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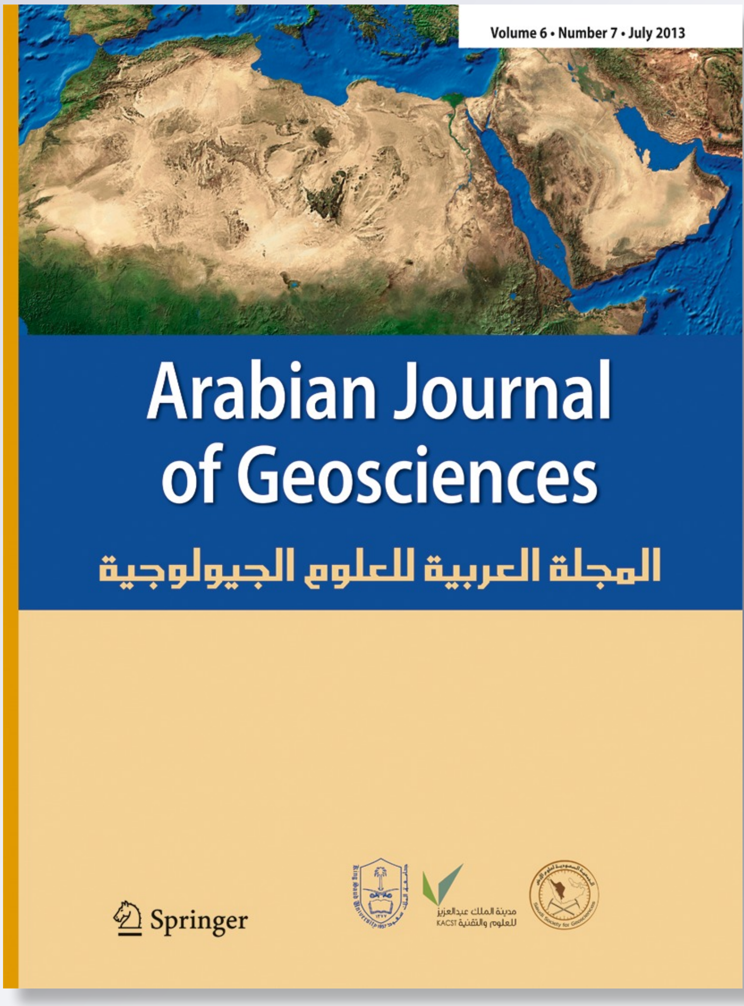
Arabian Journal of Geosciences

ISSN 1866-7511
Volume 6
Number 7

Arab J Geosci (2013) 6:2501-2518
DOI 10.1007/s12517-012-0538-1



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ORIGINAL PAPER

Hydrochemistry and pollution probability of selected sites along the Euphrates River, Western Iraq

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Received: 13 October 2011 / Accepted: 8 February 2012 / Published online: 28 February 2012

Abstract The hydrochemistry of Euphrates River in the study area which extended from Hit to Al-Saqlawia was studied in order to determine the physical, chemical, and biological properties in addition to the radiation level. Thirty-one stations along the Euphrates River were chosen, 17 of them represented the Euphrates River itself, whereas the other stations are considered as point pollution sources which all empty their load directly in the Euphrates River with an average total discharge of 32 m^3/s. Twenty-eight samples of the Euphrates water of both high- and low-flow periods were analyzed for cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), anions ($SO_4^=$, Cl^-, $CO_3^=$, HCO_3^-, NO_3^-, PO_4^{-3}), H_2S boron, dissolved oxygen, biological oxygen demand, bacteriological tests, radiation levels in addition to physical parameters such as hydrogen number (pH), total dissolved solid, electrical conductivity, total suspended solid, and temperature. This study showed that the cations and anions during periods of high and low flows are within acceptable limit with exceptional Cl^-. Hydrochemical formula during the high flow was Na-Ca-Mg-Cl-SO_4, then it changed into Na-Ca-Mg-HCO3-SO_4-Cl during the low-flow period. The average output cations and anions at downstream (Saqlawiya area) was relatively higher than those of input at upstream (Hit area); this attributed to the natural and anthropogenic activities originated mainly from agricultural activity and population communities around the river. Radiation level for ^{212}Pb, ^{214}Pb, ^{40}k, ^{220}Ac, and ^{214}Bi showed that the higher level of radiation is concentrated within sediment rather than in water, but the radiation in both is within acceptable limit.

Keywords Hydrochemistry · Pollution · Agriculture · Water quality · Chemical parameters · Euphrates River

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Introduction

The Iraqi water resources suffered from severe pollution and unreasonable management policy adopted by the previous regime during the last 15 years. Both Tigris and Euphrates Rivers were subjected to continual disposal of industrial and irrigational wastes directly to the river without any type of monitoring (Al-Rizzo 2004). The Euphrates River in the study area passes through many villages, cities, populated communities, and agricultural lands in addition to the natural pollution points like sulfide spring waters in Hit area and human activities; all these are factors that influence the Euphrates River's water quality.

Hydrogeology and hydrochemistry of the Euphrates River have been studied by many investigators. Banat et al. (1981) found that the concentration of heavy metals (Cd, Cr, Zn, and Mn) in the Euphrates River sediments to be within the natural distribution indicating that this river is still free from pollution. Al-Ubaidy (1983) mentioned that there is little pollution potential in the Euphrates River and concluded that the river water is hard; also, some trace elements are found in concentration higher than the natural geochemical distribution, except Zn which is recorded as a fit value in global clay. The

Euphrates water has been divided into two parts depending on the water chemistry; the first is the upper part in west of Iraq, which is characterized by sulfates–bicarbonates type with 499 ppm of the total sum of cations and anions; the second one is the lower part in the south of Iraq which has sulfates–chlorides type with 1,547 ppm of the total sum of cations and anions (Banat and Al-Rawi 1986). High concentration of PO_4^{-3}, F^-, and NO_3^- indicated that pollution originated from liquid wastes produced from the general establishment of phosphate in Al-Qaim, western Iraq (Al-Quwaizi 1989). In comparison between Tigris and Euphrates River, Al-Marsoumi et al. (2006) concluded that the Euphrates water has relatively higher ionic contents than Tigris water. He attributed that to the geologic, hydrologic, and irrigation agents with respect to the total hardness. The Euphrates water has been divided into two sectors, hard water in the upper portions thereof when entering Iraq from the Syrian border, and very hard at the middle and lower portions, whereas the Tigris water is hard. Al-Hayani (2009) concluded that the groundwater south of Hadetha is not suitable for irrigation and drinking. Mustafa (2009) classified the Euphrates water within Ramadi city as suitable for drinking, irrigation, and different industrial purposes.

This study deals with the Euphrates water in terms of hydrochemistry to reveal the anthropogenic and natural pollution sources and their effects on the quality of the Euphrates water and to evaluate the water quality for drinking and agricultural purposes.

Site description and location

The study area ranges from semiflat to flat area. Some of the surface water originating from valleys, springs discharge, agricultural, industrial, medical, municipal, and domestic wastes drain directly to the Euphrates River. The primary uses of Euphrates water in the study area are for drinking and irrigation. There are a number of cattle farms, farms of crop production, and other agricultural land surrounding the study area along the river. Fourteen effective point sources in the study area were determined during the field investigation (Fig. 1, Table 1). Five of them (Wadi Al-Marj, spring water, domestic waste, Wadi Al-Dawara, and Wadi Al-Muhammadi) are in Hit area and the other six (Al-Ramadi General Hospital, car washing, Albu–Aitha agricultural drain, Obstetric and Pediatrics Hospital, ceramic factory waste, and Al-Taamem water waste) are in Al-Ramadi; the three remnant points are the sewage waste water of Al-Ramadi city which drains in the Euphrates at Khaldia, Altherthar lake drain, and Al-Habbaniya lake drain in Al-Saqlawiya.

The study area extending from Hit to Saqlawiya within Al-Anbar governorate, west of Iraq, is an important part of the Euphrates River (Fig. 1). Many pollution sources are distributed along both banks of the Euphrates River. Some of these are point pollution sources like hospitals, sewage water, irrigational drainages, and domestic waters. Others are nonpoint pollution sources like infiltrated irrigation water and atmospheric pollution. All such points play an important role in the physical, chemical, and biological properties of the river water.

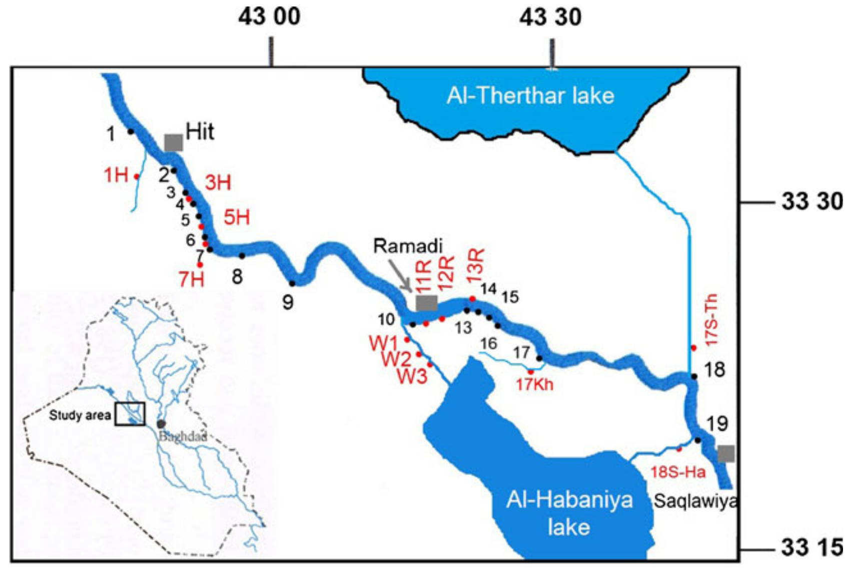
This study is carried out through 31 stations, 14 of which are effective-point polluting source, but the other 17 are the nonpoint source (Fig. 1). The name of stations and their locations are listed in Table 1. Discharge (Ahmad et al. 2009) and total dissolved solids (TDS) of the Euphrates River with some point sources are described in Table 1, which shows how these sources could influence the quality of the Euphrates River water.

Geology

The exposed formations in the study area are shown in Fig. 2. Geology plays a role and considered as one of the important factors in determining the quality of Euphrates water. Euphrates River in Iraq crosses many geological formations within the stable shelf of the Nubian–Arabian craton in Iraq (Jassim and Goff 2006). In south Turkey and west Iraq, the Euphrates River runs off on variety of metamorphic and igneous rocks, especially in the Taurus Mountains in Turkey. In Iraq, actually, the Euphrates River passes through the Stable Shelf, then goes in its way, then enter the Mesopotamian basin in central and south Iraq. The lithostratigraphy in the study area can be described as following:

Euphrates Limestone Formation (Lower Miocene) can be seen near Wadi Al-Mehemdi (Fig. 2). It has widespread exposure extending towards the south and southwest within Mesopotamian plain until Falluja. It unconformably overlies Anah Formation. It mainly consists of limestone. The Euphrates Limestone Formation is deposited under shallow marine, reef, and lagoonal environment with local coral reefs (Buday 1980). This formation hosts the Euphrates River within the study area and adds Ca^{2+} and carbonates ($CO_3^{=}$) due to dissolution processes. Fatha Formation (Middle Miocene), its lower contact with Euphrates Limestone Formation, is conformable. This formation in the study area appears to be on the top of the stratigraphic succession forming Mesa and kuesta morphs near Hit area (Fig. 2). The thickness of this formation is generally variable. In the central parts of the basin, the thickness is up to 900 m; but in the study area around Hit, it is less than 15 m. It is of evaporitic facies mainly consisting of gypsum and anhydrite interbedded with limestone, marl, and

Fig. 1 Sampling stations along the Euphrates River; *red* and *black stations* point pollution sources and non-point pollution sources, respectively



relatively fine-grained clastics (Buday 1980). Its sediments cover the marginal areas of the stable shelf and almost all of the whole unstable shelf. Injana Formation overlies Fatha Formation. Injana Formation (Upper Miocene) is exposed near Habbaniyia area around the Euphrates River. The red silt, claystone, and sandstone are the dominant sediments of this formation. The source of this formation is the high land in the north and northeastern Iraq. Quaternary deposits are comprised of Pleistocene and Holocene deposits. The Pleistocene deposit is heterogenous of fine pebbles consisting of quartz, chert, carbonate, and clay. Cement materials mainly are silica and secondary gypsum. Holocene deposit represents the valley sediments, flood plain, and eolian deposits which formed the Euphrates flood plain near Hit (Al-Habeeb 1969).

Materials and methods

Field work and sampling

The field work covered throughout the study area from Hit to Al-Saqlawiya in Iraq, which has length of about 150 km along the Euphrates River. Geological formations, topography, valleys, and drainage system are clearly observed during field trip in order to help for data interpreting. The sample sites are chosen on the base of cities distribution, population community, wastewater drain sites, agricultural areas, and other affected sites like hospitals on both banks of the Euphrates River.

The field work comprises reconnaissance trips for determining the effective sampling sites along the study area which comprises 31 stations (Fig. 1). Thereafter, water samples are collected. Many parameters are measured locally in the field because the rapid and direct readings are recommended; these measurements included the hydrogen number (pH), electrical conductivity (EC), TDS, and temperature (T) by TDS-EC-pH and T meter, HANNA, type H19811. This instrument is calibrated by buffer solutions which are a standard solution for pH and TDS to obtain accurate reading. Also, H_2S gas is precipitated directly in the field by a chemical method; then, H_2S is determined in the laboratory.

A total of 31 water samples were collected; 17 samples were collected directly from the Euphrates River representing nonpoint pollution source, whereas 13 samples were collected from variety sites empty their load in the river, these expressed as point pollution sources (Table 1). There are two basic types of pollution, point and nonpoint (Sparks 2003). Sampling was achieved during two field trips: the first trip (high-flow period) started in 22 September 2009, and the second one (low flow period) started in 29 April 2010. Field trips are planned to roughly coincide with low- and high-level periods. This strategy has permitted to target sampling periods when the total dissolved solids should be nearly maximum and minimum respectively; unfortunately, opposite expectations occurred. The high-flow period was during September, whereas the low-flow period was during April. Because the Ministry of Water Resources has followed a new plan to store the Euphrates water in Al-Qadissiya Dam (north of the study area) during the months of April, June, and July. This causes the water level decrease in this duration. All equipments (polyethylene bottles, syringes, and beakers) were rinsed and equilibrated with sample before final collection; each water sample is collected in two

Table 1 Physical parameters (1 and 2 are Iraqi Standard (2001) and WHO Standard (2006), respectively) of water samples collected from different stations; stations with asterisk are point pollution sources

Sample no.	Station name	Coordination		Elevation (m)	High-flow period				Low-flow period				
		Latitude	Longitude		TDS (mg/l)	pH	EC µs/cm	T°C	TDS (mg/l)	pH	EC µs/cm	T°C	Turbidity (NTU)
1	Euphrates-1	N33 42 57.3	E42 45 17.8	62	541	7.9	1,160	26.0	630	8.4	1,260	24.1	5.0
*1H	Wadi Al-Marj	N33 41 26.4	E42 45 11.5	63	7,630	6.7	14,116	26.0	7,700	8.0	14,630	23.0	5.7
2	Euphrates-2	N33 41 53.9	E42 45 35.9	59	610	7.6	1,210	26.0	820	8.6	1,620	23.2	5.5
3	Euphrates-3	N33 39 06.3	E42 48 44.8	56	570	7.6	1,140	26.0	750	8.5	1,520	24.1	4.0
*3H	Spring water	N33 39 05.5	E42 48 49.5	56	7780	6.6	14,005	26.0	7,890	7.5	14,991	24.5	7.7
4	Euphrates-4	N33 39 49.0	E42 48 49.6	56	630	7.8	1,260	26.0	1,000	8.0	2,010	22.3	4.5
5	Euphrates-5	N33 39 00	E42 48 53 3	56	540	7.8	1,090	26.0	640	8.3	1,280	23.4	5.1
*5H	Domestic waste water	N33 39 00	E42 48 54.1	59	530	7.9	1,080	26.0	660	7.5	1,320	23.4	5.8
6	Euphrates-6	N33 38 59	E42 48 54.8	56	540	7.8	1,090	26.0	610	8.0	1,230	24.0	4.9
*6H	Wadi Al-Dawara	N33 38 28.3	E42 49 54.2	58	560	7.8	1,100	26.0	2,910	7.4	5,810	26.4	5.0
7	Euphrates-7	N33 38 24.6	E24 50 07.7	56	550	7.8	1,100	26.0	880	8.5	1,770	26.9	4.0
*7H	Wadi Al-Mehemdi	N33 32 04.5	E42 55 32.2	54	–	–	–	–	402	7.8	690	25	6.3
8	Euphrates-8	N33 31 34.9	E43 00 41.3	54	550	7.6	1,100	26.0	690	8.5	1,390	23.8	5.1
9	Euphrates-9	N33 29 59.8	E43 02 42.3	53	570	7.7	1,160	29.0	710	8.2	1,420	23.6	4.7
10	Euphrates-10	N33 26 20.4	E43 16 25.7	50	550	7.9	1,110	27.7	690	8.1	1,390	24.4	3.9
*11R	Al-Ramadi General Hospital	N33 26 28.7	E43 18 48.9	47	610	7.9	1,220	33.2	740	8.0	1,480	24.8	4.4
*12R	Car washing	N33 26 28.7	E43 18 48.8	45	540	7.9	1,090	27.8	680	7.9	1,360	23.7	3.9
13	Euphrates-13	N33 26 48.2	E43 19 31.4	45	550	7.9	1,110	27.5	690	8.1	1,390	23.1	3.0
*13R	Albu-Aitha agricultural drain	N33 27 26.7	E43 22 24.2	46	2,260	7.9	1270	27.0	3,380	7.9	6,810	23.0	4.5
14	Euphrates-14	N33 27 26.7	E43 22 24.2	46	550	7.7	1,090	28.9	710	8.2	1,420	23.0	3.9
15	Euphrates-15	N33 27 51.7	E43 20 12.7	45	530	7.9	1,070	29.2	690	8.4	1,380	23.4	4.4
16	Euphrates-16	N33 26 55.5	E43 23 02.7	44	570	7.8	1,150	28.9	720	8.3	1,440	24.2	5.1
17	Euphrates-17	N33 24 20.4	E43 29 24.2	44	530	7.6	1,070	27.0	740	8.4	1,420	25.6	6.1
*17Kh	Sewage waste water	N33 24 10.1	E43 29 16.1	47	570	7.7	1,090	27.0	740	7.6	1,740	23.1	7.5
*17 S-Th	Al-Therthar lake outlet	N33 26 58.5	E43 36 18.6	46	630	7.9	1,260	29.7	570	7.8	1,140	24.3	5.0
18	Euphrates-18	N33 23 11.5	E43 37 07.6	43	600	7.8	1,190	30.0	590	7.7	1,210	24.5	5.9
*18 S-Ha	Al-Habbaniya lake outlet	N33 22 07.8	E43 36 16.5	45	700	7.9	1,390	29.8	950	8.2	1,910	25.2	5.0
19	Euphrates-19	N33 22 09.6	E43 37 14.5	43	590	7.9	1,180	28.0	620	8.1	1,240	23.0	6.0
Range					530–630	7.6–7.9	1,070–1,260	26–33	590–1,000	7.4–8.6	1210–2,010	22.3–26.9	3–6.1
Average					564	7.7	1,137	27.5	715	8.2	1,433	24	4.7
1 and 2					1,000	6.5–8.5	1,530		1,000	6.5–8.5	1,530		5.0

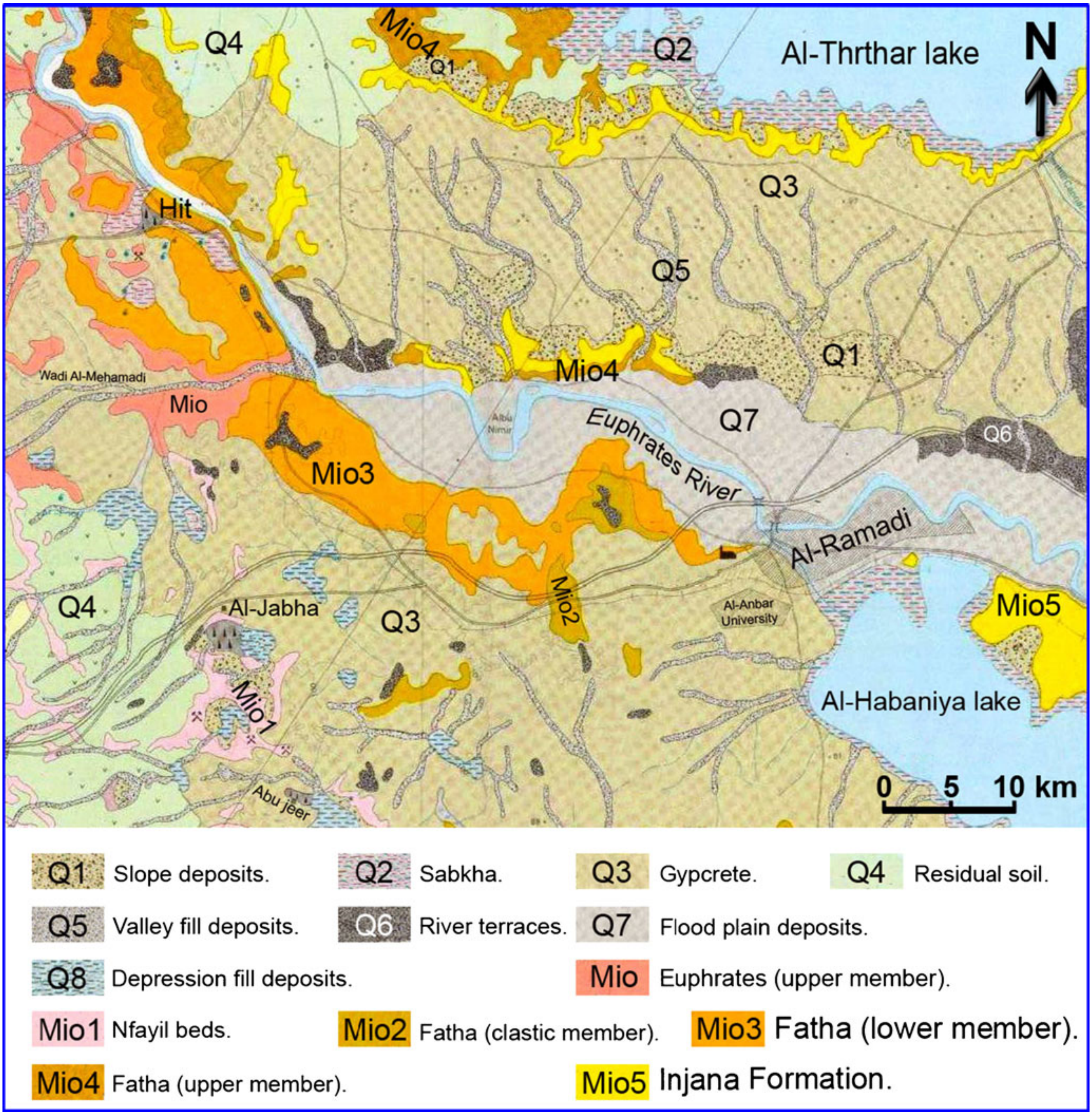


Fig. 2 Geological map of the study area

bottles; one for chemical analyses and the second one for biological analyses. One milliliter of nitric acid was added locally (in the field) to the samples intended for chemical analyses, but nitrate (NO_3^-) is determined in samples that are not acidified with HNO_3. The physical properties were done in the geochemistry laboratory at the Earth Science Department, University of Baghdad, whereas chemical, biological, and radioactivity analyses were done in the Chemical Research Center of the Ministry of Science and Technology, Iraq.

Laboratory works

All samples were analyzed for major cations (K^+, Na^+, Ca^{2+}, and Mg^{2+}) and major anions ($CO_3^=$, bicarbonates (HCO_3^-), $SO_4^=$, and Cl^-), as well as the secondary anions (PO_4^{-3}, NO_3), as well as H_2S gas and boron (B). Biological tests included dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand, and some bacteriological tests were done for selected samples. The analyses mentioned above were achieved in the Laboratories of The Center of Water Treatment Technology at the Ministry of Science and Technology using different techniques. Flame photometry was used for determining Na and K according to the procedure of Harris (1995). Calcium is determined according to the American Society for Testing and Materials (1989) by titration of the unknown water sample against ADTA (0.01 N). Magnesium was computed by subtracting the Ca concentration from total hardness. Total hardness (TH) is computed as measurement of the Ca and Mg ions in the water as milligram per liter and it can be found by the following formula: TH=2.5 Ca+4.1 Mg. The gravimetric method was used for determining the $SO_4^{=}$. The method of gravimetric titration was applied for determining Cl^- potassium chromate as the indicator (K_2CrO_4). Spectrophotometer was used for determining phosphorus. Phosphorus is oxidized to the phosphate ion (PO_4^{-3}). Reagent dye is added and the absorbance will be available for reading directly. Determination of H_2S was done directly in the field by chemical method which converts that gas to precipitated material. The detailed procedure as following; 4 ml of 20% of $(CH_3COO)_2$ Zn and 1 ml of 1 N from NaOH were transferred into volumetric flask of 100 ml, then flask was filled by sample water and closed well. In this case, H_2S became as white precipitate in form of ZnS according to the equation shown below:

$$(CH_3COO)_2Zn + 2NaOH + H_2S = ZnS + 2CH_3COONa + 2H_2O$$

H_2S concentration was computed depending on the molecular weights of S. A total of five water samples collected from stations of 4, 5H, 10, 16, and 18S-Ha are bacterially analyzed for water quality. Bacterial tests include coliform (MPN/100 ml), fecal coliform (MPN/100 ml), *Streptococcus* (MPN/100 ml), fecal streptococcus (MPN/100 ml), and total plate count (cell per milliliter; Table 4). Calibrated dissolved oxygen probe used for determining dissolved oxygen which diffuses across the membrane was measured and directly converted into DO reading expressed by milligram per liter which equal parts per million. The BOD test takes 5 days to be completed and is performed using a dissolved oxygen test kit. The BOD level is determined by comparing the DO level of a water sample taken immediately with the DO level of a water sample that has been incubated in a dark location for 5 days. Radioactivity in 1 Kg of the sediment sample is measured using Gamma spectrometer system based on a pure germanium detector with effecter 40% and resolution 2 Kev at the energy line 1.33 Mev. The soft wave program Gennie-2000 is used for measurement and analyses. Merinelli beaker geometry is used for the measurement. Energy and efficiency calibration are accomplished with the standard source MGS5-1045 (from Canbeirra Comp, USA).

Accuracy

The analytical accuracy for all water samples were computed according to Hem (1985) and expressed by equation below:

$$\%U = \frac{r\,\text{Sum of cations} - r\,\text{Sum of anions}}{r\,\text{Sum of cations} + r\,\text{Sum of anions}} \times 100$$

$$C = 1 - \text{U}$$

where, U is the uncertainty (reaction error), r represents values in equivalent per mil (epm), and C is the certainty or accuracy. When $U \leq 5$, the result could be accepted, but if $5 < U \leq 10$ the result will be accepted with risk (Hassan 2007; Al-Hamadani 2009). Accuracy of water analyses appear to be within acceptable value. Some results are out of acceptable range, this is due to addition of chlorine to water (chloritization) by sterilization processes.

Results and discussion

Physical parameters

Turbidity, color, taste, and odor

All these physical properties are considered as important and necessary parameters to be examined. Turbidity ranges from 3.0 to 6.1 NTU with average 4.7 NTU (Table 1) during the low-flow period. The NTU is nuphelometric turbidity unit. Many reasons causes color such as iron and manganese oxides, decay organism, planktons, industrial wastes (Pierce et al. 1998). Color is measured for water samples that are devoid of turbidity because turbidity gives color value more than the actual. Color appears to be less than 5 color unit (CU) during both periods of high and low flow, which is expressed as normal and within the acceptable limit according to Iraqi Standard no. 417, 2010 that determines the acceptable limit to be 10 CU.

Odor and taste probably come from a variety of sources like humic compounds, algae and fishes, and dissolved gases in water (Pierce et al. 1998). Taste and odor of the Euphrates water appear to be acceptable everywhere in the study area, but in Hit, especially around the connection of sulfate spring water with the river (sample 1H), it appeared abnormal because of the presence of dissolved H_2S gas in spring water.

Hydrogen number (pH)

Hydrogen number was measured directly in the field indicating that the water of Euphrates River is neutral and slightly tends toward alkalinity. During the high-flow period, pH ranges from 7.6 to 7.9 with an average of 7.7; whereas it recorded as 7.4–8.6 with an average of 8.2 during the low-flow period (Table 1).

Total dissolved solid

During high-flow period, TDS ranged from 530 to 630 mg/l with an average of 564 mg/l, whereas its ranged increased from 590 to1,000 mg/l with average of 715 mg/l during the low-flow period (Table 1; Fig. 3). The point sources (1H, 3H, 6H, 13R) have high TDS and therefore were considered as point source of pollution. 1H and 3H are water drain of sulfate spring, 6H is Wadi Al-Dawara which is a sewage drain of Hit town, 7H is Wadi Al-Mehemdi which is a seasonal valley supply the Euphrates with fresh water, 13R is Albu-Aitha agricultural drain in Al-Ramadi city.

Total suspended solids

Total suspended solids (TSS) ranges from 16 to 60 mg/l with an average of 30 mg/l during the period of high flow; but during low-flow period, it ranges from 11 to 52 with an average of 25 (Table 2). TSS in stations of nonpoint sources declines during low-flow periods because of low river energy, whereas it tends to be random in stations of source points because of the irregularity of their discharge.

Electrical conductivity

The EC ranges between 2 and100 µs/cm for rainwater (Hem 1985), between 50 and 50,000 µs/cm for groundwater, and it reaches 50,000 µs/cm for seawater (Sanders 1998). In water of the Euphrates River, EC ranges from 1,070 to 1,260 µs/cm with 1,137 µs/cm in average during the high-flow period, but it appears to increase during the low-flow period ranging from 1,210 to 2,010 µs/cm, with 1,433 µs/cm in average (Table 1).

Table 2 Total suspended solid (TSS) in the Euphrates River water during high- and low-flow periods; the point-pollution sources were left out of average

Sample no.	TSS mg/l		Sample no.	TSS mg/l	
	High flow	Low flow		High flow	Low flow
1	22	18	11R	20	25
1H	220	225	12R	33	27
2	25	23	13	16	20
3	20	18	13R	100	88
3H	200	204	14	36	30
4	40	15	15	16	18
5	45	38	16	20	16
5H	15	15	17	20	11
6	40	39	17Kh	20	30
6H	40	33	17S-Th	40	39
7	40	34	18	40	36
7H	–	–	18S-Ha	40	51
8	16	14	19	60	52
9	16	12	Range	16–60	11–52
10	40	31	Mean	30	25

Chemical parameters

The chemistry of water is detected mainly by ion concentrations. Composition of ions in rivers is predominantly governed by chemical weathering process and human activity (Jangwan and Semwal 2009).

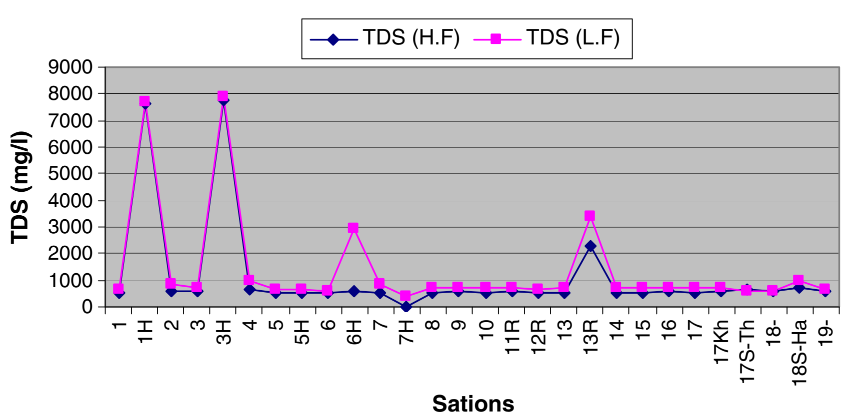


Fig. 3 Total dissolved solid of Euphrates River during the high flow (*HF*) and low flow (*LF*) periods

Table 3 Concentrations of cations and anions (ppm) of the Euphrates River during the high flow period compared with Iraqi Standard (2001)

Sample no.	K^+	Na^+	Ca^{+2}	Mg^{+2}	Total cations	$CO_3^=$	HCO_3^-	$SO_4^=$	Cl^-	PO_4^{-3}	NO_3^-	Total anions	TH	B
1	0.8	99	40	18	157	3	49	80	162	0.052	nil	294	173	–
1H	178	2,410	1,491	97	4,167	20	113	792	5,635	0.057	nil	6,560	4,125	–
2	9	147	146	21	323	15	111	200	279	0.061	nil	605	451	–
3	1.3	95	151	18	165	0.9	98	114	297	0.053	nil	510	451	0.22
3H	52	1,202	596	266	2,116	0.0	119	602	4,941	0.045	nil	5662	2,580	–
4	1.6	96	157	28	282	0.9	85	302	266	0.067	nil	654	506	0.25
5	0.5	84	40	26	150	2.3	100	199	85	0.056	nil	386	206	–
5H	0.5	87	43	30	160	2.4	76	205	83	0.053	5.0	366	230	–
6	0.3	92	51	26	169	2.6	77	217	73	0.054	3.4	370	234	–
6H	1.7	593	141	23	758	17	88	293	807	0.045	3.2	1,205	446	–
7	0.9	170	57	35	263	5	91	220	215	0.05	2.9	531	286	–
7H	–	–	–	–		–	–	–	–	–	–			–
8	0.6	86	35	34	155	0.8	90	214	87	0.0	1.8	391	227	–
9	1.0	98	44	34	177	0.7	65	224	101	0.02	3.6	391	249	–
10	0.9	99	57	24	181	2.4	68	210	88	0.05	4.0	368	241	0.21
11R	1.5	108	51	27	187	0.0	31	277	113	0.0	3.5	421	238	–
12R	0.6	95	36	30	162	3.1	104	183	86	0.0	3.3	376	213	–
13	0.8	95	40	27	162	0.9	38	254	94	0.0	2.4	387	210	–
13R	2.2	671	161	37	871	1.0	97	274	1,010	0.057	4.6	1,382	554	–
14	1.06	101	43	32	177	0.8	51	255	98	0.0	4.0	404	238	–
15	1.02	87	43	17	148	1.73	51	246	94	0.0	2.0	392	177	–
16	1.13	103	47	25	176	0.91	46	263	95	0.0	1.1	405	219	–
17	0.8	90	45	21	157	1.6	83	196	91	0.067	nil	371	198	–
17Kh	1.0	18	180	20	219	0.0	149	122	240	0.062	7.4	511	532	–
17S-Th	1.07	61	110	5.2	177	0.0	49	353	49	0.06	1.0	451	296	<0.02
18	1.8	86	58	27	173	0.0	43	301	79	0.052	4.0	423	255	–
18S-Ha	1.4	108	93	29	231	0.6	76	305	126	0.063	4.5	507	350	0.28
19	1.8	100	51	27	179	1.4	57	215	142	0.055	4.6	415	238	0.17
Rang	0.3–9	84–170	35–157	17–34		0.0–15	31–111	80–302	73–297	0.0–0.067	Nil-4.6		173–506	0.17–0.28
Average	1.44	101	63	23	181	2.3	70	219	134	0.033	2.17	426	276	0.19
Iraqi Standard (2001)	–	200	150	100		–	–	400	350	0.4	50		500	

The point-pollution sources were left out of average

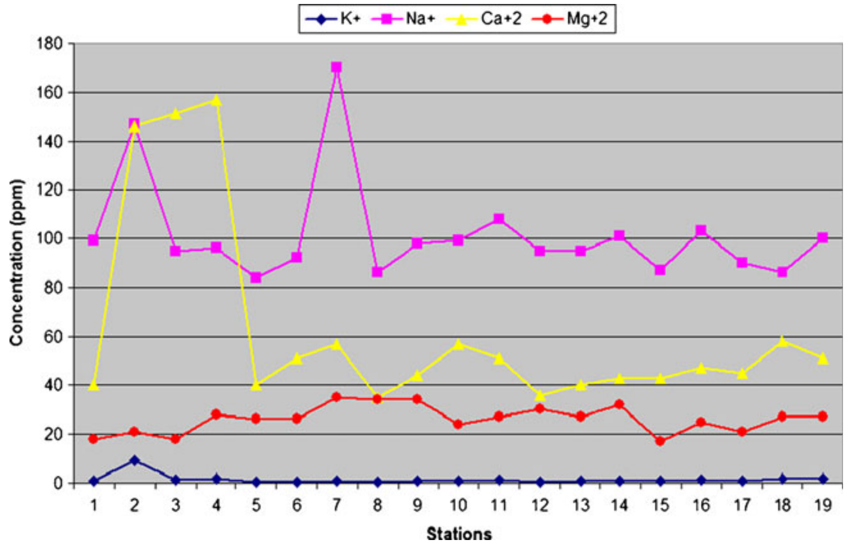


Fig. 4 Cations distribution pattern of the Euphrates River during high flow period for nonpoint source pollution sites

Cations such as calcium, magnesium, sodium, and potassium; anions such as carbonate, bicarbonate, chloride, and sulfate as well as phosphate, nitrate, and sulfide in addition to H_2S and boron have been chosen to determine the chemistry of the Euphrates water during the high- and low-flow periods. These results are listed in Table 3.

Cations

During the high- and low-flow periods, the averages of Ca (63, 119 ppm), Mg (23, 32 ppm), Na (101, 122 ppm), and K (1.44, 2.6 ppm) are within acceptable limits (Table 3). It is obvious that the concentration of cations have been affected by the quantity of river water, where they appear to have low concentration during the low water level, whereas they have high concentration during the high water level.

In both the high- and low-flow periods, the highest values of calcium appear to be in stations 2, 3, and 4 (Figs. 4 and 5) due to the influence of Wadi Al-Marj and the sulfate spring in Hit. Generally, the average concentration of Ca^{2+} in river water is 5 ppm; whereas it is 413 ppm in the sea water (Kladi et al. 1999).

Magnesium tends to have homogenous distribution during high-flow period (Fig. 4), but with high anomaly in stations 4 and 5 during the low-flow periods (Fig. 5); this ascribed to the spring water of high Mg which drains directly into Euphrates River in Hit. Magnesium, an essential nutrient for plants as well as for animals, is washed from rocks like dolomite and magnesite and subsequently ends up in water. Rivers contain approximately 4 ppm of magnesium, and a concentration of 30 ppm is recommended for drinking waters (Ravindra et al. 2003). Magnesium in Euphrates originated from weathering the dolomitic

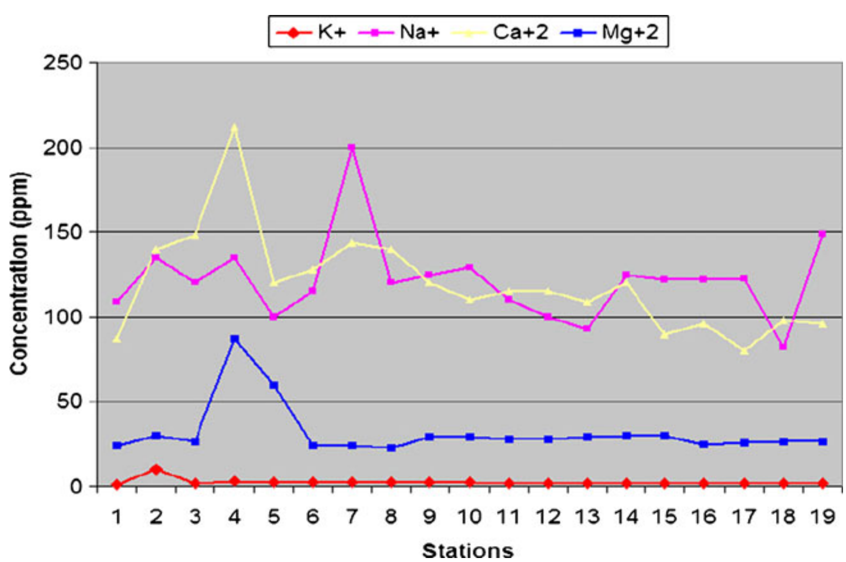


Fig. 5 Cations distribution pattern of the Euphrates River during low-flow period for nonpoint source pollution sites

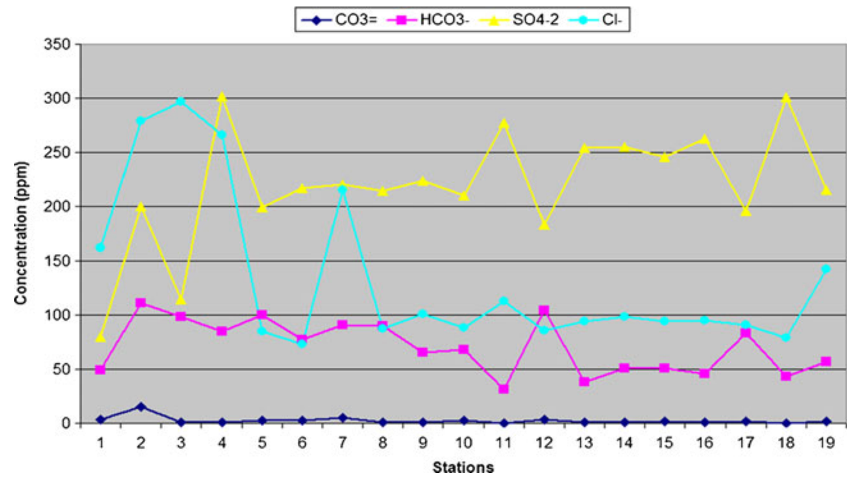


Fig. 6 Anions distribution patterns of the Euphrates River during the high-flow period for nonpoint source pollution sites

limestone formations and natural pollution of sulfate spring water. Greenwood and Earnshaw (2002) mentioned that the fertilizer application and cattle feed rises the Mg content in the rivers.

The characteristic cation in sea water is sodium ion (Na^+). Rivers that form from water that has run over mainly unweathered rocks tend to have high levels of dissolved solids and more calcium ions than sodium ions (Hem 1985). Sodium is the most abundant of the alkali metals group in nature; it mainly occurred in halite which is highly soluble and is adsorbed on fine sediment in case of high evaporation.

The highest values of sodium exist in stations 2 and 7 (Fig. 4) because the high salinity are in Wadi Al-Marj (station no. 1H) and Wadi Al Dawara (station no. 6H). During high flow, Na was found as the higher concentration among cations (Fig. 4), but it appears that shared calcium is the second cation of higher concentration during low-flow period (Fig. 5). The fluctuation of Na concentration is attributed to the adsorbtion processes on fine sediment in case of high evaporation (Hem 1985). Potassium was recorded with normal concentrations except of station of high salinity (sample 2; Figs. 4 and 5) which is located after Wadi Al-Marj.

Anions

During the high- and low-flow periods, the averages of $SO_4^{=}$ (219, 200 ppm), $CO_3^{=}$ (2.3, 3.6 ppm), HCO_3^- (70, 131 ppm), Cl^-(134, 254 ppm), NO_3^- (2.17, 2.5 ppm), and PO_4^{3-} (0.033, 0.025 ppm; Table 3). Sulfates may originate from many sources such as oxidization of sulfide ores, dissolution of evaporite rocks such as gypsum and anhydrite, and anthropogenic source which mainly resulted from agricultural activities such as fertilizers and pesticides. The Iraqi fertilizers contains S% as TSP (1.5), MAP (0.64), NP (0.58), and NPK (2.35; Al-Qaraghuli 2005), and farmers added the Iraqi fertilizers to treat the soil. A considerable quantity of $SO_4^{=}$ has been supplied from Fatha Formation which mainly comprise of gypsum. Obviously, the higher concentration among anions is sulfates (Figs. 6 and 7).

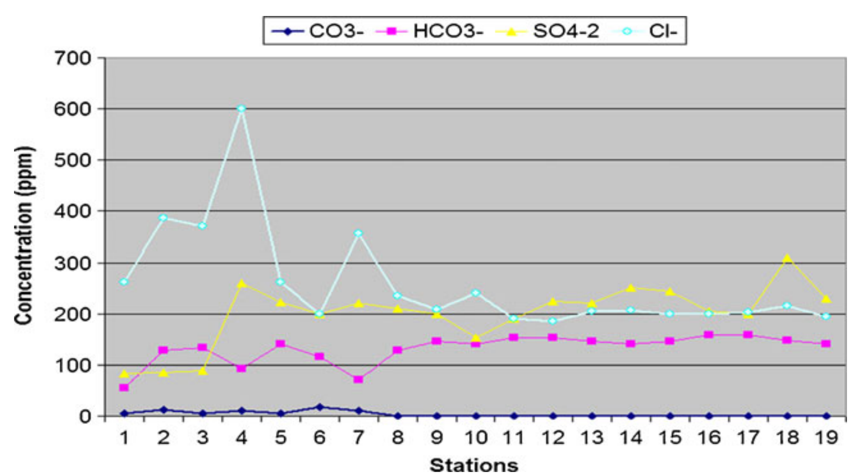


Fig. 7 Anions distribution patterns of the Euphrates River during the low flow period for nonpoint source pollution sites

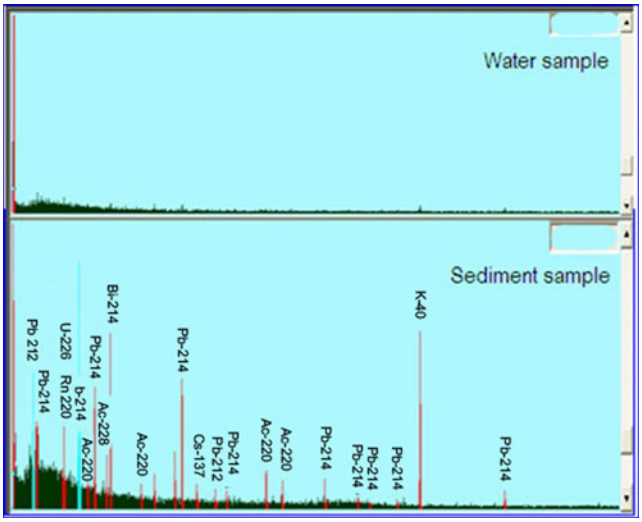


Fig. 8 Gamma spectra of the Euphrates River; the upper spectrum is for water sample collected from station no. 4 at Hit city; whereas the lower spectrum is for sediments sample collected from station no.15

$CO_3^{=}$ and HCO_3^{-} with hydroxyl comprise the total alkalinity in natural water (Gill 1997; Hassan 2007). Carbonates and bicarbonates may originate from many sources such as: atmospheric carbon dioxide (CO_2), solution of carbonate mineral and rocks like calcite and dolomite, weathering of silicate minerals like feldspar by carbonic acid, reduction of nitrate and sulfate by organic matter, and oxidation of organic matter. All these actions are possible in the rivers.

Obviously, there is an increase in $CO_3^{=}$ and HCO_3^{-} during the low-flow period. This may be ascribed to the rainwater and the runoff water which dissolved the atmospheric CO_2 forming weak acid of HCO_3^{-} which contribute to dissolving the surround rocks. Generally, $CO_3^{=}$ and HCO_3^{-} recorded lower concentration among anions (Figs. 6 and 7).

Chloride, in general, is present in all natural waters in low concentration. In most of the surface streams, chloride concentrations are lower than those of sulfate or bicarbonate. Exceptions occur where streams receive inflow of high

Table 4 Biological test of the Euphrates River water during the low flow period

Sample no	Bacteriological analysis	Result	WHO 1994
4	Coli form (MPN/100 ml)	7,000	1
	Fecal coliform (MPN/100 ml)	4,000	0
	Streptococcus (MPN/100 ml)	20	0
	Fecal streptococcus (MPN/100 ml)	20	0
	Total plate count (cell/ml)	9,000	10
5H	Coli form (MPN/100 ml)	0	1
	Facal coliform (MPN/100 ml)	0	0
	Streptococcus (MPN/100 ml)	0	0
	Fecal streptococcus (MPN/100 ml)	0	0
	Total plate count (cell/ml)	2	10
10	Coli form (MPN/100 ml)	28,000	0
	Fecal coliform (MPN/100 ml)	28,000	0
	Streptococcus (MPN/100 ml)	15,000	0
	Fecal streptococcus (MPN/100 ml)	9,000	0
	Total plate count (cell/ml)	3,900	10
16	Fecal coliform (MPN/100 ml)	1,100	0
	Total plate count (cell/ml)	240	10
18S-Ha	Fecal coliform (MPN/100 ml)	1,100	0
	Total plate count (cell/ml)	351	10

Table 5 Concentration of dissolved oxygen (DO) and biological oxygen demand (BOD) in the Euphrates River

Sample no.	DO mg/l		BOD mg/l	
	High flow	Low flow	High flow	Low flow
1	7.0	6.6	5	4.9
1H	1.2	1.1	3	2.8
2	2.1	5.8	5.1	5.3
3	7.8	6.5	5	4.3
3H	1.5	1.2	3	2.4
4	7.9	6.7	6.5	6.1
5	6.5	6.9	6.7	6.7
5H	1.6	1.9	7.8	5.4
6	8.4	5.7	5.2	4
6H	–	–	–	–
7	–	–	–	–
7H	–	–	–	–
8	8.4	7.6	4	3.9
9	7.5	6.9	3	2.5
10	10	6.1	1.2	2.6
11R	8	7.9	3.2	2.8
12R	9	8.1	0.4	1.6
13	7.6	7.4	5	4.2
13R	–	–	–	–
14	8	6.9	2.4	2
15	7	5.8	7	4.2
16	5	4.9	2.7	2.2
17	7.5	6.4	5.7	5.1
17Kh	–	–	–	–
17S-Th	4.2	9.9	16	9.6
18	2.5	9.1	3	6.7
18S-Ha	7.5	5.6	2.7	2
19	8	5.7	16.3	6.9
Range	3.1–8.4	2.9–9.9	1.2–16.3	2.2–6.9
Average	7	6	5.2	4.4
Iraqi Standard No. 417/1996	<5	<5	>5	>5

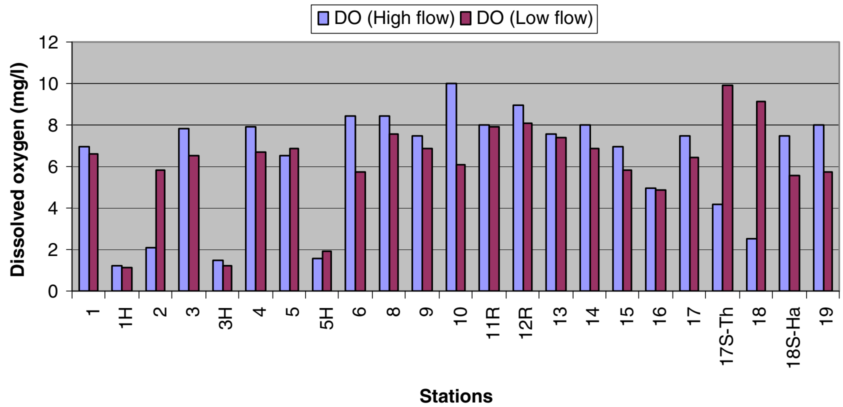


Fig. 9 Dissolved oxygen (DO) in the Euphrates River during high- and low-flow periods

chloride groundwater and industrial waste or are affected by oceanic tides (Hem 1985). Chloride is one of the major anions to be found in water and sewage. Its presence in large amounts may be due to natural processes such as the passage of water through natural salt formations in the earth or it may be an indication of pollution from seawater intrusion and industrial or domestic wastes. Potable water should not exceed 250 mg/l of chloride. Chloride during the high flow has occupied the second order after sulfate (Fig. 6); but during the low flow, it seems to share the first and the second order with sulfate (Fig. 7).

NO_3^- originates from many sources such as agricultural activities especially fertilizers, animal wastes, plant remains, industrial, and sewage disposal (Hem 1985). Ammonia is rapidly oxidized by certain bacteria in natural water systems to nitrate a process that requires the presence of dissolved oxygen. Contamination of ground and surface waters with plant nutrients such as N and P attributed to the interconnections including geology, topography, soils, climate and atmospheric inputs, and human activities related to land use (Sparks 2003). Al-Qaraghuli (2005) found the total nitrogen (N%) was NH_4 used in Iraqi fertilizers as MAP (11.4), NP (28.8), and Npk (17.9). The highest concentrations are recorded around stations 5H (domestic waste water), 6H (Wadi Al-Dowara which was expressed as agricultural drainage), 13R (Albu–Aitha agricultural drainage), 17 Kh (Sewage waste water of Al-Ramadi city), and 18S-Ha (Al-Habbaniya lake outlet). All these stations related to the agricultural activities and human wastes around Euphrates River (Fig. 1; Table 1).

The main sources of phosphate pollution are runoff from land, sewage effluent, detergents, and affects aquatic life (Hutak 2000). Natural waters have a phosphorus concentration of approximately 0.02 ppm which is a limiting factor for plant growth. On the other hand, large concentrations of this nutrient can accelerate plant growth, therefore farmers use phosphatic pesticides. Iraqi farmers use the Iraqi fertilizers and pesticides which add phosphate to the Euphrates water. The following criteria for total phosphorus were recommended by USEPA (1986):

1. No more than 0.1 mg/L for streams which do not empty into reservoirs
2. No more than 0.05 mg/L for streams discharging into reservoirs
3. No more than 0.025 mg/L for reservoirs

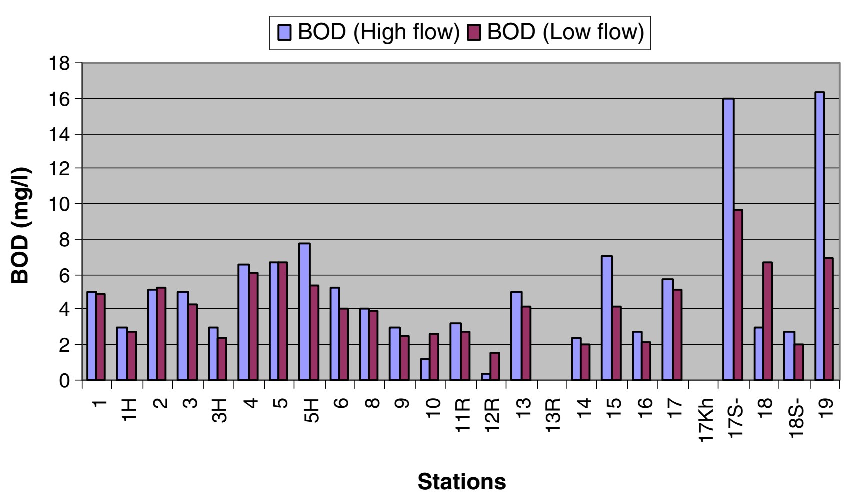


Fig. 10 Biological oxygen demand (BOD) in the Euphrates River during high- and low-flow periods

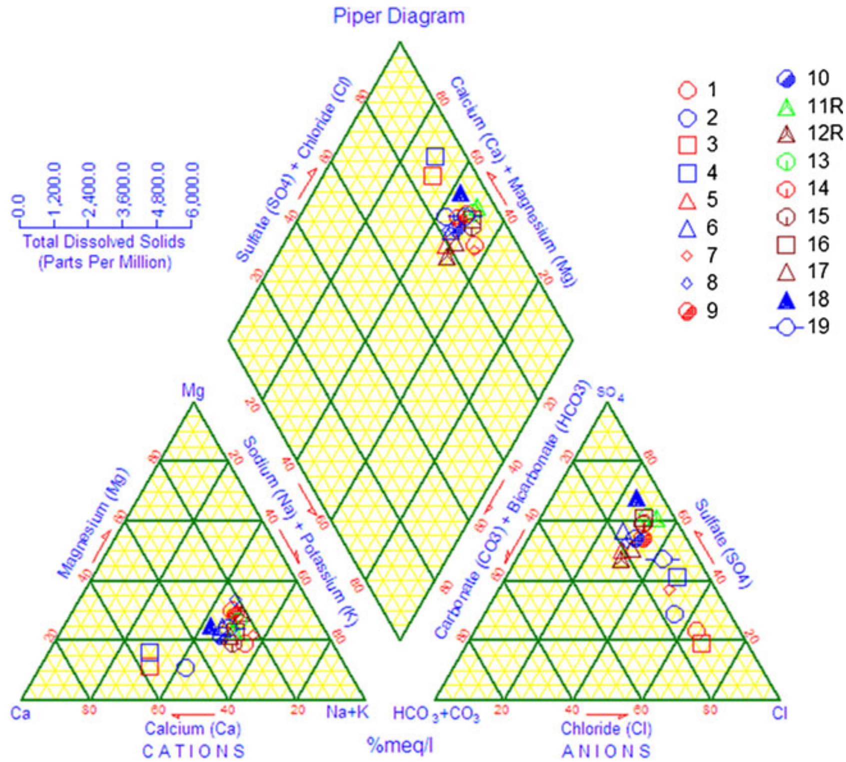


Fig. 11 Piper diagram illustrates the Euphrates River water of the high-flow period

H_2S and boron

During the low-flow period, H_2S value in station of spring water of Hit area ranges from 453 to 637 ppm with 545 ppm in average, while it recorded 244 ppm in station 4 situated after the connection of spring water and the Euphrates River (Fig. 1). This shows how H_2S decreases whenever moving away from the Hit Area. The average of H_2S has been

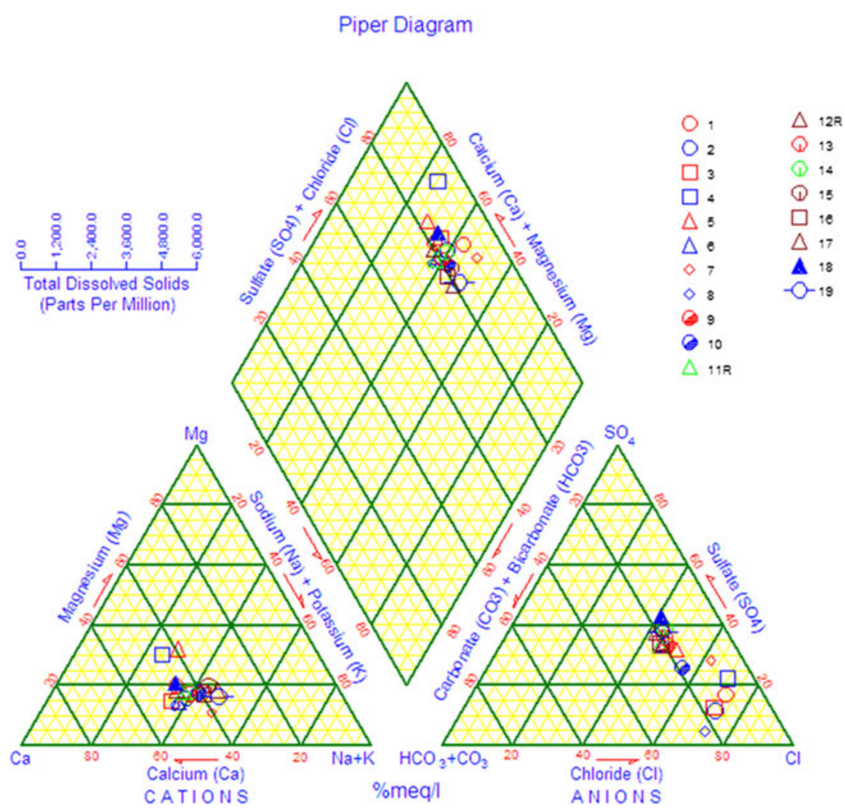


Fig. 12 Piper diagram illustrates the Euphrates river water of the low-flow period

Table 6 Different water classes according to their total hardness (Todd 1980)

Total hardness (mg/l)	Water class
0–75	Soft
75–150	Moderate hard
150–300	Hard
Over 300	Very hard

determined previously by Al-Sa'di (2010) in spring water of Hit area as 467 ppm. Al-Marsoumi et al. (2006) studied the springs in Hit area and classified those as thermal springs rich with H_2S gas (93 ppm); he mentioned that the spring water is of marine origin. The average concentration of B in the Euphrates River does not exceed 0.35 ppm (Ahmad 2008). If boron is less than 0.7 ppm, it is not harmful for plant. If it occurs between 0.7 and 3 ppm, it will be moderately harmful, but it becomes highly harmful when existing more than 3 ppm (Mohammad et al. 2002). During the high flow, B ranges from 0.17 to 0.28 ppm with an average of 0.19 ppm (Table 3).

Radiation level

The results of radiation measurements are illustrated in Fig. 8 which shows the nuclides of ^{40}K, ^{137}Cs, ^{214}Bi, ^{212}Pb, ^{214}Pb, and ^{228}Ac in the water are lower than those in the sediment. However, radiation appears to be below the detection limit; while in the sediments, radiation is within acceptable limit. This means that there is no radiation activity in the Euphrates River water.

Biological tests

A total of five water samples collected from stations 4, 5H, 10, 16, and 18S-Ha are bacterially analyzed for water quality. The results of bacterial tests are listed in Table 4. All stations are biologically polluted and they are point sources of pollution except station no. 5H which has chlorination processes (addition of chorine to water) which kill bacteria. To avoid this contamination, water should be boiled for at least 1 min at a rolling boil or install a point-of-entry disinfection unit, which can use chlorine, ultraviolet light, or ozone (Merck 2000).

Dissolved oxygen is necessary in aquatic systems for the survival and growth of many aquatic organisms and is used as an indicator of the health of surface-water bodies (Lewis 2006). The most common application for dissolved oxygen measurement occurs in wastewater treatment. During the high-flow period, DO and BOD range from 3.1 to 8.4 ppm and 2 to 16.3 mg/l with 7 ppm and 5.2 mg/l in average, respectively; but during the low flow, they range from 2.9 to 9.9 ppm and 2.2 to 6.9 mg/l with 6 ppm and 4.4 mg/l in average, respectively (Table 5). Dissolved oxygen during both periods appears to be greater than 5 mg/l and is suitable for living organism. The lowest value of dissolved oxygen was recorded in the stations 1H, 3H, and 5H (Fig. 9) indicating that these stations are pollution sources. Generally, DO and BOD in high-flow period appears to be greater than that of the low-flow period (Figs. 9 and 10), respectively.

Water quality and classification

The average of hydrochemical formula of the Euphrates River for the high-flow period is:

$$\mathrm{TDS}_{(0.6)\mathrm{gm/l}}\frac{\mathrm{SO}_{4(47.3)}\mathrm{Cl}_{(40)}}{\mathrm{Na}_{(45.7)}\mathrm{Ca}_{(32)}\mathrm{Mg}_{(22)}}\mathrm{PH}_{(7.7)}$$

Table 7 Qualified parameters of the Euphrates River water compared with standards; stations with asterisk are point pollution sources

Parameters		Present study		Iraqi Standard (2001)	WHO standard 2006
		High flow	Low flow		
pH		7.7	8.2	6.5–8.5	6.5–8.5
TDS (mg/l)		564	715	1,000	1,000
EC (µs/cm)		1,137	1,433	–	1,530
Ca^{2+} (mg/l)		63	119	150	100–300
Mg^{2+} (mg/l)		23	32	100	–
Na^{+} (mg/l)		101	122	200	200
SO_4^{2-} (mg/l)		219	200	400	250
Cl^{-} (mg/l)		134	254	350	250
NO_3^{-} (mg/l)		2.17	2.5	50	50
TH (mg/l)		276	405	500	500
Total bacteria count (cell/ml)	*pps	–	2–351	10	10
	River	–	240–9,000		

Table 8 Sodium adsorption ratio (SAR) and electrical conductivity (EC) for the Euphrates River

Sample no.	SAR		EC	
	High flow	Low flow	High flow	Low flow
1	3.2	2.6	1,160	1,260
1H	16.3	16.8	14,116	14,630
2	3	2.6	1,210	1,620
3	1.9	2.4	1,140	1,520
3H	10.3	10.3	14,005	14,991
4	1.9	3.1	1,260	2,010
5	2.6	1.8	1,090	1,280
5H	2.5	2.4	1,080	1,320
6	2.6	2.5	1,090	1,230
6H	12.1	12.2	1,100	5,810
7	4.3	4.1	1,100	1,770
7H	–	1.5	–	690
8	2.5	2.5	1,100	1,390
9	2.7	2.6	1,160	1,420
10	2.8	2.8	1,110	1,390
11R	3	2.4	1,220	1,480
12R	2.8	2.1	1,090	1,360
13	2.8	2.0	1,110	1,390
13R	12.4	11.6	1,270	6,810
14	2.8	2.6	1,090	1,420
15	3.6	2.7	1,070	1,380
16	3	2.9	1,150	1,440
17	2.8	3.0	1,070	1,420
17Kh	0.3	0.5	1,090	1,740
17S-Th	1.6	1.4	1,260	1,140
18	2.3	3.9	1,190	1,210
18S-Ha	1.9	4.3	1,390	1,910
19	2.8	3.4	1,180	1,240
Range	1.9–4.3	1.8–4.1	1,070–1,260	1,210–2,010
Average	2.8	2.7	1,137	1,433

Table 9 Classification of irrigation water based on SAR values (after Turgeon 2000)

level	SAR	Hazard
S1	<10	No harmful effects from sodium
S2	10–18	An appreciable sodium hazard in fine-textured soils of high CEC but could be used on sandy soils with good permeability
S3	18–26	Harmful effects could be anticipated in most soils and amendments such as gypsum would be necessary to exchange sodium ions
34	>26	Generally unsatisfactory for irrigation

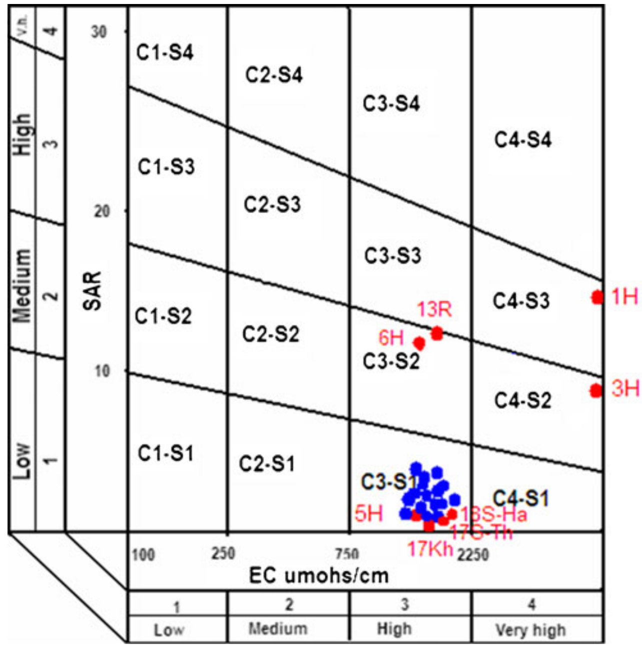


Fig. 13 Rechard classification for irrigation water of Euphrates River water during high-flow period

Accordingly, the water type is Na-Ca-Mg-Cl-SO_4, while during the low-flow period, the average hydrochemical formula is changed into:

$$TDS_{(0.62)gm/l}\frac{Cl_{(43.9)}SO_{4(37.9)}HCO_{3(18.2)}}{Na_{(47.5)}Ca_{(35.6)}Mg_{(16.5)}}PH_{(8.1)}$$

so the water type become Na-Ca-Mg-HCO_3-SO_4-Cl.

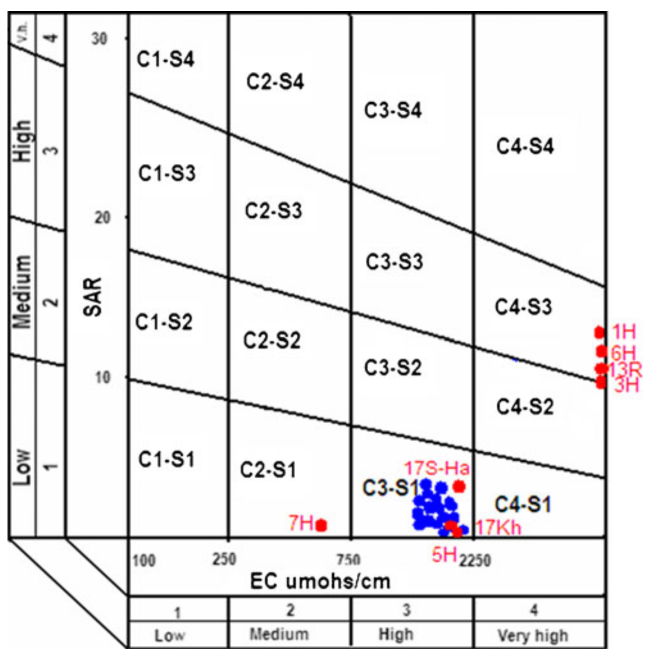


Fig. 14 Rechard classification for irrigation water of Euphrates River water during low-flow period

Piper diagram was used in order to classify the Euphrates water. All samples of Euphrates River for two periods (high and low flow) occupied the field which indicates the normal earth alkaline water with prevailing sulfate and chloride, respectively (Figs. 11 and 12).

Total hardness is essential factor to study water quality. Most important sources are the existence of limestone, dolomite, gypsum, and anhydrite in the river sediments. During the high-flow period, TH ranges from 173 to 506 ppm with 276 ppm in average; but during the low-flow period, the total hardness ranges from 79 to 887 ppm with 405 ppm in average (Table 3). According to Todd (1980), these concentrations indicate that the waters of the Euphrates River fluctuate between hard and very hard water during both periods of high and low flow, respectively (Table 6).

The essential physical, chemical, and biological parameters are compared with the Iraqi Standard (2001) and WHO Standard (2006; Table 7). All parameters during both high- and low-flow periods appear to be fit with standard, therefore the Euphrates water is considered as valid for drinking water with exception of Cl^- during the low-flow period which seems to be unfit of WHO Standard (2006); but it still within the acceptable limits according to the Iraqi Standard (2001). The point pollution source of stations 5H appear to be free of biologically pollution (Table 4) because of the temporary treatment. Station no. 17S-Ha appear to be a source of biological pollution (Table 4) because of the presence of many waste drainages empting into Warar channel-like stations of W1, W2, and W3 which eventually empty into Al-Habbaniya Lake (Fig. 1).

Sodium adsorption ratio (SAR) and Rechard classification were applied in order to classify the Euphrates River water for irrigation. During the high-flow periods, SAR ranges from 1.9 to 4.3 with an average of 2.8; whereas during the low-flow periods, it ranges from 1.8 to 4.1 with an average of 2.7 (Table 8). In comparing these data with data from Turgeon (2000), which is described in Table 9, all samples appear to be classified as S1 level which is not harmful regarding sodium. Rechard classification also was applied to classify the water. During the high- and low-flow periods, quality of the Euphrates River water appears to be C3-S1 class (Figs. 13 and 14); which is suitable for irrigation, but with active drainage system. Point pollution sources of stations 1H, 3H, 6H, and 13R represent different water classes out of C3-S1 (Figs. 13 and 14) which confirmed that these waters are bad and pollutes the Euphrates River. Stations 5H, 17Kh, 17S-Ha, and 17S-Th share the Euphrates River tend to occupy the field of C3-S1, whereas station no. 7H represents better water quality (C2-S1 class) (Fig. 14) during the low-flow period because it belongs to Wadi Al-Mehemdi which receive the water from the seasonal rains; therefore, this station is considered as positive point source supplying the Euphrates River with fresh water. Water quality index (WQI) software program assessed that the type of the Euphrates water during the two periods is medium quality (Table 10).

Conclusions

1. Physical properties of the water (TDS, pH, EC, and TSS) are within acceptable standard limit of the WHO (2006). Color, taste, and smell also found in acceptable limit; but in Hit area, there is local pollution caused by spring water which add to the unacceptable taste and smell of the water; then this local pollution will be diluted by the Euphrates River which makes it acceptable in taste and smell after a short distance.
2. Many point-pollution sources drain into Euphrates River are determined. These are: 1H (Wadi Al-Marj), 3H (spring water), 5H (domestic wastewater), 6H (Wadi Al-Dawara), 7H (Wadi Al-Mehemdi), 11R (Al-Ramadi General Hospital), 12R (car washing station), 13R (Albu-Aitha

Table 10 Water Quality Index (WQI) of the Euphrates River water during the high- and low-flow periods

Factors	High-flow period		Low-flow period	
	Value	WQI	Value	WQI
Fecal coli form (colonies/100 ml)	6,000	13	6,840	12
TDS (mg/l)	564	20	715	20
Dissolved oxygen (mg/l)	7.0	6	6.0	5
pH	7.7	91	8.2	77
Turbidity	4.0	88	3	90
Biological oxygen demand (mg/l)	5.2	55	4.4	59
Nitrate (ppm)	2.17	94	2.5	93
Phosphate (ppm)	0.033	99	0.025	99
Temperature °C	27.5	89	24	89
Final Water Quality Index		56		54
Evaluation		Medium		Medium

agricultural drain),W1 (Obstetric and Pediatrics Hospital), W2 (ceramic factory waste), W3 (Al-Taamem water waste), 17Kh (Sewage waste water in khaldia), 17S-Th (Al-Therthar lake outlet), and 18S-Ha (Al-Habbaniya lake outlet). The otal discharge of these point sources is about 70 m^3/s was empty into Euphrates River along the study area. Ten cubic meter per second comes from Al-Therthar Lake outlet which is considered as fresh water having 570 mg/l TDS.

3. According to the nature of pollution, study area is divided into three sectors; the first is Hit area which have five-point source stations characterized by natural pollution by spring water originating from Wadi al-Marj (1H) and spring water (3H) as well as the anthropogenic pollution causing by Wadi Al-Dawara (6H) which drains water of high NaCl in Euphrates River. The second sector is Al-Ramadi city which have six stations dispersing drainage into Euphrates River. Agricultural pollution caused by human activities is dominant in this sector affecting Al-bu Aitha agricultural drain (13R), the third sector represented by Khaldia and Saqlawiya area which have three-point sources (17Kh, 17S-Th, and 17S-Ha). Station no. 17Kh (sewage waste water) is a channel extending from Ramadi to Khaldia transports sewage waste water of population communities from Al-Ramadi to Khaldia; 17S-Th (Al-Therthar Lake outlet) supplies the Euphrates River with water better than that of Habbaniya lake outlet (17S-Ha).
4. The largest point sources discharged directly into Euphrates River are Al-Habbaniya and Al-Therthar outlet. Both supplies the Euphrates River with water of Ca–sulfate type during high-flow period; but during low-flow period, Al-Therthar lake outlet provides the Euphrates River with water of Ca–sulfate type whereas Al-Habbaniya lake outlet provides the Euphrates River with water of Na–chloride type.
5. Radiation level in sediments is higher than that of water of Euphrates River but both are within the acceptable limit.
6. Composition of ions in Euphrates Rivers is predominantly governed by chemical weathering process and human activity (domestic, agricultural, and medical wastes), and natural sources such as sulfide springs water.
7. The average abundance of anions and cations in the Euphrates River water could be ordered as:

   During high-flow period is $SO4^{2+}<Cl^{-}<Na^{+}<Ca^{2+}<Mg^{2}$

   During low-flow period is $Cl^{-}<SO4^{2+}<Na^{+}<Ca^{2+}<Mg^{2}$
8. The Euphrates River water is classified in the study area as suitable for drinking after refining and chlorination treatment to be free of bacteria; also, it is not harmful effect from sodium where the SAR value was <10 (Table 8) in all stations except station 1H (Wadi Al-Marj), 3H (spring water), 6H (Wadi Al-Dawara), and 13R (Al-bu Aitha) have SAR >10 which is suitable for irrigation of sandy soil of good permeability.
9. Springs water in Hit are sources for rising TDS, especially Cl^{-}, Na^{+}, and SO_4^{2-}

Recommendations

The water of the Euphrates River should be treated before drinking by using chlorine, ultraviolet ray, or ozone, all of which act to kill or inactivate total coliforms including *fecal coliform* and *Escherichia coli* as well as *Streptococcus* to ensure that all bacterial contamination is inactivated and disinfected accordingly. Avoid using the Euphrates River water for drinking directly before the required treatment.

1. The continuous supplying of Al-Habbaniya Lake with the freshwater of the Euphrates River by Al-Warar canal to avoid concentration of salts by evaporation is strongly recommended.
2. Changing the drainages of Wadi Al Marj and spring water in Hit area towards the desert in order to keep their salt loads away from the Euphrates River. This step will help to improve the water quality.
3. All types of waste must be treated before being permitted to be drained into the Euphrates River.
4. Using the scientific procedures of the irrigation, fertilization, and pesticides will decrease the contamination by some chemical elements to minimum.

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