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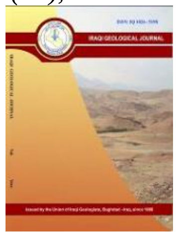

Evaluating the Groundwater and Surface Water Interaction in Southwest Iraq Using Environmental Isotopes Technique

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Abstract

This study aims to use the environmental isotopes technique to evaluate the interaction between groundwater and surface water at a location between two cities in the southwest of Iraq; namely Al-Kifl and Al-Samawa. The salinity of the Euphrates River water increases sharply as it passes in this area, to a level that affects its usage for municipal purposes. A total of 111 samples were collected from the rivers, drainages, springs, shallow and deep wells, and from Sawa Lake, and all the samples were subjected to chemical (TDS, SO_4, Cl, and B) and isotopic (deuterium and oxygen-18) analyses. The chemical and isotopic results showed no interference between the quality of the groundwater (from wells and springs) and Sawa Lake water with the Euphrates River water, in the study area, and hence, neither the groundwater nor Sawa Lake affects the river water quality. Statistically, the t-test analysis showed significant differences among those water samples (p-values less than 0.05 for almost all the chemical and isotopic parameters). On the other hand, drainage water showed a strong relationship to the river water, which indicates a high and strong influence of the drainage water on the river water quality when it mixes with the Euphrates River water.

Keywords: Water resources; Stable isotopes; Sawa Lake; Groundwater, South Iraq

1. Introduction

Environmental isotopes technique plays an important role in the assessment, management, and protection of water resources. Stable isotopes can be implemented in hydrological studies to evaluate the sources and potential risk of contamination and to investigate the interaction between groundwater reservoirs, and surface water, since they are intrinsic to the water molecule and do not undergo reaction with rock matrix at environmental temperatures (Aggarwal et al., 2005). The naturally occurring light stable isotopes of deuterium and oxygen-18 (^2H and ^{18}O) can provide a unique fingerprint of a water resource. The internationally accepted standard for reporting the hydrogen and oxygen isotopic ratios of water (δ^2H and $\delta^{18}O$) is Vienna Standard Mean Ocean Water, V-SMOW (Gat et al., 2000). The technique has been implemented in several areas in the world, while there was limited application in Iraq. Ali et al. (2015) used Hydrochemistry and stable isotope techniques to evaluate the interaction among water resources (river water, lake, and groundwater) in a semi-arid area in the western part of Iraq. (Hadi and Alwan, 2020) used stable isotopes (^2H, ^{18}O, and ^3H) reinforced with hydrochemical data to identify the interaction between groundwater and river water in Al-Diwaniya province in the southwest of Iraq, and to estimate the age of the groundwater in the research area. Hussien and Abdulhussein (2021) used stable isotopes and hydrochemical analysis of water samples to study the

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interaction between the water resources of the Euphrates River and groundwater in a limited area in the western plateau of Iraq. Al-Kubaisi et al. (2022) studied the spatial and temporal control on groundwater recharge area in the north of Iraq between Lower Zab River and Tigris River. They concluded that indicating that local rainfall is the primary source of groundwater recharge, with some interaction with surface water in the study area.

In environmental studies, both isotopes are strongly correlated with a famous formula, and it is referred to as the Global Meteoric Water Line (GMWL) (Craig, 1961).

$$\delta^2H = 8\ \delta^{18}O + 10 \quad (1)$$

Iraqi local meteoric water line (LMWL) was obtained lately to follow the following equation (Al-Naseri et al., 2022):

$$\delta^2H = 7.66 \times \delta^{18}O + 14.19 \quad (2)$$

Euphrates River water quality changes as it passes through the study area, and its salinity increases significantly for many reasons (Rahi and Halihan, 2010). This research aims to evaluate the reasons behind the drastic changes in Euphrates River salinity, by using a combination of chemical and isotopic indicators to assess the interaction between surface and groundwater in the study area and the role of groundwater in changing the quality of the surface water.

2. Study Area

Fig. 1 shows the study area. It is located in the southwest of Iraq, about 180 km to the south of Baghdad between the longitudes ($44^o00'$ - $46^o16'$) and the latitudes ($30^o44'$ - $32^o30'$). The area is characterized by an arid and semi-arid climate that receives a mean annual precipitation of (75-100 mm), with an evaporation rate of (3200-3500 mm). Euphrates River passes through the study area and is split into two branches; Al-Sabeel and Al-Atshan. The area also contains a lake (Sawa Lake), agricultural drainages, and several springs from groundwater aquifers. Sawa Lake has been studied by several authors for its environmental importance in the area, especially after its drought incident in 2022 (Al-Tememi et al., 2019; Awadh et al., 2022). The provinces in the study area are of local economic and agricultural importance. Euphrates River, with its branches; Al-Kufa and Al-Abbasia at the north and Al- Sabeel and Al-Atshan at the south boundaries of the study area are the main source of surface water. In addition, the area contains the natural salty Sawa Lake. Several springs and semi-deep wells are being exploited in the area and have been used for the cultivation of rice, barley, and some other vegetables. Each of the eastern and western Al-Shamia drainages flows into the Sabeel River from the east, while Al-Khasaf drainage flows from the west via Siphon through the Atshan River to Al-Sabeel as well.

Fig. 2 shows the geological formation of the study area. The sediments represented by the Quaternary cover all the parts adjacent to the Euphrates**,** which include the Pleistocene and Holocene deposits. Whereas, the ages of the sediments before the Quaternary era range from the Paleocene to the Pliocene which include Dammam, Euphrates, Nafayl, Fathah, Injana, Zahra, and Al-Dibdiba formations (Barwary and Slewa, 1995). The study area has been described nationally by using three main geological maps of scale 1:250,000, namely: Karbala, Najaf, and Samawa.

Tectonically, the study area is located within the stable platform of the Arab Nubian platform, while part of the area falls within the range of the sedimentary plain of the unstable platform, which is divided into two ranges Al-Rutba and Al-Salman. The most important structural elements distributed in the area are faults with different directions, east-west, northwest-southeast, and north-south (Buday and Jassim, 1987). These Faults cross with each other leading to creating a weak area represented by the presence of springs along with its extension. Hydrogeologically, the main important aquifers that exist in the study area are Dammam, Euphrates, and Recent sediments.

A small part of the same area was studied in 2013 by the Iraqi ministry of water resources (Abdul-Razzaq et al., 2013). Their study included the hydrogeological situation in Shanafya-Samawa using hydrochemical and radioisotopes techniques to evaluate the effect of the groundwater and the Sawa Lake on the quality of Al-Atshan River water. They concluded that there were no effects on the river water by groundwater.

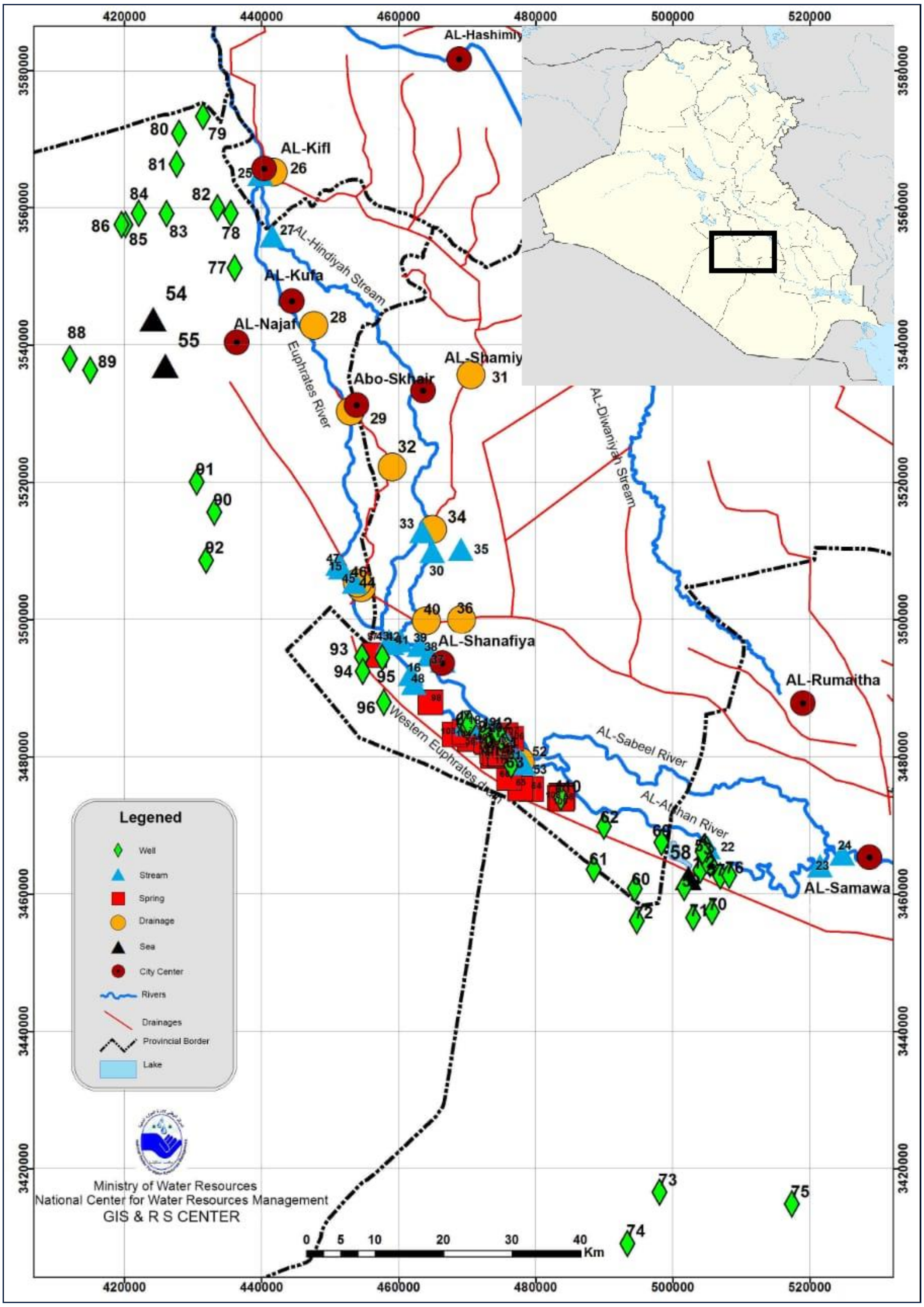


Fig. 1. Study area showing the sampling locations for wells, springs, rivers, drainages, and Sawa Lake

A limited number of published articles studied the effect of water drainage on groundwater and surface water quality in the parts of the study area, using hydrochemistry and radioisotope techniques (Al-Mitawki, 2013; Ali and Ajeena, 2016). The authors conducted a study of the chemical and stable isotopic properties of groundwater and its relationship to the surface water of Muthanna Governorate in southern Iraq (Al-Naseri and Abdul-Razzaq, 2015). Their conclusion revealed that there were no groundwater effects on the quality of the surface water in Al-Atshan River.

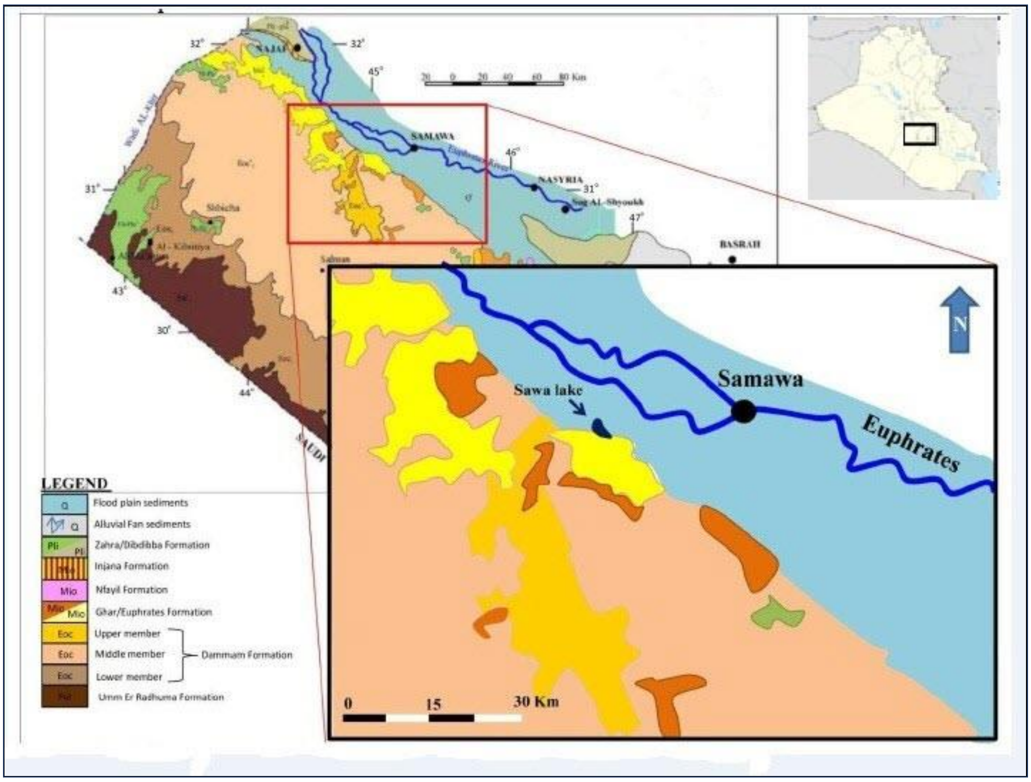


Fig. 2. Geological map of the study area and its surrounding (Awadh, et. al, 2014)

3. Material and Methods

A field sampling program was conducted to collect 111 water samples from 111 sites in the period 2018-2019. Samples included: 26 river water, 33 deep (or semi-deep) wells, 14 shallow wells (observation wells), 11 drainages water, 2 samples from Sawa Lake, and 25 samples from springs. Sampling locations are shown in Fig. 1.

All of the water samples were subjected to chemical and isotopic analysis. Stable isotopes (^{2}H and ^{18}O) were analyzed in the environmental isotope laboratory in the Ministry of Science and Technology in Baghdad using laser spectrometer type (LGR-100). Chemical analysis was conducted in the laboratories of the Ministry of Water Resources in Baghdad. It included the analysis of the concentration of total dissolved solids (TDS), SO_4, Cl, and B.

4. Results and Discussions

All the water samples from the aforementioned groups (rivers, springs, lake, deep wells, shallow wells, and drainages) have been subjected to testing for their chemical and isotopic properties. The samples were grouped into several categories; namely, the two branches of the Euphrates River (Al-Sabeel and Al-Atshan), drainage water, groundwater from deep wells, shallow wells, and springs, and finally water samples from Sawa Lake. Table 1 lists the mean values and their standard deviation for the TDS, SO_4, Cl, B, δ^2H, and δ^{18}O for each category of the water samples. This table shows that, for almost all the parameters, there are wide differences between surface water samples (Al-Atshan and Al-Sabeel) and groundwater samples (Shallow wells, deep wells, and springs). The differences are also high when comparing Sawa Lake parameters with the surface water samples. Nevertheless, the differences with drainage water samples were not that clear. Accordingly, and to evaluate the significance of these differences, a t-test was implemented to compare surface water parameters with the same parameters for each of groundwater, drainage, and Sawa Lake water sample.

Table 2 shows the p-values for the statistical t-test analysis The table shows that the p-values are far smaller than 0.05 for the groundwater, and the lake water samples, while the differences were insignificant when comparing drainage water with surface water samples. This indicates a strong correlation between surface water samples and drainage water samples, which indicates no interaction between groundwater and surface water, and the only possible interaction is between surface water and drainage water.

Table 1. Chemical and isotopic mean values and standard error deviations for each water sample category during the study period

Category	**n**	**T.D.S (mg/l)**	**SO_4 (mg/l)**	**Cl (mg/l)**	**B (mg/l)**	**δ^2H (‰)**	**$\delta^{18}O$ (‰)**
Atshan River	14	1410 ± 420	523 ± 128	333 ± 106	0.56 ± 0.16	-34.23 ± 2.44	-4.32 ± 0.40
Sabeel River	12	1632 ± 765	615 ± 271	381 ± 231	0.43 ± 0.21	-32.03 ± 5.32	-4.28 ± 1.19
Shallow Wells	14	27525 ± 26714	4228 ± 2905	12702 ± 14259	10.94 ± 13.89	-25.25 ± 3.38	-3.03 ± 0.46
Deep Wells	34	4603 ± 1857	1583 ± 634	1097 ± 843	2.07 ± 1.06	-21.74 ± 5.97	-2.84 ± 0.89
Springs	24	12743 ± 19950	3074 ± 4414	4354 ± 7843	3.39 ± 8.17	-19.70 ± 1.45	-2.43 ± 0.43
Sawa Lake	2	14923 ± 13255	4095 ± 5288	5501 ± 4796	6.04 ± 6.80	1.81 ± 41.45	2.35 ± 6.66
Drainages	11	10300 ± 21897	2539 ± 4295	4367 ± 11282	1.61 ± 2.24	-29.72 ± 4.16	-3.55 ± 0.80

Table 2. P-values of statistical t-test comparison between surface water samples and groundwater, drainage, and Sawa Lake water samples

Parameter	Ground	Drainage	Sawa
TDS	1.03E-05	0.212*	5.52E-14
SO_4	2.81E-07	0.158*	0.60344*
Cl	0.000173	0.265*	1.71E-20
B	7.59E-05	0.220*	4.99E-17
^{-18}O	9.21E-10	0.030	0.027199
^{-2}H	3.14E-15	0.051*	0.039668

*: indicates statistically no significant difference

Deuterium (^2H) and oxygen (^{18}O) were employed as indicator fingerprints of water samples through which water quality can be known and determined to identify its source. Fig. 3 shows the relationship between oxygen-18 and deuterium concentration for water samples and their comparison with the GMWL and the LMWL. The figure shows that all of the water samples are below the local and global meteoric water lines. These points were aligned to a lower slope virtual line, which is usually called the evaporation line (dotted line in the figure), due to the evaporation nature of those samples. These results are expected due to the high volume of evaporation that occurs in the river's waters along its column in the area. Groundwater samples tend to cluster in a small area away from this line with lower enrichment values for stable isotopes. Accordingly, the figure shows the formation of two distinct groups of water types (surface and groundwater).

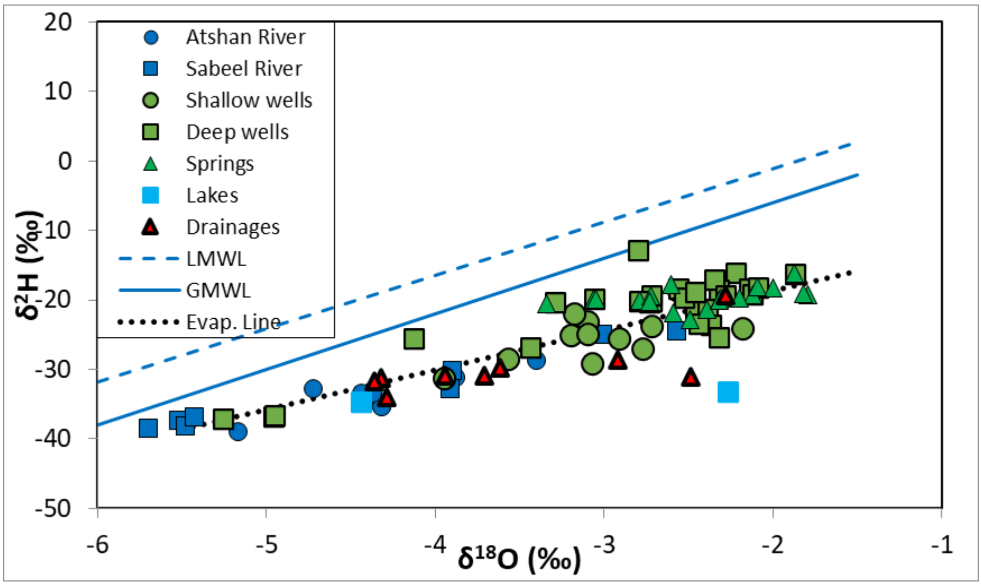


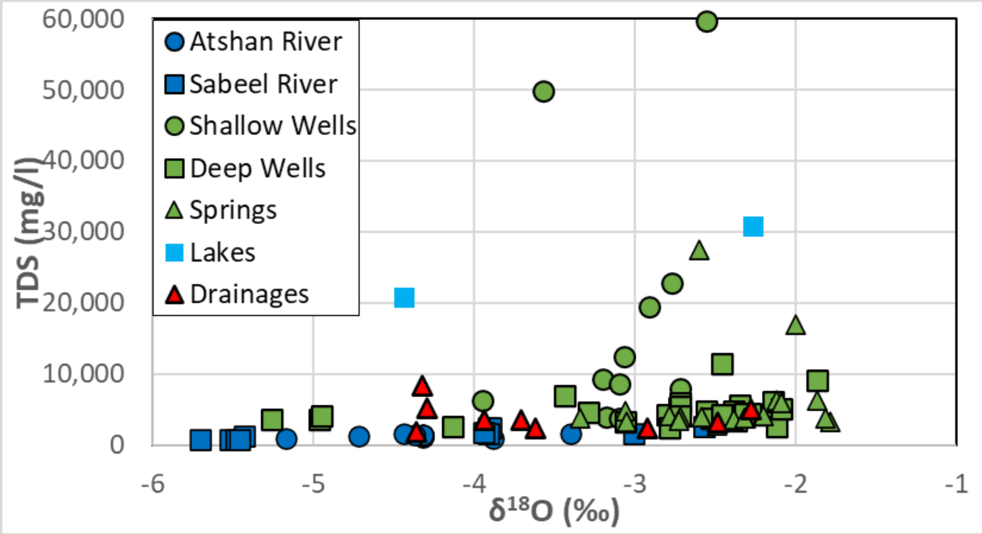
Fig. 3. Relationship between ^{18}O and ^{2}H for all of the water samples and their relation to the GMWL and LMWL

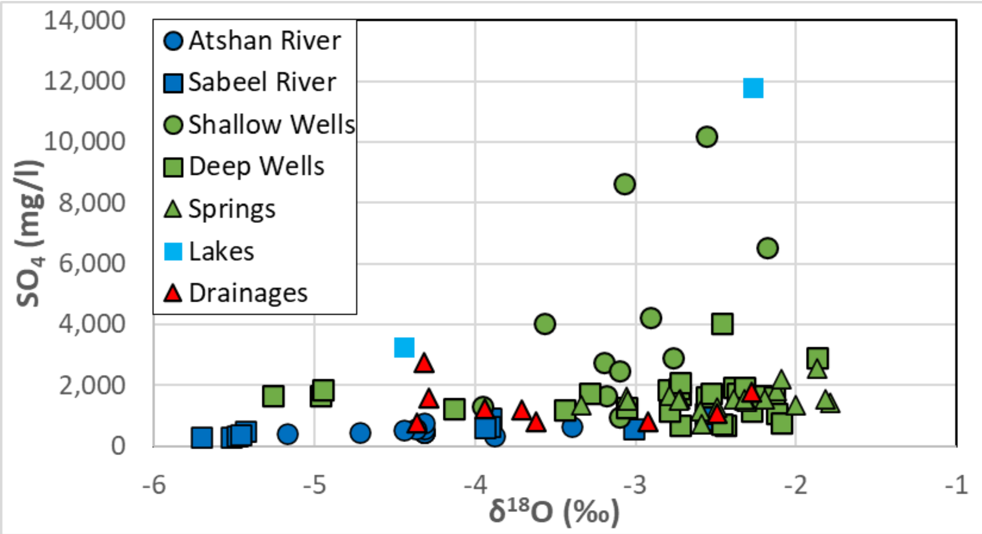
Fig. 4 (a-d), show the isotopic relationship of oxygen-18 with each of the total dissolved salt concentrations (TDS), sulfate (SO_4), chloride ion (Cl), and boron (B), for each of the surface and groundwater samples.

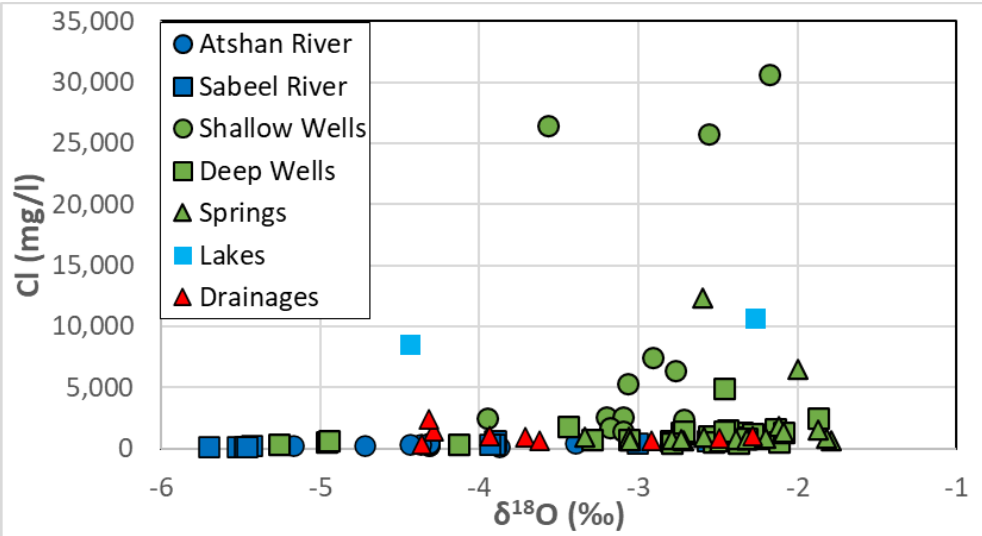
One could notice from the figures that there are slight overlaps between the springs, deep wells, and shallow wells samples for having almost the same isotopic signature of oxygen-18. Although the salt concentration is higher in shallow wells samples, they belong to the same group for their isotopic signatures. The results of the lake samples on the graph were far from river water. The results reflected no interference between the quality of the groundwater (wells and the springs) and the lake water with the river water, neither in their chemical concentration nor in their isotopic fingerprint. This confirms the above results that there is no relationship between groundwater and surface water in the study area and consequently, groundwater does not influence the river water quality.

In addition, the results showed that the highly saline water (rich in chlorine and boron ions in addition to sodium) has high isotopic concentrations, which indicates its freshness and its source is mostly rainwater coming from the west and southwest side of the desert towards Al-Atshan River. On the other hand, medium salinity groundwater has a low isotopic concentration, which indicates that the source of this water comes from somewhat deep regions towards the top of a low level of pressure.

To focus on the two groups with close characteristics, Fig. 5 (a-d) show only one part of the above results that focuses on the isotopic relationship between river water and drainage water samples. The figure shows a clear overlap between both water types, which indicates a strong correlation between them. This is an important result because it indicates a strong influence of the drainage water when it mixes with Al-Sabeel River, on the river water quality. The high salinity level of the drainage water increases significantly the river water salinity from below 1000 mg/l upstream of the study area to about 3000 mg/l downstream of the study area. The source of salinity is the drainage water evaporation and mixing during its cycle of crop irrigation and its interaction with several soil constituents.


TDS (mg/l)
60,000
50,000
40,000
30,000
20,000
10,000
0
-6
-5
-4
-3
-2
-1
δ18O (‰)
Atshan River
Sabeel River
Shallow Wells
Deep Wells
Springs
Lakes
Drainages


SO4 (mg/l)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-6
-5
-4
-3
-2
-1
δ18O (‰)
Atshan River
Sabeel River
Shallow Wells
Deep Wells
Springs
Lakes
Drainages


Cl (mg/l)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
-6
-5
-4
-3
-2
-1
δ18O (‰)
Atshan River
Sabeel River
Shallow Wells
Deep Wells
Springs
Lakes
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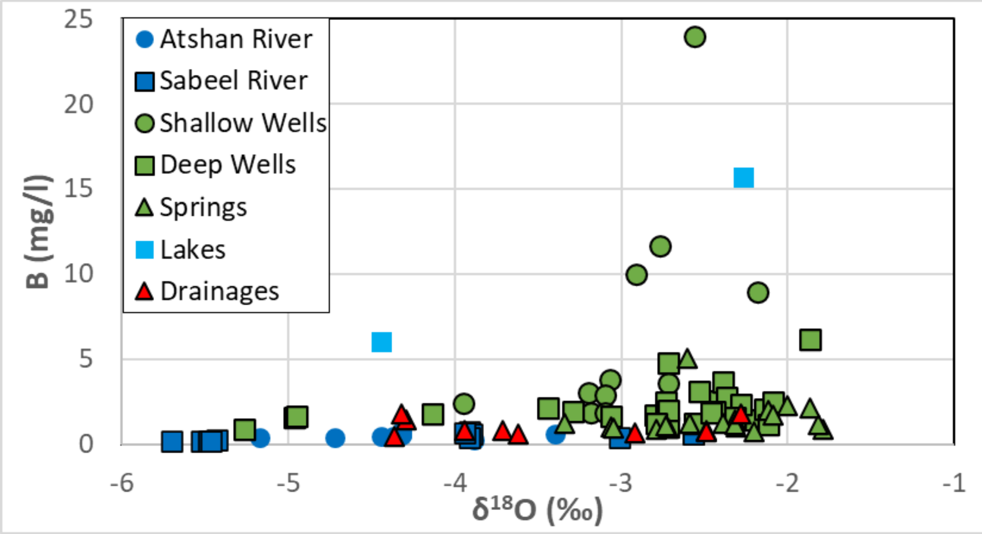
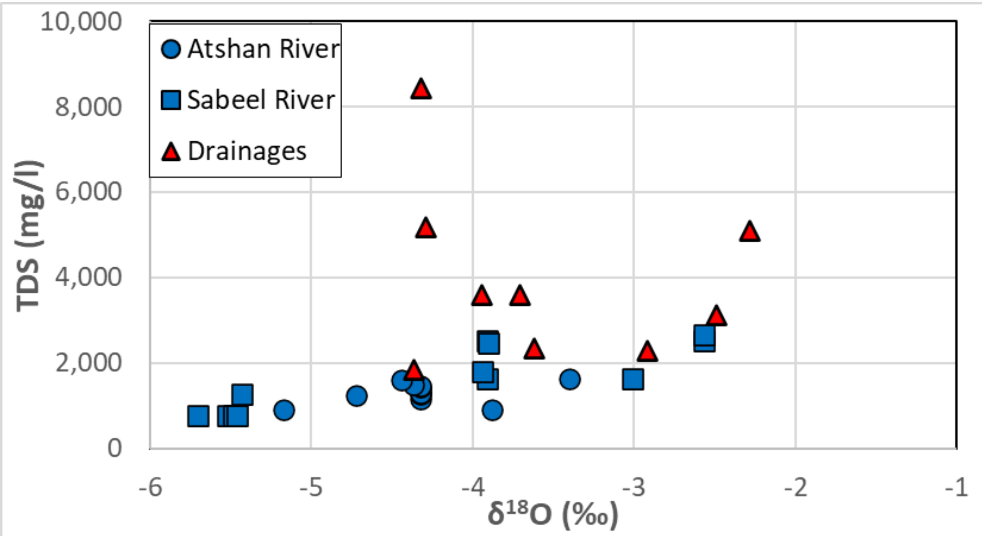
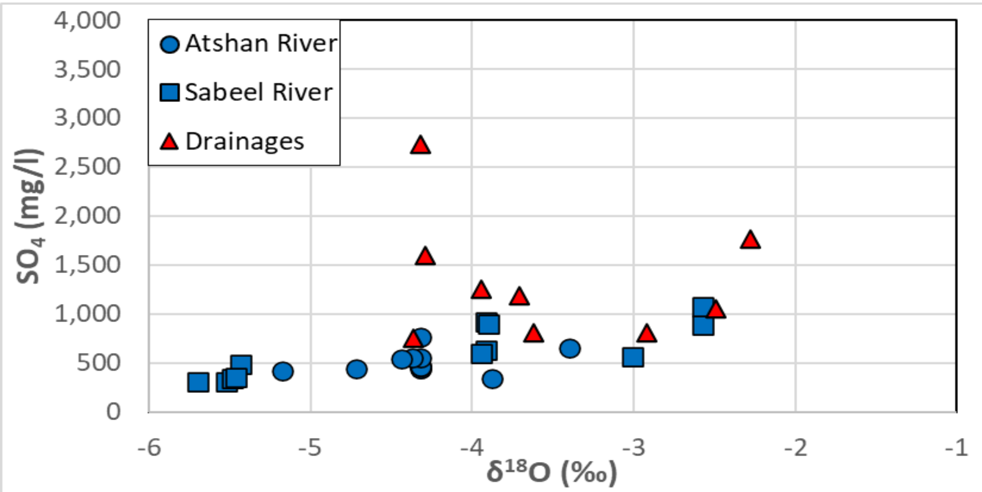
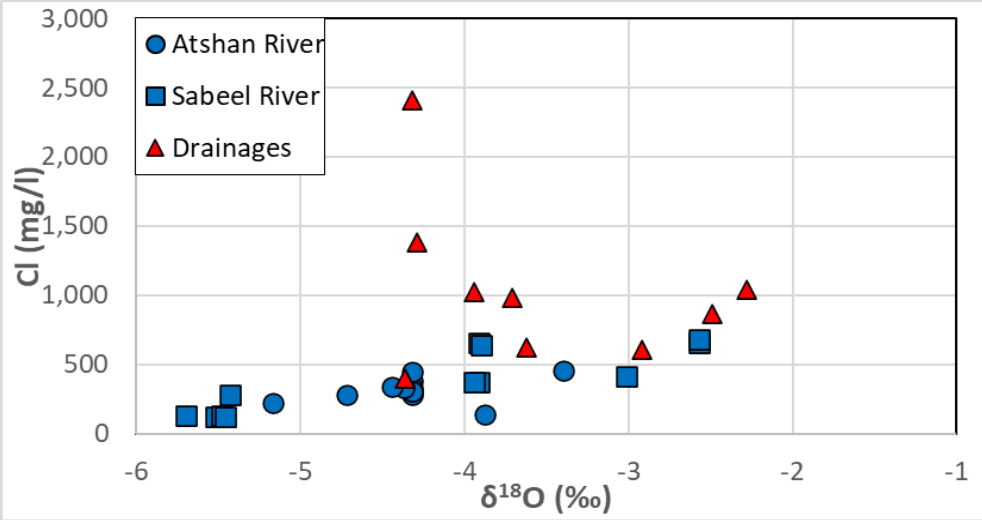


Fig. 4. (a-d) Relationship between O18 with TDS, SO_4, Cl, and B in surface and groundwater samples







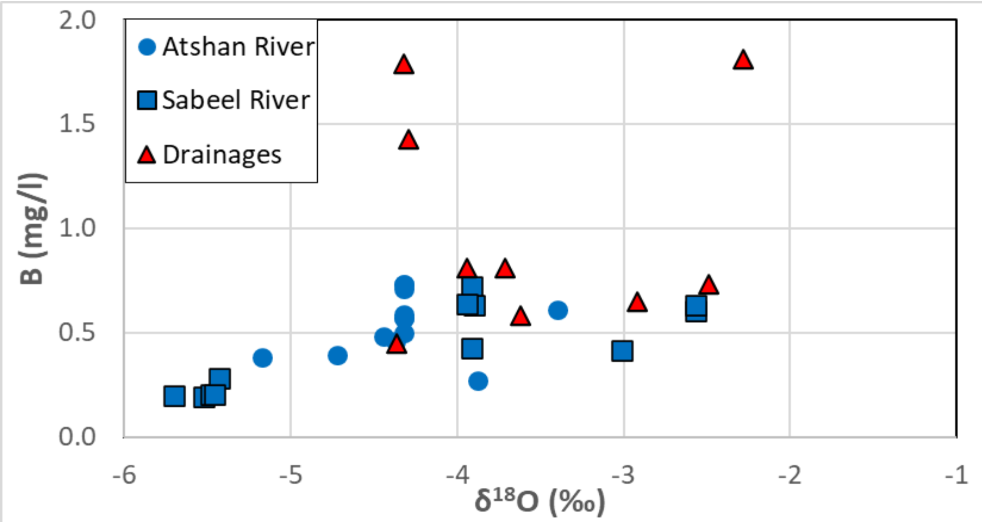


Fig. 5. (a-d) Relationship between ^{18}O with TDS, SO_4, Cl, and B in river water and drainage water samples

5. Conclusions

It is concluded from the above analysis, that the groundwater (wells and springs) in the study area has no interference with the quality of the Euphrates river water in the study area. Both chemical and isotopic fingerprints showed the same indication. Sawa Lake's water samples showed no relation with the river water, and its water quality does not affect its quality. However, drainage water samples analysis results showed that there is a good correlation between them, which indicates the strong influence of the drainage water on the river water quality when it mixes with the Euphrates River water. These results are very important to decision-makers when planning for water resources management and separating drainages from river water.

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References

Abdul-Razzaq, M.I., Dawood, K.S., Jassem, A.S., Ibraheem, D., 2013. Study the effect of groundwater on Atshan River between Shanafiya and Samawa city. A Study Submitted to the Ministry of Water Resources, National Center for Water Resources Management, Ground Water Studies Departement, Baghdad-Iraq.

Aggarwal, P.K., Gat, J.R., Froehlich, K.F.O., 2005. Isotopes in the Water Cycle: Past, Present and Future of a Developing Science. Springer/International Atomic Energy Agency (IAEA), Vieena.

Al-Kubaisi, Q.Y., Hassan, A.S., Nada, K.B., Ajeena, A.R., 2022. Using Stable Isotopes To Identify Spatial-Temporal control on Groundwater Recharge Between Lower Zab and Tigris River South of Al-Shirqat City- Iraq, in: IOP Conf. Series: Earth and Environmental Science. 1–7.

Al-Mitawki, K.G.M., 2013. The impact of drain water on ground and surface water quality in Al-Shanafiya area, southwest Iraq. M.Sc. Thesis, University of Baghdad, Unpublished.

Al-Naseri, S.K., Abdul-Razzaq, M.I., 2015. Isotopic and chemical study for the surface and ground water interaction in the south of Iraq, in: International Symposium on Isotope Hydrology: Revisiting Foundations and Exploring Frontiers. IAEA, Vienna- Austria.

Al-Naseri, S.K., Falih, A.H., Kumar, U.S., 2022. Moisture sources and spatio-temporal variation of isotopic signatures in Iraqi precipitation. Environment Earth Science, 81, 1–12.

Al-Tememi, M.K., Al-Mosawi, W. M., Abdulnabi, Z. A., 2019. Monitoring the change of water level and its effect on water quality in Sawa Lake, southwest Iraq. Iraqi Journal Science, 60, 2177–2185.

Ali, K. K., Ajeena, A. R., 2016. Assessment of interconnection between surface water and groundwater in Sawa Lake area, southern Iraq, using stable isotope technique. Arabian Journal Geoscience, 9.

Ali, K. K., Al-Kubaisi, Q. Y., Al-Paruany, K. B., 2015. Isotopic study of water resources in a semi-arid region, western Iraq. Environment Earth Science, 74, 1671–1686.

Awadh, S. M., Al-Sulttani, A. H., Yaseen, Z. M., 2022. Temporal dynamic drought interpretation of Sawa Lake: case study located at the Southern Iraqi region. Nat. Hazards, 112, 619–638.

Awadh, S. M., Muslim, R. I 2014 The Formation models of gypsum barrier, chemical temporal changes and assessments the water quality of sawa lake, southern Iraq. Iraqi Journal of Science, 55(1), 161-173

Barwary, A. M., Slewa, N. A., 1995. Geological Map of Karbala Quadrangle, (NH–38–14), Scale (1:250000). Baghdad-Iraq.

Buday, T., Jassim, S., 1987. The Regional Geology of Iraq: Tectonics, Magmatism, and Metamorphism, in: Kassab, I.I., Abbas, M.J. (Eds.), Geology of Iraq. State Establishment of Geological Survey and Mining, Baghdad-Iraq.

Craig, H., 1961. Isotopic Variations in Meteoric Waters. Science 133, 1702–1703.

Gat, J. R., Mook, W. G., Meijer, A. J., 2000. Environmental isotopes in the hydrological cycle, principles and applications. Volume II: Atmospheric water. IAEA UNESCO 2, 165–236.

Hadi, S. H., Alwan, H. H., 2020. Surface water-groundwater interaction in diwaniya, southern Iraq using isotopic and chemical techniques. Iraqi Geological Journal, 53, 89–112.

Hussien, S. J., Abdulhussein, F. M., 2021. Hydrochemical and Isotopic Study of Water Resources in Khan Al-Baghdadi Area, Al- Anbar Province / West of Iraq. Iraqi Journal Science, 62, 204–217.

Rahi, K. A., Halihan, T., 2010. Changes in the salinity of the Euphrates River system in Iraq. Reg. Environmental Changes, 10, 27–35.