Hydrogeochemical Modelling of Groundwater at Al-Nile Area, Center of Babylon Governorate, Iraq

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ARTICLE INFO
Submission date: 30/7/2018
Acceptance date: 7 /8/2018
Publication date: 14/1/2019

Abstract

The study area represented Al-Nile area at Al-Mahaweel district affiliated to Babylon governorate and just (90 km) south of Baghdad governorate and about (20 km) east of Al-Hillah city. This study covered an area about (300 km^2) which located between (44°30' & 44°36') E and (32°32' & 32°36') N. The geological setting of the study area characterized by recent sediments of the quaternary period during the Pleistocene and Holocene involves the floodplain deposits. Topographically, the Babylon governorate characterized by a lack of slope with gentle gradient about (22 cm/km) descended from northern and northwestern sides towards the eastern parts and southeastern. The mainly target of this present study is to originate a hydrogeochemical modelling of groundwater in the study area to determine the dissolution and precipitation ratios of the mineral phases along the selected flow paths and also explained the effected ratio of the surface water (Babylon stream) on the groundwater by using the hydrogeochemical mixing technique. Ground and surface water parameters show significant spatial and temporal variations in major and minor element concentrations during the two periods of the study. The mixing process shows us a highly effect of the Babylon stream in the wells (1,7,13 and 21), while show low effected on the wells (3,5,14,19 and 20) with a different contribution.

Keyword: Groundwater (GW), Surface water (SW), Hydrogeochemical modelling, Mixing process, NETPATH, Flow path, Saturation indices.

Introduction

Iraq is located in these areas where water resources face many threats and a lot of damages, especially in the second half of the last century where the drying of large parts of the marshes which represented half of water body as well as shrinking water resources of lakes and rivers because of construction of dams on the rivers (outside and inside Iraq) and also the irrigation projects which led to a large proportion of the rural population suffers from scarcity of drinking water. Reducing the amount of water entering Iraq is one of the most important environmental issues because of its close association with man, agriculture, and biodiversity.

Therefore, the need for groundwater in Iraq emerged in these places where surface water is scarce or non-existent to compensate for the decrease of surface water and meet all needs. The groundwater quantity depends on the several factors and the most important is the amount of water percolating below the ground by surface water, rainwater, and addition to other sources. The hydrochemical of groundwater is considered as a tool to study the nature of Lithology and the installation of water reservoirs [1].

The majority of the region's population profession is the agriculture and they are using the shallow groundwater as a major source of water for irrigation and other uses because of the scarcity of surface water and the lack of access significant amount to this region by Shatt Al-Hillah and its branches. In this study, we focused on the Babylon stream only because it is more important than any other streams in the region. One of the main reasons for this study is the scarcity of surface water in the studied area. Also, the significant decline in water levels of Euphrates and Shatt Al-Hillah rivers which represent the main aquatic artery of the Babylon governorate addition to its branches those falling within the study area especially Babylon streams. There are several Factors that lead to decreasing the level of Shatt Al-Hillah, such as the geologic and topographic factors, increasing levels of human pollution activities, and the large number of streams and branches that are not consistent with the ability of the Shatt Al-Hillah to provide its water. Moreover, controlling the level of the Shatt Al-Hillah through the dams which controlling the levels of Euphrates River. High temperatures and low rainfall formed the dry climate and caused a high level of evaporation accompanied with increase in desertification, and also the weak management of water projects by officials. All these factors have greatly affected the proportion of water beneficiaries in the Babylon province. Al-Nile area had a population of about (58763) citizens served with a network water about (67%) [2].

[3], [4], [5], and [6] studied the hydrochemical properties around the study area including the shallow groundwater, surface water, and the mineralogy of the soil sediments in the Babylon governorate, but no hydrogeochemical modelling study concerning the shallow groundwater and surface water in the study area by using the techniques mass transfer modelling of the minerals phases and the mixing process between the two water bodies in the study area. According to [7] and [8] classifications, the general dominant climate was sub-arid to arid in the study area affected by the Mediterranean Sea and Arabian Gulf conditions. During the period (1986- 2016), the high values of evaporation was during the dry (summer) season especially in July (356.801 mm), while the high values of precipitation was during the wet (winter) season especially in January (26.215 mm).

Materials and Methods

General settings of the study area

The study area represented Al-Nile area of Al-Mahaweel district affiliated to Babylon governorate in the central of Iraq and just (90 km) south of Baghdad and about (20 km) east of Al-Hillah city. The governorate occupies the northern parts of the Middle Euphrates region [9] and takes shape close to the triangle whose base in the south and its longitudinal extension from the north to the south about (120 km) with an area of (5119 km^2), its characterized by the Baghdad-Basrah highway that passes through it [10], as in figure (1).

Geologically, the Babylon governorate is characterized by a recent sediment of quaternary period during the Pleistocene and Holocene which has thickness exceeds (250m) involve the flood plain deposits of each of the Tigris river and Euphrates river and Euphrates branches [11], as in figure (2). Topographically, Babylon governorate is characterized by a lack of slope with gentle gradient about (22 cm/km), where the ground descended from northern and northwestern sides towards the eastern parts and southeastern [10] and [12], as in figure (3).

Sedimentalogically, the study area is consisting of quaternary deposits representing by sediments fill the depressions caused by the floods of Euphrates river and its branches which formed a thin layers of fine sand, silt, clay, and silty clay [13] that lies in a different sits of the province. Also, we can designate some of the chemical deposits (gypsum, carbonate, and salts), an older alluvium deposits (terraces deposits), some of aeolian deposits, and dry marshes distributed in a different parts of the governorate [14] as in figure (2).

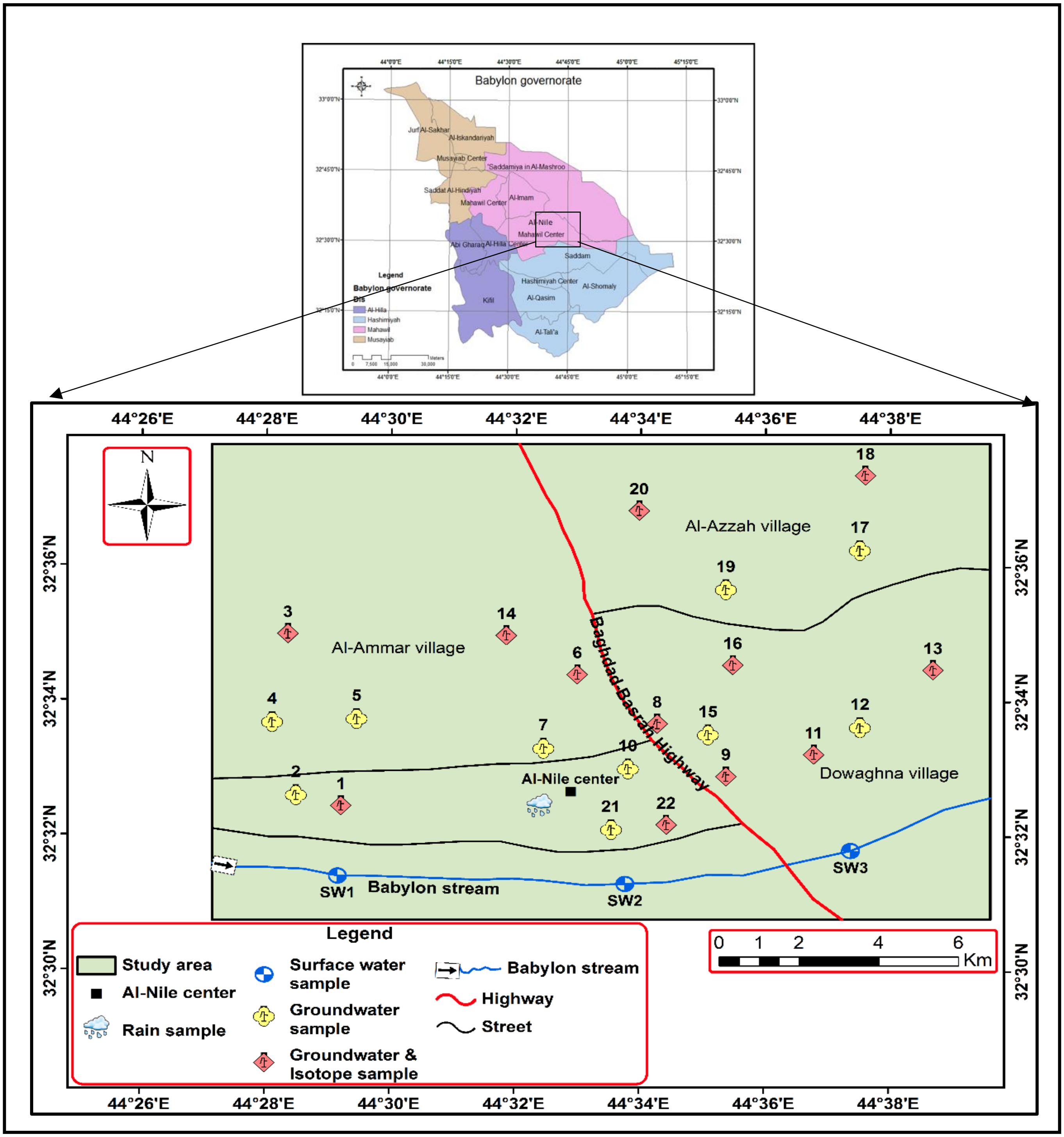

Figure (1): Location of the study area within Babylon governorate.

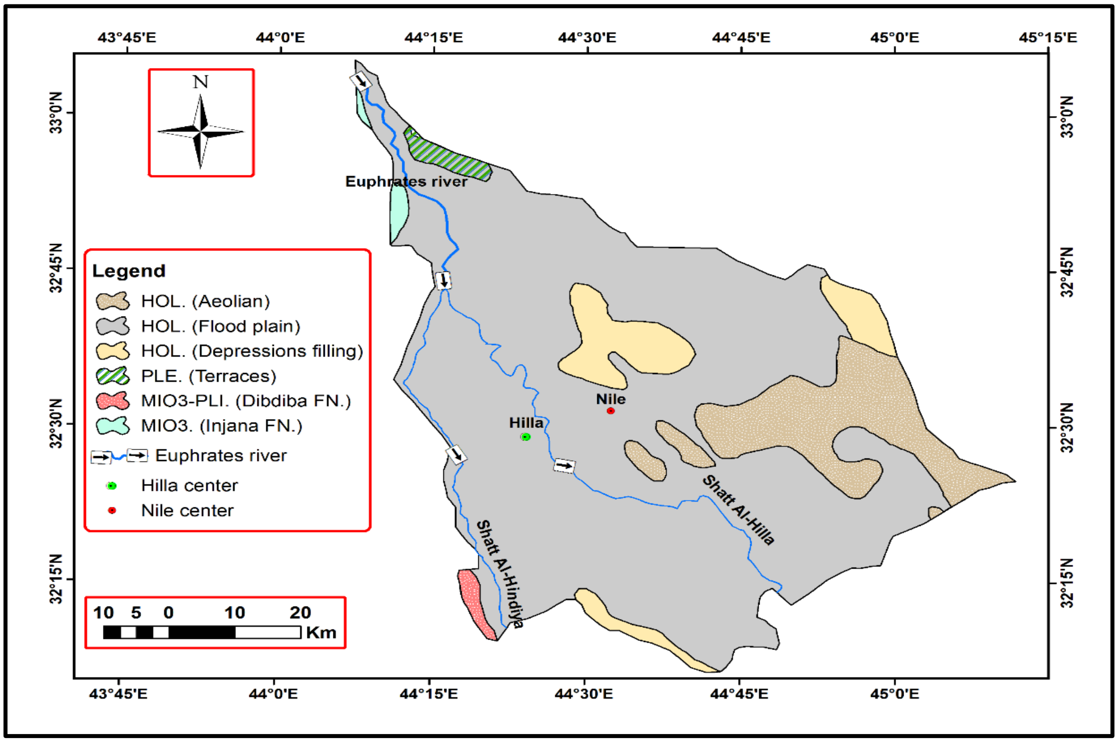

Figure (2): Distribution map of quaternary sediments for Babylon governorate and the study area [15].

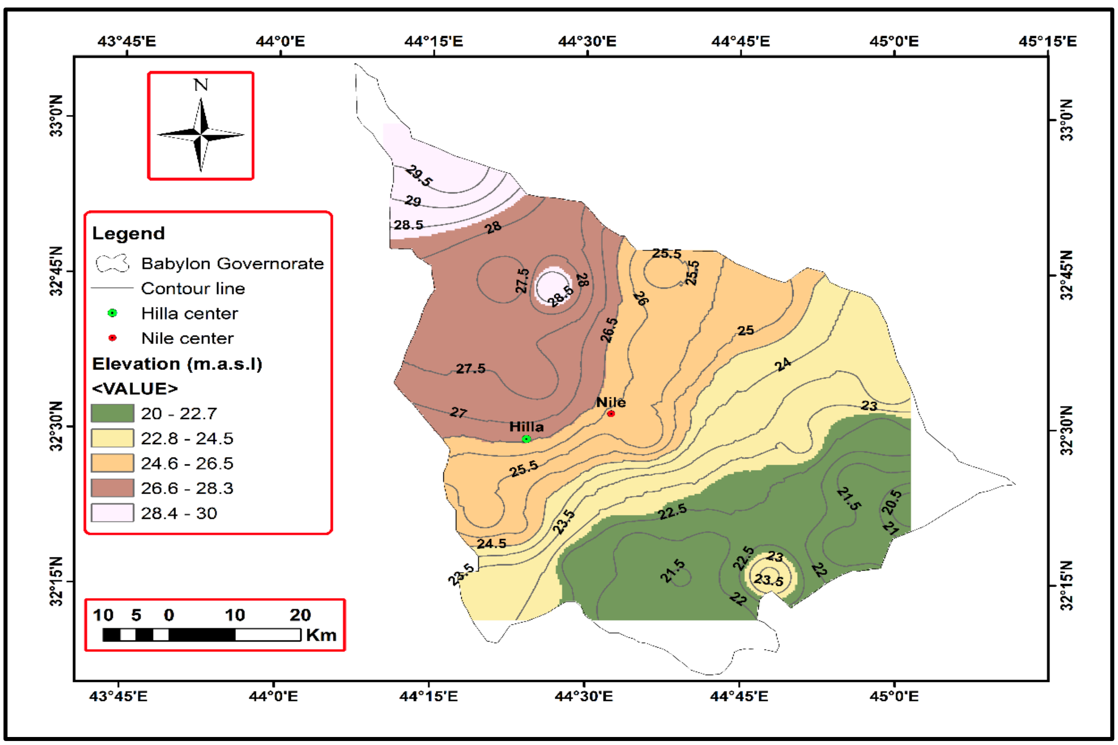

Figure (3): Topographic map of Babylon governorate [15].

Hydrological and Hydrogeological settings

Babylon governorate is characterized by numerous branches that extend to the large number of agricultural areas. Euphrates River and streams branching from the both sides represented the main water resource for the entire province. Shatt Al Hillah branched from Euphrates river in the south of Al-Musayiab district, which considered the watery artery to the province of Babylon and particularly the city of Al-Hilla, where branching out from it many drains and streams that feeding and irrigating large agricultural lands and many people, [9].

There are many streams passing throughout the study region, which are branching from Shatt Al-Hillah, most importantly are Al-Nile stream in the northern parts of the study area which suffers from lack of water with design ability to discharge about (3.50 m^3/sec) along (18 Km), while the second is Babylon stream in the southern parts with design ability to discharge about (15 m^3/sec) along (32 Km). Babylon stream represented the mainly important branch of the nutrient for most portions of the study area [4] and [16].

The hydrogeological setting of the study area characterized by many of the shallow unconfined aquifers represented by modern quaternary deposits (Quaternary unconfined aquifers). The directions of groundwater movement in the area varies and controlled by the soil permeability, withdrawal from groundwater, recharge condition, locations, and topographic setting, localized surface sources, precipitation, and evapotranspiration. The movement of the shallow groundwater flow is from that the area around the Babylon stream towards distant areas.

The hydraulic properties of the shallow aquifer consist of the hydraulic conductivity which was within the predominant zone (less than 4.1 m/day) [17], while the transmissivity (T) of the study area was ranged between (150- 220 m^2/day) according to the [18]. According to the [18], the specific yield of the unconfined aquifer in the Babylon governorate was about (0.075) and for the bank deposits around the streams was about (0.005). The soil profile in the study area includes the main layer of brown medium to very stiff silty-clay and sandy silty clay with organic materials and iron oxides. The water level was at (2.1 m) below ground surface [19], as in figure (4).

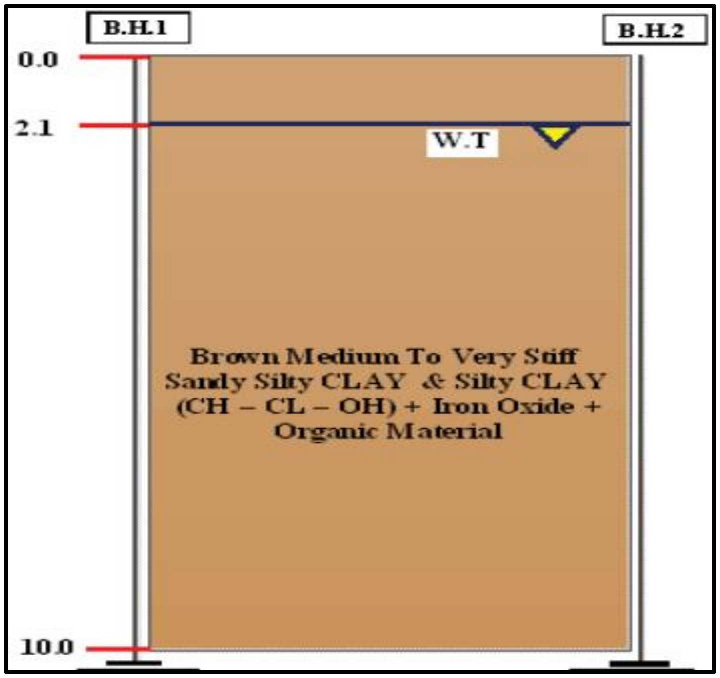

Figure (4): The soil profile at Al-Nile area (study area), [19].

Sampling and Analyses

The pre-field work, the scientific references and previous research studies were reviewed, sufficient data of climate information were assembled, preparation the equipment field work (devices & tools), and doing a reconnaissance tour in the study area to determine the necessary wells sites (shallow groundwater) about (22) sites which covered the study area and (3) sites of surface water (Babylon stream). The field work was carried out during two periods began in the dry season (Sep. 2016) and repeated in the wet season (Feb. 2017) and the collecting of water samples done directly from identified situations which were (22) samples for groundwater and (3) samples for surface water as in figure (1), collected in plastic bottles for two seasons with capacity of (2 liters). These samples were occupied after pumping operation of wells for about (5-10) minutes at the same time washing the bottles with distilled water to avoid contamination and then washed several times with the same well water, finally taken water samples until the ends of bottles and close it tightly to ejection the air bubbles perhaps affecting on the (pH, CO3 and HCO3) values [20].

Also, recorded a set of field measurements about some physical properties (temperature T°, pH, electrical conductivity EC, and total dissolved solid TDS) of each well water sample by field instruments and some information about wells such as (number of well, owner well name, depth of well, depth to water, water table, and coordinates sites). After collecting water samples, transporting them to the laboratories in order to conduct the required chemical analysis according to standard procedures, as in table (1). Chemical analysis of groundwater samples includes analysis of the major cations (K^+, Na^+, Ca^{2+}, and Mg^{2+}), major anions (Cl^-, SO_4^{2-} and HCO_3^-), minor anion (Nitrite, NO_3^- and Silica SiO_2), heavy metals (Fe^{3+}, Pb^{3+}, and Al) and some laboratory physical properties (PH, EC, and TDS). These analyses have been done in the Environment Lab./ Biology Department/ Collage of Science/ Babylon University and Collage of Environmental Science/ Al-Qassim Green University, by using the Flame photometer, Atomic absorption spectrometer, and Nano-spectrophotometer instruments.

Table (1): The chemical analysis parameters and standard procedures.

Parameters	Units	Standard procedures	References
Ph	**-**	Field electrode meter.	[21]
Temp.	**°C**	Field electrode meter.	[21]
EC	**µs/cm**	Field electrode meter.	[21]
TDS	**mg/l**	1. In field (field electrode meter). 2. In laboratory (Evaporation & drying).	[21]
Total hardness (TH)	**mg/l**	Titration with Na_2-EDTA using Eriochrome black T indicator.	[21]
Ca^{+2} & Mg^{+2}	**mg/l**	Titration with Na_2-EDTA using Murexide indicator.	[22]
Na^+ & K^+	**mg/l**	Flame photometer	[21]
Cl^-	**mg/l**	Titration with $AgNO_3$ using Potassium Di chromate indicator.	[21]
SO_4^{-2}	**mg/l**	Nano-spectrophotometer (420 nm)	[22]
HCO_3^-	**mg/l**	Titration with HCl using Orange methyl	[21]
NO_3^-	**mg/l**	Nano-spectrophotometer (543 nm)	[22]

Results and Discussion

Chemistry of the surface and groundwater samples

The hydrochemical results of this study for the groundwater (GW) included some of the physical and chemical properties (Color, Oder, Taste, T°, pH, EC, TDS, TH, major and minor, illustrated in tables (2) during two periods. Accuracy of the chemical analyses was ranged between probably certain to certain based on [23] classification. All samples in the study area were odorless and colorless, but had a salty taste due to the high total dissolved solids except the wells (1 & 2). There are a significant spatial and temporal variations in the results between surface and ground water and also between the groundwater samples themselves. The amount of total dissolved solids (TDS) and total hardness (TH) depended on the concentration of ions, type of salts, location of the groundwater relative to the surface water, depth of groundwater, type of surrounding rocks, chemical and physical processes, as well as the climate affecting, diagenesis processes and the resulting oxidation and reduction due to the erosion and weathering of the internal water movement. The TDS, EC and TH were increase during dry season and decrease during wet season due to the effect of temperature season and dilution process as a result of the rainwater during wet season. The TDS values were ranged from fresh water to saline water according to [24] classification and the EC values were ranged from high mineralize water to excessively mineralize water according to [25] classification, shows a direct relationship with TDS.

[26] and [27] show that the all samples during two periods fall in the alkaline earth with prevailing sulfate and chloride with the increase in the Ca^{+2} & Mg^{+2} due to the high concentration of secondary gypsum and chloride salts as a result of the lithology of the area and land uses of agriculture and over-irrigation. During the dry period the type of water was ranged among ($Ca-SO_4$, $Mg-SO_4$ to Mg-Cl), while during the wet period was ($Ca-SO_4$ to $Mg-SO_4$) as in figures (5 and 6).

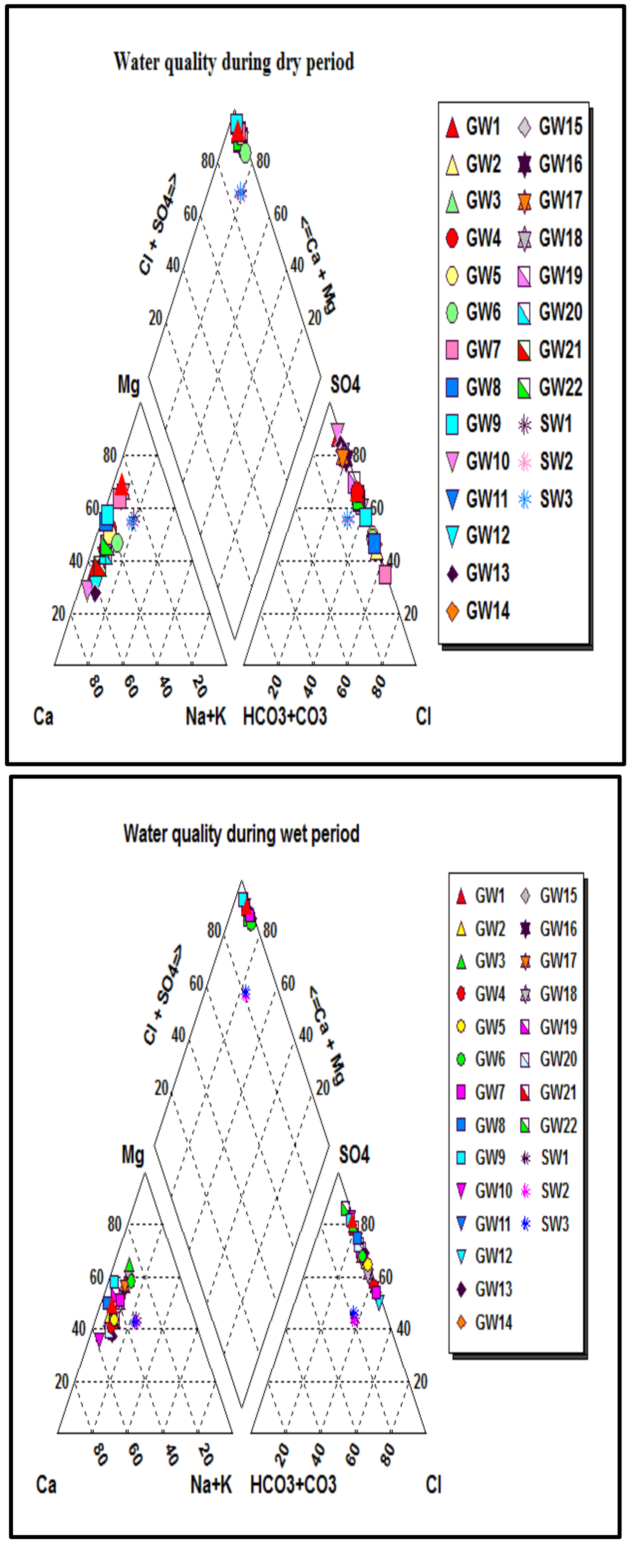

Figure (5): The water type of GW for two periods based on Piper diagram.

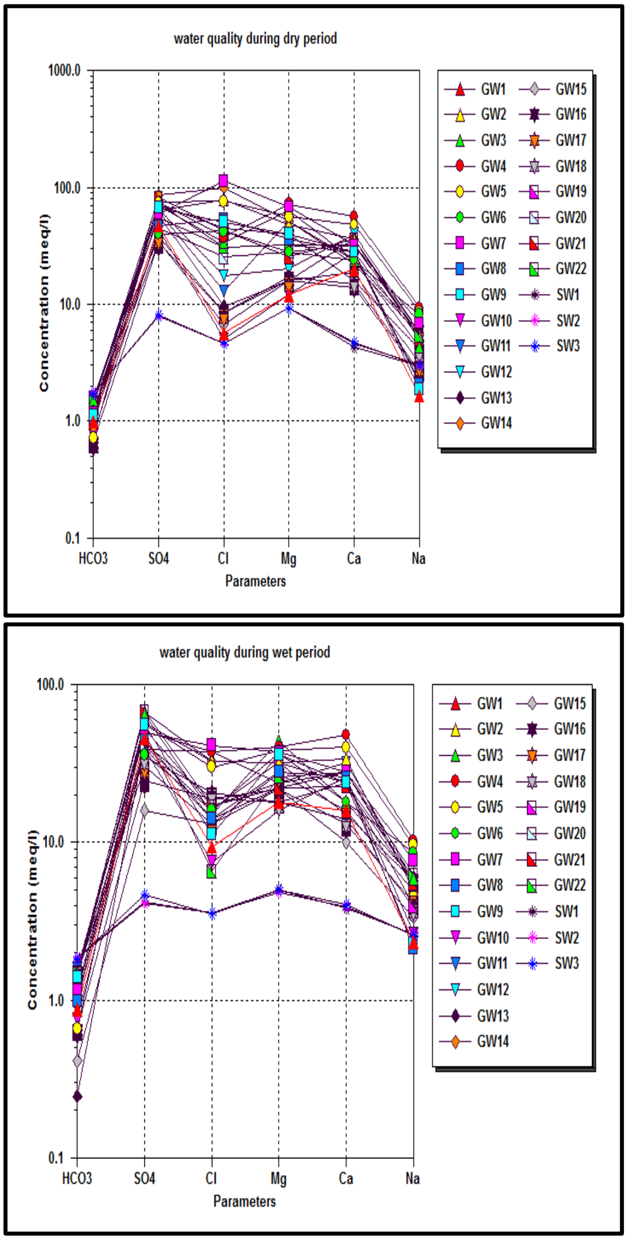

Figure (6): The water type of GW for two periods based on Schoeller diagram.

Table (2): Physical and chemical parameter of the groundwater (GW) for two periods.

Parameters	Units	Dry period		Wet period	
		Range	Mean	Range	Mean
Temp.	°C	22.8-26	23.9	22-25	23.5
pH	-	6.3-7.8	7	7-8	7.4
TDS	mg/l	934-10520	3340.7	710-4870	1945.8
EC	µs/cm	1120-9230	3532.2	987-6230	2700.4
TH	mg/l	1500.51-4802.12	3075.02	1300.5-4401.8	2706.95
Ca^{+2}	mg/l	280.56-1122.24	582.57	267.2-1002	548.21
Mg^{+2}	mg/l	176.73-777.60	393.76	149.04-534.6	325.17
Na^{+}	mg/l	43.14-240.35	117.43	48.74-234.96	121.97
K^{+}	mg/l	2.63-15.48	7.59	1.56-13.65	5.97
Cl^{-}	mg/l	164.44-2130	783.62	266.96-1468.28	641.90
SO_4^{-2}	mg/l	1356.83-3589.89	2344.63	766.58-3130.31	2011.64
HCO_3^{-}	mg/l	40.8-104.92	72.57	15.25-95.77	60.20
NO_3^{-}	mg/l	0.32-9.87	4.221	0.003-3.180	1.129
SiO_2	mg/l	5.05-14.6	11.62	-	-

Table (3): The ionic strength, PCO_2, and saturation indices of the groundwater.

Parameters	Dry period		Wet period	
	Range	Mean	Range	Mean
PCO_2	-3.233_-1.515	-2.286	-3.274_-2.321	-2.757
Ionic strength	0.031-0.181	0.086	0.037-0.106	0.068
Calcite	-1.199_0.2	0.359	-0.694_0.663	-0.071
Aragonite	-1.344_0.056	-0.503	-0.84_0.519	-0.216
Dolomite	-2.052_0.875	-0.581	-1.379_1.408	-0.072
Siderite	-2.648_-1.391	-2.157	-2.501_-1.231	-2.115
Gypsum	-0.389_0.181	-0.098	-0.588_0.112	-0.131
Anhydrite	-0.609_-0.046	-0.311	-0.808_-0.117	-0.356
Hematite	2.912-11.555	6.727	5.331-11.367	8.280
Goethite	0.525-4.921	2.430	2.303-6.435	3.658
Halite	-6.798_-4.944	-5.747	-6.844_-4.187	-5.652
Kaolinite	2.298-4.168	3.212	2.454-4.856	3.665
Illite	0.459-2.166	1.151	1.584-2.093	1.766
Montmorillonite	0.662-2.788	1.562	1.213-3.052	2.010
Albite	-2.282_--1.446	-1.773	-2.893_-1.234	-1.786
Anorthite	-3.612_-2.451	-2.981	-3.521_-2.212	-2.906
Chlorite	-2.877_-0.338	-1.733	-2.698_-0.568	-1.653

In the inverse geochemical modelling technique, the negative values represent the precipitation stage and the positive values indicate the dissolution stage. Furthermore, the cation exchange reaction between Mg^{+2}/Na^{+} was added as constraint, where the positive phase of the mass transfer illustrates the absorbs of Mg^{+2} and liberation of Na^{+} while the negative phase represents the absorbs of Na^{+} and liberation of Mg^{+2} [33]. In this existing study, the net geochemical mass balance reactions between initial and final water were identified and quantified based on the four selected flow paths in the study area, as in table (3).

According to the selected flow paths models values in table (7) for two periods, there are some differences in the dissolution and precipitation phases along two seasons and for the path ways. Where, flow paths (F.P.1 and F.P.2) showed the similar behavior, when the calcite mineral precipitate during two periods and the other minerals dissolute for the same time except the hematite and sylvite were precipitate with calcite during the wet period. The third and fourth flow paths (F.P.3 and F.P.4) reflected the differences time development between the two periods. The production minerals (precipitation) of the reactions were dolomite and hematite within the dry period and changing to calcite, hematite and sylvite during the wet period, whereas the remaining minerals had been dissolute for two seasons. The exchange reaction of cations Mg^{+2}/Na^{+} for two periods released the Mg^{+2} in the solutions and uptake Na^{+} from the solutions. The CO_2 gas appeared in the F.P.4 during the wet period as an outing gas about (-0.679).

The chief precipitation mineral is calcite while the dissolution phase represented by the dolomite mineral. The gypsum and halite minerals show a dissolution phase, whereas the hematite and sylvite minerals show different ratios of dissolution and precipitation during two periods. According to all of these features, we can distinguish the basic reaction that occurred along two periods. Dolomitization represented the dominant geochemical process reaction of the ground water, as follows equation:

$$\textbf{\textit{Dolomite + Gypsum + Halite + Sylvite + }} \boldsymbol{Mg^{+2}/Na^{+}} \longrightarrow \textbf{\textit{Calcite + Hematite}}$$

When the study area has different kinds of the water bodies for example (confined/ unconfined aquifer or surface/ground waters), The mixing modelling process become an important procedure to identify the extent of the effect occurring between the water bodies. Therefore, it is important to check up the ability of water bodies to mixing by using many of particular quantities to determine the mass transfer results and the geochemical reactions for the selected initial water and final water members for mixing [34]. In the present study, the calculated mixing process modelling had been taken for two kinds of waters represented by the surface water (Babylon stream) and the shallow groundwater (selected wells) and for two periods (dry & wet), figure (7), when the well (8) considered as the first initial water and the second initial water was the Babylon stream, whereas the final water represented the selected remaining wells.

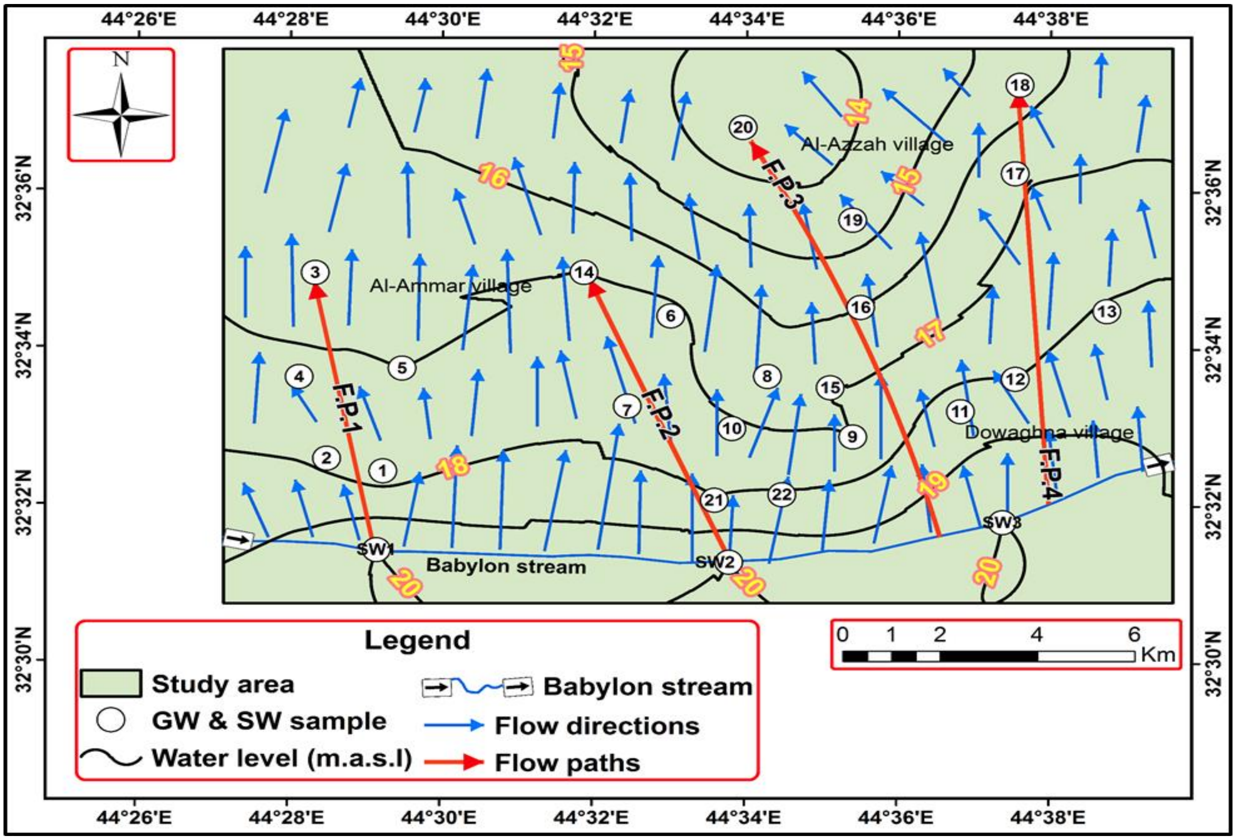

Figure (7): Selected flow paths for mixing modelling in the study area.

The wells (1,7,13, and 21) were a highly affected by the Babylon stream during the two periods where the contribution values of the stream were ranged between (0.74% to 0.98%) for the dry season and between (0.59% to 0.84%) for the wet season, while the other wells (3,5,14,19, and 20) reflected the low contribution of the stream and high involvement of the groundwater during two periods. The mass transfer of the mixing models shows equivalent reactions of the mineral phases same of the flow reaction models.

There are many of factors which affected on the mixing models such as the hydraulic head, connectivity of the river, temperature, pressure and the chemical/physical variations along the flow path controlling on the mixing ratios along the flow path [35].

Conclusions

1- The hydrogeological setting of the study area characterized by many of the shallow unconfined aquifers represented by modern quaternary deposits (Quaternary unconfined aquifers). The hydraulic properties of the shallow aquifer consist of the hydraulic conductivity (less than 4.1 m/day), the transmissivity (T) between (150- 220 m^2/day), and the specific yield of the unconfined aquifer in the Babylon governorate was about (0.075) and for the bank deposits around the streams was about (0.005). The soil profile in the study area includes the main layer of brown medium to very stiff silty-clay and sandy silty clay with organic materials and iron oxides.

2- According to Mather (1974) and Al-Kubaisi (2004) classifications, the general dominant climate was sub-arid to arid in the study area affected by the Mediterranean Sea and Arabian Gulf conditions.
3- According to Piper diagram (1944) and Schoeller classification (1972), the water type of the all samples during two periods fall in the alkaline earth with prevailing sulfate and chloride with the increase in the Ca^{+2} & Mg^{+2}. During the dry period the type of water was ranged among ($Ca-SO_4$, $Mg-SO_4$ to Mg-Cl), while during the wet period was ($Ca-SO_4$ to $Mg-SO_4$).
4- The inverse hydrogeochemical modelling shows that the dolomitization represented the dominant geochemical process reaction of the ground water. The chief precipitation mineral is calcite while the dissolution phase represented by the dolomite mineral. The gypsum and halite minerals show a dissolution phase, whereas the hematite and sylvite minerals show different ratios of dissolution and precipitation during two periods, as follows equation:

Recommendations

1- The problem of drinking water in the study area should be solved by setting up treatment plants located on the Shatt Al-hilla and its tributaries such as Babylon stream and the use of modern irrigation techniques to reduce water losses due to over-irrigation in the area.
2- Designing a numerous of measuring stations approved by the competent authorities in differences parts of the province for the purpose of obtaining hydrological and hydrogeological information for the Babylon governorate.
3- Develop a set of suggestions for controlling and quantifying groundwater by designing a mathematical model for the shallow open aquifer in the area.
4- Design a 3D mathematical model to determine the flow directions of groundwater for different depths.
5- The study of unstable isotopes, especially tritium and helium to understanding the age evolution of groundwater in the region.

CONFLICT OF INTERESTS.
There are non-conflicts of interest.

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الخلاصة

تمثل منطقة الدراسة منطقة النيل في قضاء المحاويل التابعة الى محافظة بابل والتي تبتعد بحوالة (90 كم) جنوب محافظة بغداد وبحوالي (20 كم) شرق مدينة الحلة. غطت هذه الدراسة مساحة قدرها (300 كم^2) واقعة مابين خطي طول (44° 30′ & 44° 36′) وما بين دائرتي عرض (32° 32′ & 32° 36′). الوضع الجيولوجي لمنطقة الدراسة يتميز بالترسبات الحديثة للعصر الرباعي خلال فترتي البليستوسين والهولوسين متضمنة في الغالب ترسبات السهل الفيضي. طبوغرافياً، تتميز محافظة بابل بقلة الانحدار مع تدرجات خفيفة بحوالي (22 سم/كم) تنحدر من المناطق الشمالية والشمالية الغربية باتجاه المناطق الجنوبية والجنوبية الشرقية. ان الهدف الأساسي للدراسة الحالية هو انشاء موديلات هيدروجيوكيميائية للمياه الجوفية في منطقة الدراسة لغرض تحديد نسب الذوبان والترسيب للأطوار المعدنية على طول مسارات التدفق المختارة وكذلك لغرض توضيح مدى تأثير المياه السطحية (جدول بابل) على المياه الجوفية من خلال استخدام تقنية الخلط الهايدروجيوكيميائية. أظهرت المعاملات الكيميائية للمياه السطحية والجوفية تغيرات مكانية وزمانية هامة من خلال تراكيز العناصر الرئيسية والثانوية خلال فترتي الدراسة. يدل التفاعل الجيوكيميائي الرئيسي في منطقة الدراسة على وجود طور الذوبان في معادن الدولومايت، الجبسوم، الهالايت والسلفايت، أما طور الترسيب فهو يشمل معادن الكالسايت والهيماتايت على طول المسارات المختارة. كما أوضحت عملية الخلط بان هناك تأثير عالي لجدول بابل على الابار (1،7،13 و21)، ويكون اقل تأثيراً على الابار (3،5،14،19 و20) وبنسب مختلفة.

الكلمات الدالة: مياه جوفية، مياه سطحية، النمذجة الهيدروجيوكيميائية، عملية الخلط، نت باث، مسار الجريان، ادلة التشبع.