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Evaluation of Water Quality for Lesser-Zab River for Various Applications

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ABSTRACT

The purpose of this research was to study suitability of water in Lesser-Zab River for drinking, irrigation, fish production, swimming, and construction. Raw water samples from Lesser-Zab River were collected for eight months, from February 2013 to September 2013. The samples were analyzed for 15 water quality experiments. Sodium adsorption ratio, sodium percentage, and alkalinity percentage were also determined. The maximum values for temperature, pH, total acidity, total alkalinity, total hardness, chloride, turbidity, electrical conductivity, total salts, dissolved oxygen, five day biochemical oxygen demand, total solids, total suspended solids, total dissolved solids, and sulfate were 21.2 ^{o}C, 8.18, 20 mg/L, 188 mg/L, 180 mg/L, 11 mg/L, 127 FTU, 420 µmhos/cm, 268.8 mg/L, 9.2 mg/L, 6 mg/L, 1200 mg/L, 400 mg/L, 900 mg/L, and 0.0 mg/L, respectively. Lesser-Zab water can be categorized as a moderately polluted water with moderately hard to hard water. The water quality of the river remains within the standards for drinking water, but still requires appropriate treatment processes prior to consumption. Water in Lesser Zab River is considered excellent to good and entirely safe for irrigation. This water is also fit for fish and other aquatic animals and safe for construction, but not appropriate for swimming.

Keywords: Lesser-Zab river, water quality, water standards, evaluation

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تقييم نوعية مياه نهر زاب الصغيرللأستخدامات المختلفة

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الخلاصة

الهدف من هذا البحث دراسة خصائص مياه نهر الزاب الصغير (الزاب الأسفل) و تقييم امكانية استخدامه لغرض الشرب، الري، تربية الأسماك، السباحة والأستخدام الأنشائي في المباني. تم جمع نماذج مختلفة من ماءالنهر لمدة ٨ اشهر اعتبارا من شباط ٢٠١٣ الى ايلول من العام نفسه. و تم تحليل هذه النماذج لخمسة عشر فحصا لنوعية الماء.اضافة الى ايجاد نسبة امتصاص الصوديوم، النسبة المئوية للصوديوم و النسبة المئوية للقاعدية. اقصي قيم لدرجة الحرارة، الأس الهيدروجيني، الحامضية الكلية، القاعدية الكلية، العسرة الكلية، الكلورايد، الكدرة، التوصيل الكهربائي،الأملاح الكلية، الأوكسجين المذاب، المتطلب البايوكيميائي للأوكسجين، المواد الصلبة الكلية، ألمواد العالقة، ألمواد الذائبة الكلية و الكبريتات و كانت على التوالي *21.2 °C*، *8.18*، *20 mg/L*، *188 mg/L*، *180 mg/L*، *11 mg/L*، *127 FT U*، *420 µmhos/cm*، *268.8 mg/L*، *9.2 mg/L*، *6 mg/L*، *1200 mg/L*، *400 mg/L*، *900 mg/L*، *0.0 mg/L*. و على ضوء هذه النتائج يمكن تقييم مياه نهر الزاب الصغير بمياه متوسطة التلوث و متوسطة العسرة الى مياه عسرة. و بهذا تقع نوعية مياه للنهر ضمن مواصفات مياه الشرب بشرط وضع بعض وحدات التصفية قبل الأستخدام من قبل المستهلك. لذا تعتبر مياه نهر الزاب الصغير مياه من نوع ممتازة الى جيدة و امنة لغرض الري و مناسبا لتربية الأ سماك و الأحياء المائية الأخرى و امن للأ ستخدام الأنشائي و لكن غير مناسبا للسباحة.

الكلمات الدالة: نهر زاب الصغير، نوعية الماء، مواصفات المياه، التقييم

1. Introduction

Lesser-Zab River (also known as Lower or Little River) is one of the five main catchments in Northern Iraq [1]. The other four catchments are Khabour, Greater-Zab, Ozem, and Sirwan [1]. Lesser-Zab originates in Iran and meets the Tigris River in Iraq [2-3]. The river covers an area of 15 600 km^2 with a total perimeter of 1398 km. The total area of this watershed is 20030 km^2 and its total perimeter is 1537 km [1]. The tributary of Lesser-Zab produces one of the primary tributaries of the Tigris River with a length that extends 400 km over an area of 22,250 km^2 from its origin in Iran [2-3]. The Dukan dam was constructed on Lesser-Zab to control river flow and electrical generation, irrigation, support fish production, and attract tourists [1-2].

Several studies were conducted on the parameters of water quality, monitoring, and impact of Greater-Zab [1, 4-8]. Aziz studied the suitability of water in Greater-Zab River for drinking and irrigation [9]. Other research focused on the limnological effects of Lesser-Zab on the characteristics of water in the Tigris and Lesser-Zab Rivers [1-3, 10].

The present study examined the parameters of water quality of Lesser-Zab by measuring temperature, pH, total acidity, total alkalinity, total hardness, chloride, turbidity, electrical conductivity (EC), total salts, dissolved oxygen (DO), five-day biochemical oxygen demand (BOD_5), total solids, suspended solids (TSS), total dissolved solids (TDS) and sulfate. This study also determined the suitability of water in Lesser-Zab for drinking, irrigation, fish production, swimming, and construction.

2. Materials and methods

2.1. Description of the Site

Approximately 76% of the Lesser -Zab watershed area is situated within the border of Iraq and the remainder is positioned within the Iranian border (Figures 1 and 2). The elevations of this watershed approximately range from 100 m to 3550 m above sea

Kirkuk University Journal /Scientific Studies (KUJSS)
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level [1, 11]. The site is situated at lat 35°45′41″ N, long 44°08′52″ E [10]. In Iraq, the length of the river spreads to around 175 km with a width of approximately 200 m. The river has a gravel base [3]. The average flow of the river is 197.8 m^3/s, whereas its maximum documented discharge is 3420 m^3/s. In the north side, Lesser-Zab is constrained by the basin of Greater-Zab and surrounded by the basins of Ozem and Diyala Rivers. The parallel mountain ranges of the Zagros comprise limestone folds that rise to heights of more than 3000 m. Water erosion fills the Lesser-Zab valley, whereas the foot hill zone southwest of the Zagros is filled with layers of conglomerate, gravel, and sandstone. Annual precipitation along the course of the river ranges from over 1000 mm in the Iranian Zagros to less than 200 mm at the area where the Lesser-Zab River meets the Tigris River. The river valleys are characterized by hydrophilic plants and marshy zones that result from the nonappearance of drainage. These zones are breeding grounds for malaria-carrying mosquitoes. The foothill zone, particularly the plain of Erbil, is significantly cultivated, and patches of natural vegetation with abundant phloem herbs remain [12].

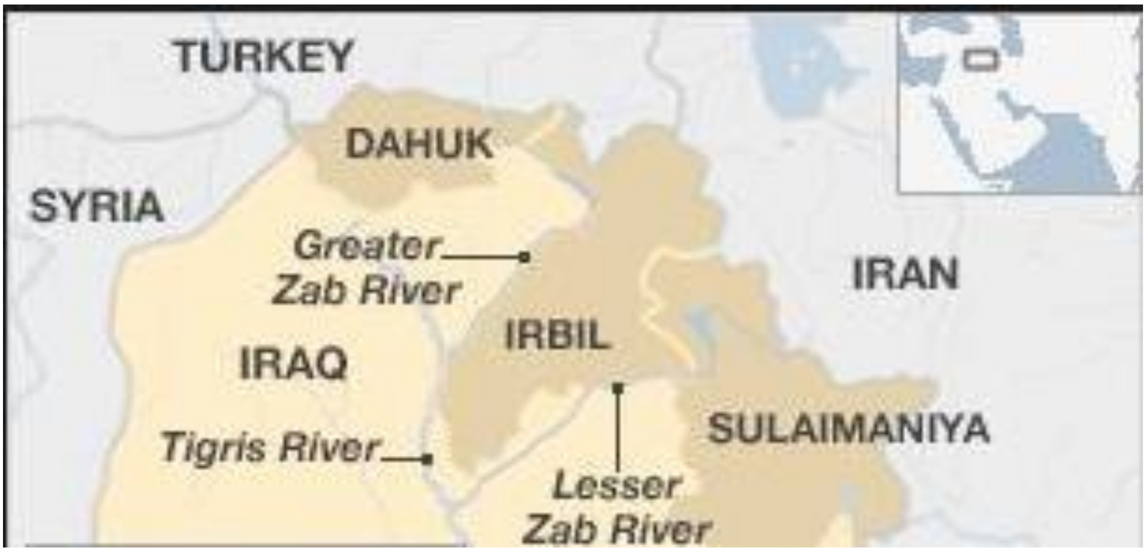

Figure (1): Location of Lesser-Zab River

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 12, Issue 4, September 2017
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Figure (2): Satellite image of Lesser-Zab River sampling point

2.2. Sample Collection and Characterization

Raw water samples were collected from the Lesser-Zab River monthly from February 2013 to September 2013. The samples were collected using polyethylene containers and rinsed with the water sample several times. The containers were then filled and tightly sealed. The samples were kept in the laboratory under a dark and cool condition and maintained in accordance with standards [13]. The samples were stored at 4 °C in the laboratory to deactivate microorganisms activity [13].

Several physical and chemical experiments were conducted to examine the collected samples. The samples were analyzed for temperature, pH, total acidity, total alkalinity, total hardness, chloride, turbidity, EC, total salts, DO, BOD_5, total solids, TSS, TDS, and sulfate. The tests were conducted at the laboratory of the College of Engineering of Salahaddin University–Erbil, Iraq. All physical and chemical examinations were conducted in accordance with standard procedures [13].

2.3. Instruments and Experiment Methods

The following instruments and methods were used for measuring water quality parameters for Lesser-Zab water. Water temperature of the samples was measured in the field by using a clean mercury thermometer with an accuracy of 0.1 °C. Turbidity was measured in the lab by using turbidity meter model WTW 550 Germany. EC and pH were measured using Combined CCMD 625. Total salt was determined mathematically from the EC values. Total acidity, total alkalinity, total hardness, and chloride were determined via titration methods in accordance with the APHA standard [13]. BOD_5 values were determined based on DO figures upon initial collection and after five days [13]. Total solids, TSS, and TDS were determined using oven, filter paper, evaporating dish, flasks, and sensitive electrical balance. The sulfate for the samples were detected in accordance with standard procedures [13].

2.4. Mathematical Equations

Beside of normal water quality parameters, sodium adsorption ratio (SAR), Na%, and Alkalinity % are essential parameters for irrigation water quality [9, 14]. The proportion of sodium ions in the water was generally measured by SAR. Normally SAR represents the sodium hazards of water and is defined as follows [9, 14]:

$$SAR = \frac{(Na)(meq/l)}{\sqrt{\frac{(Ca+Mg)(meq/l)}{2}}} . \qquad \ldots (1)$$

Irrigation water with high Na% will produce a soil with a large percentage of replaceable colloidal sodium. Na% can be calculated using the following equation [9, 14]:

$$Na\% = \frac{Na(meq/l)*100}{(Ca+Mg+Na+K)(meq/l)} . \qquad \ldots (2)$$

In addition, Alkalinity % is necessary parameters for evaluation of irrigation water quality. Alkalinity % is determined using the following equation [9, 14]:

$$Alkalinity\% = \frac{(Na + K)(meq/l) * 100}{(Na + K + Ca + Mg)(meq/l)} . \qquad \ldots(3)$$

3. Results and Discussions

3.1. Characteristics of Water in Lesser-Zab

Table 1 shows the results of water quality analysis, including water and atmospheric temperature. The minimum and maximum temperatures for the Lesser-Zab River water were 12.4 °C and 21.2 °C, respectively, whereas the temperature figures for the atmosphere were 14.6 °C and 38.6 °C. Minimum water temperature was recorded in February 2013, while the maximum was in May 2013. These results are consistent with the previous findings of 7.5 °C to 27.7 °C in [2]. In contrast to this finding, previous authors stated that the water and ambient temperature of Lesser-Zab ranged between 10 °C and 27 °C and between 12 °C and 36 °C, respectively [3]. The variations of water temperatures in Greater-Zab for 14 months ranged between 7 °C and 30 °C [5]. The results for the Lesser-Zab River in the present study are consistent with previous findings [2-5, 15]. The measured temperatures in this study showed that atmospheric temperatures were higher than water temperature, which are consistent with the findings of Abdul Jabar et al. [3] The reported temperatures in Iraq from May to August are normally the highest values, which tend to decrease in September. Thus, this study concentrated on hot and cold seasons. The data published by previous authors supported the present results [3].

Table 1 shows that the pH values for the river water ranged from 7.41 to 8.18. Previous findings on the pH values of the Lesser-Zab River water are consistent with those obtained in the current study [2-3]. A similar range of pH values from 7.45 to

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 12, Issue 4, September 2017
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8.82 for Greater-Zab water was recorded by Aziz [4]. The pH values in the present study are also consistent with the reported data for the water in Greater-Zab [4-6].

Table (1): Results of water quality parameters for Lesser-Zab River

Months	Standard

Tests	February	March	April	May	June	July	August	September	
Atm. temperature (°C)	14.6	19.8	21.4	33.5	35	36.7	38.6	27	
Water temperature (°C)	12.4	13.3	13.8	21.2	20	18	20.6	21	
pH	8.18	7.8	7.6	7.5	7.66	7.45	7.41	8.07	6.5-8.5
Total acidity (mg/L)	14	16	12	15	14	20	20	10	
Total alkalinity (mg/L)	188	171	175	138	140	146	148	144	200
Total hardness (mg/L)	180	150	120	108	128	132	140	120	200
Chloride (mg/L)	11	4	8	10	10	10	8	2	250
Turbidity (FTU)	127	31	20.87	57	75.13	62.46	65.4	13.67	5
EC (µmhos/cm)	400	420	340	330	325	275	290	260	1000
Total salts (mg/L)	256	268.8	217.6	211.2	208	176	185.6	166.4	
DO (mg/L)	9.3	5.2	6.8	-	-	-	7.3	5.5	
BOD_5 (mg/L)	6	0.707	1.8	-	-	-	5	1.4	
Total solids (mg/L)	1100	900	1200	500	300	600	300	700	500
TSS (mg/L)	360	200	400	280	200	320	200	350	
TDS (mg/L)	900	700	800	100	100	400	100	500	
$SO4^{=}$ (mg/L)	0	0	0	0	0	0	0	0	250

The total acidity values of water in Lesser-Zab ranged from 12 mg/L to 20 mg/L. The quality of water resources in north of Iraq remains within the standard alkaline range because of geological formation, which mainly contains limestone.

The total alkalinity of water in the Lesser-Zab River ranged from 138 mg/L to 188 mg/L. Previous study reported a range of 52 mg/L to 208 mg/L for Lesser-Zab, which was higher than the current result [3]. The present results for the Lesser-Zab (146 mg/L to 212 mg/L) and Greater-Zab Rivers (151 mg/L to 187 mg/L) fall within the ranges previously published by Aziz [4] and Toma [6], respectively.

The total hardness of water in Lesser-Zab ranged from 108 mg/L and 180 mg/L. Kassim et al. [2] published a high value of 376.2 mg/L for Lesser-Zab thereby classifying the water as hard water. Another study stated that the total hardness of water in Lesser-Zab ranged from 65 mg/L to 540 mg/L [3], which was considered very hard water. The alkalinity values obtained in the present study were higher than the total hardness values. The alkalinity components and hardness values of water are related [13]. Existing literature classifies water in Lesser-Zab River as moderately hard to hard water [4].

The minimum and maximum values of chloride in the Lesser-Zab samples were 2 mg/L and 11 mg/L, respectively. Large values that ranged from 23.1 mg/L to 65.7 mg/L in Lesser-Zab were reported [3]. Similar ranges of 10.6 mg/L to 28.4 mg/L were also published for Greater-Zab [4]. Toma [6] showed that chloride values of water in Greater-Zab ranged from 6.6 mg/L to 12.8 mg/L. The present findings confirm previous results of chloride values in Greater-Zab water that ranged from 2.4 mg/L to 6 mg/L [7]. High concentrations of chloride are commonly reported during summer. This phenomenon might be attributed to the increase in temperature and evaporation with decreased flow; concentration during December might be attributed to dilution by rain [4].

The minimum and maximum turbidity values of water in Lesser-Zab were 13.7 FTU and 127 FTU, respectively. The current results are within the range of 0.73 NTU to 111 NTU for the Lesser-Zab River [3]. A similar range of 39.2 NTU to 123 NTU for Greater-Zab was also published [6]. Treatment processes are important to remove the impurities caused by increased turbidity. Maximum turbidity was observed in

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 12, Issue 4, September 2017
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January, which was a result of rainfall and surface runoff in the river. Turbidity values also increased from May to August because of fishing, swimming, and agricultural activities. Direct filtration process is a cost-effective approach to treating turbidity values of less than 100 NTU because it can decrease total treatment cost by approximately 30% [17]. A previous study reported similar values and suggestions and proposed the use of direct filtration process on the Tigris and Greater-Zab Rivers [15-16]. Direct filtration process differs based on traditional treatment methods. According to the committee for the coagulation–filtration processes of AWWA's water quality detachment, direct filtration is a water treatment process, wherein filtration is not preceded by in-plant sedimentation of flocculated water [17].

The minimum and maximum values for EC of water in Lesser-Zab were 260 µmhos/cm and 420 µmhos/cm, respectively. Total salts ranged from 166.4 mg/L to 268.8 mg/L. Existing literature reported a value higher than 965 µmhos/cm for Lesser-Zab [2]. According to Aziz and Fakhrey [7], total salts in Greater-Zab water ranged from 210 mg/L to 711 mg/L. Toma [6] stated that EC values of water in Greater-Zab ranged from 347 µmhos/cm to 580 µmhos/cm, whereas total salts varied from 187 mg/L to 289 mg/L. The findings of present study are consistent with the data published by researchers [2, 6-7, 9].

The DO values of water in Lesser-Zab ranged from 5.2 mg/L to 9.3 mg/L. The present results showed that water in Lesser-Zab was well aerated because of high mixing processes, water discharge, and low volume of organic matter. A previous study reported the same findings (Kassim et al., 2007). The range of 5.2 mg/L to 10.4 mg/L for DO in Lesser-Zab was also recorded [3]. The present results agree with the reported data (5.85 mg/L to 7.6 mg/L) for water in Greater-Zab [18]. In contrast to this finding, Aziz [9] recorded high DO values (9.2 mg/L to 10.2 mg/L) for Greater-Zab. Literature indicated that DO decreases in hot season because of high temperature and increased organic matter in wastewater; consumption of organic materials also requires a significant amount of oxygen [4, 13]. The obtained DO results and EPA

[19] classify the Lesser-Zab River as non-polluted (DO $\geq$ 6.5 mg/L) and lightly polluted (6.5 mg/L < DO $\geq$ 4.6 mg/L), respectively.

The BOD_5 values of water in Lesser-Zab ranged from 0.7 mg/L and 6 mg/L. Previous study reported the range of 0.6 mg/L to 4.6 mg/L for the BOD_5 values of water in Lesser-Zab [3], which supported the present finding. The measured BOD_5 values also agree with the BOD_5 values for Greater-Zab reported by Aziz [9] (1.3 mg/L to 4.6 mg/L) and Aziz and Fakhrey [7] (0.2 mg/L to 4.2 mg/L). Based on the obtained BOD_5 values, Lesser-Zab can be classified as non-polluted ($BOD_5 \leq$ 3 mg/L) to moderately polluted (5 mg/L $\leq BOD_5 \leq$ 15 mg/L) [19].

The total solids of water in Lesser-Zab ranged from 300 mg/L to 1200 mg/L, whereas TSS ranged from 200 mg/L to 400 mg/L. A previous study reported a range of 8.8 mg/L to 42.1 mg/L for TSS of water in Lesser-Zab water [2]; another study recorded similar ranges of total solids (500 mg/L to 900 mg/L) and TSS (200 mg/L to 600 mg/L) of water in Greater-Zab [7]. Treatment units, particularly sedimentation and filtration, are needed to eliminate excessive amounts of solids. The suspended solids found in Lesser-Zab water were higher than 100 mg/L. Given this finding, Lesser-Zab may be classified as a severely polluted river [19].

The sulfate value of Lesser-Zab water during the period of data collection was 0 mg/L. Existing literature published high values for water in Greater-Zab, which ranged from 63.57 mg/L to 140.67 mg/L and 70 mg/L to 700 mg/L [5]. Toma [6] reported sulfate values of 68 mg/L to 78 mg/L for water in Greater-Zab. Sulfate concentration of water in Lesser-Zab was 250 mg/L lower than that in the present work. These results indicate that the water in Lesser-Zab remains safe [20]. The sulfate values in Lesser-Zab and Greater-Zab varied because of distinct geological formation and sources of river water and wastewater.

Microorganism problems in Lesser-Zab water were not studied in the present work. But based on literature, authors reported that Greater-Zab contained MPN-Coliform

(>16/100 mL) and MPN-E Coli (>16/100 mL) [5, 9]. To overcome microorganisms problems in Lesser-Zab water, disinfection process is necessary.

3.2. Uses of Water in Lesser-Zab

3.2.1. Drinking

pH values fell within the allowable limits for drinking water. The present results demonstrate that the total alkalinity and hardness values of water in Lesser-Zab remain within the standard values for drinking water. Total acidity and chloride are within the quality standards for drinking water [6, 20-22]. Turbidity values were higher than the standards for drinking water [6, 22]. Water in Lesser-Zab requires treatment processes prior to consumption. The standards for drinking water require a total solid value of less than 500 mg/L [6, 21-22]. The majority of the measured values for total solids in the present study surpassed the standards for drinking water. Table 1 shows that the EC values of less than 1000 μmhos/cm remain within the allowable limits for drinking [6]. Sulfate problems were not observed in Lesser-Zab water.

3.2.2. Irrigation

Normal range of pH for the quality of irrigation water is 6.5 to 8.4 [23]. The pH values obtained for Lesser-Zab water remained within that standard. No restrictions were imposed on the chloride concentration of Lesser-Zab water for irrigation purposes [23].

Table 2 shows that the calculated SAR value was 0.14. The result in the present study was consistent with that of Aziz [9], who reported a range of 0.06 to 0.18. Abbas [24] stated that the SAR of water in Tigris River ranged from 0.731 to 16.119. SAR with high values were returned to the concentration of cations, especially that of sodium. Based on SAR, water in Lesser-Zab can be classified as low sodium water (S1) as shown in Table 3 [25-27]. Abbas [24] referred to Todd and classified water in Lesser-Zab water as entirely safe for irrigation; the result is shown in Table 4.

If the value of Na% is high, the aggregation of soil grains breaks down and the soil becomes less permeable with proper tilth. Water content of 85% or higher will likely cause impermeability in soil after prolonged use, even on sandy soil with good drainage. Constant irrigation of high-sodium water transforms soil into plastic; soil also becomes sticky when wet and form clods and crust upon drying [25].

Table (2): Details of some irrigation water quality parameters

Parameter	Unit	Value	References
Calcium	mg/L	95.80	[2]
Magnesium	mg/L	35.10	[2]
Sodium	mg/L	6.45	[7]
Potassium	mg/L	1.05	[6]
Sodium adsorption ration (SAR)		0.14	
Alkalinity	%	3.82	
Sodium	%	3.52	

Table (3): Classification of irrigation water based on SAR value [25]

No	Type of Water	Use in Irrigation

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 12, Issue 4, September 2017
ISSN 1992 – 0849

1	Low sodium water (S1), SAR value between 0 and 10	Can be used for irrigation on almost all soils and for almost al crops except those which are highly sensitive to sodium, such stone-fruit trees and avocadoes, etc.
2	Medium sodium water (S2), SAR value between 10 and 18	Appreciably hazardous in fine textured soils, which may require gypsum, etc. but may be used on coarse-textured or organic soils with good permeability.
3	High sodium water (S3), SAR value between 18 and 26	May prove harmful on almost all soils and do require good drainage, high leaching, gypsum addition, etc. for proper irrigation.
4	Very high sodium water (S4), SAR value above 26	Generally not suitable for irrigation.

Table (4.): Classification of irrigation water according to Todd [24]

Class of Irrigation Water	**TDS meq/L**	**Cl meq/L**	**SAR**	**Alkalinity %**
Class : Entirely safe for irrigation	700	150	10	60
Class 2: Intermediate for certain crops	2000	500	10-26	60-75
Class 3: Too great to be safe for irrigation	>2000	>500	>26	>75

Table 2 shows the calculated Na% was 3.52%, which is consistent with the published data (2.35 % to 5.4%) for Greater-Zab River [9]. A superior range of 15.83% to 58.05% was reported for water in the Tigris River [24], whereas high values of Na% were associated with sodium concentration. According to Abbas [24], water in Lesser-Zab can be classified as excellent for irrigation (Table 5).

Kirkuk University Journal /Scientific Studies (KUJSS)
Volume 12, Issue 4, September 2017
ISSN 1992 – 0849

Table (5): Permissible limits for different classes of irrigation water according to Scofield [24]

Class of Irrigation Water	EC µs/cm	TDS mg/L	Na %	Cl meq/L	SO_4 meq/L
Class 1: Excellent	250	175	20	4	4
Class 2: Good	250-750	175-225	20-40	4-7	4-7
Class 3: Permissible	750-2000	525-1400	40-60	7-12	7-12
Class 4: Doubtful	2000-3000	1400-2100	60-80	12-20	12-20
Class 5: Unsuitable	>3000	>2100	>80	>20	>20

Table 2 shows that the alkalinity value of water in Lesser-Zab was 3.82. This result is consistent with the data (2.7% to 6.09%) reported for the Greater-Zab River. A range of 10.81% to 59.031% was recorded for water in the Tigris River [24]. The low concentration of sodium in Lesser-Zab water resulted in alkalinity percentage lower than that in the Tigris River. Abbas [24] cited classified water in Lesser-Zab as safe for irrigation (Table 4).

The EC values of water in Lesser-Zab ranged from 260 µmhos/cm to 400 µmhos/cm. Abbas [24] classified the water in Lesser-Zab as suitable for irrigation (Table 5). Table 6 shows that water in Lesser-Zab has medium salinity (Class C2). This measurement was based on other classifications of the quality of irrigation water. Table 5 shows that water in Lesser-Zab water is considered excellent for irrigation purposes. This classification was based on the obtained sulfate values.

Table (6): Classification of irrigation water based on salt content [25]

No.	Type of Water	Suitability for Irrigation
1	Low salinity water (C1), EC between 100 and 250 µ mhos/cm at 25 ºC.	Suitable for all types of crops and all kinds of soils. Permissible under normal irrigation practices except in soils of extremely low permeability.
2	Medium salinity water (C2), EC between 250 and 750 µ mhos/cm at 25 ºC.	Can be used if a moderate amount of leaching occurs. Normal salt tolerant plants can be grown without much salinity control.
3	High salinity water (C3), EC between 750 and 2250 µ mhos/cm at 25 ºC.	Unsuitable for soil with restricted drainage. Only high-salt tolerant plants can be grown.
4	Very high salinity water (C4), EC more than 2250 µ mhos/cm at 25 ºC.	Unsuitable for irrigation.

3.2.3. Fish Production

The acceptable pH level for fish production in fresh water in Australia, Brunei, Canada, Kenya, Malaysia, New Zealand, and the Philippines ranges from 5 to 9 [28-29]. The obtained pH values for water in Lesser-Zab River are acceptable for fish production. Reported data explained that the acceptable DO value of fresh water in Australia, New Zealand, and the Philippines should be higher than 5 mg/L, above 5.5 mg/L in the United Kingdom, and between 3 mg/L and 7 mg/L in in Malaysia [28-29]. The obtained DO values were higher than 5.2 mg/L. This finding indicates that water in Lesser-Zab River is aerobic and the environment is suitable for fish and other aquatic animals.

3.2.4. Swimming

The tolerable pH, total alkalinity, calcium hardness, TDS, and turbidity of water for swimming are 7.2 to 7.8 pH, 60 mg/L to 150 mg/L, 150 mg/L to 1000 mg/L, 1500

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mg/L, and ≤10 NTU, respectively [30] (APSP, 2000). The pH values of water in Lesser-Zab are slightly higher than the permitted level. The obtained total alkalinity values (138 mg/L to 188 mg/L) also surpassed the permissible level. The measured values for total hardness (108 mg/L to 180 mg/) are safe for swimming. The TDS values were less than 1500 mg/L. Turbidity values were higher than 10 FTU. These findings indicate that water in Lesser-Zab is not suitable for swimming. Fresh water from Lesser-Zab is not suitable for swimming and requires treatment. As mentioned before in section 3.1, MPN-Coliform (>16/100 mL) and MPN-E Coli (>16/100 mL) were reported in Greater-Zab water [5, 9]. To overcome microorganisms problems in Lesser-Zab water, disinfection process is necessary.

3.2.5. Construction

The results obtained for water in Lesser-Zab showed chloride content values that ranged from 2 mg/L to 11 mg/L. Water quality standards for construction require chloride concentrations of 500 mg/L for reinforced concrete and 2000 mg/L for plain concrete [31]. The obtained chloride values show that water in Lesser-Zab can be used for construction because the concentrations of chloride were less than 500 mg/L. Maximum TSS for construction is 2000 mg/L. Water in Lesser-Zab is safe for construction because the TSS value ranged from 200 mg/L to 400 mg/L [31]. Sulfate figures were zero and less than the declared standards (400 mg/l). Thus, water in Lesser-Zab is safe for construction. The pH values were within neutral conditions and remained within acceptable limits.

4. Conclusions

The Lesser-Zab River is commonly classified as moderately polluted with moderately hard to hard water. In spite of the existence of pollutants, the water quality of Lesser-Zab remains within the standards for drinking water. However, suitable treatment processes are required before using by consumers. Water in Lesser-Zab is generally classified as excellent to good and entirely safe for irrigation. This water is also appropriate for production of fish and other aquatic animals and is safe for construction. However, this water is not suitable for swimming.

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Nomenclature:

Atm.: Atmosphere

BOD: Biochemical oxygen demand

DO: Dissolved oxygen

EC: Electrical Conductivity

FTU: Formazin turbidity unit

NTU: Nephelometric turbidity unit

SAR: Sodium adsorption ratio

TDS: Total dissolved solids

TSS: Total suspended solids

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