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ASSESSMENT OF WATER QUALITY ALONG GREATER ZAB RIVER WITHIN IRAQI LANDS

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EXTENDED ABSTRACT

Con il presente studio si è inteso valutare la qualità delle acque del fiume Greater Zab (GZR - Greater Zab River), il maggiore e più importante affluente del fiume Tigri , per il quale contribusce a circa il 40% del volume totale di acqua, costituendo un grande bacino idrografico di estrema rilevanza per l'utenza civile .

A partire dalle aree vicino al lago Van in Turchia, dove il F. Greater Zab nasce, il GZR rappresenta il recapito di numerosi corsi d'acqua compresi quelli della regione del Kurdistan iracheno attraverso il quale scorre fino a confluire nel fiume Tigri, a circa 40 km a sud della città di Mosul. Nel suo percorso il GZR interessa diverse formazioni geologiche, la maggior parte delle quali costituite da rocce carbonatiche composte da calcite e dolomite, fortemente solubili per effetto delle precipitazioni. Pertanto gli affluenti maggiori (i fiumi Shamdinan, Haji Beg, Rawandooz e Khazir – Gomal), oltre a decine di piccoli affluenti e torrenti stagionali, confluiscono e si riversano nella valle principale del GZR, trsportando i prodotti dell'erosione di queste rocce come ioni solubili.

Le fluttuazioni nella concentrazione dei principali cationi e anioni sono dovute all'effetto dell'alimentazione idrica di affluenti e torrenti, alla tipologia delle rocce esposte e all'effetto dell'erosione chimica sulle rocce e sul suolo che ne deriva.

Il presente studio ha mostrato, attraverso i risultati dell'analisi chimica dei principali cationi {(Ca^{2+} = 58-41) mg/l, (Mg^{2+} = 18,5-33) mg/l, (Na^{+} = 3-7 mg/l, (K^{+} = 1,6 - 2,5) mg/l} e anioni {(HCO_3^- = 181 - 214) mg/l, $SO_4^=$ = 39-64) mg/l, Cl^- = 4-12) mg/l, NO_3^- = 5-32) mg/l}, oltre alla misura del pH (7,1-7,4), della conducibilità elettrica (EC = 471-587 µs/cm), dei sali disciolti totali (TDS = 250-310 mg/l) , della durezza totale (TH = 168-244) mg/l) e della torbidità (Tr. = 7,3-16,1 NTU), che l'acqua del GZR rientra nei limiti fissati dall'Organizzazione Mondiale della Sanità come idonea per scopi potabili, mediante l'utilizzo dell' indice di qualità WQI.

Con un WQI compreso tra 26,71 e 39,84, l'acqua del GZR è valutata come acqua buona, ed è considerata acqua dolce, potabile ed idonea all'uso civile (tenendo conto del trattamento del fattore di torbidità con l'acqua, come attualmente applicato).

Inoltre, in base agli standard di percentuale di sodio (SSP = 2,41-6,26), del rapporto di adsorbimento di sodio, (SAR = 0,08-0,2), della quantità di carbonato di sodio residuo (RSBC = -1,92 - -0,96) e della percentuale di magnesio (MAR = 34,53-55,82), l'acqua del GZR è risultata anche idonea all'utilizzo in agricoltura e conseguentemente all'irrigazione: la percentuale di sodio per tutti i campioni è inferiore al 60%, con una percentuale di adsorbimento sodico che non supera il valore di 2.5, quindi l'acqua è classificata a basso contenuto di sodio (S1) e non è stato rilevato alcun effetto sulla quantità di carbonato di sodio residuo, poiché in tutti i campioni risulta inferiore a 1,25 meq/l.

In conclusione l'acqua del GZR è classificata ottima per l'uso irriguo, perché i valori di CE e Na% sono inferiori rispettivamente a 1000 e 60, ed è ulteriormente classificata come buona per l'irrigazione in base ai valori di EC e SAR che collocano l'acqua del GZR nel campo C2-S, oltre ad essere, secondo l'American Salinity Laboratory, un'acqua adatta anche a quasi tutte le colture, in quanto in base ai valori SAR e MAR è considerata di classe S1.

In generale è possibile affermare che l'acqua del Grat Zab River (GZR) influisce sulla qualità dell'acqua del fiume Tigri poichè, a valle della confluenza dei due fiumi, si registra una diminuzione delle concentrazioni di cationi e anioni nell'acqua del fiume Tigri.

ABSTRACT

The current study examined the assessment of the waters of the Greater Zab River GZR because it represents the most important and largest tributary of the Tigris River due to its participation in about 40% of the Tigris River water and because it is a large basin and catchment area. The GZR consists of the gathering of streams, starting from the areas near Lake Van, and then entering Iraqi lands in the Kurdistan region towards the Tigris River. It passes through several geological formations, most of which are containing carbonate rocks composed of calcite and dolomite, which have solubility due to the effect of rainwater. Therefore, several streams gather and empty into the main valley GZR carrying the weathering products of these rocks as soluble ions. It was found through chemical analyzes of the main cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO^{3-}, $SO^{4=}$, Cl^{-}, NO^{3-}), as well as measuring the pH, electrical conductivity (E.c.), total dissolved salts (TDS), total hardness (TH) and turbidity (Tr.), The GZR waterfalls within the natural limits set by the World Health Organization for drinking purposes through the use of the water quality index (WQI) as well as its suitability for agricultural purposes according to the standards of Sodium Percentage (SSP), Sodium Adsorption Ratio, (SAR), and the amount of Residual Sodium Carbonate (RSC). As well as, the percentage of magnesium (MAR).

Keywords: *Greater Zab River, water quality, water assessment, water utilization, Tigris River, rivers in Iraq*

INTRODUCTION

Water is the most important pillar of the ecosystem, and therefore its preservation is one of the most important conditions for the sustainability of society and the systems associated with it. However, due to the continuous increase in the population and the diversification of their activities in the field of manufacturing, agriculture and the use of fertilizers, both chemical and organic, water resources, especially rivers, are exposed to the effects of pollution and the change of their chemical and physical characteristics above the permissible limits, which affected the water quality (Basavaraja *et alii*, 2011; and Leizou *et alii*, 2017). Especially since the rivers represent the most used source and therefore changing its characteristics or contamination will directly affect human life and the food chain through the water supply, or indirectly through agricultural activity (Ahmad et al., 2009). Water quality standards are of great importance for monitoring the quality and validity of water and are closely related to human life, environmental safety and sustainable economic development (Vishnupriya Sowjanya *et alii*, 2015 and Leizou *et alii*, 2017).

The GZR is one of the main tributaries of the Tigris River, and one of the most important water basins that feed the Tigris River with more than 40% of the annual water income, (Abbas *et alii,* 2016). It is about 462 kilometers from its source near Lake Van in Turkey to its meeting point with the Tigris River at the Al-Makhlat area, about 40 km south of Mosul city (Shareef & Muhamad, 2008), (Fig. 1). The GZR originates in the alpine regions near Lake Van in Turkey and during its course, it is fed by a large number of streams. Then it enters the Iraqi lands in the Kurdistan region near the border point with Turkey east of the village of (Jali) and continues towards the southeast within the Dohuk governorate, where several streams and tributaries flow into it, such as the Rishin tributary at the entrance to Kali Balanda, where the river is then known as the Greater Zab and continues its path in the northern part of Erbil governorate through a large number of mountains that direct its course towards the southwest towards the Tigris River.

The Greater Zab Basin is located between latitudes 36-38 degrees north and longitudes 43.3-44.3 degrees east. The area of the basin is 26,473 km^2, of which 65% is located within Iraqi territory and the rest within Turkish territory (Abbas *et alii*, 2016).

The feeding basin of the GZR is about 40300 square kilometers (in Iraq attains about 13708 Km^2 (Sissakian, 2013)) and through its bath; a large number of tributaries, the main four tributaries, called; Shamdinan, Haji Beg, Rawandooz and Khazir – Gomal rivers, besides tens of small tributaries and seasonal streams, which are mainly fed by water collected from areas of rain and snowmelt, as a result of which the river continues to run throughout the year, (Abbas *et alii*, 2016 and Ismaiel *et alii*, 2018).

The catchment's areas of the GZR and its tributaries are covered mainly by carbonate rocks (limestones) which succeeded (in some formations) with marly limestones, dolomite, marl and shale of many formations, which range in age from Triassic to Pliocene – Pleistocene, beside igneous and metamorphic rocks, especially in the northeastern parts, (English *et alii*, 2015). Moreover, marl, limestone and gypsum of the Fatha Formation, fine clastics of Injana and Mukdadiya formations, and coarse clastics of Bai Hassan Formation cover a considerable area, downstream Bekhma area, (Sissakian, 2013).

Saaeed's study (2009) showed that the water of the GZR improve some of the physical and chemical specifications of the water of the Tigris River as a result of the process of dilution due to the large discharge of the GZR and its mixing with the Tigris River. Electrical negativity, total solids, and suspended solids decrease by 27.7%, 23.6%, and 40%, respectively, and the concentrations of sulfate, chloride, and calcium ions decrease by 33%, 20%, and 16%, respectively.

Toma (2013) classified the water quality of GZR as poor to very poor according to WQI, he depends on 13 parameters: turbidity, pH, electrical conductivity, total dissolved solids, alkalinity, total hardness, calcium, magnesium, sodium,

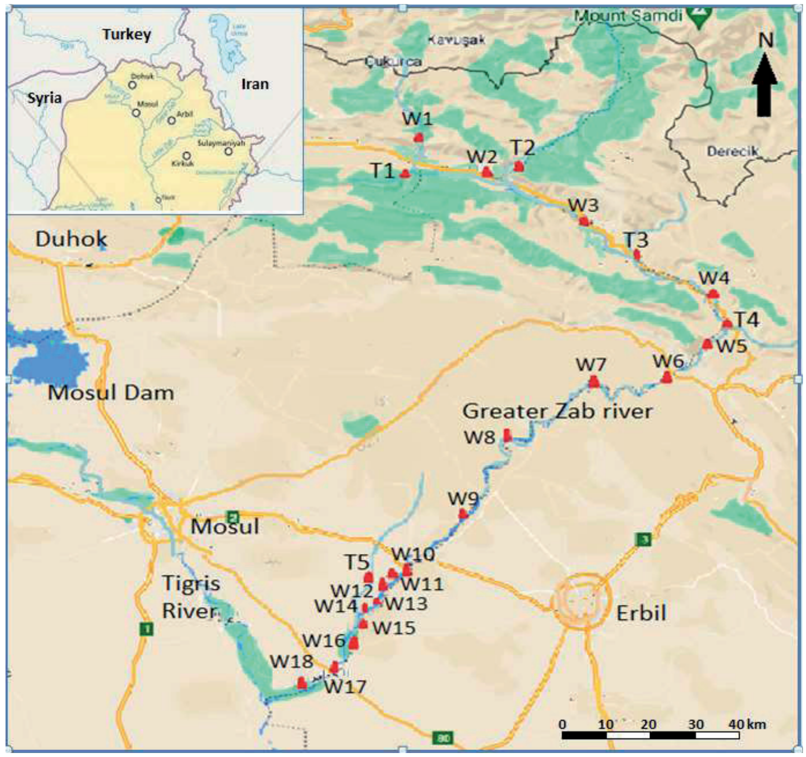

Fig. 1 - Location map and sampling of Greater Zab River

potassium, chloride, nitrate and sulfate. He also declares that all parameters are within the acceptable ranges of the WHO guide for drinking water. These two conclusions are opposite because using turbidity as an important parameter to calculate the WQI is not suitable. Turbidity is an important physical parameter neither a chemical parameter, and it is very easy for the supply water station management and even the individual citizen to remove or reduce the turbidity, so the assessment of water quality does not depend on turbidity. Therefore, QWI results of a previous study appeared to be inconsistent with the values of the parameters.

Shekha (2016) studied the factors that controlled the water quality of GZR by using some statistical methods like multivariate analysis (e.g. principal component analysis, factor analysis and cluster analysis. He classified the GZR water as hard water depending on the high sulfate content. He attributed this to the effect of wastewater discarded as a result of civil uses. On the other hand, he declares that all parameters are within the permissible levels according to the Iraqi drinking water standards and the guideline of WHO. In addition to the weathering, mineral salts and domestic wastes are the main factors controlled the water quality of the GZR.

To determine the appropriate places to implement water harvesting projects, it is necessary to take into account several criteria such as catchment areas, rainfall, evaporation rate, topographic slope, soil type, vegetation cover and agricultural management, (Alwan *et alii*, 2019). Rasheed, (2010) analyzed the drought periods in northeastern Iraq for the period 1941-2002 using the Standard Rain Index (SPI) and indicated that the region experiences dry periods of about 56% of the study period and classified the area in general as moderately humid and moderately arid. The rainfall ranges between 225-525 mm in moderate drought years, between 175-425 in medium dry years, and between 120-320 mm in very dry years, despite high rainfall rates. He also indicated the need to study the water balance of the region to benefit from rain rates in wet years by implementing water harvesting projects in the main valleys to benefit from them in dry years, especially during the supplementary irrigation period.

Abbas *et alii*, (2016) studied the water resources system of the Greater Zab Basin according to climate change, using the Soil and Water Assessment Tool, which showed variability and increase in droughts and floods in the region throughout the year and for several years in the future. Climate change is directly reflected in the hydrological cycle by changing the balance between evapotranspiration and precipitation, which exacerbated the water problem in light of droughts.

Many researchers demonstrated that GZR water is considered as low Na content and safe for irrigation (Shareef & Muhamad, 2008). Aziz (2008) indicated that the water of the Great Zab River is suitable for irrigation purposes because it has a medium salinity content (Class C2) and falls within the safety standards for irrigation uses according to the American Salinity Laboratory. It can also be classified as excellent to good according to EC, TDS, sulfate, and chloride values. Greater Zab River water cannot be used for drinking directly. According to the United States Salinity guidelines, this river is of type B and is acceptable for irrigation. It can be classified as good to excellent according to EC, TDS, SO4, Cl, Na and safe for fish (Shareef & Muhamad, 2008 and Shareef *et alii*, 2009).

MATERIALS AND METHODS

Eighteen samples were collected (as a duplicate) along the GZR, from its entry into Iraqi lands to its mouth in the Tigris River, in addition to five samples taken from the main five tributaries, (Table 1). All samples were taken through October –November / 2019.

	Sample No.	Location	N - ordinate	E - ordinates
Great Zab River	GZW1	Deralouk	37 05 06.65	43 39 38.21
	GZW2	Sheladiz	37 01 57.51	43 45 40.12
	GZW3	Barzan	36 54 53.55	44 01 21.37
	GZW4	Shanidar	36 47 18.90	44 15 58.51
	GZW5	Bakhma	36 39 35.00	44 13 43.70
	GWZ6	Qandil	36 38 24.92	44 11 30.87
	GZW7	Gawian	36 35 24.31	43 59 39.09
	GZW8	Gopal	36 30 38.88	43 51 58.55
	GZW9	Kar	36 18 58.97	43 43 45.01
	GZW10	Aski Kalak	36 15 57.67	43 38 26.24
	GZW11	Harki	36 13 41.92	43 36 27.35
	GZW12	Syfaia	36 12 04.04	43 35 07.04
	GZW13	Gahatli 1	36 08 47.64	43 32 17.28
	GZW14	Gahatli 2	36 07 17.97	43 30 47.30
	GZW15	Hawerah 1	36 05 49.38	43 30 35.16
	GZW16	Hawerah 2	36 04 16.64	43 30 29.05
	GZW17	Al Kuwayr	36 02 58.65	43 29 40.66
	GZW18	Al'Adiah	36 00 57.82	43 23 56.76
Tributaries	GZT1	Sherana valley	37 03 04.57	43 39 43.83
	GZT2	Shamdinan valley	37 01 03.63	43 50 11.84
	GZT3	Haji Beg valley	36 51 44.99	44 07 19.00
	GZT4	Rawanduz valley	36 42 44.49	44 17 36.12
	GZT5	Khazir – Gomel river	36 10 22.72	43 32 36.91

Tab. 1 - Location and ordinations of the samples.

The pH measurements by HANNA PH211, the electrical conductivity (Ec) by HANNA EC214, the dissolved salts (Total dissolved solids; TDS) and the total hardness (TH), as well as the chemical analyzes of the main cations and anions were carried out in the laboratory of geochemistry in the Dams and Water Resources Research Center – Mosul University. The routine chemical methods were used to estimate (Ca^{2+}, Mg^{2+}, HCO_3^- and Cl^-) by titration methods and (Na^+, K^+) using the flame-photometer of JENWAY PEP7 according to (APHA, 1998). $SO_4^=$ and NO_3^- were estimated by turbidity method using a UV- Spectrophotometer type (OGAWA, OSK 7724), as well as, using electronic balance type (Mettler H54 AR). The process of sampling and analysis was carried out in 2019.

The Water Quality Index (WQI) represents the conversion of all data on water quality into a mathematical number that reflects the level of water quality (Leizou *et alii*, 2017) to determine the suitability of the GZR water. For drinking and civilian purposes, the water quality index (WQI) was calculated using all the above parameters and depending on the standards of the World Health Organization (Tribble *et alii*, 1995 and WHO, 2006). The turbidity parameter has not been included in the WQI because this parameter does not affect the quality of the water, likewise, all water users at the government level or individuals are working to get rid of turbidity to the lowest possible level.

Calculation of water quality index (WQI) depending on (Tyagi *et alii*, 2013; Kapoor *et alii*, 2016 and Gupta & Misra, 2018), (Table 2).

Water quality scale	Quality of water
0 - 25	Excellent
26 - 50	Good
51 - 75	Poor
76 - 100	Very poor
100 and above	Unsuitable to drink

$$WQI = \sum Qi * Wi / \sum Wi \qquad (1)$$

*Qi : 100 X (Vm - Vi) / (Vs - Vi) ……*for each parameter.

Tab. 2 - Water Quality Index (WQI) scale for drinking water (Gupta & Misra, 2018)

Qi: the quality rating of the ith parameter for a total of n water quality parameters.

Vm : measured value of the water samples for quality parameters estimated from analysis.

Vi: ideal value of that water quality parameter can be obtained from the standard tables, Ideal value is equal to zero for most parameters except for pH = 7.

Vs: standard of the water quality parameters given by WHO

Wi = K / Vs ; (K = proportionality constant = 1).

Wi: relative unit weight of nth parameter.

The concentrations of cations and anions were calculated in the form of meq/l to calculate the water balance of the analysis results that reflect the accuracy of the data, as well as that some factors used in the classification of water depend on the values of the concentrations in the formula of meq/l such as soda, and it is calculated to express the extent of the impact Sodium in irrigation water such as the percentage of sodium (Na%), the sodium adsorption ratio (SAR), and the amount of residual sodium carbonate (Residual Sodium Carbonate, RSBC), (Aghazadeh & Mogaddam, 2010):

$$SSP = Na^+ X\ 100\% / (Na^{+}+K^{+}+ Ca^{2+}+Mg^{2+}) \qquad (2)$$

$$SAR = Na+/((Ca2++Mg2+)/2)0.5 \qquad (3)$$

$$RSBC = (CO32- + HCO3-) - (Ca2++Mg2+) \qquad (4)$$

$$MAR = Mg^{2+} X\ 100 / (Ca^{2+}+Mg^{2+}) \qquad (5)$$

RESULTS AND DISCUSSION

Several small streams consist of melting snow and falling rain in the areas near Lake Van that gathered and formed the beginning of the GZR in Turkish lands. These streams usually pass between mountains, which consist mainly of igneous and metamorphic rocks as well as carbonate rocks. But when the GZR enters Iraqi lands in the Kurdistan region, most of the mountains are convex folds consisting of carbonate rocks mostly, especially limestone and Marley Limestone. This case also applies to the main tributaries feeding the GZR, especially the tributaries (GZT1, GZT2, GZT3 and GZT4), which opens the way for the effect of carbonate rocks on the chemistry of the GZR by dissolving some mineral phases that composed these rocks. Therefore, a significant increase in the concentrations of calcium and bicarbonate in the waters of the GZR, specifically in the area following the confluence of each tributary with the GZR, (Fig. 2 and Fig. 3).

As for the small tributaries that are usually active during rainy seasons, the length of the tributary does not allow for a large dissolution process, and therefore the effect of these tributaries along the GZR does not work to raise the concentrations of calcium and bicarbonate in the river (Fig. 2 and Fig. 3), because these tributaries are small and bath through short distances.

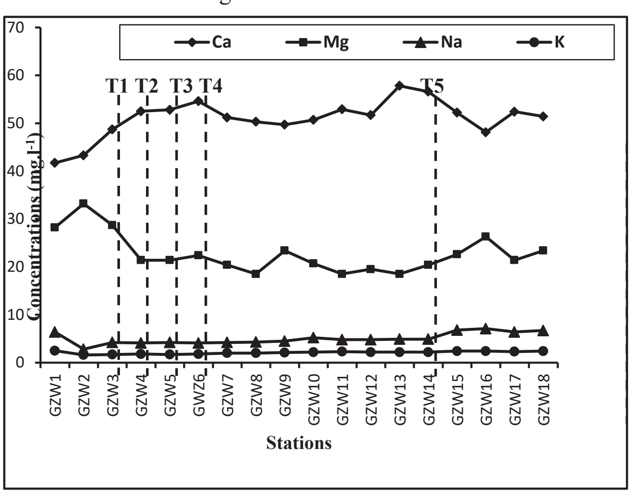

Fig. 2 - Cation concentrations along GZR

This situation is repeated when the Rawanduz tributary meets the GZR (before the Bakhma Dam area), which is one of the long tributaries that passes through several formations made of carbonate rocks and significantly raises the concentration of both calcium and bicarbonate. However, feeding the small tributaries gradually reduces these concentrations and along the rest of the river downstream. As for the rise in calcium after the Al-Kuwayr area, it is attributed to the effect of dissolution of gypsum rocks belong to Fat'ha Fm. that is exposed in that region, as it is observed from figures 2 and 3, a relative rise in the concentration of calcium and sulfate, while no increase in the concentration of bicarbonate is observed.

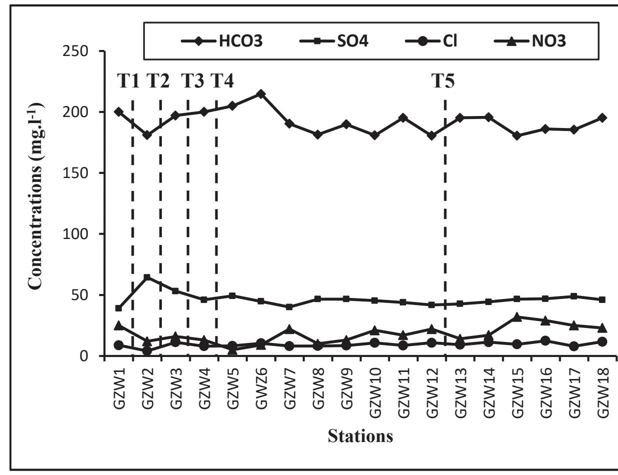

Fig. 3 - Anion concentrations along GZR

The pH values of the water samples ranged between 7.1-7.7, (Tab. 3). Which fall within the natural limits for drinking, civil and irrigation purposes, which ranges between 7.0-8.5 (Abawi & Hassan, 1990; WHO, 2006). The pH values shift towards the alkaline side of neutrality, due to the effects of rock types exposed in almost area, which composed mainly of $CaCO_3$ (Abdulwahid, 2013), as the process of dissolving gases, especially carbon dioxide in rainwater, usually causes a decrease in the pH, which is attributed to the activity of water infiltrating through the soil by the activities of dissolution and washing, especially on carbonate rocks.

The electrical conductivity (E.C.) reflects the water content

Samp. No.	pH (*unit*)	E.C (*μs/cm*)	T.D.S (*mg/l*)	T.H (*mg/l*)	Tur. (*NTU*)
GWZ1	7.4	536	280	224	7.34
GWZ2	7.4	587	310	244	9.68
GWZ3	7.4	549	300	212	12.5
GWZ4	7.6	520	290	220	10.1
GZW5	7.5	541	290	224	9.6
GWZ6	7.5	533	290	228	7.9
GZW7	7.4	535	300	220	9.4
GZW8	7.4	471	250	184	8.9
GZW9	7.5	538	280	228	9.6
GZW10	7.6	514	280	168	8.7
GZW11	7.7	533	280	212	16.1
GZW12	7.5	528	290	216	14.4
GZW13	7.4	556	280	220	12.1
GZW14	7.5	526	290	220	11.6
GZW15	7.5	558	310	225	10.8
GZW16	7.5	547	300	228	10.2
GZW17	7.5	550	300	220	10.3
GZW18	7.5	561	290	224	10.1
GZT1	7.1	905	480	404	11.7
GZT2	7.5	540	290	220	17.2
GZT3	7.5	567	310	248	14.2
GZT4	7.5	492	250	204	13.4
GZT5	7.5	620	340	248	10.3

Tab. 3 - Physical parameters of the Greater Zab river of dissolved salts, and its values in the study models range from 471-587 µs/cm, (Table 3). Perhaps these relatively low values are due to the low rate of dissolution of carbonate components in the limestone and dolomitic rocks of most of the formations exposed in the areas of the flow of the GZR and its main and small tributaries, which depend on the amount of carbon dioxide dissolution in the falling rainwater in the area that intersects the cracks, fractures and joints in the rocks. The infiltration of water is preserved within the carbonate rocks and allows dissolving some of its components and then feed the Greater Zab Valley through many springs in the region at the end of the slopes of the mountains and the many streams associated with it. As for the electrical conductivity values in the main tributaries, they vary according to the type of rocks exposed in each valley.

The concentrations of total dissolved salts (TDS) generally represent the water content of dissolved minerals (salts), (Fig. 4), which control the assessment of the suitability of water for use, whether for drinking, watering animals, and irrigation. Especially in the subsurface rock layers close to the ground,

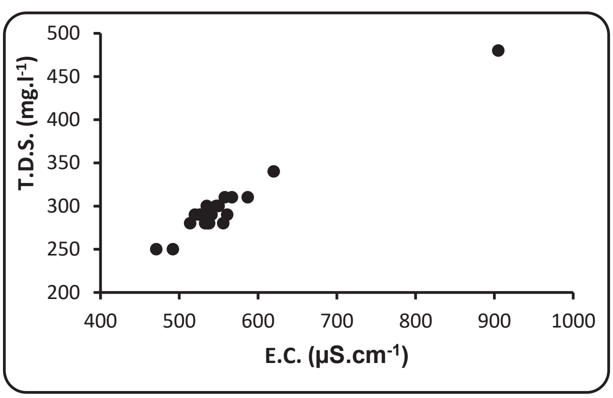

Fig. 4 - The relationship of E.C. vs TDS in GZR water

where the effect of feeding water from the dewatering zone is on the dissolving activities of the minerals that make up those layers, such as carbonate minerals, especially calcite and dolomite in the limestone rocks that make up most formations. The process of water seepage through the joints, fractures and cracks in the rocky layers leads to the occurrence of chemical weathering and changes in the conditions of stability of the mineral phases, as the rain water works to dissolve the crushed and weathering fragments of limestone and dolomite, as well as the cement material in marl and clay minerals in the soil and then leaching water to the subsurface layers. Carbon dioxide dissolved in the rain and the vital activity of plants, as well as microorganisms, play a role in the dissolution process. In addition to the Pleistocene formations include sediments of conglomerates, gravels, and coarse sand, as well as deposits of sand, silt, and clay, and appear on the banks of the river, especially after the Bakhmah Strait towards the downstream (Aziz, 2006).

The values of TDS ranged from 250-310 mg/l, which generally indicates a decrease in the effect of the dissolution process due to the infiltration of rainwater, which raises the value of water validity for different uses (Todd, 1980). While it is relatively high in the tributaries, especially the Sherana and Khazir tributaries.

Total hardness (TH) expresses the amount of dissolution of some mineral phases that are unstable by the chemical weathering process under the acidic influence of carbonate dioxide dissolved in rainwater, mainly on the carbonate phases, therefore, hardness is called carbonate hardness. Total hardness values ranged from 168-244 mg/l, (Table 3) which reflects the low concentration of calcium and magnesium.

Table 3 indicates that the turbidity values are low, but they are higher than their normal limits according to (WHO, 2006), which is (5NTU). The reason is attributed to the effect of the erosion process on the sediments of the GZR and the tributaries that flow into it. It is expected that turbidity values will be high in periods of heavy rainfall, because the basin associated with the wadi valley represents a large catching area for rainwater (Aziz, 2006, 2008 & 2009).

Calcium concentrations appear high relative to the rest of the other cations, as they ranged between 58-41 mg/l within the valley path (Table 4), which is below its normal limits of 75 mg/l according to (WHO, 2006). Figure 5 shows a clear direct relationship between the concentrations of calcium and bicarbonate, indicating that they are in the same mineral phases, which are calcite and dolomite that formed the rocks of most of the formations of the region. Table 4 shows that there is a relative rise in calcium concentrations along the GZR after the main tributaries were connected to it. It also appears from Fig. 5 that the tributaries' values are not subject to the relationship between calcium and bicarbonate, indicating the variation of water sources in these tributaries according to the type of rocks that each tributary passes through.

Magnesium concentrations range from 18.5-33 mg/l, which are within normal limits, and these concentrations are attributed to the effect of chemical weathering and dissolving activities on the carbonate rocks of the formations containing dolomite and calcite containing magnesium (Mg-calcite) as well as the solubility of the denuded carbonate constituents on the soil surface. Figure 2 shows a relative rise in magnesium concentrations in the waters of Sherana, Shamdinan and Haji Beg valleys. The reason may be attributed to the effect of weathering activities on the basic igneous and metamorphic rocks, that are rich in minerals containing magnesium such rocks belong to the Taurus-Zagros Fold-and-Thrust Belt is an area of great geological complexity (Al-Juboury *et alii*, 2020). Figure

6 also shows the absence of a correlation between calcium and magnesium concentrations, which is attributed to the presence of calcium in many mineral carbonate phases within the formations containing carbonate.

Sodium concentrations are 3-7 mg/l in the GZR water samples, and less than this range in the waters of the main tributaries. It is observed from Table 4 and Figure 3 a relative rise in sodium concentrations in the waters of the GZR at the sites located after the Bakhme Dam towards the downstream, and it is believed that the effect of the gentle slope of the topography of the area towards the course of the valley, works to direct the infiltrated water through the recent sediments and soil to sub-surface water, especially since the region is exposed to periods of rainfall and periods of high temperature, which leads to the precipitation of sodium chloride salts from the leachate washing water after exposure to the activities of the capillary reaction and sedimentation of sodium chloride salts on the surface of the soil, (Al-Youzbakey *et alii*, 2018), and its re-dissolution and leaching through surface water to the GZR, (Fig. 7).

Usually, potassium concentrations are low concerning sodium, although it is one of the elements with high solubility and mobility, and this is due to the ability of clay minerals in the soil and recent sediments to stabilize and adsorb it. The potassium concentrations in the waters of GZR reached 1.6 - 2.5 mg/l. The absence of a relationship between sodium and potassium in the studied samples indicates the absence of potassium as salts of secondary halides in the soils of the surrounding area of the GZR valley.

The pH values did not exceed the limit (8.3) that qualifies it to contain carbonates despite the presence of a percentage of alkalinity represented by bicarbonate ions in the water, and this is considered normal in shallow surface and semi-surface waters that contain high rates of anions that cause acidity, (Phillips

Samp. No.	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	$SO_4^{=}$	Cl^-	NO_3^-
GWZ1	41.7	28.2	6.4	2.5	200	39	8.8	25
GWZ2	43.3	33.2	2.8	1.6	181	64.3	4.1	12
GWZ3	48.7	28.7	4.2	1.7	197	53.1	11.2	16
GWZ4	52.5	21.4	4.1	1.8	200	46	8	13
GZW5	52.8	21.4	4.2	1.7	204.9	49.2	8.3	5
GWZ6	54.6	22.4	4.1	1.8	214.7	44.7	10.4	9
GZW7	51.2	20.4	4.2	2	190.3	40	8.1	22
GZW8	50.3	18.5	4.3	2	181.4	46.6	8.2	10
GZW9	49.7	23.4	4.5	2.1	189.8	46.6	8.5	13
GZW10	50.7	20.7	5.2	2.2	180.8	45.3	10.7	21
GZW11	52.9	18.5	4.8	2.3	195.2	43.9	8.6	17
GZW12	51.7	19.5	4.8	2.2	180.5	41.7	10.8	22
GZW13	57.8	18.5	4.9	2.2	195.2	42.7	9.2	14
GZW14	56.6	20.4	4.9	2.2	195.6	44.3	11.3	17
GZW15	52.2	22.6	6.8	2.4	180.5	46.6	9.5	32
GZW16	48.1	26.3	7.1	2.4	186	46.8	12.4	29
GZW17	52.4	21.4	6.4	2.3	185.4	48.8	7.9	25
GZW18	51.4	23.4	6.7	2.4	195.2	46	11.7	23
GZT1	64.2	59.5	3.2	2.2	239.1	142.8	8.5	32
GZT2	48.1	24.3	4.2	2.3	175.6	49.8	6.7	21
GZT3	67.4	19.5	3.6	2.1	219.6	36.7	6.2	24
GZT4	43.3	23.4	4.9	2.2	209.8	28.7	7.2	11
GZT5	44.7	30.2	7.1	2	224.4	51.3	9.1	14

Tab. 4 - Chemical analysis of cations and anions ($mg.l^{-1}$) of the Greater Zab water.

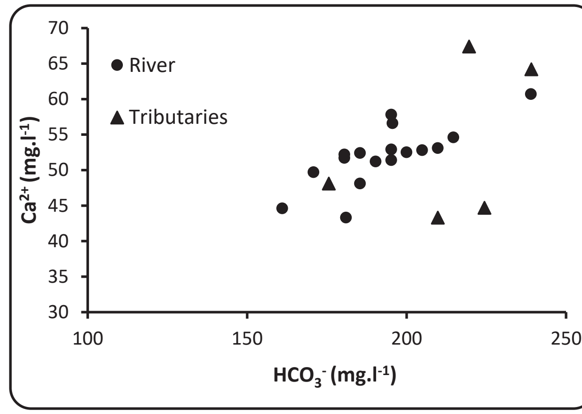

Fig. 5 - The +ve relationship between calcium and bicarbonate ions

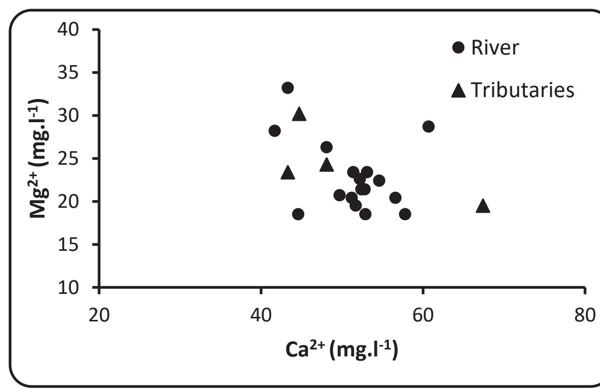

Fig. 6 - The relationship between calcium and magnesium ions

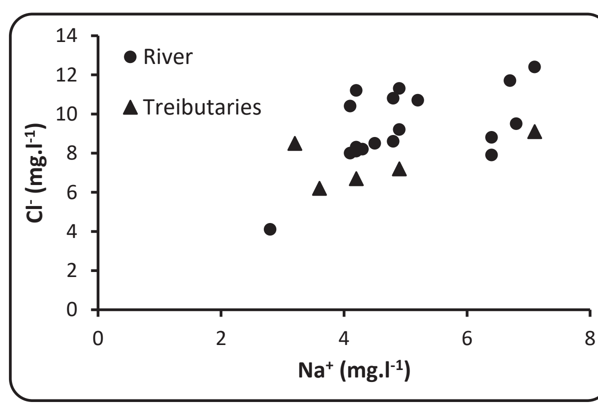

Fig. 7 - The +ve relation between Sodium and Chloride ions

& Castro, 2004). Limestone is the source of bicarbonate because the mineral phases that formed limestone are affected by dissolving activities. The concentrations of bicarbonate in water samples ranged 181 - 214 mg/l. Several factors control the solubility and thus the bicarbonate concentration, such as carbon dioxide pressure, pH, reservoir limestone quality, temperature, and the presence of sulfates in the medium

(Deming, 2002). As mentioned previously, the emergence of a relative rise in bicarbonate concentrations due to the influence of tributaries (Fig. 3).

Sulfate concentrations in the studied samples are (39-64) mg/l, and the source of the sulfate is attributed to the presence of some rock fragments that are derived from the erosion of gypsum rocks exposed in some areas, especially those related to the Gercus Formation, The sulfate minerals formed during the main early diagenetic phase in the Gercus Formation, that represented the post-depositional breakdown of the unstable ferromagnesian minerals within the interstitial waters below the desert surface (Al-Juboury *et alii*, 2020). Gercus Formation rock exposed as widely spread in the mountainous regions of northern Iraq. This exposes it to the effect of the chemical weathering process during the rainy seasons, and then its flow towards the GZR. Therefore, figure (8) shows that there is no correlation between bicarbonate and sulfate, indicating that it does not exist in the same type of rocks.

Surface water contributes to dissolving chloride salts in the soil (especially the soil surface) during their passage and leaching into the subsurface layers. Therefore, its concentration in surface waters in any area depends on the type of rocks and the topography of the area (Chappelle, 2004). Chloride concentrations are 4-12 mg/l in the GZR water.

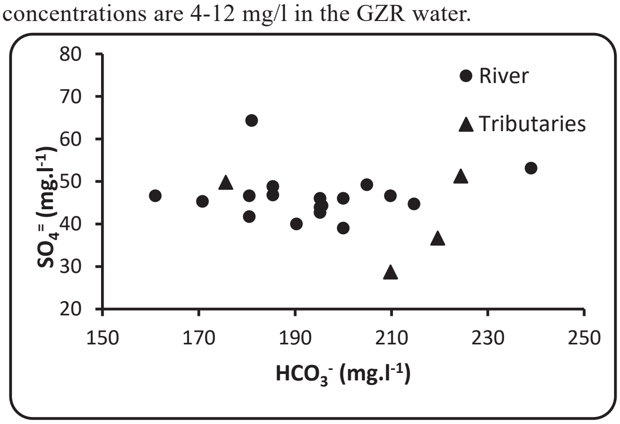

Fig. 8 - The random relationship between bicarbonate and sulfate in GZR water

Nitrate concentrations range from 5-32 mg/l. Despite the multiple sources of nitrates in the water, either because of rainfall (and its fixation by bacteria in the soil), agricultural activity (such as organic and chemical fertilization), or biological activities (such as sewage discharges and animal wastes) (Jones, 1997). However, figure (9) shows the existence of a relationship between the concentrations of potassium and nitrates, which indicates the effectiveness of organic or chemical fertilization with the use of compound fertilizers (K.N.P.), which are the most influential sources in supplying water with nitrates.

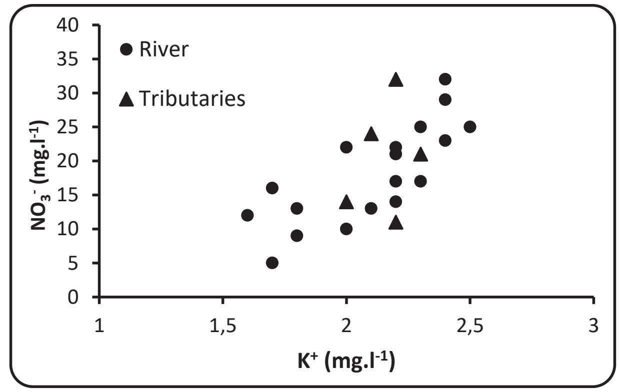

Fig. 9 - The relationship between potassium and nitrate

Water classification

There are not many studies on water quality, such as the Water Quality Index (WQI) in the Kurdistan region, including the GZR, (Abdulwahid, 2013). The GZR represents the largest source of surface water is used in the city of Erbil and the small cities close to the river for drinking and civil purposes as well as other uses within agricultural and industrial activities in addition to the use of groundwater, (Aziz, 2006; Aziz, 2009; Shareef & Muhamad, 2008; Ismaiel *et alii*, 2018). Shareef *et alii*, (2009) concluded that most of the chemical and physical parameters (except turbidity) of GZR water were within the guidelines given by WHO. While others indicated that the water is not suitable, depending on the amount of turbidity that does not fall within WHO's determinants of five, as the amount of turbidity varies according to the amount of rainfall, which is generally more than 5 (NTU). Many researchers suggested using the direct filtration method instead of the rapid filtration method, especially in the period of heavy rain to reduce the turbidity (Aziz, 2006, 2008 and 2009).

This study deal with the water quality of the GZR along its path from entering the Iraqi borders to its mouth in the Tigris River. The physical (except for turbidity) and chemical parameters showed that they fall within the limits set by the World Health Organization (Table 5). As for the turbidity of the water, it represents the easiest treatment that can be deal with to improve the quality of water for drinking purposes by traditional methods based on sedimentation of mud and suspended solids.

Table 6 shows the results of the chemical analyses calculated in milli-equivalents/liters to estimate the accuracy of the results through the equivalent values of the sum of positive ions compared to the total of negative ions. In addition to calculating the parameters of water classifications for irrigation purposes, the values of which are listed in Table 7. It appears from table 7 that the values of the WQI for all samples

	pH	E.C.	T.D.S	T.H.	HCO_3^-	$SO_4^=$	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Vs	8.5	1400	1000	500	400	400	250	50	75	50	200	55
Wi	0.1176	0.0007	0.0010	0.002	0.0025	0.0025	0.004	0.020	0.0133	0.020	0.005	0.0182

Tab. 5 - The chemical standard specifications (Vs) for drinking water according to the WHO (2006)

range from 26.71-39.84, therefore, water is classified as good according to divisions (Gupta & Misra, 2018) (Tab. 2).

The sodium content is an important factor in studying the risks of sodium in irrigation water to agriculture. As the high percentage of sodium in irrigation water may impede plant growth or cause damage and reduce soil permeability, which is an important factor in the process of aeration and water penetration into the soil (Joshi *et alii*, 2009) compared to calcium

Samp. No.	Ca^{2+}	Mg^{2+}	Na^+	K^+	Total	HCO_3^-	$SO_4^=$	Cl^-	NO_3^-	Total
GWZ1	2.081	2.319	0.278	0.064	**4.74**	3.278	0.812	0.248	0.403	**4.74**
GWZ2	2.161	2.730	0.122	0.041	**5.05**	2.967	1.338	0.116	0.194	**4.61**
GWZ3	2.430	2.360	0.183	0.043	**5.02**	3.229	1.105	0.316	0.258	**4.91**
GWZ4	2.620	1.760	0.178	0.046	**4.60**	3.278	0.958	0.226	0.210	**4.67**
GZW5	2.635	1.760	0.183	0.043	**4.62**	3.358	1.024	0.234	0.081	**4.70**
GWZ6	2.725	1.842	0.178	0.046	**4.79**	3.519	0.930	0.293	0.145	**4.89**
GZW7	2.555	1.678	0.183	0.051	**4.47**	3.119	0.833	0.228	0.355	**4.54**
GZW8	2.510	1.521	0.187	0.051	**4.27**	2.973	0.970	0.231	0.161	**4.34**
GZW9	2.480	1.924	0.196	0.054	**4.65**	3.111	0.970	0.240	0.210	**4.53**
GZW10	2.530	1.702	0.226	0.056	**4.51**	2.963	0.943	0.302	0.339	**4.55**
GZW11	2.640	1.521	0.209	0.059	**4.43**	3.199	0.914	0.243	0.274	**4.63**
GZW12	2.580	1.604	0.209	0.056	**4.45**	2.959	0.868	0.305	0.355	**4.49**
GZW13	2.884	1.521	0.213	0.056	**4.67**	3.199	0.889	0.259	0.226	**4.57**
GZW14	2.824	1.678	0.213	0.056	**4.77**	3.206	0.922	0.319	0.274	**4.72**
GZW15	2.605	1.859	0.296	0.061	**4.82**	2.959	0.970	0.268	0.516	**4.71**
GZW16	2.400	2.163	0.309	0.061	**4.93**	3.049	0.974	0.350	0.468	**4.84**
GZW17	2.615	1.760	0.278	0.059	**4.71**	3.039	1.016	0.223	0.403	**4.68**
GZW18	2.565	1.924	0.291	0.061	**4.84**	3.199	0.958	0.330	0.371	**4.86**
GZT1	3.204	4.893	0.139	0.056	**8.29**	3.919	2.973	0.240	0.516	**7.65**
GZT2	2.400	1.998	0.183	0.059	**4.64**	2.878	1.037	0.189	0.339	**4.44**
GZT3	3.363	1.604	0.157	0.054	**5.18**	3.599	0.764	0.175	0.387	**4.93**
GZT4	2.161	1.924	0.213	0.056	**4.35**	3.439	0.597	0.203	0.177	**4.42**
GZT5	2.231	2.484	0.309	0.051	**5.07**	3.678	1.068	0.257	0.226	**5.23**

Tab. 6 - The chemical analysis in (meq.l^{-1})

and magnesium ions. The effect of sodium can be measured by several parameters such as the percentage of soluble sodium (SSP), which represents the percentage of sodium concerning the positive ions, the amount of residual sodium bicarbonate (RSBC), which represents the amount of sodium carbonate precipitation due to the acidity of water, which leads to soil degradation, and the percentage of Sodium adsorption (SAR), which represents the percentage of sodium adsorption by the soil, which affects the availability of water that tends to enter into cation-exchange reactions in the soil, (Aghazadeh & Mogaddam, 2010).

It is noted from Table 7 that sodium, in general, does not affect the properties of GZR water in terms of its use for irrigation purposes, as the percentage of sodium for all samples is less than 60% (Todd, 1980), and the sodium adsorption percentage does not exceed the value 2.5, so the water is classified as the low sodium class (S1) (according to the American Salinity Laboratory), it also showed that there was no effect on the amount of residual sodium carbonate, as all the samples were below 1.25 meq/l, and thus the water is suitable for irrigation. (Abawi & Hassan, 1990).

According to the classification of Willcox, 1948 (in Todd, 1980), which depends on E.C. and Na%, the GZR water is classified as excellent to the good of irrigation use because the values of E.C. And Na% are less than 1000 and 60, respectively. It is supported by the classification of Richard, 1954 (in Abawi & Hassan, 1990) which is based on E.C. and SAR indicates that GZR water falls within the C2-S1 field and is good for irrigation use. The water is also suitable for almost all crops, according to the American Salinity Laboratory, as it is considered Class S1, depending on SAR values.

Samp. No.	WQI	SAR	SSP	RSBC	MAR
GWZ1	31.00	0.19	5.87	-1.12	52.71
GWZ2	29.45	0.08	2.41	-1.92	55.82
GWZ3	29.85	0.12	3.64	-1.56	49.27
GWZ4	35.75	0.12	3.87	-1.10	40.18
GZW5	30.46	0.12	3.95	-1.04	40.05
GWZ6	31.63	0.12	3.72	-1.05	40.34
GZW7	29.59	0.13	4.09	-1.11	39.64
GZW8	26.71	0.13	4.38	-1.06	37.74
GZW9	32.14	0.13	4.20	-1.29	43.69
GZW10	36.93	0.16	5.01	-1.27	40.22
GZW11	39.84	0.14	4.71	-0.96	36.56
GZW12	33.28	0.14	4.69	-1.22	38.33
GZW13	28.31	0.14	4.56	-1.21	34.53
GZW14	32.97	0.14	4.47	-1.30	37.26
GZW15	35.95	0.20	6.13	-1.50	41.64
GZW16	35.77	0.20	6.26	-1.51	47.40
GZW17	34.35	0.19	5.91	-1.34	40.23
GZW18	34.34	0.19	6.02	-1.29	42.87
GZT1	29.85	0.07	1.68	-4.18	60.43
GZT2	33.70	0.12	3.94	-1.52	45.43
GZT3	35.13	0.10	3.02	-1.37	32.29
GZT4	31.15	0.15	4.89	-0.65	47.11
GZT5	33.45	0.20	6.08	-1.04	52.68

Tab. 7 - The parameters of water classification for drinking and irrigation.

Residual sodium carbonate (RSBC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purposes (Aghazadeh & Mogaddam, 2010), and the increase of magnesium in the water negatively affects the agricultural yield because the soil content will be saltier, and according to this parameter, the water is suitable for irrigation purposes if its MAR values are less than 50 (Joshi *et alii*, 2009) as the most of the water samples of the GZR, (table 7), except for the two samples (GWZ1 & GWZ2), as well as the Shirana Valley sample (GZT1), which contains high concentrations of magnesium according to the effect of weathering on the basic igneous and metamorphic rocks that GZR pass through it before entering the Iraqi borders, these type of rocks are belong to the Zagros Suture Zone (Sissakian, 2013).

CONCLUSION

In general, the fluctuation in the concentrations of the main positive and negative ions is due to the effect of the streams and small tributaries that flow into the GZR along its path until it meets with the Tigris River, as the quality of the exposed rocks and the effect of chemical weathering activities on the rocks and soil derived from them change the concentrations of these ions.

The current study showed, through the results of chemical analysis and the use of water quality index for classification of water for drinking, the GZR water is considered as freshwater, suitable for drinking and civil uses (taking into account the treatment of the turbidity factor with water, as is currently applied). On the other side, these waters are suitable for agricultural purposes, based on the classification parameter for irrigation.

In general, the water of the GZR (the largest tributary of the Tigris River) affect the water quality of the Tigris River, as the concentrations of cations and anions in the river water decrease after the confluence of the two rivers (near the location of GZW18) as shown in the appendix table III.

REFERENCES

Abawi S. A. & Hassan M. S. (1990) - *The Practice Engineering for Environment. Water Analysis.* Dar Al-Hekma for Publishing, University of Mosul. Engineering for Environment

Abbas N., Wasimi S. A. & Al-Ansari. (2016) -*Climate Change Impacts on Water Resources of Greater Zab River, Iraq*. Journal of Civil Engineering and Architecture, **10** (12): 1384–1402.

Abdulwahid S. (2013) - *Water quality index of delizhiyan Springs and Shawraw river within Soran district Erbil Kurdistan*.pdf. Journal of Applied Environmental and Biological Sciences, **3** (1): 40–48.

Aghazadeh N. & Mogaddam A. A. (2010) - *Assessment of Groundwater Quality and its Suitability for Drinking and Agricultural Uses in the Oshnavieh Area, Northwest of Iran.* Journal of Environmental Protection, **01** (01): 30–40.

Ahmad, A. K., Mushrifah I., & M. S.O. (2009) - *Water quality and heavy metal concentrations in sediment of Sungai Kelantan, Kelantan, Malaysia: A baseline study.* Sains Malaysiana, **38** (4): 435–442.

Al-Juboury A. I., Hussain S. H., McCann T., & Aghwan T. A. (2020) - *Clay mineral diagenesis and red bed colouration: A SEM study of the Gercus Formation (Middle Eocene), northern Iraq.* Geological Journal, **55** (12): 7977–7997.

Al-Youzbakey K. T., Sulaiman A. M., & Ismaeel D. A. (2018) - *The Evaluation of Chemical Characterization for Selected Wells Water in Mosul – Bahshiqa – Shalalat Area, Ninivah Governorate, Northern Iraq.* The 9th Periodical Scientific Conference for Dams and Water Resources Research Center, 28-29 Nov. 2018, 201–2016.

Alwan I. A., Karim H. H., & Aziz N. A. (2019) - *Selecting the Potential Water Harvesting Sites Using Fuzzy GIS-Based Spatial Selecting the Potential Water Harvesting Sites Using Fuzzy GIS-Based Spatial Multi-Criteria Evaluation in Salah Al-Din Governorate , Iraq.* Engineering and Technology Journal, **37**, Part C (2): 220–227.

APHA, AWWA, & WPCF. (1998) - *No Title*.

Aziz, Sh. Q. (2006) - *Assessment of Greater-Zab River Water Quality for Drinking and Irrigation Purposes.* Journal of Zanco, **18** (3): 131–144.

Aziz, Sh. Q. (2008) - *Monitoring Variation of Some Water Quatity Parameters of Greater-Zab River atlfraz Station During Fourteen Months*. Zanco, J0urhal Offuile Ahb Appliei} $Ehc, **20** (3): 115–133.

Aziz S. Q. (2009) - *Treatment of Greater-Zab Water by Direct Filtration.* Thirteenth International Water Technology Conference, IWTC 13 2009, Hurghada, Egypt: 169–180.

Basavaraja S., Hiremath S. M., Murthy K.N.S., Chandrashekarappa K. P., N. A. N. & Puttiah E. T. (2011) - *Analysis of water quality using physico-chemical parameters Hosahalli Tank in Shimoga District, Karnataka, India*. Global J. Sci. Frontier Res, **11**: 31–34.

Chappelle, F. H. (2004) - *Geochemistry of Groundwater*. In H. D. Holland & K. K. Turekian (Eds.), *Treatise On Geochemistry* (first edit, 425–449 pp). Elsevier Pregamon.

Deming, D. (2002) - *Introduction to Hydrogeology.* McGraw-Hill Company.

English J. M., Lunn C. A., Ferreira L. & Yacu G. (2015) - *Geologic evolution of the Iraqi Zagros, and its influence on the distribution of hydrocarbons in the Kurdistan region*. AAPG Bulletin, **99** (2): 231–272.

Gupta R. & Misra A. K. (2018) - *Groundwater quality analysis of quaternary aquifers in Jhajjar District, Haryana, India: Focus on groundwater fluoride and health implications.* Alexandria Engineering Journal, **57** (1): 375–381.

Ismaiel I. A., Bird G., McDonald M. A., Perkins W. T. & Jones T. G. (2018) - *Establishment of background water quality conditions in the Great Zab River catchment: influence of geogenic and anthropogenic controls on developing a baseline for water quality assessment and resource management*. Environmental Earth Sciences, **77** (2): 1–12.

Jones, J. A. A. (1997) - *Global Hydrology, Processes, resources and environmental management.* Longman.

Joshi D. M., Kumar A. & Agrawal N. (2009) - *Assessment of the irrigation water quality of River Ganga in Haridwar District India.* J. Chem, **2** (2): 285–292.

Kapoor B. B., Inam F. & Deo S. S. (2016) - *Assessment of Physico-Chemical Quality of Ground Water in Some Rural Areas Receiving Industrial Wastewater*

Discharges in Nagpur District, Maharashtra State, India. TIJST, **4** (5): 149–155.
Leizou K. E., Nduka J. O. & Verla A. W. (2017) - *Evaluation of Water Quality Index of the Brass River, Bayelsa State, South-South, Nigeria*. International Journal of Research - Granthaalayah, **5** (58): 277–287.
Mahmood H. J. (2013) - *The Content and Relations of Mahor, Trace and Rare Earth Elements in Dissolved and suspended Forms in Tigris River Water between Fishkhaboor and Biji during 2011*. Unpublished Ph. D. Thesis, College of sciences – University of Mosul, 151pp.
Phillips F. M. & Castro M. C. (2004) - *Groundwater Dating and Residence-time Measurements.* In H. D. Holland & K. K. Turekian (Eds.), *Treatise on geochemistry* (First edit, 451–497 pp). Elsevier Pregamon.
Rasheed A. M. M. (2010) - *Analysis of Rainfall Drought Periods in the North of Iraq Using Standard Precipitation Index (SPI)*. AL-Rafdain Engineering Journal (AREJ), **18** (2): 60–72.
Saaeed M. A. (2009) - *Effect of Upper Zab River Confluence Point on The Quality Characteristics of Tigris River Water.* Tikrit Journal of Engineering Sciences, **16** (2): 66–81.
Shareef K. M. & Muhamad S. G. (2008) - *Natural and drinking water quality in Erbil, Kurdistan*. Current World Environment, **3** (2): 227–238.
Shareef K. M., Muhamad S. G. & Shekhanim N. M. (2009) - *Physical and Chemical Status of Drinking Water from Water Treatment Plants on Greater Zab River.* Journal of Applied Sciences and Environmental Management, **13** (3): 89–92.
Shekha Y. A. (2016) - *Evaluation of Water Quality for Greater Zab River by Principal Component Analysis / Factor Analysis*. Iraqi Journal of Science, **57** (48): 2650–2663.
Sissakian V. K. (2013) - *Geomorphology and morphometry of the Greater Zab River Basin, north of Iraq.* Iraqi Bulletin of Geology and Mining, **9** (3): 21–49.
Todd D. K. (1980) - *Ground Water Hydrology* (2nd Editio). John Wiley & Sons.
Toma J. J. (2013) - *Evaluating Raw and treated water quality of Greater Zab River within Erbil city by index analysis.* International Journal of Emerging Technologies in Computational and Applied Sciences, **3** (2): 147–154.
Tyagi S., Sharma B., Singh P. & R. D. (2013) - *Water Quality Assessment in Terms of Water Quality Index.* American Journal of Water Resources, **1** (3): 34–38.
Vishnupriya Sowjanya I., Pavan B. V. & Raja Sekhar P. S. (2015) - *Assessment of Coastal Water Quality through Weighted Arithmetic Water Quality Index around Visakhapatnam, Bay of Bengal, India.* IJIRSET, **4** (12): 1175–1181.
WHO (2006) - *Guideline for drinking water quality*. Vol. Recommendation. World Health Organization.

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Appendix I

Qi	ph	E.C.	T.D.S	T.H.	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3-	$SO_4^{=}$	Cl^{-}	NO_3^{-}
GWZ1	26.67	38.29	28.00	44.80	55.60	56.40	3.20	4.55	50.00	9.75	3.52	50.00
GWZ2	26.67	41.93	31.00	48.80	57.73	66.40	1.40	2.91	45.25	16.08	1.64	24.00
GWZ3	26.67	39.21	30.00	42.40	64.93	57.40	2.10	3.09	49.25	13.28	4.48	32.00
GWZ4	40.00	37.14	29.00	44.00	70.00	42.80	2.05	3.27	50.00	11.50	3.20	26.00
GZW5	33.33	38.64	29.00	44.80	70.40	42.80	2.10	3.09	51.23	12.30	3.32	10.00
GWZ6	33.33	38.07	29.00	45.60	72.80	44.80	2.05	3.27	53.68	11.18	4.16	18.00
GZW7	26.67	38.21	30.00	44.00	68.27	40.80	2.10	3.64	47.58	10.00	3.24	44.00
GZW8	26.67	33.64	25.00	36.80	67.07	37.00	2.15	3.64	45.35	11.65	3.28	20.00
GZW9	33.33	38.43	28.00	45.60	66.27	46.80	2.25	3.82	47.45	11.65	3.40	26.00
GZW10	40.00	36.71	28.00	33.60	67.60	41.40	2.60	4.00	45.20	11.33	4.28	42.00
GZW11	46.67	38.07	28.00	42.40	70.53	37.00	2.40	4.18	48.80	10.98	3.44	34.00
GZW12	33.33	37.71	29.00	43.20	68.93	39.00	2.40	4.00	45.13	10.43	4.32	44.00
GZW13	26.67	39.71	28.00	44.00	77.07	37.00	2.45	4.00	48.80	10.68	3.68	28.00
GZW14	33.33	37.57	29.00	44.00	75.47	40.80	2.45	4.00	48.90	11.08	4.52	34.00
GZW15	33.33	39.86	31.00	45.00	69.60	45.20	3.40	4.36	45.13	11.65	3.80	64.00
GZW16	33.33	39.07	30.00	45.60	64.13	52.60	3.55	4.36	46.50	11.70	4.96	58.00
GZW17	33.33	39.29	30.00	44.00	69.87	42.80	3.20	4.18	46.35	12.20	3.16	50.00
GZW18	33.33	40.07	29.00	44.80	68.53	46.80	3.35	4.36	48.80	11.50	4.68	46.00
GZT1	6.67	64.64	48.00	80.80	85.60	119.00	1.60	4.00	59.78	35.70	3.40	64.00
GZT2	33.33	38.57	29.00	44.00	64.13	48.60	2.10	4.18	43.90	12.45	2.68	42.00
GZT3	33.33	40.50	31.00	49.60	89.87	39.00	1.80	3.82	54.90	9.18	2.48	48.00
GZT4	33.33	35.14	25.00	40.80	57.73	46.80	2.45	4.00	52.45	7.18	2.88	22.00
GZT5	33.33	44.29	34.00	49.60	59.60	60.40	3.55	3.64	56.10	12.83	3.64	28.00

Appendix II

Qi*Wi	ph	E.C.	T.D.S.	T.H.	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3-	$SO_4^{=}$	Cl^{-}	NO_3^{-}	Total
GWZ1	3.137	0.027	0.028	0.090	0.741	1.128	0.016	0.083	0.125	0.024	0.014	1.000	6.414
GWZ2	3.137	0.030	0.031	0.098	0.770	1.328	0.007	0.053	0.113	0.040	0.007	0.480	6.093
GWZ3	3.137	0.028	0.030	0.085	0.866	1.148	0.011	0.056	0.123	0.033	0.018	0.640	6.175
GWZ4	4.706	0.027	0.029	0.088	0.933	0.856	0.010	0.060	0.125	0.029	0.013	0.520	7.395
GZW5	3.922	0.028	0.029	0.090	0.939	0.856	0.011	0.056	0.128	0.031	0.013	0.200	6.301
GWZ6	3.922	0.027	0.029	0.091	0.971	0.896	0.010	0.060	0.134	0.028	0.017	0.360	6.544
GZW7	3.137	0.027	0.030	0.088	0.910	0.816	0.011	0.066	0.119	0.025	0.013	0.880	6.122
GZW8	3.137	0.024	0.025	0.074	0.894	0.740	0.011	0.066	0.113	0.029	0.013	0.400	5.527
GZW9	3.922	0.027	0.028	0.091	0.884	0.936	0.011	0.069	0.119	0.029	0.014	0.520	6.650
GZW10	4.706	0.026	0.028	0.067	0.901	0.828	0.013	0.073	0.113	0.028	0.017	0.840	7.641
GZW11	5.490	0.027	0.028	0.085	0.940	0.740	0.012	0.076	0.122	0.027	0.014	0.680	8.242
GZW12	3.922	0.027	0.029	0.086	0.919	0.780	0.012	0.073	0.113	0.026	0.017	0.880	6.884
GZW13	3.137	0.028	0.028	0.088	1.028	0.740	0.012	0.073	0.122	0.027	0.015	0.560	5.858
GZW14	3.922	0.027	0.029	0.088	1.006	0.816	0.012	0.073	0.122	0.028	0.018	0.680	6.821
GZW15	3.922	0.028	0.031	0.090	0.928	0.904	0.017	0.079	0.113	0.029	0.015	1.280	7.437
GZW16	3.922	0.028	0.030	0.091	0.855	1.052	0.018	0.079	0.116	0.029	0.020	1.160	7.400
GZW17	3.922	0.028	0.030	0.088	0.932	0.856	0.016	0.076	0.116	0.031	0.013	1.000	7.106
GZW18	3.922	0.029	0.029	0.090	0.914	0.936	0.017	0.079	0.122	0.029	0.019	0.920	7.104
GZT1	0.784	0.046	0.048	0.162	1.141	2.380	0.008	0.073	0.149	0.089	0.014	1.280	6.174
GZT2	3.922	0.028	0.029	0.088	0.855	0.972	0.011	0.076	0.110	0.031	0.011	0.840	6.971
GZT3	3.922	0.029	0.031	0.099	1.198	0.780	0.009	0.069	0.137	0.023	0.010	0.960	7.267
GZT4	3.922	0.025	0.025	0.082	0.770	0.936	0.012	0.073	0.131	0.018	0.012	0.440	6.445
GZT5	3.922	0.032	0.034	0.099	0.795	1.208	0.018	0.066	0.140	0.032	0.015	0.560	6.920

**Mahmood (2013)*

Appendix III

location	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	TDS
Before mixed with Tigris River*	79	23	22	3	200	124	21	312
G.Z. at the end point (GZW18)	51	23	7	2	195	46	12	290
after mixed with Tigris River*	75	21	18	2	200	111	12	301

MAHMOOD (2013)