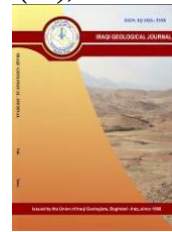




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Distribution of Environmental Isotopes ^{18}O and ^2H in Water Resources in the Al-Taji Area, Northern Baghdad, Iraq

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Abstract

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In this study, the stable isotope ^{18}O and ^2H has been used to investigate the interaction of surface water (SW), and groundwater (GW) in Al-Taji district/ Northern Baghdad for two seasons (March and August 2022). 16 Samples were collected from water resources in the Al-Taji district (Tigris channel, Tigris River, and groundwater), in each season water samples from 8 Tigris channel, 5 drilled wells, and 3 Tigris River were taken for the analysis of the isotopes ^{18}O and ^2H . The average analysis results of ^{18}O and ^2H in the Tigris channel, Tigris River, and groundwater were found to be -3.435‰ and -18.6094‰, -2.07167‰ and -17.81‰, -4.125‰ and -34.707‰ respectively. The results, generally, show a comparable range of isotope content on the Tigris Channel and groundwater (W1 about 1 km from the Tigris Channel). This indicates a mixing/interconnection between groundwater and the Tigris River, and it could be concluded that the wells (W1 and Ch1 and Ch2) near the Tigris channel have been recharged or mixed from them.

Keywords: Stable isotopes; Deuterium excess; Tigris River; Tigris channel; Groundwater; Baghdad; Iraq

1. Introduction

Hydrogen and oxygen stable isotopes are significant for understanding hydrological processes (Gat and Gonfiantini, 1961; Zhang et Al., 2016). Stable natural isotopes have a role in a range of hydrological, hydrogeological, and geochemical applications, such as demonstrating water source knowledge, water quality, groundwater recharge and movement (Verhagen et al., 1991; Izbicki et al., 1998). Water chemistry determines surface water quality, which influences environmental functions in aquatic environments (Gurung et al., 2018; Abdul-Razzaq and Al-Naseri, 2023).

Environmental isotopes have recently been used to determine recharge areas, hydrological processes, groundwater origin, flow patterns, as well as interactions of several bodies of water (Alabadi and Alshamma'a, 2015). Natural isotopes have an important role in a variety of hydrogeological, hydrological, also geochemical applications (Al-Dulaimi and Al-Shammaa, 2018). Surface and groundwater interactions are complicated and vary based on climate, landform, and geology (Hussein and Abdulhussein, 2021). Numerous studies on the application of water isotopes in hydrological processes have been conducted in recent years have been done and published in Iraq. Ajeena (2014) studied the isotopic contain in Al-Shanafia-Samawa area and Sawa lake. (Al-Dulaimi and Al-Shammaa, 2018) Studied the use of isotopes to identity the origin of surface water and groundwater in Ameriyat

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Al-Fallujah, Center Iraq. Nada et al. (2020) used stable isotopic technique to study the relationship between groundwater and wand dam in Diayala Governorate. Alhalbaasi et al. (2022) studied investigation the origins of groundwater salinity in Baghdad city by using environmental isotopes and hydro-chemical techniques. Nada et al. (2022) conducted the study in Al-Razzaa lake by using isotope techniques to identify the source of salinity. As well as, many specialized studies covering the most of Iraq regions (Ali et al., 2015) isotopic study of water resources in a semi-arid region, western Iraq (Ali and Ajina, 2016). Assessment of interconnection between surface water and groundwater in sawa lake area - southern Iraq using stable isotope technique. Al-Khafagi (2018) study hydro-chemical and isotopic for estimating of groundwater mixing South Razzaza Lake. Abbas (2019) evaluated the interaction of Diyla River and groundwater in Jisr Diyala Area within Baghdad City- Iraq. Abbas and Ali (2020) studied water quality of groundwater and Diyala River in Jisr Diyala area within Baghdad City-Iraq. Very recently, Al-Naseri et al. (2023) achieved a study for evaluating the groundwater and surface water interaction in southwest Iraq using environmental isotopes techniques.

The aims of this study are to use the isotopic techniques for investigating the interaction between surface water (Tigris channel) and groundwater surrounding it.

2. Study Area

The study region is located between latitudes $33^{\circ} 28'$ to $33^{\circ} 30'$ N and longitudes $44^{\circ} 10'$ to $44^{\circ} 17'$ E, with a total area of 55 km^2 . The elevation of the catchment area ranges from 31 m to 42 m above sea level (Fig. 1).

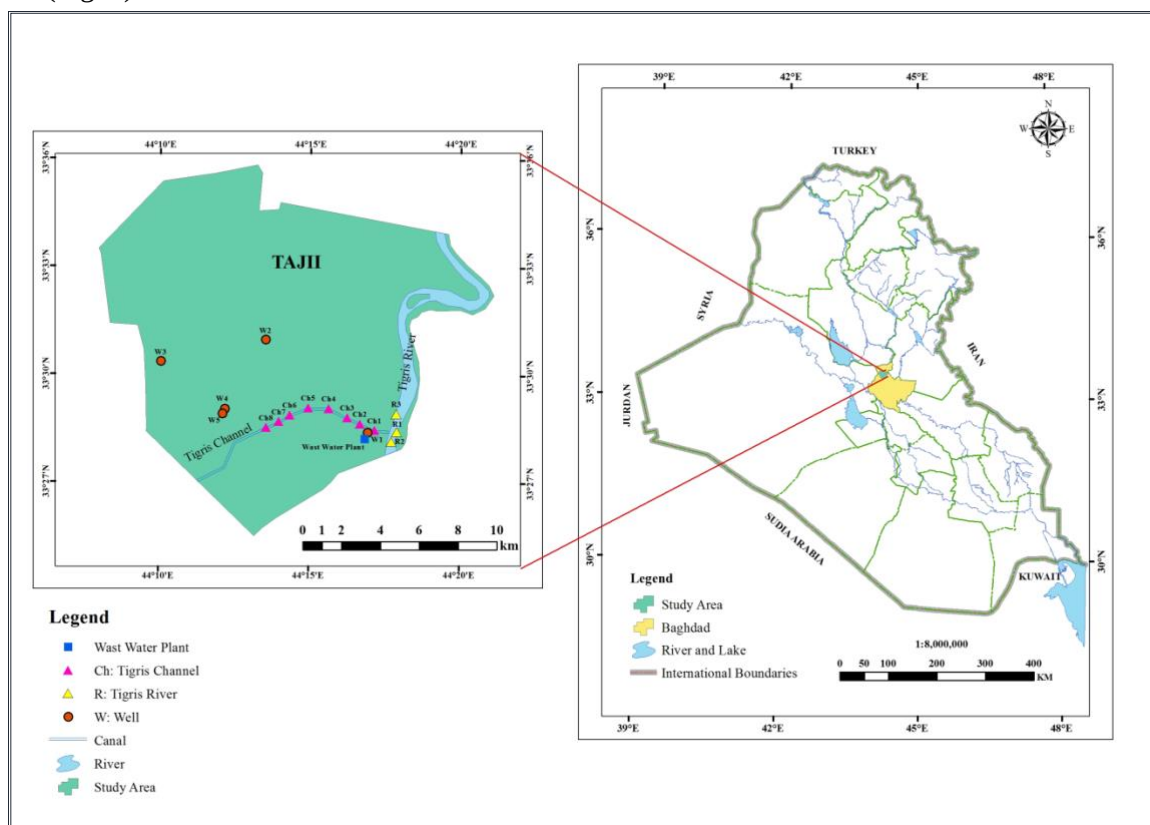


Fig. 1. Location map of the study area

The mean monthly values of climate parameters (temperature, evaporation, annual rainfall, relative humidity, and wind speed) are 44.7°C - 4.6°C , 516.6 mm- 67.6 mm, 0.10 mm- 24.32 mm, 23.78%- 69.10%, and 4.2 m/sec- 2.5 m/sec, respectively.

Geologically, the study area is primarily covered by Quaternary sediments and the exposed Pre-Quaternary rocks are only covered by Injana Formation (Jassim and Goff, 2006). Hydrogeologically, an excellent sand aquifer has been discovered below the surface at depth of 8-20 m. There is an interaction between groundwater (wells) and surface water (Tigris River) in the studied area (Al-Hadithy et al., 2019). The Tigris Channel its usefulness in the region for irrigation, livestock and building purpose. Length of Tigris Channel is 11.5 Km and depth in region is 20 m. The Tigris Channel fed from Tigris River. Depth of groundwater is 17 m and source of recharge is from rainfall and Tigris Channel.

3. Methodology

3.1. Field works

Sixteen samples were collected from water resources in Al-Taji district represented by Tigris channel, Tigris River and groundwater surrounding Tigris channel, in each season, 8 water samples from Tigris channel (Ch1 to Ch8), 5 samples from drilled wells (W1 to W5), and 3 Tigris River (R1 to R3) were taken as shown in Fig. 1 and Table 1.

Table 1. The details locations of sampling sites in the study area.

Name	Symbol	Longitude (E) ° ' "	Latitude (N) ° ' "	Elevation	water level	Water Type
Tigris River	R1	44 17 55	33 28 25	32	-	Surface water
River (AlFalihat Bridge)	R2	44 17 44	33 28 09	42	-	Surface water
River	R3	44 17 54	33 28 55	32	-	Surface water
Channel before Bzebez Bridge at 5k	Ch1	44 17 11	33 28 28	32	-	Surface water
Channel beforBzebez Bridge at 4k	Ch2	44 16 42	33 28 39	31	-	Surface water
channel before Bzebez Bridge at 3k	Ch3	44 16 16	33 28 49	33	-	Surface water
channel before Bzebez Bridge at 2k	Ch4	44 15 39	33 29 04	32	-	Surface water
channel before Bzebez Bridge at 1k	Ch5	44 14 58	33 29 05	32	-	Surface water
channel (Bzebez Bridge)	Ch6	44 14 21	33 28 53	33	-	Surface water
Channel after Bzebez Bridge 1k	Ch7	44 13 59	33 28 42	32	-	Surface water
Channel Channel after Bzebez Bridge 2k	Ch8	44 13 34	33 28 32	31	-	Surface water
Well (Emadabaar)	W1	44 16 57	33 28 24	33	18	Groundwater
Well (Adel shallal)	W2	44 13 32	33 30 59	36	18	Groundwater
Well (Adnan ussein)	W3	44 10 03	33 30 22	34	10	Groundwater
Well (Saleh Majed)	W4	44 12 11	33 29 03	34	21	Groundwater
Well (Omer Hatem)	W5	44 12 07	33 28 55	34	17	Groundwater

For the analysis of the isotopes during two seasons (August 2022 and March 2022), the samples were taken in 50 ml special bottles. The bottles were then sealed with two lids and kept in a cool box. All collected samples were, labeled, preserved, and transported to the lab, where they were made ready for routine inspection. Additionally, the EC was measured in the field by using EC meter.

3.2. Laboratory works

Stable isotopes of ^{18}O and ^2H were analyzed in the isotopes laboratory in Research Center Laboratories/ Ministry of Science and Technology. These analysis were carried out utilizing Liquid Water Isotopes Analyzer (LWIA) technique (according to IAEA, 2005). The analytical precision for the $\delta^{18}\text{O}$ and $\delta^2\text{H}$ was less than $\pm 0.2\text{‰}$ and $\pm 0.6\text{‰}$, respectively.

4. Results and discussion

The composition of stable isotope ($\delta^{18}\text{O}$ and $\delta^2\text{H}$) in Tigris channel, Tigris River and groundwater in the studied area for two seasons are provided in Table 2.

Table 2. Values of stable isotopes of water resources in Al-Taji district for both periods

Station	Wet period				Dry period			
	EC	$\delta^{18}\text{O}$	$\delta^2\text{H}$	d-excess	EC	$\delta^{18}\text{O}$	$\delta^2\text{H}$	d-excess
R1	777	-3.5	-22	2.5	823	-3.22	-20.26	5.52
R2	1257	-1.38	-16.83	-14.17	1331	-0.34	-15.50	-12.70
R3	1113	-2.6	-16.8	1.4	1178	-2.39	-15.47	3.68
Ch1	1105	-2.89	-16.48	3.75	1170	-2.66	-15.17	6.11
Ch2	1117	-3.22	-17.16	5.38	1182	-2.96	-15.80	7.92
Ch3	1118	-3.1	-16	5.7	1182	-2.85	-14.73	8.10
Ch4	1100	-3.2	-16	6.4	1164	-2.94	-15.65	7.92
Ch5	1101	-3.1	-16	5.7	1165	-2.85	-14.92	7.92
Ch6	1100	-6.92	-38.6	9.84	1164	-6.37	-35.55	15.43
Ch7	1113	-3.0	-17.0	4.0	1178	-2.76	-15.65	6.44
Ch8	1100	-3.2	-17.2	5.2	1164	-2.94	-15.84	7.73
W1	2284	-3.2	-28.09	-8.49	2419	-2.57	-25.87	-5.24
W2	2340	-4.21	-32.75	-3.28	2478	-3.87	-30.16	0.85
W3	2493	-5.9	-46.43	-5.13	2703	-5.43	-42.76	0.70
W4	2468	-4.65	-38.9	-6.35	2615	-4.28	-35.82	-1.56
W5	1176	-3.93	-34.51	-7.0	1245	-3.61	-31.78	-2.82

4.1. Stable Isotopic Relationship of Tigris Channel and Tigris River

The mean, min and max values of $\delta^{18}\text{O}$ in surface water over the two periods are -1.90‰, -3.22‰ and -0.34‰, respectively, in Tigris River, and -3.45‰, -6.37‰ -2.39‰) in Tigris channel in dry period while, -2.07‰, -3.5 ‰ and 0.38‰ in Tigris River and -3.84‰, -6.92‰ and -2.89‰ in Tigris channel in wet period. The corresponding $\delta^2\text{H}$ values in surface water are -17.39‰, -20.26 ‰ and -15.47‰, in Tigris River and -19.32‰, -35.55‰ and -14.73‰ in Tigris channel in the dry periods while, -18.88‰, -22‰ and 16.8‰ in Tigris River and -21.02‰, -38.6‰ and -16‰ in Tigris channel in the wet period, respectively. The mean ,min and max values of EC were 1110.667 $\mu\text{S}/\text{cm}$, 823 $\mu\text{S}/\text{cm}$ and 1331 $\mu\text{S}/\text{cm}$ in Tigris river, 1171.125 $\mu\text{S}/\text{cm}$,1164 $\mu\text{S}/\text{cm}$ and 1182 $\mu\text{S}/\text{cm}$ in Tigris channel in dry period while, 1049 $\mu\text{S}/\text{cm}$, 777 $\mu\text{S}/\text{cm}$ and 1257 $\mu\text{S}/\text{cm}$ in Tigris river, and 1106.75 $\mu\text{S}/\text{cm}$, 1100 $\mu\text{S}/\text{cm}$ and 1118 $\mu\text{S}/\text{cm}$ in Tigris channel in the wet period (Figs. 2 and 3).

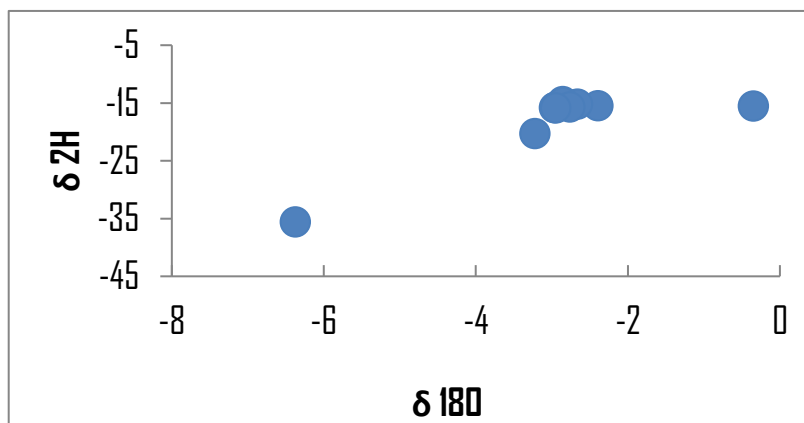


Fig. 2. Distribution of isotopic values in surface water (dry season).

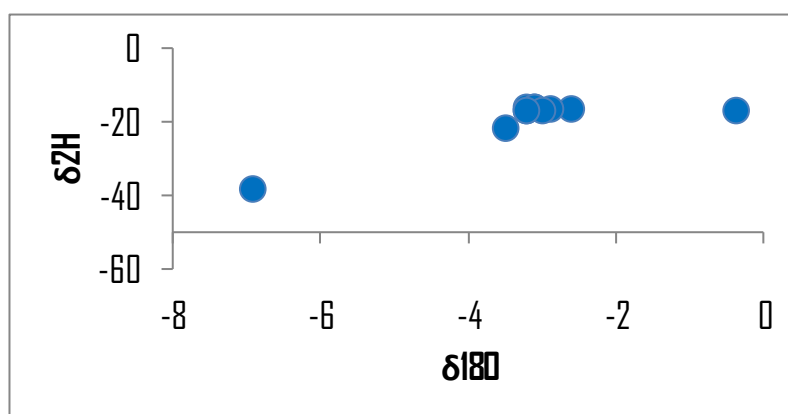


Fig. 3. Distribution of isotopic values in surface water (wet season).

In generally, surface water isotope measurements are enriched in dry season (August) while depleted in wet season (March). Low variation of isotopic values of the Tigris channel in both studied periods is due to the differences in water level and discharge from wastewater point to the Tigris channel as well as the effect of climate parameters. The isotope value range of Tigris channel water is not close with that of Tigris river water due to differences in source of recharge, depth of water, dilution processes, and the impact of water movement and velocity. A gain results of ^{18}O and ^2H data show very enriched in the station Ch2. This Indicating that the Tigris channel contributed to the Tigris River in some locations, this supports the mixing and dilution between them in addition the effect of human activities on the meeting point between the Tigris River and the Tigris Channel. Channel Ch2 which is not much different from Ch8 because there is human activity little than Ch6, the Ch6 is different from the rest of the stations because there is a lot of human activity such as livestock and a restaurant.

4.2. Groundwater Isotopic Composition in the Studied Area

Stable isotopes in groundwater (wells) are utilized not only as groundwater tracers, but also to examine contamination processes, groundwater quality, rock-water interaction, salinity origin, recharge processes, and geochemical evaluation (Ibraheemet.al, 2020). Mean, min as well as max values of $\delta^{18}\text{O}$, ^2H in groundwater over the two seasons are, respectively, -3.97‰ , -5.43‰ and -2.57‰ and -33.57‰ , -42.76‰ and -25.87‰ in dry period while -4.31‰ , -5.9‰ and 2.8‰ and -36.45‰ , -46.43‰ and -28.09‰ in wet period. The mean, min and max values of EC 2292 $\mu\text{S/cm}$, 1245 $\mu\text{S/cm}$ and 2703 $\mu\text{S/cm}$

in dry period while, 2152.2 $\mu\text{S}/\text{cm}$, 1176 $\mu\text{S}/\text{cm}$ and 2493 $\mu\text{S}/\text{cm}$ in the wet period, respectively, (Figs. 4 and 5). The EC values and isotopic data of groundwater were shown in Table 2.

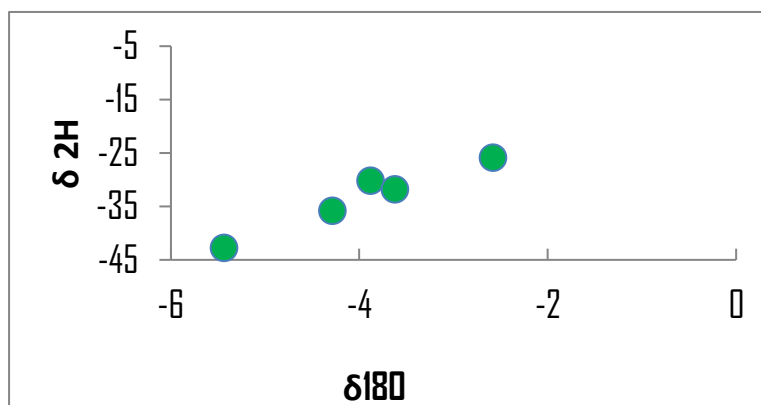


Fig. 4. Distribution of isotopic values of groundwater (dry season).

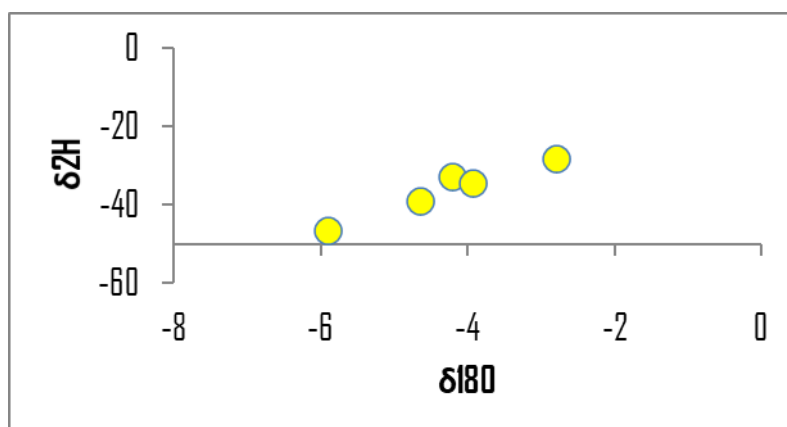


Fig. 5. Distribution of isotopic values of groundwater (dry season).

Table 2. The EC values and isotopic data of groundwater in the study area.

Station	Wet period				Dry period			
	EC	$\delta^{18}\text{O}$	$\delta^2\text{H}$	d-excess	EC	$\delta^{18}\text{O}$	$\delta^2\text{H}$	d-excess
W1	2284	-3.2	-28.09	-8.49	2419	-2.57	-25.87	-5.24
W2	2340	-4.21	-32.75	-3.28	2478	-3.87	-30.16	0.85
W3	2493	-5.9	-46.43	-5.13	2703	-5.43	-42.76	0.70
W4	2468	-4.65	-38.9	-6.35	2615	-4.28	-35.82	-1.56
W5	1176	-3.93	-34.51	-7.0	1245	-3.61	-31.78	-2.82

The mean, min and max values of $\delta^{18}\text{O}$ in groundwater over the two periods are, respectively, -4.37‰, -5.9‰ and -3.2‰ in wet period, while in dry period are respectively, -3.95‰, -5.43‰ and -2.57‰. The corresponding $\delta^2\text{H}$ values in groundwater are -36.13‰, -46.43‰ and -28.09‰, in wet period, while -33.27‰, -42.76‰ and -25.87‰ in dry period. The mean, min and max values of EC were 2152.2 $\mu\text{S}/\text{cm}$, 1176 $\mu\text{S}/\text{cm}$ and 2493 $\mu\text{S}/\text{cm}$ in wet period, while 2292 $\mu\text{S}/\text{cm}$, 1245 $\mu\text{S}/\text{cm}$ and 2703 $\mu\text{S}/\text{cm}$ in dry period.

Figs.4 and 5 show a clear variation in isotopic values in the study area's groundwater samples because of two effects namely, altitude effect on wells that were recharged directly by precipitation, and the evaporation effect on rainfall before recharging to the aquifer. Isotopic composition of well W1 is more similar in isotopic values together with EC values to that in some Tigris channel stations; this

indicates there is a connection between them. Globally, when depend on $\delta^{18}\text{O}$ and δD (i.e $\delta^2\text{H}$).Craig (1961) published the Global Meteoric Water Line (GMWL) for the precipitation as follow:

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

When the slope is 8, the Global Meteoric Water Line (GMWL) is the name given to this line. In Iraq, many researchers determined the Local Meteoric Water Line such as Al-Paruany (2013); Al-Naseri, et al. (2022). However, Al-Paruany (2013) determined the Local Meteoric Water Line (LMWL), utilized in the current work, which based on the weighted annual mean of precipitation across eighteen locations using a linear model.

$$\delta\text{D} = 7.53 \delta^{18}\text{O} + 11.97 \quad (2)$$

Fig. 6 represented the relationship between $\delta^{18}\text{O}$ and δD (GMWL) (IAEA, 2005), Local Meteoric Water Line (LMWL) (Al-Paruany, 2013), and all samples from the current study. It can be seen, that most of the samples in the studied area (Tigris channel, Tigris river, and groundwater) are situated below (GMWL) global meteoric water line and (LMWL), the contents of δD and $\delta^{18}\text{O}$ in different water resources in the studied area (all studied points) that Tigris channel and Tigris river samples are distributed on the lower right side of LMWL, indicating that all water samples are of a local meteoric origin, while other samples are situated in other locations to the LMWL. This may be referred, that there are different linear relationships between δD and $\delta^{18}\text{O}$ contents due to multiple evaporation processes.

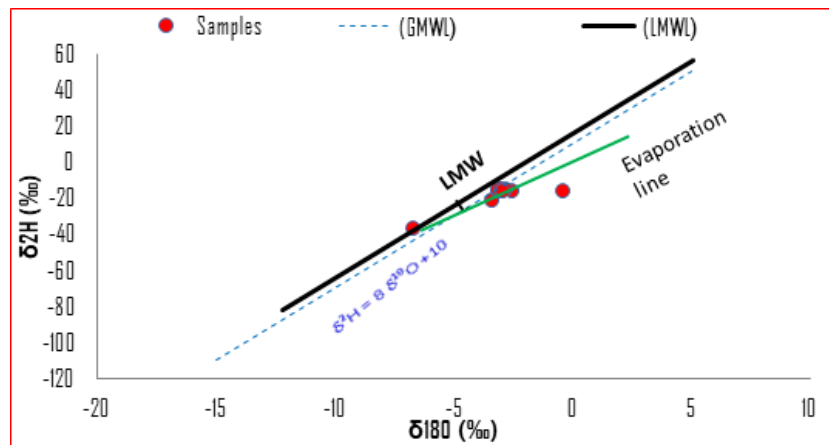


Fig. 6. The relationship $\delta^{18}\text{O}$ and δD in the water resources samples in studied stations with LMWL and GMWL during August 2022 and March 2022

4.3. Deuterium Excess (D-Excess) in the Study Area

The average global d-excess in precipitation is 10‰ (Craig, 1961), this is due to evaporation from an average ocean surface at a temperature of 25 degrees Fahrenheit and a relative humidity of 80% (Merlivat and Jouzel, 1979). d-excess given in equation 3, refers to the climate conditions (evaporation and moisture source) (Clark and Fritz, 1997). The deuterium excess is a typical character showing the origin of air masses from which precipitation is formed and the increase of deuterium has been attributed to isotopic exchange, moisture, and lower humidity conditions.

$$d\text{-excess (‰)} = \delta^2\text{H} - 8 \delta^{18}\text{O} \quad (3)$$

The value of deuterium excess in all samples in this study area is given and shown in Fig. 7. Through dry season, d values of the Tigris channel varied from 3.68% to 15.43%, from 1.270% to 5.52% for the Tigris river water, and from -5.24% to 0.85% for groundwater, while D of the Tigris channel from 3.75% to 9.89%, from -14.17% to 2.5% for the Tigris river water, and from -8.49% to -3.28% to groundwater for wet season. However, d values in the Tigris River are lower than in the Tigris channel, whereas d values of the water resources in the studied area were lower in August compared to

March. August is often warm month with high sun radiation, warm air, and little flow. This may be referred, that other elements, such as river recharge sources and climate conditions, may have a significant impact on d-excess and are not only dependent on the evaporation state.

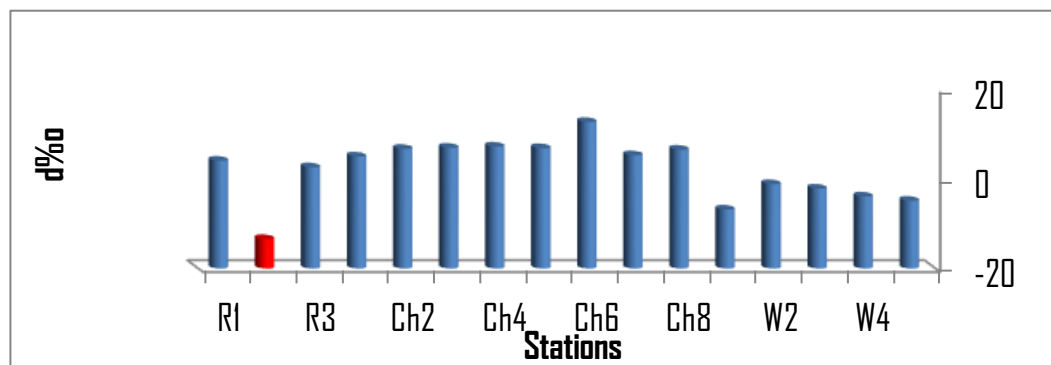


Fig. 7. d-excess values of surface water and groundwater in the study area.

5. Conclusions

The isotopic composition of the water supply samples varies throughout time in the studied area, this indicates the existence of heterogeneity due to differences in the depth of water, as well as, is related to the same recharge conditions and the amount of rainwater that reaching to the river and channel. The isotopic composition of groundwater, on the other hand, varies ($\delta^{18}\text{O}$, $\delta^2\text{H}$) because of the depth of groundwater level and climate effect. In the examined region, the Tigris Channel and groundwater often have comparable isotope contents (W1) about 1 km from the Tigris Channel. This indicates that there is a mixing/interconnection between groundwater and the Tigris River, and it could be concluded that the wells W1 and Ch1 and Ch2 near the Tigris channel have been recharged or mixed from them.

Additionally, the water resources in the study area had lower d values in August as that in March. August is the warmest month, with high solar radiation, warm air, and low river discharge. This can be referred, that other elements, such as river recharge sources and climate conditions, may have a significant impact on d-excess and not only dependent on the evaporation state.

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