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A GEOCHEMICAL STUDY OF THE MAIN VALLEYS' WATERS ON THE LEFT PART OF MOSUL (IRAQ)

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EXTENDED ABSTRACT

L'aumento della popolazione e l'espansione delle operazioni industriali e agricole si traducono in un aumento dei rifiuti agricoli e industriali, nonché dei rifiuti della comunità residenziale che vengono scaricati direttamente nei fiumi e nei torrenti. Questi inquinanti tipicamente inquinano l'acqua dei fiumi o dei torrenti, così come altre fonti d'acqua in cui sono smaltiti, il che ha un effetto sulla qualità della stessa. Questo studio si concentra sugli effetti delle acque reflue domestiche, industriali e agricole sulla qualità dell'acqua delle cinque valli principali nella parte sinistra della città di Mosul: Al Rashediya, Al-Kharrazi, Al-Khosar, Al-Danffilli e Al- Breve.

Quarantotto campioni dell'acqua di queste valli sono stati analizzati in campo per le loro caratteristiche fisiche (pH, EC, TDS, S.S e Tr); E.c (524-2315) µS/cm, pH (6,1-8,3), TDS (257-1163) mg/l, S.S (20-2240) mg/l e Tr (0,36-94,5) NTU.

Le proprietà chimiche (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^- e NO_3^-), gli elementi pesanti (Fe, Cu, Pb, Co e Mn) e le materie organiche (OM), sono state analizzate presso il laboratorio del Centro Ricerche Dighe e Risorse Idriche dell'Università di Mosul. I risultati delle analisi chimiche sono stati: Ca^{2+} (86-504) mg/l, Mg^{2+} (43-188) mg/l, Na^{+} (23-150) mg/l K^{+} (2-29) mg/l, HCO_3^- (234-742) mg/l, SO_4^{2-} (75-1300) mg/l, Cl^- (56-233) mg/l, NO_3^- (3-190) mg/l e TH (512-2028) mg/l; invece, per gli elementi pesanti: Fe (0,13-3,74) mg/l, Cu (0,64-1,38) mg/l, Pb (0,11-1,41) mg/l, Co (0,01-0,07) mg/l e Mn (0,06-0,48) mg/l e OM (1030-4820) mg/l.

L'acqua della valle di Al-Shor ha mostrato un pH inferiore a 7 e un'elevata conduttività elettrica; secondo le ipotesi industriali prevalenti, il pH di questa valle era leggermente superiore a 7 in altre valli. Secondo l'OMS (2017) e IQS (2009), i componenti di frammenti rocciosi nel suolo e le rocce carbonatiche e gessose esposte, hanno portato i valori di durezza totale ad aumentare oltre i limiti consentiti (2009).

I risultati hanno indicato che il calcio e il bicarbonato sono più abbondanti rispettivamente di altri cationi e anioni. Ciò indica principalmente l'impatto del contenuto di frammenti carbonatici del suolo e delle rocce carbonatiche esposte all'erosione chimica negli affioramenti sulla qualità dell'acqua. Lo ione magnesio riflette l'esposizione della dolomite nei frammenti del suolo alla dissoluzione da parte delle acque superficiali. Le maggiori concentrazioni di sodio e potassio sono dovute, rispettivamente, all'effetto degli usi civili e agricoli, nonché ai minerali clorurati secondari presenti nello strato superficiale del suolo. La principale fonte di accumulo di solfato nell'acqua deriva dai componenti del gesso presenti nei terreni. Mentre le fonti di nitrati variano a seconda di come vengono utilizzati i fertilizzanti organici nelle fattorie vicino alle valli. La maggior parte delle acque ha mostrato la presenza di diversi metalli pesanti in quantità elevate che hanno superato i limiti previsti dalle norme internazionali a causa delle acque reflue domestiche, industriali e agricole. Le diverse quantità di metalli pesanti nelle acque sono influenzate dalla presenza di sostanza organica, depositi argillosi e canneti, molto diffusi nei corsi vallivi.

Per quanto riguarda i fattori di inquinamento da elementi pesanti, sono stati considerati: l'indice di inquinamento da metalli pesanti (*HPI*), l'indice di valutazione dei metalli pesanti (*HEI*), l'indice di metalli (*MI*) e l'indice di contaminazione (C_d), che hanno generalmente indicato che l'acqua nell'area di studio è altamente inquinata e non adatta all'uso agricolo. Tutti i campioni dell'area di studio, infatti, rientravano nella categoria di alto inquinamento considerando gli indici *HPI*, *HEI* e C_d.

I quantitativi di inquinanti nei fiumi delle valli di Al-Shor e Al-Danffilli risultano essere superiori a quelli delle altre valli in quanto queste valli sono generalmente le più esposte ai rifiuti, soprattutto industriali.

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ABSTRACT

Increases in population and the expansion of industrial and agricultural operations result in an increase in agricultural and industrial trash as well as residential waste that is dumped directly into rivers and streams. These pollutants typically pollute river or stream water. This study focuses on the effects of domestic, industrial, and agricultural waste water on the water quality of the five main valleys in the left part of Mosul City: Al-Rashediya, Al-Kharrazi, Al-Khosar, Al-Danffilli, and Al-Shoar.

Forty-eight samples of the water from these valleys were measured in the field for their physical characteristics (pH, EC, TDS, and Tr). The chemical properties (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-} and NO_3^{-}), the heavy elements (Fe, Cu, Pb, Co and Mn) and the organic maters, were analyzed. The results indicated that calcium and bicarbonate are more abundant than other cations and anions, respectively. This mainly indicates the impact of carbonate fragment contents and calcareous cementing materials in the soils that exposed to chemical weathering in the outcrops on water quality.

Heavy element pollution factors {The heavy metal pollution index (HPI), Heavy metals rating index (HEL), Metal Index (MI), and Contamination Index (Cd)} generally indicated that the water in the study area is highly polluted and unsuitable for agricultural use. The amounts of pollutants in the rivers of Al-Shoar and Al-Danffilli valleys appear to be higher than those of the other valleys since these valleys are generally the most exposed to waste, especially industrial waste.

Keywords: *water quality, geochemistry of water, irrigation water, water pollution, Mosul, Nineveh Governorate*

INTRODUCTION

The increase in the population, the upward growth of industrial and agricultural activities, and the subsequent large number of agricultural and industrial pollutants and the waste of residential communities that are directly dumped into rivers lead to the pollution of rivers and other water sources (Jazza *et alii*, 2022). Water pollution is one of the main problems facing water resources and decreasing the field of their investment, because this problem can cause great risks to humans when using this water directly, or through its use for irrigation and watering animals, without real knowledge of the environmental reality of these sources. The environmental reality of water sources varies depending on the abundance of renewable fresh water for the water source, and on the concentration of pollutants that flow into the water (Wang *et alii*, 2016).

Water pollution with heavy metals is considered a serious environmental problem as it causes damage to the environmental, natural, biological and agricultural systems, when its value exceeds the permissible limit in water (Kroze *et alii*, 2016). The main sources of heavy metals in the ecosystem are either natural sources resulting from mechanical and chemical weathering of rocks and soils or human sources represented in wastewater, agricultural and industrial activities, residential and factory waste (Jazza *et alii*, 2022).

The study area

Mosul city is located in northern Iraq, between longitudes 43º16″E-43º30″E and latitudes 36º15″N-36º27″N. The Tigris River passes through the Mosul city from north to south and divides the city into two parts, where the left part is located to the east of the Tigris River. Mosul is considered an important commercial and industrial center, with two industrial areas located on both parts of the city, Fig. 1. The city also has extensive agricultural activity and a large livestock wealth. The city's climate is characterized by being semi-arid, and the annual rainfall rate is 375 mm (Awchi & Jasim, 2017).

The geology of the area

The study area is located within the low folded zone, surrounded by the north and northeast side Tiat by a number of low folds. On the left (eastern) part, there are folds of Bashiqa, Al-Fadhliya and Ain Al-Safra in the eastern part of the city (Al-Jumaily & Al-Azzawi, 2018). The most important geological formations in the study area are the Fat'ha Formations (Middle Miocene), consisting of alternating successions of gypsum, limestone and marl rocks. Injanah Formation (Upper Miocene) consists of an alternation of sandstones, siltstones and claystones. The Muqdadiyah Formation (Pliocene) is consisting of gravel sandstone, sandstone, siltstone, and mudstone. The Bi Hassan Formation (Pliocene) consists of conglomerates, mudstones, and sandstones, (Fouad, 2015). The sediments of the Quaternary age (Pleistocene) consist of sediments of compactions and deposits of gravel, sand and clay that have eroded from the exposed formations in the high areas located in the eastern part of the province, such as Ain Al-Safra Mountain and Bashiqa Mountain (Al-Nuaimi, 2013). The area also covers soil transported by the valleys scattered in the area that descends from the highlands towards the Tigris Fig. 1.

Geomorphology of the study area

A group of landforms appears in the study area, resulting from a series of interactions between fluvial processes and erosion and sedimentation processes. Generally, Mosul represents part of a flat plateau surrounded by high terrain represented by low-rise mountains of tectonic origin on both parts of the city within the range of low folds such as Ain Al-Safra, Bashiqa and Al-Fadhliya folds represented by Ain Al-Safra Mountain (about 510 m.a.s.l.) and Bashiqa Mountain (about 600 m.a.s.l.), respectively (Al-Daghastani, 2007) in the eastern part. The valleys under study are one of these forms. Discharge patterns vary, affected by the

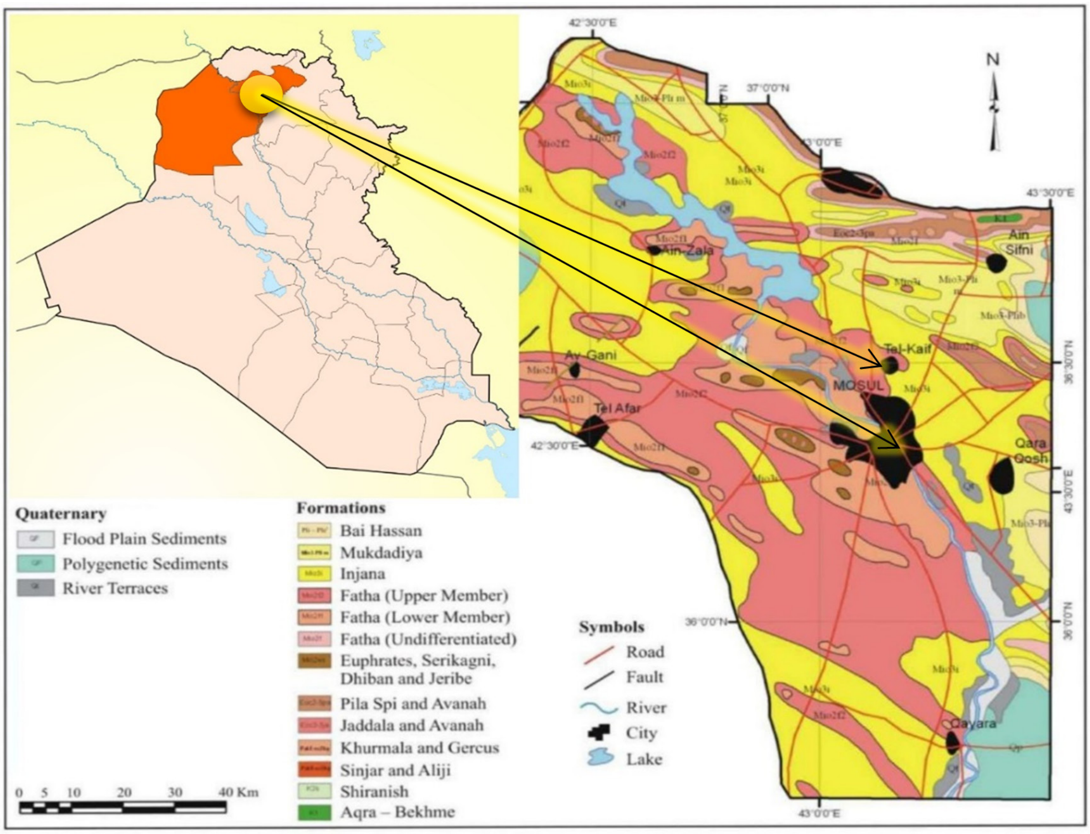

Fig. 1 - Geological map of most parts of Nineveh governorate Scale 1:1000000 (after Sissakian *&* Fouad*, 2012)*

topographical factor as well as the urban and agricultural activity factor. The tree and semi-tree patterns are the dominant patterns, as well as the parallel and semi-parallel patterns near the mountain feet. Other geomorphological forms are the flood plain, that extends along the Tigris River and is covered with water during the flood season. The fluvial terraces are relatively flat topographic surfaces, horizontal or slightly inclined, and represent the remnants of the ancient flood plains of the Tigris River (Al-Jbouri, 1988).

Description of the valleys in the study area

The valleys in Mosul city play an important and essential role in the drainage of rainwater towards the Tigris River, Fig. 2. These valleys are natural channels, most of which are lined with stone and cement. These valleys suffer from neglect and the accumulation of solid waste, especially in the last two decades, in addition to having become natural sewers to drain sewage and various types of industrial, domestic and agricultural wastes, etc. The heavy accumulation of waste at culverts and box sewer entrances is one of the most important reasons that lead to a rise in the water level in the valleys, causing the flooding that these valleys are exposed to in the rainy season. These valleys are characterized by the presence of a diverse vegetation cover of reeds, weeds and bushes, and these plants play a role in absorbing and accumulating heavy metals, and after their death and decomposition, these metals return to the soil to repeat this cycle in succession (Altaf *et alii*, 2021).

1. Al-Rashediya: which is located to the northeast of Mosul city. Its length from its beginning in Tel Kaif town to Tigris River is about 14.6 km. The valley passes through Al-Qausiyat area and Al-Malayeen area, then Al-Rashediya, where it passes through a number of residential areas and agricultural lands (Al-Dabbagh, 2022).
2. Al-Kharrazi: it is one of the natural valleys that extends from the northeastern regions of Mosul and consists of two branches: the first branch starts from the villages of Sada and Ba'wiza and passes through the neighborhoods of (Al-Siddeeq, Al-Hadbaa' and Al-Baladiyat) where household wastewater is dumped, and the second branch starts from the north of Al-Kindi facility, passing through Al-Kindi neighborhood, then they meet near the university's printing house and go through Al-Andalus neighborhood and the forests

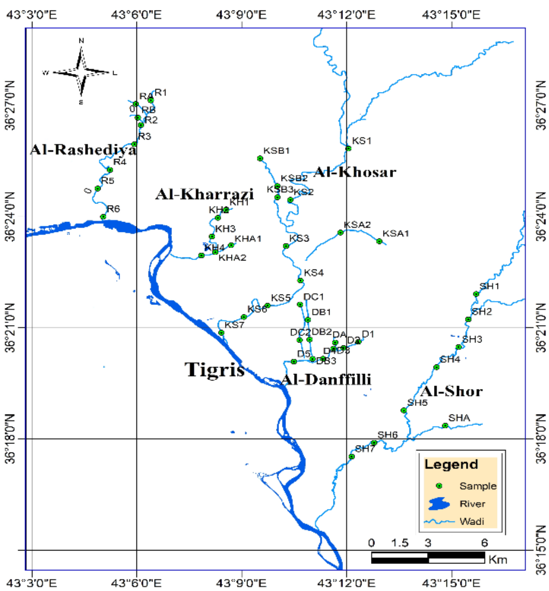

Fig. 2 - The main valleys on the left side of Mosul city and the sample locations

of Nineveh to flow into Tigris River near the tourist island (Al-Jazeera Al-Siyahiya). Its length, from the meeting point to its estuary in the Tigris River, is approximately 2.2 km.

3. Al-Khosar River: the tributaries of the waters of Al-Khosar are located in the foothills of the highlands, represented by the folds of Bashiqa, Maqlub, Qand, Ain Sifni, and Alqosh, as well as many small springs at the middle of the main course of the basin. Before Al-Khosar River enters the city of Mosul, it passes through a number of villages and residential communities, in addition to agricultural lands and fields of poultry and livestock that are located on both sides of the river. Thus, high concentrations of chemical and organic pollutants are transmitted to the Tigris River, as well as different types of microorganisms, which contribute to the high concentrations of various pollutants in the waters of the Tigris River, in addition to the contribution of the Al-Khosar River to the transfer of large quantities of sediments (Mustafa & Al-Youzbakey, 2021).
4. Al-Danffilli: the valley is about 5.9 km. It starts from the Al-Khadhraa' apartments located in the east of the city in the industrial area, and flows into the Tigris River (Al-Dabbagh, 2022). It is one of the most polluted valleys of the city, where industrial waste is spread near the valley.
5. Al-Shor: the valley is located to the northeast of the city in Bashiqa mountain and the village of Topzawa. The length of the valley basin is about 47.6 km. The valley penetrates the industrial area in which there are plumbing workshops and small factories. Sewage, industrial waste, and the waste of the slaughterhouse there pour into the valley. The valley moves afterwards through agricultural lands, ends in the Al-Salam neighborhood, and finally flows into the Tigris River (Al-Dabbagh, 2022).

Al-Dabbagh and Al-Youzbakey (2021) studied the geochemical evaluation of heavy metals in the sediments of the main valleys on the western part of Mosul City; the results of the study showed an increase in the concentrations of heavy metals along the course of the valleys as a result of erosion, transport, water movement and human activity represented by industrial, agricultural and civil activities.

Khattab and Fadhel (2008) studied the negative effects of the water of the Al-Khosar river on the Tigris River in the estuary region, where the results of analyzing heavy metals showed an increase in the values of these metals compared to their concentrations in the Tigris River and the concentration of (Cd) and (Pb) are above the global permissible limits of drinking water, which will result in great dangers to the organisms in general, as for the results of the biological analysis, they showed bacterial contamination in the water of Al-Khosar River.

Al-Danffilli valley has been studied through several environmental and biological studies, where Al-Safawi and Al-Assaf (2014) conducted a study of the liquid wastes of Al-Danffilli valley, which transports large quantities of torrential water and domestic and industrial waste to Tigris River, causing an increase in the burden of pollution in it. The results of the study indicated that there was a relative increase in the concentration of sulfate ions as a result of the decomposition processes of the protein substances thrown into the valley.

The study aims

The study aims to conduct a geochemical study of the waters of the valleys in the eastern part of the city of Mosul. Determine the impact of household, industrial and agricultural proposals on heavy metal pollution using pollution indexes. Classification of water for use in irrigation of farms adjacent to valleys.

MATERIALS AND METHODS

Sampling and analyses

Forty eight water samples were collected during the month of September, with 9 samples for Al-Rashediya valley, 9 for Al-Kharrazi valley, 10 for Al-Khosar valley, 11 for Al-Danffilli valley, and 9 for Al-Shor valley, which were selected at almost equal distances along the valley until its estuary into Tigris River, Fig. 2. The samples were collected in tight plastic bottles, and stored in the fridge at 4°C. Field pH measurements were carried out with a (pH Meter type Handheld pH ORP Meter, Shanghai Boqu Instrument Co., Ltd.) and (TDS, EC) with a Boqu Dds-1702 Portable Conductivity Meter Handheld, Shanghai Boqu Instrument Co., Ltd., in addition to measuring the Tr using a Turbidity Meter, type Hanna HI 93703. Organic material and heavy metals (Fe, Cu, Pb, Co and Mn) were analyzed by Flame method (Baird *et alii*, 2017) using Atomic Absorption Spectrophotometer- single tube, type GBC sinser, in the laboratory of the College of Agriculture - University of Mosul. The cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and TH and anions (HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-,) were analyzed in the laboratory of Dams and Water Resources Research Center - University of Mosul. For the sake of analytical precision and dependence on its average, duplicate samples were analyzed.

Calibration methods were used to estimate (TH, Ca^{2+}, Mg^{2+}), bicarbonate and chloride and to estimate the organic material. The colorimetric method using UV- Spectrophotometer type (OGAWA, OSK 7724) was used to estimate sulfate and nitrate. Sodium and potassium were analyzed by using a Flame photometer, type (JENWAY PEP7).

Water pollution index of heavy metals

The pollution coefficients that are calculated to assess water quality give an idea of the state of pollution in water, as a number of pollution coefficients in water have been developed to evaluate the quality of surface water, where coefficients of pollution with heavy metals have recently gained great importance in surface water (Jazza *et alii*, 2022).

1. The heavy metal pollution index (*HPI*) is one of the most important parameters for evaluating the content and degree of water pollution with heavy metals. It explains the variation in heavy metal concentrations and their influence on water quality; where the critical value of *HPI* is 100, *HPI* is calculated using the formulas below:

$$\boldsymbol{HPI = \sum_{i=1}^{n} W_i\, Q_i \Big/ \sum_{i=1}^{n} W_i}$$

$$\boldsymbol{W_i = 1/S_i}$$

$$\boldsymbol{Q_i = \sum_{i=1}^{n} |M_i - I_i|/S_i - I_i\, x100}$$

Where:
W_i = the relative weight of the element coefficient;
Q_i = the sub-coefficient of the metals;
n = the number of metals used;
M_i = the concentrations of heavy metals measured in ppb;
I_i = the ideal value of the metals *i*;
S_i = the standard value of the metals *i*, the negative sign (-) indicates the numerical difference between the two values (Jazza *et alii*, 2022).

2 Heavy metals rating index (*HEI*): this index gives an assessment of the water quality within the range of heavy metals depending on the water content of heavy metals, so it helps to easily explain the level of water pollution. it is calculated using the following formula (Moldovan *et alii*, 2022):

$$\boldsymbol{HEI = \sum_{i=1}^{n} H_c/H_{MAC}}$$

Where:
H_c = heavy metals concentrations measured in ppb;
H_{MAC} = maximum value allowed for metals.

3 Metal Index (*MI*): this index is one of the ways to determine the quality of water and assess the concentrations of heavy metals in it. It gives water pollution status depending on its content of heavy metals. *MI* is calculated using the following formula (Charles *et alii*, 2018):

$$\boldsymbol{MI = \sum_{i=1}^{n} C_i/(MAC)_i}$$

Where:
C_i = the values of the concentrations of heavy metals measured in ppm;
MAC_i = maximum permissible concentration of the metals *i*.

4. Contamination Index (C_d): C_d is used to find out the degree of water pollution with heavy metals and represents the total pollution coefficients present in the sample. Both the degree of pollution index (C_d) and *Cf*, which represents the contamination of the sample with individual metals, are calculated as in the following formulas proposed by (Hakanson, 1980 and Ustaoğlu & Aydin, 2020):

$$\boldsymbol{C_d = \sum_{i=1}^{n} Cf_i}$$

$$\boldsymbol{Cf_i = CA_i - 1/CN_i}$$

C_d = contamination degree index;
Cf = contamination factor;

Cf_i = contamination factor of the sample;
CA_i = element concentration in the sample (measured);
CN_i = the highest permissible concentration of the element.

The standard values of (HPI, HEI, C_d and *MI*) are according to SIEGEL (2002) and WHO (2011), (Table 1).

Metals	Si	Ii	MAC*	MAC**/MI
Fe	300	200	300	200
Cu	2000	1000	2000	1000
Pb	100	10	10	1.5
Co	100	10	10	0.01
Mn	400	100	400	50

*: (WHO,2011); **: (Siegel,2002)

Tab. 1 - Standard values of (HPI, HEI, C_d and MI) according to WHO (2011) and (SIEGEL, 2002)

Microsoft Office Excel 2010 was used in most of the data processing operations and in finding the Correlation Coefficient (*r*).

RESULTS AND DISCUSSION

Geochemistry

The physical properties of the water in the study area include some important field measurements, which give a preliminary idea of the water quality in the field. These measurements include (Table 2):

Temperature: it is one of the factors affecting the dissolution of solid materials and the dissolution of gases in river water, especially oxygen and carbon dioxide. It is also one of the important factors in determining the activity and effectiveness of aquatic organisms and bacteria, and in determining some properties of water, such as density and electrical conductivity.

Turbidity: the presence of suspended objects in the water, such as colloidal objects, silt and organisms (De Roos *et alii*, 2017). The turbidity values for each valley vary between acceptable values and high values. The reason behind this is the variation of activities along the course of the valley according to the prevailing type of activity, Table 2.

pH: the pH values for the water of the study area ranged between 6.11-8.30 (Table 2), as it falls within the standard limits of the World Health Organization (WHO, 2017) and the Iraqi Quality Specifications (IQS, 2009). In general, the waters of the study valleys tend towards the basic ones. The reason is attributed to the effects of exposed rock types in the region, as well as the soil that contains clastic components as a result of erosion of exposed rocks, which are mainly composed of calcium carbonate and calcium sulfate (AL-YOUZBAKEY & SULAIMAN, 2021). On the other hand, Al-Shor valley appears acidic, perhaps due to the addition of chlorine that is released into the water through residential wastes, detergents, and industrial chemical wastes that characterize this valley more than the rest valleys (JEAN-FRANCOIS *et alii*, 2018).

Samp.	EC µS/cm	pH	TDS (mg/l)	S.S (mg/l)	Tr (NTU)	TH (mg/l)
R1	651	6.5	325	120	8.99	692
R2	706	7.3	353	1080	4.03	772
R3	578	7.3	289	160	2.68	608
R4	570	7.3	285	200	2.13	808
R5	549	7.3	277	1200	0.71	740
R6	567	7.3	283	520	1	696
R7	576	7.1	290	480	0.36	760
R8	570	7.1	288	1760	2.32	584
RA	583	7.3	293	10	59.5	888
Min	549	6.5	277	010	0.36	584
Max	706	7.3	353	1760	59.5	888
Z1	577	7.6	289	20	10.24	512
Z2	615	7.4	312	1120	14.31	652
Z3	563	8.3	281	800	94.5	592
Z4	620	7.6	314	120	1.83	584
Z5	578	7.2	290	640	1.34	620
Z6	524	7.2	257	680	21.52	740
Z7	574	7.2	289	640	3.94	576
ZA	612	7.2	306	240	2.56	584
ZB	677	7.2	338	40	8.2	544
Min	524	7.2	257	20	1.34	512
Max	677	8.3	338	1120	94.5	740
K1	936	7.1	470	520	0.84	868
K2	905	7.2	455	520	4.39	796
K3	937	7.4	478	1400	9.03	624
K4	853	7.3	442	600	9.31	648
K5	853	7.2	432	240	5.46	740
K6	870	7.3	436	480	12.4	740
K7	880	7.3	444	2240	3.5	820
K8	902	7.3	457	520	11.17	784
KA	957	7.4	481	1520	24.9	636
KB	609	7.3	311	1920	0.46	520
Min	609	7.1	311	240	0.46	520
Max	957	7.4	481	2240	24.9	868
D1	592	7.5	297	320	0.98	632
D2	652	7.7	329	520	15.55	668
D3	797	7.3	400	1080	9.05	716
D4	781	7.6	390	160	3.88	716
D5	786	7.3	393	200	2.82	880
DA	562	7.5	283	1520	5.01	660
DB	629	6.8	333	320	1.07	536
DC	894	7.8	449	960	2.01	840
DD1	530	7.3	267	40	11.76	900
DD2	666	7.3	337	1160	1.03	752
DE	1842	7.7	926	1920	27.9	1168
Min	530	6.8	267	40	0.98	536
Max	1842	7.8	926	1920	27.9	1168
SH1	2300	6.3	1163	680	11.17	1528
SH2	1240	6.7	622	200	1.6	832
SH3	1831	6.6	907	480	2.64	996
SH4	1933	6.4	955	720	1.11	1212
SH5	1902	6.4	959	1120	0.51	1280
SH6	2315	6.1	1157	640	2.04	2028
SH7	1340	6.2	674	1840	0.74	1180
SH8	1553	6.7	780	760	12.39	1060
SH9	1632	6.7	819	560	2	1272
Min	1240	6.1	622	200	0.51	832
Max	2315	6.7	1163	1840	12.39	2028
WHO,2017	<1000	6.5-8.5	1000		5	500
IQS,2009	1500	6.5-8.5	1000		5	500

Tab. 2 - The physical properties of the water in the studied valleys

Electrical conductivity (EC): the EC values ranged between 524-2315 µS/cm (Table 2), where the water of the study area falls within WHO (2017) and IQS (2009) except for the two samples SH6, DE which exceed standards (WHO, 2017 and

IQS , 2009), and the samples (SH3, SH4, SH5, SH8, SH9) of Al-Shor valley correspond to WHO (2017) and exceed IQS (2009). The electrical conductivity value is an approximation of the number of dissolved salts in the sample. In general, it is noted that the electrical conductivity increased in Al-Shor valley due to the discharge of sewage and industrial water to the water of the study area.

Total dissolved solids (TDS): it represents all ionized and non-ionized solids in water and does not include suspended substances, colloids and dissolved gases. The amount of dissolved solids depends mainly on the concentration of cations and anions present in the sample. As for the chemical composition of it, it does not follow a specific system but rather depends on the geology of the area and the chemical composition of the components through which water passes and the severity of erosion in the water of the study area (Al-Nuaimi, 2013 and Butler & Ford, 2018). Table 2 indicates that the study area water samples fall within WHO (2017) and IQS (2009), except for the samples SH1, SH6 due to wastewater disposal.

Total hardness (TH): the value of the total hardness depends on the concentrations of divalent ions. Calcium and magnesium are among the most hardening ions in natural water. The hardness salts in water are in the form of (carbonates, bicarbonates, chlorides, sulfates and nitrates) (Wachinski, 2016). The total hardness values ranged from 512-2028 mg/l (Table 2), and exceeded WHO (2017) and IQS (2009), which allows a rate of 500 mg/l, due to the calcareous nature of the Fat'ha Formation rocks through which the water of the study area passes, and due to the enrichment of the soil with rock fragments (carbonite and gypsum), which represent the products of erosion of carbonite rocks and evaporites belonging to Fat'ha Formation.

The chemical properties are one of the main factors of water quality by determining the concentrations of the main ions in the water content (cations and anions). Some of the valley water samples did not achieve the water balance because the water sources are affected by the discharged wastes, such as the samples of Al-Danffilli Valley and the samples (Z1, Z5, K8, SH6, SH7, SH8, R2, R3, R6, R7, R8) in which water sources are unnatural and affected by sewage, industrial, domestic and agricultural wastes, which in turn affected the quality of this water and did not achieve the water balance. Among the most important ions present in the water are as follows:

Calcium ion (Ca^{2+}): calcium ion is one of the most important cation dissolved in continental waters. The chemical weathering of carbonate and evaporite rocks in adition to the dissolution of carbonate and evaporite fragments and calcarous and gypsiferous cements in soils is one of the most important processes that prepare calcium ion into water (Worthington *et alii*, 2016; Gaur *et alii*, 2022 and Medici & West, 2022). Calcium ion concentrations ranged between 86-504 mg/l (Table 3) and exceeded WHO (2017) but fall within IQS (2009), except for the samples DE, SH1, SH4, SH5, SH6 and SH9 that exceeded IQS (2009) because of the nature of the soil rich in rock fragment of carbonates and sulfates, that the water of the study area passes through. This found a strong correlation between calcium and each of magnesium and bicarbonate, indicating the presence of limestone rocks represented by calcite mainly ($CaCO_3$) with a small presence of dolomite mineral $CaMg(CO_3)_2$ (Table 4). Figure 3 shows that there is a strong correlation between calcium and sulfate, which is more pronounced in the Al-Shor valley than in the other valleys. This is because the Al-Shor valley is longer than the other valleys (except Al-Khosar river), and the soil in the Al-Shoar valley has bits of calcium carbonate and calcium sulfate in it, as a result of the erosion processes that took place in the rocks beneath the soil and the exposure of the soil to water, the water dissolves the carbonite and sulfate minerals in the soil. Although there is no influence of calcium sulfate in the soil in these valleys, the effect of the wastes is pronounced. However, the relationship between these two factors is unclear in the other valleys due to their shorter lengths than Al-Shoar valley. As for the positive relationship between calcium and each of (Cl^-, K^+ and Na^+), it reflects the effect of the weathering process as a main supplying factor for these ions (Table 4).

Magnesium ion (Mg^{2+}): the values of magnesium ions ranged between 43-188 mg/l (Table 3); in general, the waters of the studied valleys fall within limits (WHO, 2017 and IQS, 2009). One of the most significant natural sources of magnesium ion is the chemical weathering of the dolomite found in the rock pieces in the soil through which the water of the study region travels. The strong relationship between the magnesium ion and each of (Ca^{2+} and HCO_3^-) indicates that dolomite as one of the main sources of magnesium ion in the waters of the studied area, Table 4 and Fig. 3.

Sodium and potassium (K^+ and Na^+): sodium and potassium are characterized by their mobility in the aquatic environment, their sources are multiple, and their concentration increases in the presence of sedimentary rocks such as evaporites. They may move from very distant sources with ground and surface waters (Marove *et alii*, 2022). It is reported that the high concentration of sodium and potassium indicates water pollution with sewage and agricultural lands water. The values of sodium ions ranged between 23-150 mg/l (Table 3), where they fall within WHO (2017) and IQS (2009) standards. As for potassium ion (K^+), its concentrations range between 2-29 mg/l (Table 3). It falls within WHO (2017) except for some samples (DE and SH1) and exceeded IQS (2009) except for the samples Z2, Z3, Z4, Z6, Z7, ZA, D1, D2, DA, DD1 and SH6, because most of them are agricultural areas, especially in Al-Kharazi valley (Table 4). It's noted a strong relationship between each Na^+ with the

Sample	Ca^{+2} (ppm)	Mg^{+2} (ppm)	Na^{+} (ppm)	K^{+} (ppm)	HCO_3^{-} (ppm)	SO_4^{-2} (ppm)	Cl^{-} (ppm)	NO_3^{-} (ppm)	OM ppm	Area classification
R1	105	70	29	7	293	165	65	17	4130	Agricultural and residential area
R2	144	72	30	9	234	130	62	18	1030	Residential area
R3	90	96	25	6	254	110	56	16	3790	Residential area
R4	145	85	27	7	254	175	90	16	3440	Residential and agricultural area
R5	133	79	23	6	234	210	62	10	3240	agricultural and residential area
R6	118	85	27	6	249	120	81	16	3720	Residential area
R7	130	92	26	7	239	110	79	13	2620	Residential area
R8	92	84	30	6	259	85	85	16	2600	Residential area
RA	170	77	27	7	288	145	71	11	4000	Residential and agricultural area
Min	90	70	23	6	234	85	56	10	1030	
Max	170	96	30	9	293	210	90	18	4130	
Z1	86	64	32	4	244	100	69	5	3650	Residential area
Z2	133	43	34	3	244	125	67	14	4130	Reconstruction area
Z3	107	61	35	3	268	100	75	13	4330	agricultural area
Z4	102	66	38	3	288	120	77	7	3510	agricultural area
Z5	105	76	29	4	244	120	69	28	3100	Residential area
Z6	140	67	24	3	254	105	73	17	2060	agricultural and residential area
Z7	100	67	28	3	249	100	79	19	4000	agricultural area
ZA	104	63	34	2	317	150	69	15	3380	Residential area
ZB	95	63	35	5	298	110	92	4	3510	agricultural area
Min	86	43	24	2	244	100	67	4	2060	
Max	140	76	38	5	317	150	92	28	4330	
K1	157	90	60	4	346	240	81	29	3930	Residential area
K2	141	87	62	5	390	245	98	30	2060	Residential area
K3	95	95	57	5	298	250	100	10	4000	Residential area
K4	107	84	60	4	312	230	79	11	4130	Residential area
K5	124	93	55	4	351	210	90	10	4130	Residential and agricultural area
K6	126	90	56	4	312	215	81	38	4480	Residential area
K7	147	87	59	5	346	255	77	33	4480	Residential area
K8	134	95	60	5	317	220	71	33	4270	Residential area
KA	101	88	85	6	459	220	85	8	4130	Residential area
KB	114	58	48	5	278	105	62	3	4480	Residential area
Min	95	58	48	4	278	105	62	3	2060	
Max	157	95	85	6	459	255	100	38	4480	
D1	100	90	29	3	298	115	62	17	4270	Industrial area
D2	118	74	40	3	307	80	75	30	3860	Industrial area
D3	120	90	61	4	312	100	117	29	3790	agricultural area
D4	121	88	53	4	303	100	117	30	3440	Residential area
D5	168	77	52	4	303	135	96	30	4070	Residential area
DA	112	80	23	3	298	100	75	10	4480	Residential area
DB	86	74	49	4	259	75	79	44	3100	Residential area
DC	153	85	26	4	371	100	146	16	4480	Industrial area
DD1	174	76	32	3	312	89	75	9	4130	Industrial area
DD2	130	88	80	4	312	85	83	13	4480	Livestock area
DE	212	156	65	29	317	270	233	35	3790	Livestock area
Min	86	74	23	3	259	75	62	9	3100	
Max	212	156	80	29	371	270	233	44	4480	
Sh1	305	178	150	14	742	575	210	6	4070	Industrial area
Sh2	143	98	75	10	498	200	127	14	4130	Residential and industrial area
Sh3	182	133	100	11	678	245	179	5	3790	agricultural area
Sh4	243	148	120	8	654	275	204	175	3440	Residential area
Sh5	271	147	125	9	737	390	208	190	3790	Residential area
Sh6	504	188	120	3	410	1300	127	15	3790	Residential area
Sh7	180	177	55	4	400	390	81	15	4820	Residential area
Sh8	164	159	65	4	386	385	96	18	4130	Residential area
Sh9	230	132	85	4	425	575	92	21	3790	agricultural area
Min	143	98	55	3	386	200	81	5	3440	
Max	504	188	150	14	742	1300	210	190	4820	
WH	75	100	200	12	350	250	250	50	-	-
IQS,	200	150	200	3	200	250	250	50	-	-

Tab. 3 - The chemical properties and organic matter in the studied valleys

ions (Ca^{2+}, Cl^{-} and SO_4^{2-}). Figure 3 shows a clear relationship in Al-Shor valley. The main reason is that it contains fragments of secondary halite due to the nature of secondary gypsum formed as a result of dissolution and precipitation processes, but this relationship weakens in the rest of the valleys due to the presence of other sources of both chlorine and sodium related to civil consumption, such as the use of detergents and some chemicals in industrial areas that contain chlorine. As for the positive relationship between sodium and potassium on the one hand and the rest of the main ions, it may refer to the weathering process as a source of supplying these ions and the accumulation of concentrations along the course of the valleys, considering them as highly soluble ions in addition to the residential, industrial and agricultural effects.

Bicarbonate (HCO_3^-): the bicarbonate ion values ranged between 234-742 mg/l (Table 3), where they exceeded IQS

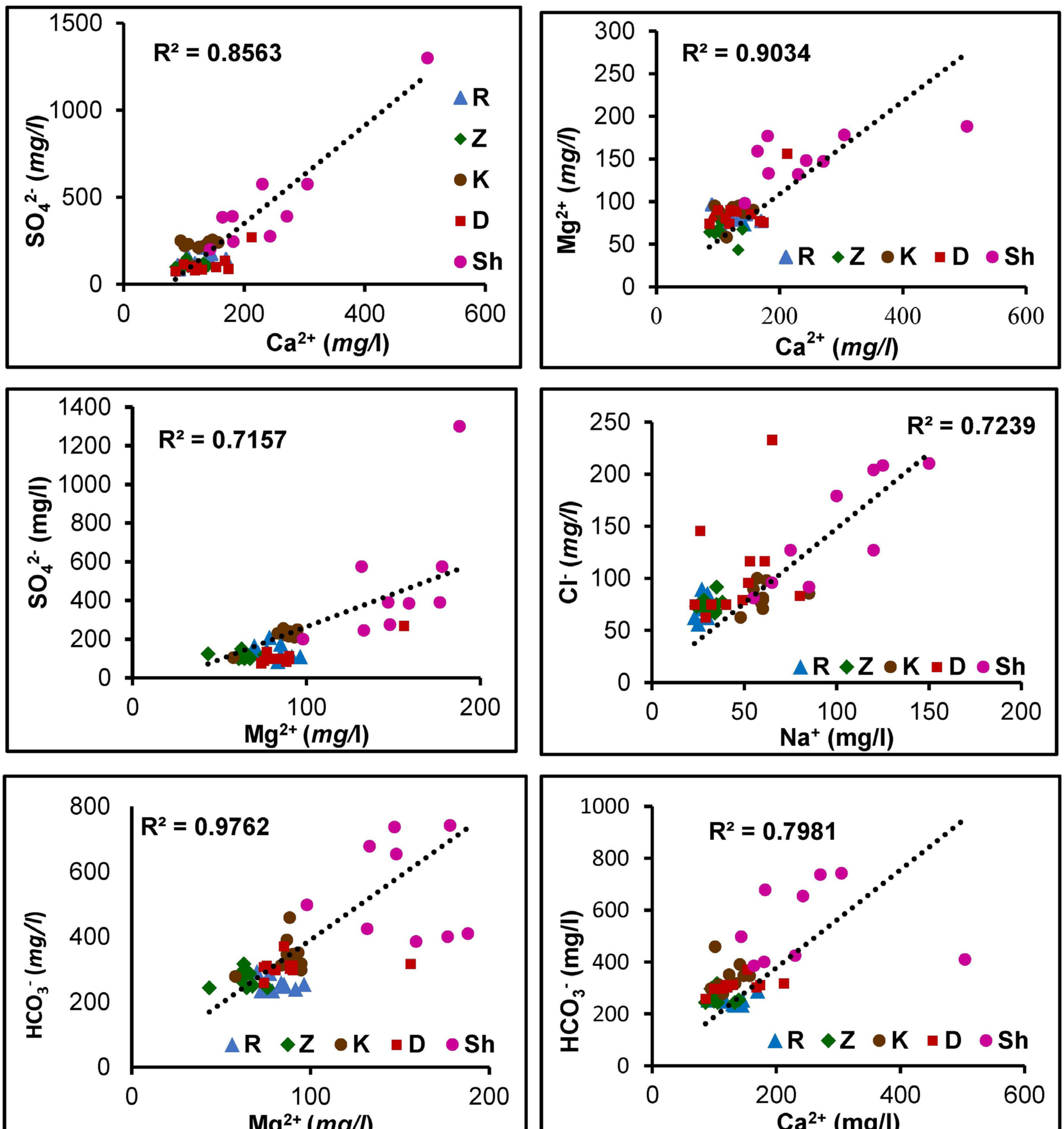

Fig. 3 - The relationships among the main cations and anions in the studied valleys (R=Al-Rashediya; Z=Al-Kharrazi; K=Al-Khosar; D=Al-Danffilli and Sh=Al-Shor)

	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	EC	pH	TDS	S.S	Tr
Ca	1.00**												
Mg	0.77**	1.00**											
Na	0.71**	0.75**	1.00**										
K	0.25	0.42**	0.32*	1.00**									
HCO_3	0.57**	0.68**	0.88**	0.32*	1.00**								
SO_4	0.90**	0.76**	0.67**	0.11	0.46**	1.00**							
Cl	0.58**	0.68**	0.73**	0.68**	0.78**	0.37*	1.00**						
NO_3	0.31*	0.33*	0.47**	0.16	0.53**	0.12	0.53**	1.00**					
EC	0.82**	0.91**	0.89**	0.48**	0.82**	0.78**	0.81**	0.41**	1.00**				
pH	-0.47	-0.56	-0.43	-0.05	-0.37	-0.56	-0.16	0.04	-0.51	1.00**			
TDS	0.82**	0.91**	0.89**	0.48**	0.82**	0.78**	0.81**	0.41**	0.98**	-0.50	1.00**		
S.S	0.07	0.21	0.14	0.25	0.06	0.09	0.16	0.08	0.17	0.07	0.17	1.00**	
Tr	-0.06	-0.15	-0.12	0.11	-0.12	-0.10	-0.05	-0.12	-0.10	0.39**	-0.10	-0.02	1.00**
TH	0.97**	0.88**	0.74**	0.32*	0.63**	0.88**	0.62**	0.31*	0.88**	-0.53	0.88**	0.09	-0.08
OM	0.04	0.17	0.17	-0.07	0.18	0.08	0.10	-0.04	0.13	0.03	0.14	0.09	0.17

*p value 0.05 = 0.28; **p value 0.01 = 0.38

Tab. 4 - The correlation coefficient matrix among the chemical, physical properties and organic matter (N=48)

(2009) while it matches WHO (2017), with the exception of the entire samples of Al-Shor valley in addition to K2, K3, KA and DC due to the nature of the soil derived from carbonite rocks or gypsum or both, which is predominant in areas subject to erosion factors. Bicarbonate is derived from carbonate rocks that belong to the formation of the Fat'ha and soil containing rock fragments of limestone and dolomite. This resulted a highest concentration of bicarbonate within the studied area, and this is also indicated by the positive correlation between bicarbonate and each of the calcium and magnesium ions, Table 4 and Fig. 3.

Sulfate ions (SO_4^{2-}): sulfate is one of the common ions in all natural water sources, its concentration in water depends on the environmental conditions, the quality and components of the rocks in contact with the water (Merkel *et alii*, 2005). The sulfate ion values ranged between 75-1300 mg/l (Table 3), which generally falls within limits WHO (2017) and IQS (2009) except the samples K7, DE, SH4, SH5, SH6, SH7, SH8, and SH9. Soil is the main source of sulfate ion in the water of the study area that contains clastic granules of gypsum. A positive relationship between sulfate and calcium is noted in Table 4 and Fig. 3, which indicates their presence within the gypsum phase ($CaSO_4.2H_2O$) as the main source of these ions in the water of the study area. and perhaps the positive relationship between sulfates and each of (K^+, Cl^-, Mg^{2+}, Na^+) indicates the compatibility of these ions within the rocks of the formation of the Fatha and also the weathering factor as a main source of supply for all these ions.

Chloride ion (Cl^-): the chloride ion is characterized by very high solubility. The values of the chloride ion ranged between 56-233 mg/l (Table 3), which falls within standards WHO (2017) and IQS (2009). The sources of chloride are multiple, the most important of which are the chlorides present in the rocks of evaporites. Table 4 and Fig. 3 indicate the strong relationship between Cl^- and Na^+, which in turn indicates the secondary halite mineral (NaCl) as the main source of chloride ions in the water of the study area, as well as the similarity of their geochemical behavior during washing and transportation activities. Perhaps the positive relationship between chloride and each of calcium and sulfate refers to the chemical weathering processes of evaporite rocks that belong to the Fat'ha Formation as a main source of these ions in the waters of the study area.

Nitrate ions (NO_3^-): nitrate is one of the ions whose concentrations are often low or secondary in natural river water, and the increase of nitrate in water indicates a state of pollution, where sewage water, organic waste and water of agricultural land that uses fertilizers are the most important sources of the increasing nitrate in rivers (Sundaray *et alii*, 2009). The nitrate ion values ranged between 3-190 mg/l, (Table 3), where they fall within limits WHO (2017) and IQS (2009) except for two samples (SH4, SH5) because of organic wastes in the water and contamination of this water with fertilizers. The main source of nitrate ions in the water of the study area is mostly coming from organic fertilizer used for soil, especially in agricultural areas, in addition to sewage water, as well as the air source of nitrates as a result of the dissolution of nitrogen oxides in rainwater.

Organic substance: it is one of the most important evidence used to identify the pollution of the water source, as the organisms in the aquatic environment live in a state of equilibrium. This equilibrium is between energy-producing organisms represented by plants and others consuming them, including benthic animals and zooplankton, as well as micro-

Sample	Fe ppm	Cu ppm	Pb ppm	Co ppm	Mn ppm
R1	1.72	0.96	0.79	0.01	0.09
R3	0.85	1.33	0.7	0.01	0.12
R5	1.07	0.76	0.11	0.01	0.15
R6	1.03	1	1.3	0.07	0.14
R8	0.85	1.06	0.86	0.01	0.27
Min	0.85	0.76	0.11	0.01	0.09
Max	1.72	1.33	1.3	0.07	0.27
Z1	1.09	1.03	0.59	0.01	0.23
Z2	1.31	0.78	0.96	0.01	0.07
Z4	0.95	1.02	0.43	0.01	0.21
Z6	1.96	1.1	1	0.01	0.17
Z7	1.15	0.64	1.41	0.01	0.09
ZA	1.49	0.65	0.89	0.01	0.16
ZB	0.82	1.07	0.3	0.02	0.28
Min	0.82	0.64	0.3	0.01	0.07
Max	1.96	1.1	1.41	0.02	0.28
K1	1.22	0.72	2.61	0.01	0.28
K3	1.79	0.96	1.5	0.02	0.14
K4	1.67	1.12	0.44	0.01	0.12
K5	1.46	1.03	0.45	0.01	0.24
K7	1.37	0.72	0.44	0.01	0.28
KA	3.38	0.74	1.18	0.06	0.19
KB	0.85	0.7	0.24	0.07	0.25
Min	0.85	0.7	0.24	0.01	0.12
Max	3.38	1.12	2.61	0.07	0.28
D2	1.76	0.99	0.38	0.01	0.06
D3	1.3	1.03	1.22	0.04	0.07
DA	1.01	1.21	0.83	0.01	0.16
DC	0.67	1.12	0.7	0.02	0.28
DD2	1.1	0.82	0.38	0.03	0.37
Min	0.67	0.82	0.38	0.01	0.06
Max	1.76	1.21	1.22	0.04	0.37
Sh1	0.45	1.26	0.27	0.06	0.4
Sh2	0.47	0.85	0.55	0.01	0.36
Sh4	0.13	0.85	0.4	0.02	0.3
Sh5	1.07	1.1	0.77	0.01	0.08
Sh6	1.01	1.38	0.58	0.02	0.48
Sh8	3.74	1.04	0.67	0.01	0.09
Min	0.13	0.85	0.27	0.01	0.08
Max	3.74	1.38	0.77	0.06	0.48
WHO,2017	0.3	2.0	0.01	0.005	0.1
IQS,2009	0.3	1.0	0.05	0.005	0.1

Tab. 5 - The concentrations of heavy elements (ppm) in the water of the studied valleys

organisms of bacteria and fungi that live in water (Wang *et alii*, 2021). However, human activities that affect the aquatic environment led to an imbalance in this equilibrium and thus affect the growth, density and quality of this life. The presence of the organic substance is an indication of water pollution with human and animal waste (Trevett *et alii*, 2004). The organic substance has been examined as shown in Table 2, and it's noted in Table 3, that there is no relationship between the organic substance and the main ions or heavy metals, and the reason is that its main source is sewage waste.

Heavy elements

They are considered dangerous environmental pollutants that are toxic even at low concentrations. Heavy elements are usually found in nature in very low concentrations. Some elements were measured in the present study are the following:

Iron (Fe^{2+}): iron is found in many oxides, hydroxides and sulfide minerals (e.g Hematite and pyrite). The values of iron concentrations ranged between 0.13-3.74 ppm (Table 5) and these values exceeded limits WHO (2017) and IQS (2009), except for SH4, which is not more than 0.3 ppm in the water samples. Industrial activities, the process of washing contaminated soils, and the effects of agricultural lands are among the main factors in raising the concentration of iron in the water. The rocks of geological formation are one of the causes of water pollution with iron, especially clay and sandy rocks that contain iron oxides phases (Singh *et alii*, 2013).

Copper (Cu^{2+}): it is found as an adsorbent on the surfaces of clay minerals and organic substances (Khattab & Fadhel, 2008). The values of copper concentrations in the water ranged between (0.64-1.38 ppm), Table 5, within WHO (2017), where it recommends 2ppm but exceeds IQS (2009) except for some samples (R1, R5, R6, Z2, Z7, ZA, K1, K3, K7, KA, KB, D2, DD2, SH2, SH4), which recommend a rate of no more than 1 ppm. Most of copper pollution sources are pesticides, agricultural fertilizers, sewage, industrial, and domestic water (Al-Saydeh *et alii*, 2017).

Lead (Pb^{2+}): lead is one of the chalcophile metals, and it is considered one of the heavy elements polluting the environment. Its most important natural sources are Galena (PbS), Anglesite ($PbSO_4$) and Cerussite ($PbCO_3$), and the most important unnatural sources are gasoline combustion processes, the battery industry and lead mines (Akessé *et alii*, 2022). The values of lead concentrations in the water of the study area ranged between 0.11-2.61 ppm (Table 5) and these values exceed WHO (2017) which is 0.01 ppm, and also exceed IQS (2009) which is 0.05 ppm. The high concentrations of lead in the water are attributed to the agricultural and industrial human activities, that pollute water by variety of sources, including heavy traffic, domestic waste and organic and chemical fertilization operations. As well as, the industrial wastewater when it is thrown into the sewage stream (Shala *et alii*, 2015).

Cobalt (Co^{2+}): cobalt is found in nature in some minerals, sulfide and carbonate compounds or in the form of hydroxide compounds such as (Co, Fe) AsS, $CoCO_3$, $Co(OH)_2$. And it may be adsorbed on the grain surfaces of clay minerals (Salminen *et alii*, 2006). The values of cobalt concentrations ranged between 0.01-0.07 ppm (Table 5) and these values exceed standards (WHO, 2017 and IQS, 2009), due to the direct dumping of agricultural, industrial and household waste into the water of the study area (Al-Saydeh *et alii*, 2017).

Manganese (Mn^{2+}): the values of manganese concentrations ranged between 0.48-0.06 ppm (Table 5) and these values exceed WHO (2017) and IQS (2009) of 0.1 ppm except for the samples R1, Z2, Z7, D2, D3, SH5 and SH8, which fall within the permissible range. The most important sources of manganese in the water of the study area is its dissolving from the source rocks and released to the surface water. It's used in the manufacture of fertilizers, batteries and other industries factories and workshops (Ljung *et alii*, 2007), whose waste is thrown into valleys.

Figure 4 shows the concentration of heavy elements in the water along the course of the main valleys on the left part of Mosul city. In general, fluctuations in the concentrations of these elements may appear due to the multiplicity of waste disposal sites that are a source of these elements, as well as the diversity of activities in these sites, whether residential, industrial or agricultural. The presence of organic matter, clay deposits and reed plants, which are highly prevalent in the course of valleys, contributes to the fluctuation of concentrations of heavy elements in water.

Water pollution indexes

Table 6 shows that all the water samples of the study area exceeded the critical value of (*HPI*) values, which are greater than 100, and the water of the study area is classified as being highly polluted depending on (*HPI*), the reason is mainly due to industrial activities, (Tiwari *et alii*, 2015) and that the water of the study area is generally unfit for use.

All samples of the study area were within the category of high pollution depending on the *HEI* pollution index, where the values are greater than 20 due to domestic, industrial wastewater and household waste, which are among the main sources of some heavy elements, except for the R5 sample, as it falls within the category of moderate pollution, and therefore the water of the study area is generally unusable.

Table 7 shows that the waters of the study area vary in their classification based on *MI* according to (Siegel, 2002), but they are often few-moderate pollution, depending on the extent to which the sample is affected by domestic, industrial or agricultural wastes in addition to its location.

According to the Contamination Index (C_d), all the samples were within the category of high pollution where were greater than 32 (Table 6) due to domestic wastewater, sewage and industrial water that are dumped in valleys and cause high concentrations of some of the heavy elements and thus make them highly polluted except for the sample R5 which was within the category of moderate pollution and therefore the water in the study area are generally unfit for use.

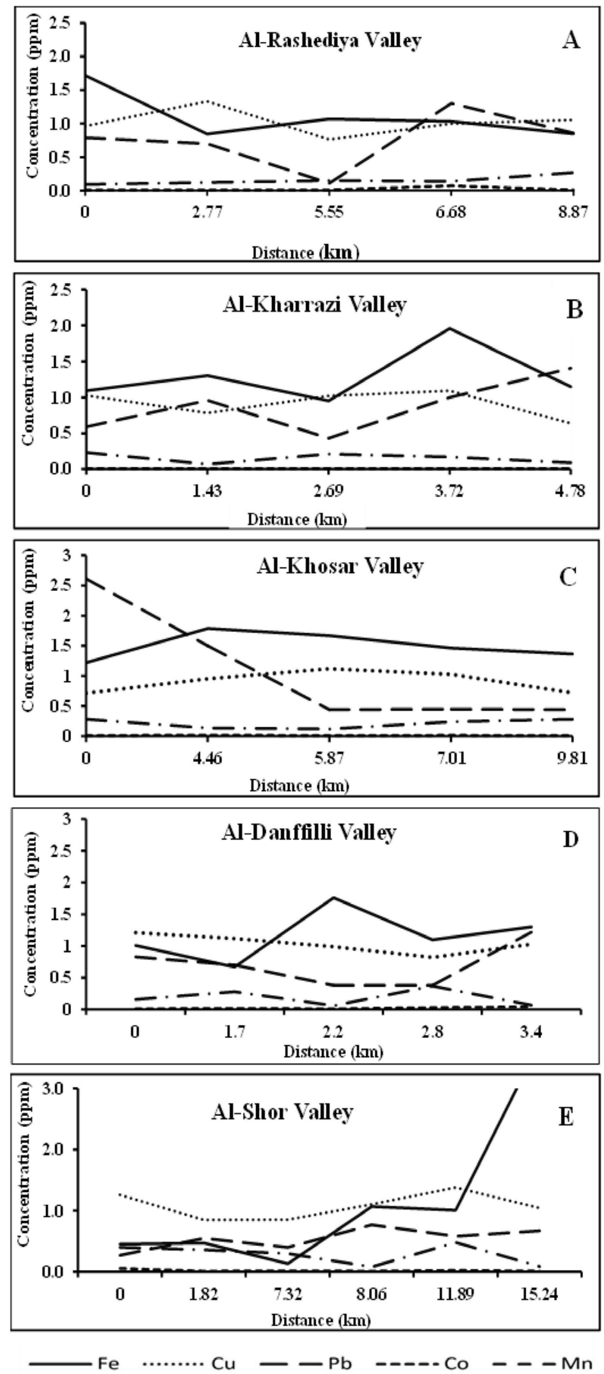

Fig. 4 - The Concentration of heavy elements in water along the main valleys on the left side of Mosul city

Sample	HPI	Contamination Degree[a]	HEI	Contamination Degree[b]	C_d	Contamination Degree[c]
R1	204	H Level of heavy metal C	86	High Contamination	86	Very High Degree of Contamination
R3	171	H Level of heavy metal C	75	High Contamination	75	Very High Degree of Contamination
R5	121	H Level of heavy metal C	16	Moderate	16	Moderate Degree of Contamination
R6	773	H Level of heavy metal C	142	High Contamination	141	Very High Degree of Contamination
R8	110	H Level of heavy metal C	91	High Contamination	91	Very High Degree of Contamination
Z1	168	H Level of heavy metal C	65	High Contamination	65	Very High Degree of Contamination
Z2	209	H Level of heavy metal C	102	High Contamination	102	Very High Degree of Contamination
Z4	148	H Level of heavy metal C	48	High Contamination	48	Very High Degree of Contamination
Z6	231	H Level of heavy metal C	108	High Contamination	108	Very High Degree of Contamination
Z7	247	H Level of heavy metal C	146	High Contamination	146	Very High Degree of Contamination
ZA	208	H Level of heavy metal C	96	High Contamination	95	Very High Degree of Contamination
ZB	184	H Level of heavy metal C	36	High Contamination	35	Very High Degree of Contamination
K1	365	H Level of heavy metal C	267	High Contamination	267	Very High Degree of Contamination
K3	360	H Level of heavy metal C	159	High Contamination	159	Very High Degree of Contamination
K4	169	H Level of heavy metal C	51	High Contamination	51	Very High Degree of Contamination
K5	206	H Level of heavy metal C	52	High Contamination	52	Very High Degree of Contamination
K7	162	H Level of heavy metal C	51	High Contamination	50	Very High Degree of Contamination
KA	712	H Level of heavy metal C	136	High Contamination	136	Very High Degree of Contamination
KB	630	H Level of heavy metal C	35	High Contamination	34	Very High Degree of Contamination
D2	166	H Level of heavy metal C	46	High Contamination	45	Very High Degree of Contamination
D3	512	H Level of heavy metal C	131	High Contamination	131	Very High Degree of Contamination
DA	188	H Level of heavy metal C	88	High Contamination	88	Very High Degree of Contamination
DC	294	H Level of heavy metal C	76	High Contamination	76	Very High Degree of Contamination
DD2	337	H Level of heavy metal C	46	High Contamination	46	Very High Degree of Contamination
Sh1	524	H Level of heavy metal C	36	High Contamination	36	Very High Degree of Contamination
Sh2	147	H Level of heavy metal C	59	High Contamination	59	Very High Degree of Contamination
Sh4	175	H Level of heavy metal C	43	High Contamination	43	Very High Degree of Contamination
Sh5	184	H Level of heavy metal C	82	High Contamination	82	Very High Degree of Contamination
Sh6	290	H Level of heavy metal C	66	High Contamination	65	Very High Degree of Contamination
Sh8	251	H Level of heavy metal C	81	High Contamination	81	Very High Degree of Contamination

[a] (Saleh et al., 2019); [b] (Saleh et al., 2019); [c] (Hakanson, 1980).

Tab. 6 - The values and classification of contamination factors (HPI, HEI and C_d) in the water of the studied area

Uses of sewage water for irrigation

The The use of sewage water to irrigate crops deteriorates the soil, due to the accumulation of heavy elements in the short or long term of irrigation. The sewage water leads to changes in the chemical properties of the soil, increase the salinity of the soil, and It also increases the concentrations of heavy elements and their accumulation to sometimes toxic levels (Mateo-Sagasta *et alii*, 2015).

According to the total hardness, based on the classification of Sawyer & McCarthy (1967) and Todd & Mays (2005) the water of the study area were classified as very hard water because they exceeded 300 mg/l (Table 1 and 8) and this is due to the dissolution of carbonate and sulfide minerals that are part of the clastic components of the soil prevalent in the region (Al-Naqib *et alii*, 2018). Therefore, the water in the study area is not suitable for irrigation of crops. Various studies also indicate that the increased hardness of water makes it unsuitable for domestic and industrial uses.

The values of iron concentrations fall within the criteria of (IRAQI FACTS, 2012), and therefore, the waters of the study area are suitable for irrigation on the basis of iron values, (Table 9). with respect to the cobalt concentrations, (except for the samples R6, KA, KB, SH1), the waters are suitable for irrigation too. Most samples except (R8, Z1, Z4, ZB,K1, K5,

Sample	MI	Characteristic
R1	1.54	Slightly affected
R3	1.47	Slightly affected
R5	1.08	Slightly affected
R6	8.15	Seriously affected
R8	1.58	Slightly affected
Z1	1.40	Slightly affected
Z2	1.65	Slightly affected
Z4	1.30	Slightly affected
Z6	1.68	Slightly affected
Z7	1.95	Slightly affected
ZA	1.60	Slightly affected
ZB	1.81	Slightly affected
K1	2.75	Moderately affected
K3	3.01	Moderately affected
K4	1.31	Slightly affected
K5	1.79	Slightly affected
K7	1.31	Slightly affected
KA	6.73	Seriously affected
KB	7.02	Seriously affected
D2	1.26	Slightly affected
D3	5.07	Strongly affected
DA	1.56	Slightly affected
DC	2.96	Moderately affected
DD2	3.46	Moderately affected
Sh1	5.89	Moderately affected
Sh2	1.38	Slightly affected
Sh4	1.84	Slightly affected
Sh5	1.52	Slightly affected
Sh6	2.84	Moderately affected
Sh8	1.47	Slightly affected

Tab. 7 - Element Index classification of the studied area

Water class	Total hardness in terms of mg/l (CaCO3)
Soft	0-55
Relatively hard	56-100
Moderate hardness	100-200
Very hard	201-500

Tab. 8 - The classification of water quality according to (Sawyer & Mccarthy, 1967)

K7, KB, DC, DD2, SH1, SH2, SH4, SH6) have manganese within the limits of IRAQI FACTS (2012). While the values of copper and lead concentrations exceed the criteria of IRAQI FACTS (2012). Thus, the water of the study area is not suitable for irrigation, (Table 9).

Variables	Determinants (mg/l)
Iron (Fe)	5
Copper (Cu)	0.2
Cobalt (Co)	0.05
Lead (Pb)	0.1
Manganese (Mn)	0.2

Tab. 9 - Iraqi national determinants of irrigation water (IRAQI FACTS, 2012)

CONCLUSION

The geochemical study of the main valleys in the city of Mosul by determined the physical, chemical and heavy properties of the water, the following conclusions were obtained:

1. The water of the study area is classified as very hard water, that attributed to the nature of the carbonate rocks present in the Fat'ha Formation through which the water of the study area passes.
2. It was found that the calcium ion is predominant over the cations, and the bicarbonate is predominant over the anions that lead the water of the study area tends towards the basic, pH ranged 6.11-8.30 with an avearage 7.2.
3. The water of the study area is characterized by high values of heavy metals that exceed international standards, especially the elements (Pb, Mn, Co), and this is due to the direct dumping of agricultural, industrial and household waste into the water of the study area, and therefore the water of the study area is not suitable for irrigation.
4. Using the pollution coefficients for heavy metals (*HPI*, *HEI* and C_d), it has been concluded that the water in the study area is generally unhealthy for use.

RECOMMENDATIONS

The valleys are open channels at the present time, they must be converted into box sewers and connected it with the sewage networks, and treatment stations should be built for each valley before releasing its waters into the Tigris River.

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