permeability of the pre-Quaternary sediments. This variation influences the hydrochemical properties of the groundwater in the study area. The main factor that affects the evolution and quality of chloride-type groundwater in the Quaternary aquifer is evaporation, while in Pre-Quaternary fracture-type aquifer the chemical evolution of the groundwater is controlled by the dissolution of the evaporate rocks (gypsum and anhydrite) and the weathering of the carbonate rocks. The groundwater in the Quaternary sediments is not suitable for any use due to the high salinity; whereas the groundwater of the Pre-Quaternary fracture-type aquifer can be used for livestock drinking and to irrigate some salt tolerant crops especially when considering the high infiltration capacity of the sediments.

[1] Senior Chief Geologist, Iraq Geological Survey, (GEOSURV) P.O. Box 986, Baghdad, Iraq, e-mail: al_basrawi1262@yahoo.com
[2] Chief Geologist, Iraq Geological Survey, (GEOSURV) P.O. Box 986, Baghdad, Iraq.
[3] Lecturer, Ministry of Higher Education and Scientific Research, Baghdad, Iraq.

الوضع الهيدروجيولوجي والهيدروكيميائي لخزانات ترسبات العصر الرباعي وقبل الرباعي في الجزء الجنوبي الغربي من السهل الرسوبي/ العراق

نصير حسن البصراوي، حسين عبد جساس و جمال حميد عواد

المستخلص

تمت دراسة التغيرات الرئيسية للصفات الهيدروجيولوجية والهيدروكيميائية للمياه الجوفيه في الخزانات العلوية الرئيسية في الجزء الجنوبي الغربي من السهل الرسوبي، من خلال نمذجة 16 بئرا بمختلف الأعماق والأماكن تم حفرها من قبل هيأة المسح الجيولوجي العراقية خلال فترة الجفاف من عام 2011. اجريت عمليات الضخ الاختباري لتلك الآبار لتقييم الوضع الهيدروجيولوجي فضلا عن إجراء تقييم هيدروكيميائي من خلال قياس الحامضية والتوصيلية الكهربائية في الحقل إضافة الى النمذجة الكيميائية للابار المذكوره أعلاه وتحليل أيوناتها الرئيسية الموجبة والسالبة، وقد بينت النتائج والاختبارات انها متسقه مع المعلومات القديمة المتوفرة عن المنطقة. تغطي ترسبات العصر الرباعي غالبية منطقة الدراسة وتضم الخزانات الغروية الرئيسية، في حين تشكل خزانات تكويني الفرات والدمام الكاربوناتية الحاوية على التكسرات الخزانات العلوية الرئيسية في الجزء الجنوبي الغربي من المنطقة. المياه الجوفية في الخزانات الضحلة ضمن ترسبات العصر الرباعي مالحة جدا الى مياه المحلول الملحي وذات نوعية كلوريدية، عدا بعض المناطق الممتدة قرب الانهار والجداول حيث تكون المياه الجوفيه اقل ملوحة. أما مياه الخزانات الكاربوناتية فهي ذات نوعية كبريتاتية وملوحتها قليلة الى متوسطة. هنالك إختلافات مهمة في العوامل الهيدروجيولوجية تعود الى الاختلاف الجانبي لطبيعة الترسبات في العصر الرباعي إضافة الى الاختلاف في توزيع قيم النفاذية لرواسب العصر قبل الرباعي، هذه الاختلافات تؤثر على الخواص الهيدروكيميائية في المنطقة، حيث يعتبر التبخر العامل الرئيسي الذي يجعل نوعية المياه في الترسبات الحديثة ذات نوعية كلوريدية، فيما تمتاز مياه الخزانات قبل العصر الرباعي بأنها مياه كبريتاتية ناتجة من إذابة صخور المتبخرات (الجبس والانهايدرايت) إضافة الى عمليات التجوية للصخور الحاوية. تعتبر مياه خزانات العصر الرباعي غير ملائمة لأي إستخدام نتيجة ملوحتها العالية، فيما تمتاز مياه خزانات العصر قبل الرباعي بإمكانية استخدامها لشرب الحيوانات وري بعض المحاصيل المتحملة للملوحة خصوصا عندما تكون قابلية النفاذية للتربة عالية.

INTRODUCTION

Iraq, as other countries in the Middle East, is facing severe water shortages across most parts of the country, where more than 7.6 million Iraqis lacking access to safe drinking water, and an agriculture sector suffering from years of drought (UNESCO, 2010). The hydrological system has endured dramatic change over the last 30 years as a result of rising demand for a resource of progressively more limited supply. Thus, the reservoirs, lakes and rivers are diminished to critical levels due to the shortage of perennial surface water. The climate changes and the hydraulic structures in the neighbor countries, have diversely affected the Tigris and the Euphrates rivers. These rivers, which represent the primary source of water, have fallen to less than a third of normal capacity with deterioration of its water quality. In the light of this fact, a comprehensive view of groundwater resources in the country is an important issue in helping local and national authorities to identify accurately the water resources and manage sustainably this valuable resource. This can be done through conducting hydrogeological survey campaigns and analyzing the hydrogeological database using modern scientific tools and methods to fill the significant spatial and temporal gaps of the outdated studies.

The study area represents the southwestern part of the Mesopotamia and covers more than 15000 Km^2 of the extensively cultivated Iraqi flood plain. The evaluation of the hydrogeological conditions of this area has been previously carried out by different workers as part of the Government's efforts to cover the shortfall in surface water. Among these workers are (Parsons, 1957; Krasny, 1982; Shareef, 1982; GEOSURV, 1983; Araim, 1990; Shareef and Al-Dabbaj, 1999; Al-Basrawi, 2004; Krasny *et al*., in Jassim and Goff, 2006; and Al-Jiburi and Al-Basrawi, 2010 and 2011). The previous studies dealt with groundwater flow system, salinity and chemical type of water, and concluded that there is a significant spatial variation in quality and quantity of groundwater which is generally not suitable for different uses. In general, the understanding of groundwater dynamics and availability in Iraq is incomplete and needs to be updated through using new data and modern techniques. This study aims to evaluate the hydrogeological and hydrochemical situation of southwestern part of the Mesopotamia by combining old and modern hydrogeological data. In this work the authors discuss the groundwater origin and hydrochemical evolution, groundwater flow direction, recharge and discharge zones, and the suitability of the groundwater for different uses.

The study area is located in the south of Iraq between latitude 31° 00' 00", 32° 00' 00" and longitude 45° 00' 00", 46° 30' 00" and covers 15700 Km^2 (Fig.1). The topography of the area is represented by a digital elevation model (DEM, 90 × 90 m) in meter above sea level (m. a.s.l.) (Fig.1). The elevation ranges from 7 m (a.s.l) in the southeastern part to 96 m (a.s.l.) in the southwestern part. The general characteristics of the climate in the area of interest were obtained from the data recorded at Al-Nasiriya and Samawa meteorological stations during the period (1970 – 2008) (Table 1 and Fig.2). The area is characterized by Mediterranean climate of dry hot summer and cold rainy winter with annual mean rainfall of about 129 mm, annual mean potential evaporation of about 2995 mm, annual mean relative humidity of about 41% and annual mean temperature is about 25 °C. According to the aridity index (UNEP, 1992 and IOM, 2000), the study area is classified as an arid region.

River-fed agriculture is one of the most important activities of the people in this region. The Euphrates River and Al-Gharraf River, which is branched from the Tigris River, represent the main source of water in the area. However, during the last three decades the flow rate of these two rivers has declined significantly due to the huge number of hydraulic structures in the neighbor's upstream countries, especially in Turkey. Therefore, groundwater has been used to compensate the shortage in surface water.

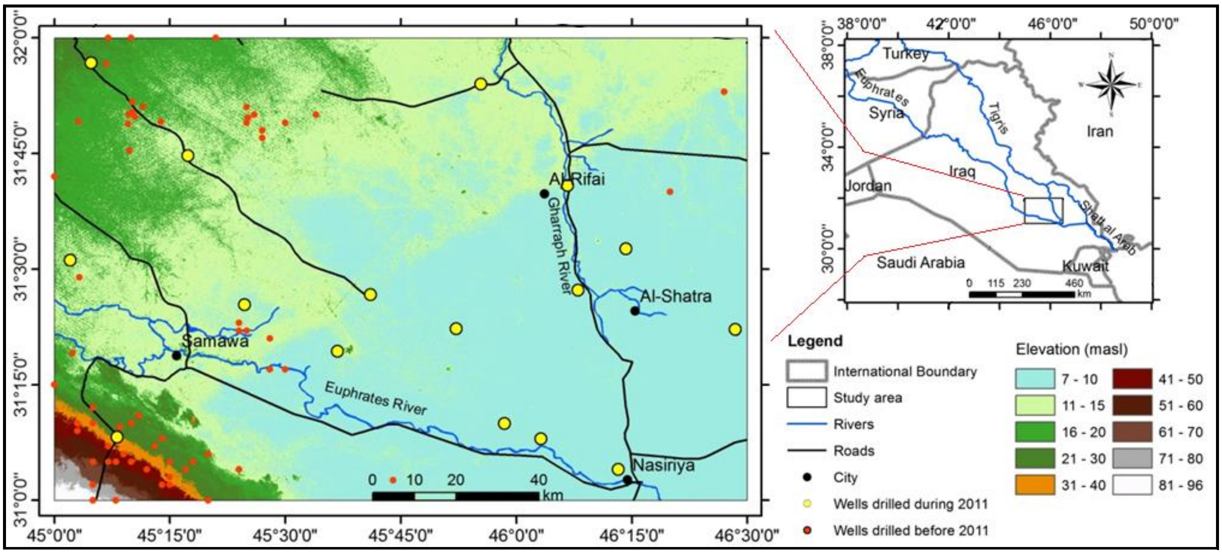

Fig.1: Location map of the study area showing the topography, represented by DEM and the positions of the sixteen wells drilled during 2011 (yellow circles) and the wells of the old database (red circles)

Table 1: Monthly mean values of climatic parameters in Al-Samawa and Al-Nasiriya meteorological stations for the period (1970 – 2008)

Months	Rainfall (mm)	Temperature (°C)	Relative humidity (%)	Pan evaporation (mm)	Wind speed (m/sec)
OCT.	6	26.5	36.65	224	2.95
NOV.	14.65	18.55	51.9	114.5	2.8
DEC.	21.1	13.1	65.35	74.2	2.75
JAN.	30.15	11.3	67.85	73.4	2.95
FEB.	19.65	14.15	58.6	106	3.45
MAR.	22.5	18.45	49.45	165	3.85
APR.	11.1	24.95	40	243	4.0
MAY	3.25	30.9	29.75	349.5	4.05
JUNE	0.1	34.8	22.85	433.5	4.95
JULY	0	36.45	22.1	469.5	4.85
AUG.	0	36.15	23.25	418.5	4.35
SEPT.	0.35	33.15	27.05	323.5	3.55
TOTAL/ AVERAGE	**129**	**25**	**41.2**	**2995**	**3.7**

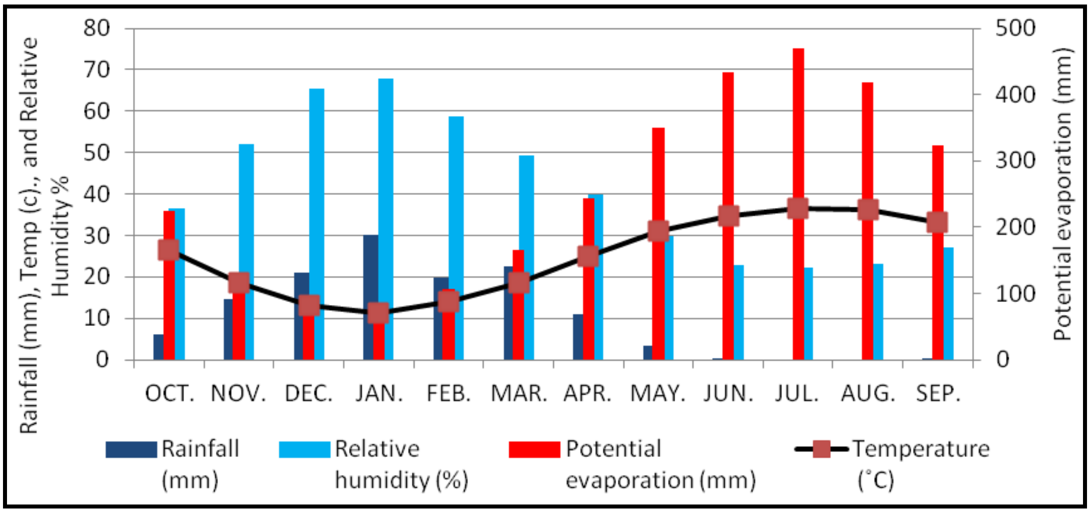

Fig.2: Monthly mean values of Rainfall (mm), Potential evaporation (mm), Relative humidity (%) and Temperature (°C) in Al-Samawa and Al-Nasiriya meteorological stations in the period (1970 – 2008)

GEOLOGICAL AND STRUCTURAL SETTINGS

The geological and structural settings of the study area is well described by Deikran and Mahdi (1993). More than 95% of the area is covered by Quaternary sediments which consist mainly of the Flood Plain sediments of the Euphrates and Tigris rivers (Fig.3). These sediments host the main Quaternary groundwater aquifer and generally consist of stratified clay, silt and sand. The Pre-Quaternary sediments are exposed at the southwestern part of the study area and consist mainly of carbonate rocks of the Euphrates and Ghar formations (Lower Miocene) and Dammam Formation (Eocene).

Structurally, the majority of the map area lies within the Unstable Shelf (Mesopotamian Zone) while the rest of the area (small area of desert plateau) lies on the Stable Shelf (Salman subzone) of Buday and Jassim (1984), which have been recently identified as the Mesopotamia Foredeep and Inner Platform of the Arabian Plate respectively (Fouad, 2012). The Abu-Jir Fault Zone extends along the southwestern part of the study area and consists of several NW – SE trending faults that extend for about 600 Km from Anah Graben, across the Euphrates River valley to Hit, Awasil, Abu-Jir, Shithatha, along the western side of the Euphrates River through Kerbala, Najaf and Samawa to meet Al-Batin lineament west of Basrah and northwest Kuwait (Fouad, 2007). The faults in the study area are subsurface strike slip faults and their effect is represented by a series of springs and depression (like Sulaibat depression) as shown in the southwestern part of the study area (Fig.3). Below is a brief description of the pre-Quaternary and Quaternary sediments according to Deikran and Mahdi (1993):

- **Dammam Formation (Eocene)**

The formation crops out at the southwestern part of the study area. It exhibits either discontinuous exposures or covered by a thin mantle of polygenetic sediments. Stratigraphically, the formation is divided into three members, two of them occur in the area of interest; the Upper Member (Upper Eocene) and Middle Members (Lower Eocene). The Middle Member covers the majority of the southwestern part, either in the form of outcrops or hidden beneath a mantle of polygenetic sediments. This member was divided into two parts according to lithographic limestone beds, which consist of massive and bedded whitish grey recrystallized dolomitic limestone. Only the upper part (7 – 10 m) of this member crops out in the map area which consists of massive, white, fairly hard, partly chalky dolomitic limestone. The upper member represents the uppermost beds of Dammam Formation. In the map area, it is exposed as small patches at the southwestern part and is characterized by reddish brown silty claystone.

- **Ghar Formation (Lower Miocene)**

The Ghar Formation is exposed in the southwestern part of the map area, with exposed thickness of about 5 m. It is composed of greenish grey massive sandy marly limestone, with abundant sand grains at the base.

- **Euphrates Formation (Lower Miocene)**

The Euphrates formation is composed of massive yellowish grey to grey, hard, highly cavernous conglomerate at the base. The conglomerate is overlain by thick bedded yellowish grey, porous shelly limestone. The exposed thickness, of the formation in the area is about 6 m.

- **Zahra Formation (Pliocene)**

The Zahra formation locally overlays the Dammam Formation and consists of fluvio-lacustrine and karst-fill facies of fresh water limestone, marl, and marly sandstone.

- **Quaternary Sediments**

The Quaternary period includes different types of sediments which are classified according to their genesis as fluvial, lacustrine, aeolian, polygenetic and anthropogenic sediments.

– **Polygenetic sediments (Pleistocene-Holocene):** It is restricted to desert plateau covering the Tertiary sediments. Lithologically, they are composed of unconsolidated admixture of sand, silt, clay and rock fragments. Its thickness does not exceed 1.0 meter.

– **Flood plain sediments:** The flood plain sediments are contaminated in their upper part by irrigation channel sediments. The sediments are distributed all over the map area except the southwestern corner, where the Tertiary sediments are exposed. The flood plain sediments were laid down by the Euphrates and Al-Gharaf Rivers. The processes of flood are held by means of main channel of the Euphrates River, distributaries and network of irrigation channels (see the map). These facies are natural levees, crevasse splay and flood plain. Lithologically, the flood plain sediments are built up of silty clays, clayey silt, silts and sands. The silt and sand are more dominant in the older layers of the floodplain and represent the groundwater aquifer in these sediments.

– **Shallow depression sediments:** Fine-texture sediments of silty clays and clayey silts are the most common constituents of these sediments. They are grayish brown and greenish grey in colour indicating stagnant or semi-stagnant water environment. They are mostly massive and aggregated, locally show impressions of lamination and banding due to colour change and grain size variation. Salt content is relatively higher than the flood plain sediments. Shells of mollusks are frequent at the surface, with humificated plant roots. Most of the shallow depression sediments, in the map area are dry, especially at the northern part, but they could be flooded by water during rainy seasons or flooding of rivers.

– **Marsh sediments:** The marsh sediments are characterized by fine texture, consisting of silty clay and clayey silt. They are rich in carbonate fraction and humificated organic materials. Greenish and bluish grey or black colours are dominant. The marshy beds are massive and rich in macro-fauna.

– **Sabkha sediments:** This type of sediments reflect the aridity of the climate in the region. It is developed in the southwestern parts of the map area, near the border with the desert area. The Sabkhas, in the map area belong to inland sabkha type. The sediments are rather complex being affected by aquatic and aeolian sedimentation with intense surface evaporation. The surface of sabkha has sandier fraction and scattered gypsum crystals, than the deeper parts. Moreover, the surface is covered by a thin and highly cracked salt crust forming a puffy surface.

– **Aeolian Sediments:** Two well-developed fields of aeolian sediments exist in the map area. The first field is in the central part, west of Al-Gharaf River and extends toward northwest. The sediments are distinct on the geological map by three geomorphologic units: barchan dune, continuous sand sheet and discontinuous sand sheet. All the aforementioned geomorphologic units of Aeolian Sediments rest mainly on the flood plain of the Euphrates River. The aeolian sand is composed essentially of fine sand with clay and silty clay with small and fragments of mollusks shells, especially near the marshy area. The source of the above sediments is mainly flood plain sediments of the Tigris and Euphrates rivers and related branches, particularly those of ancient age.

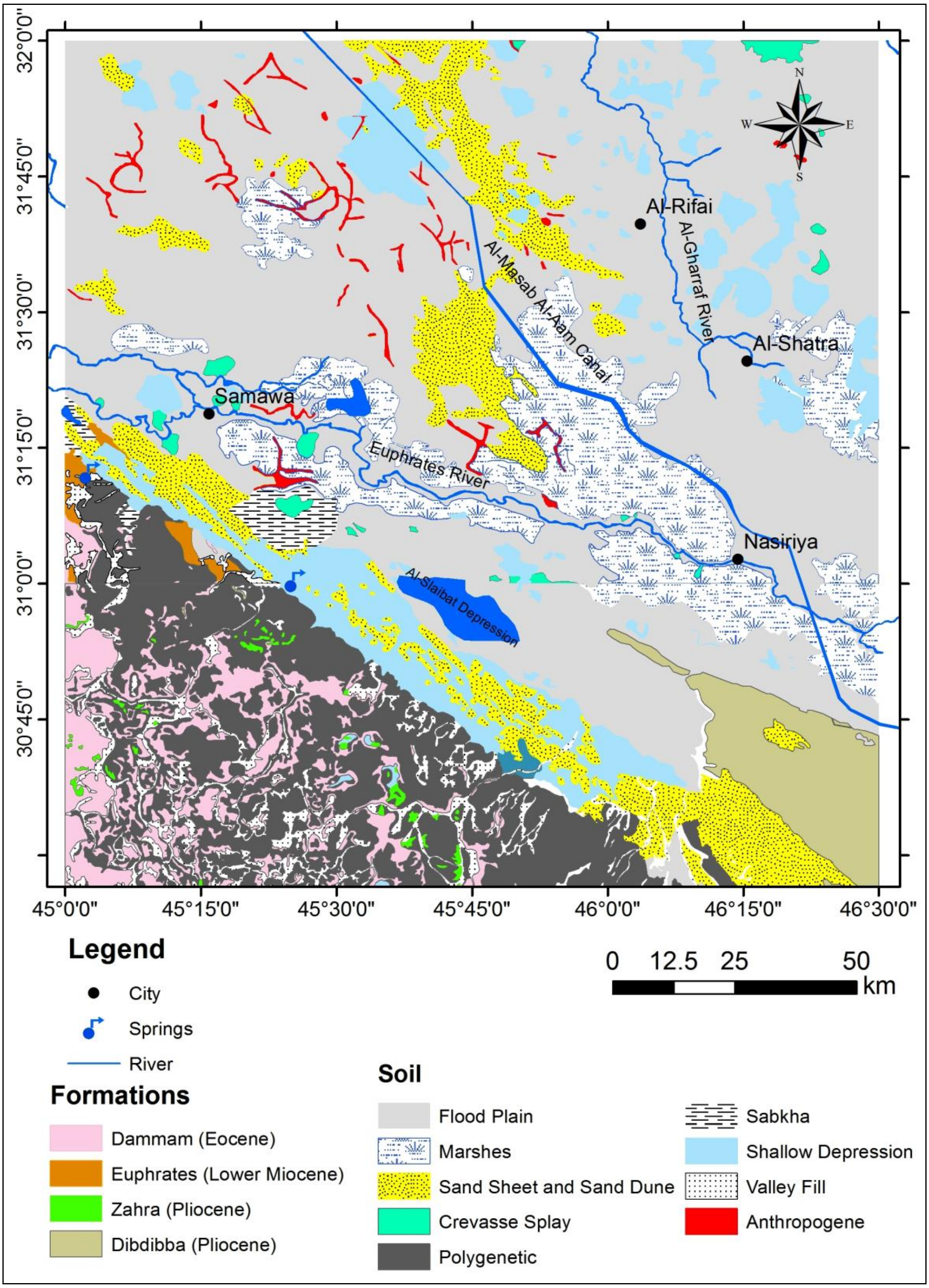

Fig.3: Geological map of the southwestern part of the Mesopotamia
(Modified after Deikran and Mahdi, 1993)

METHODOLOGY

Sixteen wells drilled in the area of interest were sampled to evaluate the hydrochemical and hydrogeological parameters (Fig.1). These wells were cleaned and developed before conducting the pumping tests, which were carried out in order to measure the hydrogeological parameters by analyzing the pumping test data by Aquifer Test Pro software (Version 2011.1). The groundwater samples were collected after pumping when pH, electrical conductivity (EC), and temperature became constant to ensure collecting fresh groundwater samples needed for accurate assessment. Sixteen groundwater samples were collected during the dry season of 2011 in clean and pre-rinsed 1 liter plastic bottles. All samples were stored in a cool box at a temperature of less than 4 °C and transported later to the water laboratory of GEOSURV to determine the cations and anions concentrations. Sample location was determined using Garmin GPS (eT rex 20) during field work and data collection. Water temperature (T), pH, and EC were measured in the field with a portable multi-parameter water analyzer (WTW-Multi 3430) device. The techniques and methods followed for analyzing the cations and anions are those given by APHA (1995).

Total hardness (TH) was calculated using the formula suggested by Hem (1985)

$$\text{TH (as } CaCo_3) \frac{mg}{L} = (Ca^{2+} + Mg^{2+}) \times 50 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

where Ca^{2+} and Mg^{2+} concentration are represented in meq/l.

The Sodium Adsorption Ratio (SAR) was calculated by the following equation given by Richards (1954) as:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Where concentrations are in meq/L

ArcGIS program was used to prepare the maps and to conduct the geostatistical analysis. Trainer diagram (Piper, 1944) was used to define the hydrochemical facies with the help of Graphical User Interface software, coded by Winston (2000). PHREEQC software (version 2.18.0.0) was used with the WATE4QF data-base, to compute analytical precision of cations and anions and to compute the Saturation Index (SI) of calcite and gypsum by comparing the chemical activities of the dissolved ions of these minerals (ion activity product, IAP) with their solubility product (K_{sp}) using the equation,

$$SI = \log \frac{IAP}{K_{3P}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

The suitability of groundwater for drinking purpose was evaluated by comparing the values of TDS, cations and anions with limits suggested by World Health Organization (WHO, 2010) and Iraqi Standard IRS (C.O.S.Q.C, 1996) as in Table 2. The suitability of the groundwater for irrigation was evaluated based on SAR and EC as in (Richards, 1954) (Table 3), and the suitability for animals was estimated according to (Ayers and Westcot, 1989) (Table 4). To evaluate the suitability of groundwater for industrial uses, the hydrochemical results were compared with the standards proposed by Salvato (1982) (Table 5).

Table 2: Suitability of groundwater for human drinking according the World Health Organization (WHO, 2010) and Iraqi Standard IRS (C.O.S.Q.C, 1996)

Ions and TDS (mg/L)	WHO Standard	Iraqi Standard
K^+	12	-
Na^+	200	200
Mg^{++}	50	50
Ca^{++}	75	50
Cl^-	230	250
$SO4^=$	250	250
$HCO3^-$	350	-
$NO3^-$	50	50
TDS	1000	1000

Table 3: Suitability of water for agricultural purposes according to Richards (1954)

SAR	Index	EC	Index
≤ 10 > 10 – ≤ 18 > 18 – ≤ 26 > 26	S_1 S_2 S_3 S_4	≤ 250 > 250 – ≤ 750 > 750 – ≤ 2250 > 2250	C_1 C_2 C_3 C_4
C_1S_1		Excellent	
C_1S_2, C_2S_1, C_2S_2		Good	
C_1S_3, C_3S_1		Permissible	
C_2S_3, C_3S_2, C_3S_3		Marginal	
C_1S_4, C_2S_4, C_3S_4 C_4S_1, C_4S_2		Poor	
C_4S_3, C_4S_4		Very poor	

Table 4: Suitability of water for animal drinking according to Ayers and Westcot (1989)

Remarks	Suitability of Water	Electrical conductivity (Micromohs/cm)
Used for all animals	Excellent	< 1500
Can be used for all animals	Good	1500 – 5000
Causes Diarrhea for cattle and death for poultry and shrinkage in growth	Accepted for animals and not accepted for poultry	5000 – 8000
Cannot be used for pregnant animals and not accepted for poultry	Limited in use for animals and not accepted for poultry	8000 – 11000
Not accepted for animals	Very limited in use	11000 – 16000
Dangerous and cannot be used	Not be recommended for use	> 16000

Table 5: Suitability of water for industrial purposes according to Salvato (1982)

Type of Industry	pH	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Cl	SO_4	Ca	Mg	`Fe (mg/l)
				(meq/l)				
Food Industry	6.5 – 8.5	500	310	8.462	5.205	5.988	8.226	0.4
Chemical Industry	6 – 9	500	1000	14.103	17.697	9.98	–	5.0
Cement Industry	6.5 – 8.5	400	–	7.052	5.205	–	–	25
Petroleum Industry	6 – 9	–	900	45.13	11.867	10.978	6.992	15
Paper Industry	6 – 9	–	475	5.641	–	0.998	0.987	2.6

RESULT AND DESCUSSION

- **Hydrochemical Results**

The results of the chemical analysis of 16 groundwater samples collected from the SW part of the Mesopotamia during 2011 and the data from the hydrochemical database (Table 6) were checked by PHREEQC program to evaluate the analytical precision, and the samples with error percentage more than 5% were ruled out. The chemical composition of the samples reflects the predominance of chloridic water type in most of the Quaternary sediments aquifers (flood plain aquifers). Whereas the aquifers in southwestern parts, represented by the Pre-Quaternary sediments (Euphrates and Dammam formations), are of sulfatic water type. The bicarbonate water type with low TDS is restricted to a local scale, especially along river courses and irrigation channels, where the seepage from the river dilute groundwater salinity. Generally, the groundwater of chloridic type is characterized by salty groundwater and even brine groundwater (TDS >50000 mg/l), especially in depressions near the marshes. This can be explained by the soil waterlogging and the high potential evaporation (Pan Evaporation ≈3000 mm/year), where the salt accumulates near the surface, as salt crust, then dissolves by the infiltrated rainfall water, leading, with time, to salt accumulation in the groundwater. On the other hand, the slightly brackish groundwater in the Quaternary sediments aquifers may be found in the areas where influent seepages from the rivers and irrigation channels occur, especially along Al-Gharraf River, with Ca (Mg) – Bicarbonate water type. In the area along the Euphrates River, TDS seems to be not affected by the dilution of the river leakage, where the groundwater there commonly feeds the river. The sulfatic groundwater in the Pre-Quaternary aquifers is of brackish water type and the TDS generally ranges from 2000 mg/l to 5000 mg/l. The groundwater in the study area is classified, based on the TDS values, into five classes (Table 7), but the predominant class is the salty water class. This classification is modified after Altoviski (1962), where the range of (3000 – 5000) mg/l (moderate brackish water) and (5000 – 10000) mg/l (highly brackish water) are added to evaluate the brackish water which can be used to irrigate some of the crops. Generally, the chloridic groundwater in the Quaternary sediments is not suitable for any purpose (human drinking, animals drinking, agriculture and industrial uses). It is of meteoric origin and very hard water. In the Pre-Quaternary fractured aquifer, the groundwater can be used for animal drinking, irrigation (some salt tolerant crops) and for some chemical industries.

The results of correlation matrix of major ions of the chloridic type and the sulfatic type groundwaters are shown in Tables 8 and 9, respectively. The correlation matrix of the chloridic type groundwater illustrates that Na^+ and Cl^- are positively correlated ($r > 0.95$ at $P < 0.001$) and TDS shows positive correlation with Na^+, Cl^- ($r > 0.95$ at $P < 0.001$) indicating that such ions are derived from the same source and have a significant effect on water salinity. Therefore, we can conclude that rainfall and returned irrigation water are the main source of these two ions and the evaporation process is the main factor affecting the water chemistry by concentrating ions under the arid condition and low recharge rate. In sulfatic groundwater type, the positive correlation ($r = 0.97$ at $P < 0.001$) between SO_4^{-2} and Ca^{+2} (Table 9) is an indicator of evaporate rocks dissolution (gypsum and anhydrite) which is considered as the main geochemical process that affects the sulfatic water quality. In addition, in sulfatic groundwater, the positive correlation ($r > 0.86$ at $P < 0.001$) between HCO_3^- and the alkali earth metals (Ca^{2+} and Mg^{2+}) suggests weathering of carbonate rocks (limestone and dolomite). Figure 4 shows the distribution of the sulfatic and chloridic hydrochemical facies in the Piper Diagram, while (Fig.5) shows the spatial distribution of the Total Dissolved Solids (TDS) and groundwater type.

Mineral Saturation Index indicates whether water will tend to dissolve or precipitate a particular mineral. Its value is negative when the mineral tends to be dissolved, positive when it may be precipitated and zero when the mineral is in chemical equilibrium with water. As shown in Table 6, most of the samples are over saturated or in equilibrium with regard to calcite and the water tend to precipitate this mineral, while gypsum is under saturation in most of the groundwater samples.

Table 6: Hydrochemical analyses results of the groundwater samples collected during 2011 (**bold)** and the remaining 5 samples are from the database for samples analyzed in different dates before 2011

Number In Data Bank	pH	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	TDS	EC	Water Type	SAR	Total Hardness	Saturation Index	
															Calcite	Gypsum
1178	7.6	501	292	710	20	408	3	1818	1250	5400	8170	Sulfatic	1.2	5400	-0.2025	-4.7605
11794	7.5	261	129	430	1	216	6	944	685	2910	4390	Sulfatic	1.6	1182	-0.1203	-1.017
11757	7.6	60	14	107	1	70	7	192	125	860	1285	Sulfatic	2.2	207	0.2042	-0.8687
11782	7.4	100	48	184	5	141	12	385	238	1400	1964	Sulfatic	1.8	447	-0.0113	-0.9433
11765	7.5	181	60	285	3	244	18	490	355	1750	2630	Sulfatic	2.1	698	0.3934	-0.8314
14146	**7.4**	**337**	**187**	**926**	**40**	**116**	**18**	**2350**	**781**	**4740**	**6771**	**Sulfatic**	**10.04**	**1609**	**0.5132**	**-0.306**
14150	**7.5**	**100**	**122**	**112**	**3**	**207**	**24**	**515**	**178**	**1158**	**1654**	**Sulfatic**	**1.78**	**750**	**1.1306**	**-0.4747**
14151	**7.0**	**192**	**59**	**270**	**3**	**107**	**7.2**	**945**	**107**	**1640**	**2380**	**Chloridic**	**57.82**	**10552**	**1.389**	**0.2465**
14152	**7.6**	**673**	**2654**	**13848**	**1573**	**634**	**36**	**15971**	**19525**	**54764**	**78234**	**Chloridic**	**53.66**	**12601**	**0.1601**	**-1.0521**
14153	**7.5**	**770**	**360**	**20611**	**200**	**464**	**36**	**14614**	**23288**	**61324**	**87606**	**Chloridic**	**153.72**	**3401**	**-0.467**	**-1.4429**
14155	**7.6**	**914**	**88**	**16293**	**99**	**262**	**18**	**9161**	**20164**	**47956**	**68509**	**Chloridic**	**137.88**	**2642**	**0.2937**	**0.1919**
14156	**7.4**	**1034**	**1293**	**18864**	**244**	**373**	**29**	**8416**	**28471**	**59344**	**84777**	**Chloridic**	**92.3**	**7902**	**0.5114**	**-0.5529**
14157	**7.5**	**521**	**1507**	**6142**	**123**	**312**	**24**	**5964**	**10295**	**26060**	**37229**	**Chloridic**	**30.84**	**7501**	**0.6752**	**0.1788**
14158	**7.1**	**802**	**3038**	**14812**	**128**	**310**	**19**	**13274**	**23253**	**59696**	**85280**	**Chloridic**	**53.5**	**14501**	**1.6071**	**0.1921**
14159	**7.7**	**1082**	**3293**	**16662**	**284**	**488**	**90**	**9634**	**29998**	**63912**	**91303**	**Chloridic**	**56.85**	**16252**	**-0.0405**	**-1.0907**
14160	**8.4**	**1096**	**3539**	**20511**	**111**	**220**	**19**	**10626**	**36033**	**72916**	**104166**	**Chloridic**	**67.82**	**17301**	**0.5804**	**0.1077**
14161	**7.3**	**970**	**3482**	**14224**	**68**	**134**	**24**	**10305**	**26181**	**56664**	**80949**	**Chloridic**	**47.8**	**16751**	**0.8506**	**-0.2025**
14162	**6.9**	**1178**	**4121**	**19278**	**129**	**220**	**101**	**9653**	**36743**	**78912**	**112731**	**Chloridic**	**59.44**	**19902**	**-0.0988**	**-0.5741**
14163	**7.3**	**866**	**2328**	**17178**	**110**	**311**	**36**	**11192**	**26448**	**58776**	**83966**	**Chloridic**	**68.95**	**11741**	**0.6618**	**0.1501**
14164	**7.3**	**637**	**1849**	**8919**	**113**	**205**	**19**	**7234**	**14910**	**34064**	**48663**	**Chloridic**	**40.44**	**9201**	**0.5612**	**-0.5675**
14166	**7.8**	**649**	**87.5**	**8049**	**70**	**364**	**50**	**1187**	**12745**	**23096**	**32994**	**Chloridic**	**78.65**	**1981**	**0.3083**	**-0.0676**

Note: all ion concentrations, TDS, Total Hardness, are in mg/l, EC is in (µs/cm)

Table 7: Classification of groundwater according to TDS content (modified after Altoviski, 1962)

Class of water	TDS (mg/l)
Fresh Water	< 1000
Slightly Brackish Water	1000 – 3000
Brackish Water	3000 – 5000
Highly Brackish Water	5000 – 10000
Salty Water	10000 – 50000
Brine	> 50000

Table 8: correlation matrix of the chloridic groundwater type in the Quaternary intergranular aquifers

	Na	**K**	**Ca**	**Mg**	**Cl**	**NO_3**	**SO_4**	**HCO_3**	**TDS**
Na	1								
K	0.431	1							
Ca	0.595**	0.040	1						
Mg	0.606**	0.427	0.314	1					
Cl	0.972**	0.345	0.672**	0.695**	1				
NO_3	0.126	0.139	-0.017	0.228	0.154	1			
SO4	0.647**	0.717**	0.146	0.646**	0.544*	0.113	1		
HCO3	-0.182	0.126	0.062	-0.154	-0.220	-0.482*	0.030	1	
TDS	0.978**	0.477*	0.607**	0.746**	0.976**	0.148	0.708**	-0.154	1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Table 9: correlation matrix of the sulfatic groundwater type in the Pre-Quaternary fractured aquifers

	Na	**K**	**Ca**	**Mg**	**Cl**	**NO_3**	**SO_4**	**HCO_3**	**TDS**
Na	1								
K	0.796*	1							
Ca	0.897**	0.807*	1						
Mg	0.859*	0.874*	0.911**	1					
Cl	0.873*	0.839*	0.946**	0.917**	1				
NO_3	-0.010	0.160	-0.167	0.022	0.023	1			
SO_4	0.925**	0.783*	0.970**	0.907**	0.868*	-0.186	1		
HCO3	0.664	0.793*	0.868*	0.918**	0.899**	0.051	0.790*	1	
TDS	0.920**	0.856*	0.988**	0.931**	0.980**	-0.056	0.945**	0.879**	1

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

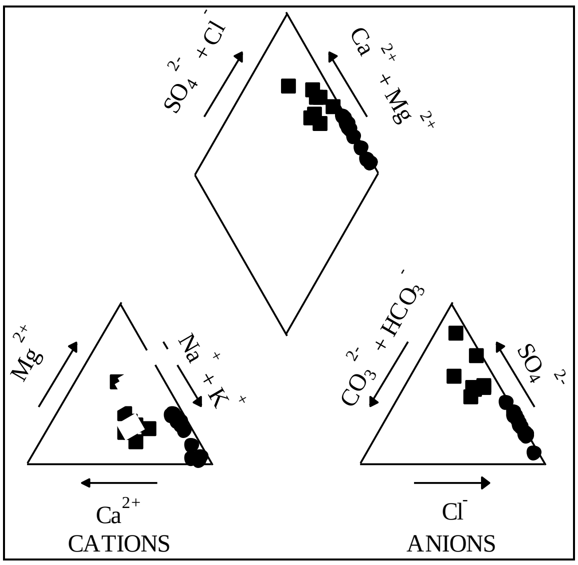

Fig.4: Piper diagram representing hydrochemical facies, the square is groundwater of sulfatic type and the circle is chloridic type

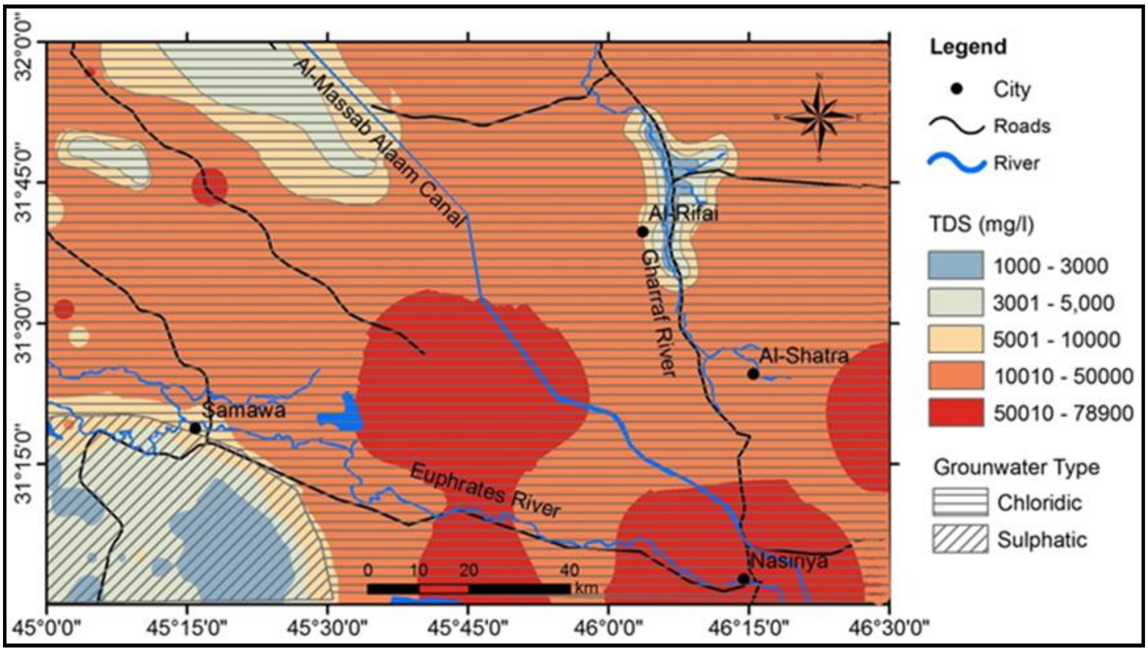

Fig.5: Spatial distribution of the Total Dissolved Solids (TDS) and groundwater types

It can be conclude that the main factor affecting the chloridic groundwater type in the intergranular aquifers of the Quaternary sediments is the evaporation under the arid condition, where the rare rainfall water is concentrated near the surface by evaporation and the salt accumulates with time in the groundwater by the infiltrated rainfall and returned irrigation water. The sulfatic groundwater of the Pre-Quaternary fractured aquifers is significantly affected by the dissolution of evaporates rocks, where the lower member of the Dammam Formation is in contact with evaporates rocks of the Rus Formation. In general, the chemical composition of the groundwater shows significant spatial variation. This refers to a considerable spatial variation in the lithological and hydrogeological parameters of the anisotropic flood plain sediments and the distribution of the fractures and fissures in the carbonate rocks of the fractured aquifers.

- **Hydrogeological Results**

The study area is mainly covered by Quaternary sediments which are generally composed of alternation of clay, silt, and sand. The layers of sand and silt which represent the oldest part of these sediments represent aquifers, while those of silty clay and clay represent aquitards. The distribution of aquifers and aquitards differs significantly from one place to another, but in general some regional regularity can be followed in the Mesopotamia Plain. The upper part of the sediment sequence is usually formed by aquitards with thickness ranging from 10 m to 20 m, while the extensions of aquifers are generally downward below the depth of (20 – 25) m. During winter and spring, the rainfall is the main source of recharge, as well as, water in the form of influent seepage from rivers and streams and irrigation channels. Unlike the Euphrates River, the water level in Al-Gharraf River is higher than the groundwater level in the surrounding areas, so that the river is considered as a recharge source to the groundwater in these areas. This can explain the relatively lower salinity of groundwater along Al-Gharraf River. The Transmissivity (T) in the Quaternary sediments aquifers are ranges between 10 m^2/day and 143 m^2/day with an average of 34 m^2/day (Table 10). The spatial variation of the transmissivity reflects the lateral variation in the lithology which is a feature of the flood plain sediments.

Table 10: Hydraulic parameters of the groundwater in the wells tested during 2011

Number In Data Bank	**Latitude**	**Longitude**	**Elevation (m above S.L)**	**Total Depth (m)**	**Water Depth (m)**	**SWL**	**DWL**	**Q**	**S_C**	**K**	**T**
14146	31.13695	45.13583	31	150	9.5	9.5	12	650	260	7.4	414
14150	31.68092	46.11061	9	25	1.8	1.8	4.2	345	143.8	1.1	10.5
14151	31.90036	45.9229	13	97	2.2	2.2	3.6	232.3	166	0.5	17
14152	31.37008	46.47387	6	22	1.5	1.5	5.9	65	14.8	3.3	13
14153	31.06715	46.22042	3	22	2.1	2.1	5.8	138.5	37.4	7.3	23
14155	31.54412	46.23721	8	21.8	1.5	1.5	4.7	207.4	64.8	11	55
14156	31.13381	46.05246	9	21	2.3	2.3	9.2	69	10	2.2	19.5
14157	31.1669	45.97398	7	22	2.2	2.2	5.8	173	48.1	28.7	143.7
14158	31.37199	45.86922	6	22	3.5	3.5	7.2	173	46.8	3.9	31.3
14159	31.32244	45.61283	9	24	6	6	13.7	86.4	11.2	1	8.4
14160	31.74587	45.28911	17	22	1.9	1.9	5	156	50.3	2.9	17.4
14161	31.94633	45.07894	21	25	2.1	2.1	6.2	311	75.9	0.5	11
14162	31.44537	45.68395	10	22	5.6	5.6	8.9	70	21.2	0.7	6
14163	31.51966	45.03384	16	22	3	3	7.7	260	60.5	1.7	13.6
14164	31.42354	45.41089	11	22	1.8	1.8	4.5	432	160	22.5	131.8
14166	31.45537	46.13325	7	22	1.4	1.4	6.6	138.2	26.6	2.3	9.2

SWL: Static Water Level (m B.G.S.), **DWL:** Dynamic Water Level (m B.G.S.), **Q:** Discharge (m^3/day), **S_C:** Specific Capacity (m3/day/m), **K:** Hydraulic conductivity (m/day), **T:** Transmissivity (m^2/day).

The Dammam Formation (Upper Eocene) and the Euphrates Formation (Lower Miocene) represent the Pre-Quaternary aquifers in the study area and are exposed in the southwest parts. They are composed mainly of limestone and dolomitic limestone. The permeability of these fractured aquifers decreases with depth. Rain-fall represents one of the most important sources for the aquifer recharging besides water leakage from valleys in hydraulic contact with these aquifers. The Dammam and Euphrates formations are covered by impermeable beds in the regions near to discharge area (western bank of Euphrates River), so the aquifers are confined in this area and the groundwater is discharged through a series of springs along the Abu Jeer Fault. The results of hydrogeological parameters of the Dammam Formation in the study area is obtained from the pumping tests of well (14146) which penetrates the upper parts of this aquifer. The transmissivity coefficient is about 414 m^2/day, hydraulic conductivity is about 7.4 m/day, discharge of well about 650 m^3/day, specific capacity about 260 m^3/day/m and static water level about 9.5 m below ground surface (Table 10). The high values of transmissivity coefficient indicate the presence of karstified canals and cavities within the rocks of the formations, which represent good passages, for groundwater. The thickness of Euphrates Formation aquifer ranges from 30 m to 100 m and in some boreholes it reaches to more than 100 m (Al-Rawi *et al*., 1975; Ahmad and Al-Basrawi, 2004). The Euphrates Formation aquifer is characterized by little quantity of groundwater compared to the Dammam aquifer, where the availability of caves allows rain water to penetrate and moves underground towards river valleys or may appear as springs in the discharge area. The Euphrates Formation aquifer changes from confined to semi-confined in the study area, with low pressure. There is no information about the hydraulic parameters of the Euphrates Formation aquifer, due to lack of wells producing water from this formation.

The general direction of groundwater flow is from the northwest towards the southeast, and from southwest towards northeast, with local divergences near to rivers and irrigation channels, as along Al-Massab Al-Aam Canal and Al-Gharraf River (Fig.6). The groundwater of the Quaternary and Pre-Quaternary aquifers is discharged through springs or by leakage into the Euphrates River and into the overlaying Quaternary sediments. This can explain the increases in the TDS values in the Euphrates River during dry season, where the river is considered as a big drain of groundwater.

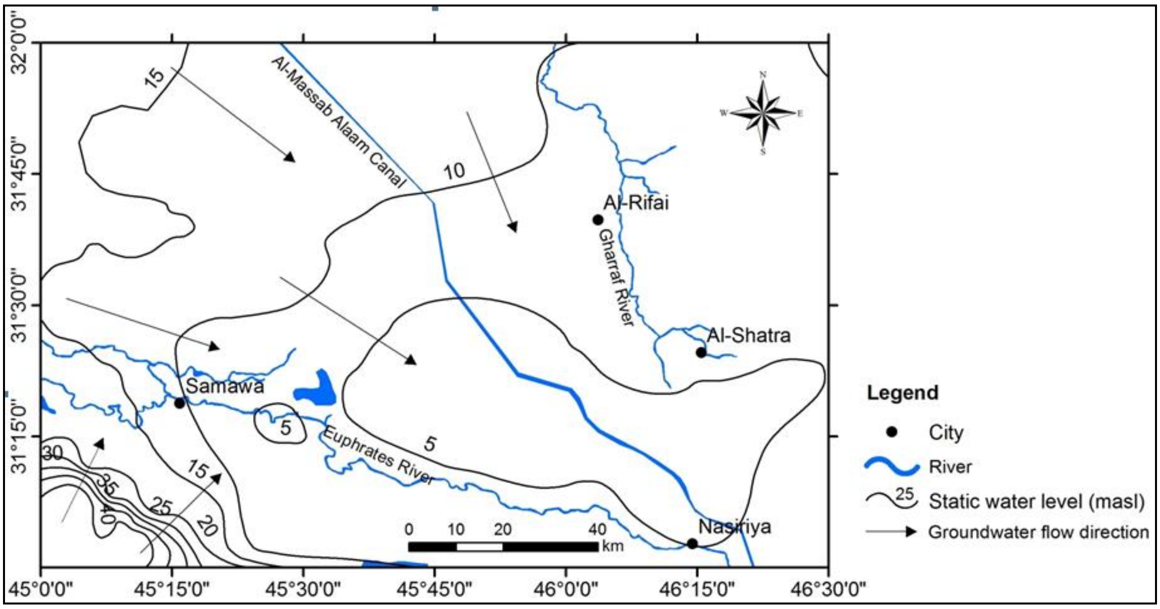

Fig.6: General direction of groundwater flow in the uppermost aquifer

CONCLUSIONS

The Quaternary sediments, Euphrates and Dammam formations represent the important upper aquifers in the SW parts of the Mesopotamia. The main factor affecting the groundwater quality in the Quaternary sediments aquifers is the evaporation under the arid condition and the low recharge rate, where the salt accumulates in groundwater through washing of the salt crust by infiltrated rainfall and returned irrigation water. The groundwater in these aquifers is of high salinity and not suitable for any use, except in the area along Al-Gharraf River, where the river is feeding the groundwater and the groundwater is turned into brackish water. The Dammam Formation represents the main aquifer in the SW parts. It is confined and in some places mixed with the Euphrates Formation aquifer. The groundwater of the Dammam Formation aquifer is brackish, and of sulfatic type, where the main factor affecting the groundwater quality is the dissolution of evaporate rocks (gypsum and anhydrite). The Euphrates Formation aquifer has a little significance regarding groundwater quantity. It is in hydraulic connection with the underlying Dammam Formation aquifer and the recharged water infiltrate deeper into the Dammam Formation aquifer or into the Euphrates River. The groundwater in the Pre-Quaternary aquifers can be used to irrigate some salt-tolerant crops and in chemical industries.

The general direction of groundwater flow is from NW to SE and from SW to NE, with local flow direction towards the rivers, drain channels and depressions. During the dry season the water level of the Euphrates River decreases and the salty groundwater is drained into the river deteriorating its quality. On the other hand, the water level in Al-Gharraf River is higher than the surrounding groundwater level, so the river is feeding the unconfined aquifer along the river course and dilutes its salinity.

The significant spatial variation in the hydrochemical and hydrogeological properties of the Quaternary aquifers may be attributed to the lateral variation in lithology which is a feature of the flood plain sediments. The variation in spatial distributing of the fractures, fissures and the karstification processes are spatially affecting the hydrogeological properties of the Pre-Quaternary fractured aquifer and in turn its hydrochemical properties.

REFERENCES

Ahmad, H.S. and Al-Basrawi, N.H., 2004. Studying the development of Salty Solution Production in Al-Samawa Saline. GEOSURV, int. rep. no. 2864.

Al-Basrawi, N.H., 2004. Hydrogeological and hydrochemical study of Al-Nasiriya Quadrangle (NH-38-3), scale 1: 250 000, GEOSURV, int. rep. no. 2911.

Al-Jiburi, H.K. and Al-Basrawi, N.H., 2010. Hydrogeological conditions and groundwater uses in thie Qar Governorate. GEOSURV, int. rep. no. 3289.

Al-Jiburi, H.K. and Al-Basrawi, N.H., 2011. Hydrogeology of the Mesopotamia Plain, Iraqi Bulletin of Geology and Mining, special issue.

Al-Rawi, N.N., Al-Rawi, I. and Laboutka, M., 1975. Hydrogeology of Samawa Salt Sediments, GEOSURV, int. rep. no. 684.

Altoviski, M.E., 1962. Handbook of Hydrogeology, Gosgeolitzdat, Moscow, USSR (in Russian) 614pp.

APHA, 1995. Standard Methods for the Examination of Water and Wastewater, 19th edit., American Public Health Association (APHA), American Water Works Association (AWWA) and Water Pollution Control Federation (WPCF), Washington, D.C.

Araim, H.I., 1990. Regional Hydrogeology of Iraq, GEOSURV, int. rep. no. 1450.

Ayers, R.S. and Westcot, D.W., 1989. Water quality for agriculture, Irrigation and Drainage, paper 29, Rev.1, FAO, Roma, Italy, 174pp.

Buday, T., and Jassim, S.Z., 1984.Tectonic Map of Iraq. GEOSURV, Baghdad, Iraq.

Deikran, D.B. and Mahdi, A.H.I., 1993. Series of geological maps of Iraq, scale 1: 250 000, Al-Nasiriya Quadrangle (NH-38-3), GEOSURV, int. rep. no. 2258.

Fouad. S.F.A., 2007. Geology of the Iraqi Western Desert. Tectonic and Structural Evolution. Iraqi Bulletin of Geology and Mining, special issue, p. 29 – 50.

Fouad, S.F.A., 2012. Tectonic Map of Iraq scales 1: 1000 000, 3rd edit., GEOSURV, Baghdad, Iraq.

GEOSURV, 1983. Hydrogeological and Hydrochemical Exploration of Blocks (1, 2, 3). GEOSURV, int. rep. nos. 1250 – 1254.

Iraqi General Organization for Meteorological Information (IOM), 2000. Atlas of climate of Iraq for the years (1981 – 2000).

Hem, J.D., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. In USGS Water-Supply Paper 2254.

Krasny, J., 1982. Hydrogeology and hydrochemistry of Diwaniya – Samawa area, Mesopotamian Plain Project, GEOSURV, int. rep. no. 1335.

Krasny, J., Al-Sam, S. and Jassim, S.Z., 2006. Hydrogeology of Iraq, chapter 19. In: Jassim and Goff (Eds.), Geology of Iraq. Dolin, Prague and Moravian Museum, Brno.

Parsons, R.H., 1957. Groundwater Resources of Iraq, Vol.11, Mesopotamian Plain, GEOSURV, int. rep. no. 423.

Piper, A., 1944. A graphic procedure in the geochemical interpretation of water analysis. Trans Am Geophys Union 25, 25, p. 914 – 923.

Richards, L., 1954. Diagnosis and improvement of saline and alkali soils. Agricultural Handbook 60., New Delhi, India: USDA and IBH Publishing Co. Ltd.

Salvato, P.E., 1982. Environmental Engineering and Sanitation, New York, U.S.A., 1163pp.

Shareef, S., 1982. Pumping tests of four boreholes in Samawa Area. GEOSURV, int. rep. no. 1243.

Shareef, S. and Al-Dabbaj, A.A., 1999. Hydrogeological study of Al-Buddha region. GEOSURV, int. rept. no. 2498.

UNESCO, 2010. Launches initiative to identify groundwater and alleviate water shortages in Iraq. Retrieved from http://www.unesco.org/new/en/unesco_launches_initiative_to_identify_groundwater_and_allev/.

UNEP, 1992. World Atlas of Desertification, London, UK.

WHO, 2010. Guidelines for drinking water quality 3rd edit., Geneva, Switzerland: World Health Organization.

Winston, R.B., 2000. Graphical User Interface for MODFLOW, Version 4: U.S. Geological Survey Open-File Report 00-315, 27pp.

About the Authors

Dr. Naseer H. Al-Basrawi, graduated from the University of Mosul in 1983, with B.Sc. degree in Geology He got his M.Sc. and Ph.D. degrees in Hydrogeology from the University of Baghdad, 1989 and 1996 respectively. He joined GEOSURV in 2000 and currently, is working as the Head of the Hydrogeology Division. He has 90 documented reports in GEOSURV library and 16 published articles in hydrogeology. His major field of interest is hydrogeology.

e-mail: al_basrawi1262@yahoo.com
Mailing address: Iraq Geological Survey, P.O. Box 986, Baghdad, Iraq

Dr. Hussein A. Jassas, graduated from University of Baghdad in 1995, with B.Sc. degree in Geology, he got his M.Sc. in Hydrogeology from University of Baghdad in 2008 and Ph.D. degrees in 2015 from TU Bergakadimie Freiberg - Germany. He joined GEOSURV in 2000 and currently, is working as the Responsible of Mineral Investment Division. He has 6 documented reports in GEOSURV's library and 5 published articles in international journals and 3 articles in national journals. His major field of interest is water resources management.

e-mail: husseinjassas@yahoo.com
Mailing address: Iraq Geological Survey, P.O. Box 986, Baghdad, Iraq