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RESEARCH PAPER

Secondary data collected from Ifraz-2 Erbil for Drinking Water Quality Assessment

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ABSTRACT:

The goal of the current study was to use the Water Quality Index (WQI) to evaluate the overall drinking water quality status in Erbil (at Ifraz two), Kurdistan Region of Iraq, by estimating the quality of the Greater Zab River (raw water) and the water treatment plant WTP at Ifraz-2 on the Greater Zab River, a tributary of the Tigris River. Thirteen physicochemical parameters, including turbidity, pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, alkalinity, chloride, sodium, potassium, nitrate, and sulfate, were evaluated between 2010 and 2021 using the WQI. The calculated WQI for the Greater Zab River's raw water quality ranged from (140.532) to (422.455) and the calculated WQI for WTP (Ifraz-2) ranged from (44.197) to (69.118). Accordingly, the results of Greater Zab River water were categorized as "very poor," "poor," and "unsuitable" for drinking purposes during the studied period (2010–2021). Furthermore, the results of the computed WQI for WTP of (Ifraz-2) are classified as "Excellent" and "Good". According to WQI, the WTP of Ifraz-2 from the current study was of good quality and suitable for consumption by humans. As a result, the efficiency (E%) of the Ifraz-2 WTP was found to be more efficient in 2016 (89.49%) than in other years and suitable for drinking. Except for a few samples, the physicochemical quality of most drinking water samples during the current study was within WHO guideline.

KEY WORDS: WQI; Greater Zab River; Raw water; Treated water; Erbil City
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1. INTRODUCTION :

Water is regarded as an important resource that, when safely and adequately provided, becomes critical for maintaining and protecting the health of people and the environment (Zhang et al. 2020); thus, life on this planet is not possible without water (Zubaidi et al. 2020). Clean and safe water is a fundamental necessity for good health and a productive life (Sharma, 2005). According to the WHO, 80% of diseases in developing nations are caused by poor water and sanitation (WHO, 2006). Because of this, having access to safe water is crucial for community life (Janna and Al-Samawi, 2014), and its availability in large quantities and good quality is greatly needed worldwide (Zhang et al., 2020).

Water treatment plants (WTPs) are applied to surface water sources. It is common knowledge that the goal of any water treatment plant is to create water that is safe, palatable, and suitable for household use. Water treatment entails the elimination of all contaminants that could be detrimental to water supplies for human consumption (Mohammed, 2015). In order to provide populations with clean water, different treatment procedures, including flocculation, sedimentation, filtration, and disinfection, can be used to treat raw water (Alobaidy et al., 2010). Raw water source characteristics, as well as the technical and operational circumstances in treatment plant units, have a major impact on the quality of treated water (Zhang et al., 2012). The WQI is one of the most useful tools for expressing water quality and can be used as a crucial parameter for the evaluation and management of the water source, providing a good idea of the

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tendency of water quality to change over time (Reza and Singh, 2010). The WQI comprehensively summarizes a significant amount of water quality data into a single number, into a simple phrase (e.g., excellent, good, poor, etc.), in order to send water quality information to the general public, water distributors, planners, managers, and policymakers (Damo and Icka, 2013).

The population of the Iraqi Kurdistan Region is rising quickly. A lack of national water quality criteria now inhibits efficient water resource management through legislative control over water quality (Shareef and Muhamad, 2008). Currently, Erbil City receives its water from both surface water and groundwater resources. The Greater Zab River (Bahdinan River) is the only surface water source in Erbil-City that provides water for drinking and other uses. On this river, three water treatment plants (WTPs) named Ifraz 1, Ifraz 2, and Ifraz 3 were built to generate drinking water for Erbil City. The main objective of the study is to determine the water quality of Greater Zab River (raw water) and the quality of water at Water Treatment Plant WTP (Ifraz 2) by WQI, as well as to estimate the efficiency of the Water Treatment Plant (Ifraz 2) for purification or cleaning water for drinking purposes.

2.MATERIALS AND METHODS

2.1 Study area description

Erbil City is located in Iraq's Kurdistan Region, 380 kilometers north of Baghdad; Erbil Province is the capital of Iraqi Kurdistan, with a population of around two million people, and is located in northeast Iraq. It was located at longitude 43°15′ E to 45°14′ E and latitude 35°27′ N to 37°24′ N (Shalash, 1966). While the average annual rainfall in Erbil City is 440 mm, the climate most closely matches that of Irano-Turanian. The yearly rainfall may also approach 1000 mm. (1950, Zohary). At the moment, groundwater and surface water supply Erbil City. The City of Erbil is served by over 1,000 deep wells, which supply about 40% of the total demand for drinking water. Surface water, however, is Erbil's secondary principal source of drinking water. The only source of surface water in Erbil City for drinking and other uses is the Greater Zap River (Bahdinan River) (Shareef and Muhamad, 2008).

The Greater Zab River flows out of Turkey and is partially controlled by the Bekhme Dam; it is 392 km long from its source to where it joins the Tigris River. The Ifraz 1, Ifraz 2, and Ifraz 3 water treatment plants (WTPs) were built on this river in three distinct locations. These plants are the main sources of drinking water and other necessities in Erbil City (Aziz, 2009). Ifraz 2, built in 1985,provides around 44000 m^3/day, Figure 1 (Toma, 2013). Screening, sedimentation (coagulation and flocculation), filtering, and chlorination are the four primary steps in the Ifraz 2 treatment operations (Shareef and Muhammad, 2008).

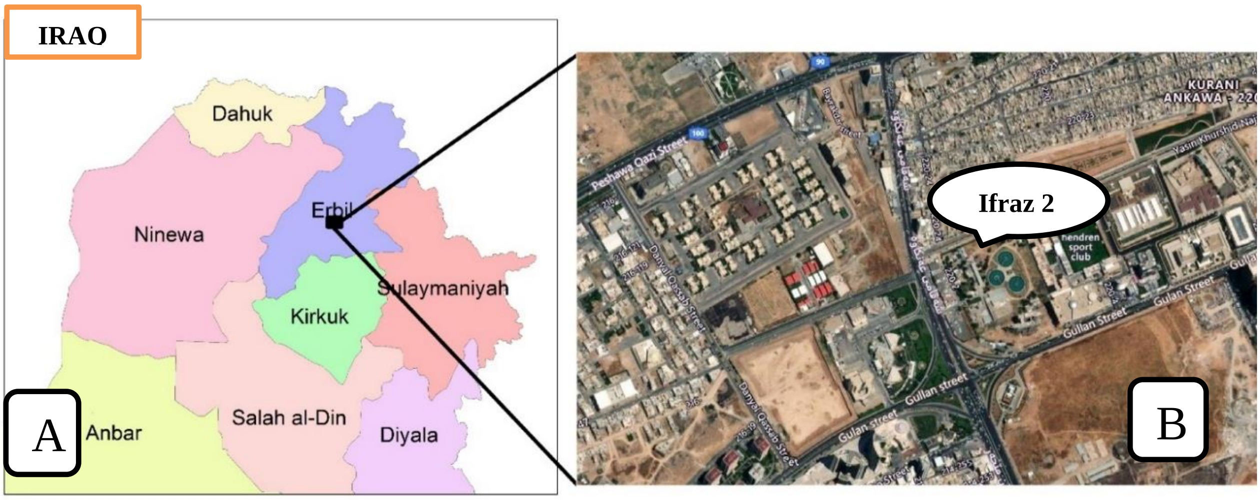

Figure (1): A- Shows the map of Iraq and Erbil City. B- Shows the Ifraz 2 Water Treatment Plant (WTP).

2.2Sample Collection and Analysis

Drinking water from the WTP (Ifraz 2) has historically been continually evaluated every month in the laboratory division of the General Directorate of Water & Sewerage Quality Assurance– Drinking Water Quality Control Department in Erbil during the years 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, and 2021. Additionally, from January 2010 to August 2021, monthly samples of raw water from the Greater Zab River were taken and after analysis by General Directorate of Water & Sewerage Quality Assurance – Drinking Water Quality Control dep. in accordance with the procedures provided in the Standard Method for Examination of Water and Wastewater (APHA, 1998). Turbidity, pH, electrical conductivity, total dissolved solids, alkalinity, total hardness, calcium, magnesium, sodium, potassium, chloride, nitrate, and sulfate were determined and selected as the primary indicators.

2.3 Application of Water Quality Index (WQ1)

Horton created the water quality index (WQI) at the beginning (Horton, 1965). Later, Brown introduced a new modified WQI that was comparable to Horton's index (Brown, 1970). We have employed a weighted mathematical water quality index method to assess whether surface water is fit for human consumption. Numerous scientists frequently employ this technique to evaluate the quality of water (Adimalla and Venkatayogi, 2018; Aly et al., 2015; Toma, 2013). The WQI's computation and formulation comprised the following steps:

1) In the first step, each of the thirteen parameters (turbidity, pH, electrical conductivity, total dissolved solids, alkalinity, total hardness, calcium, magnesium, sodium, potassium, chloride, nitrate, and sulfate) is assigned a weight (wi) depending on its importance to the overall quality of drinking water. Due to its critical role in determining water quality, the parameter nitrate has been given a maximum weight of 5, as indicated in (Table 1). Since alkalinity has no bearing on how well the water is rated, it was given a minimum weight of 1. (Srinivasamoorthy, 2008).

2) In the second step, the relative weight (RW) was calculated using the following equation (Horton, 1965):

$$RW = wi \,/ \textstyle\sum_i^n \mathrm{Wi} \qquad (1)$$

Where n is the number of parameters, wi is the weight assigned to each parameter, and RW is the relative weight. Table 1 also includes the calculated relative weight (RW) values for each parameter.

Table 1: Shows the WHO standard weight (wi) as well as the calculated relative weight (Wi) for each parameter

Parameters	**Unit**	**WHO**	**Weight (wi)**	**Relative Weight (RW)**
Turbidity	NTU	5	3	0.090909
pH		6.5 – 8.5	4	0.121212
EC	µs/ cm	1000	3	0.090909
TDS	mg/ L	500	3	0.090909
Alkalinity	mgCaCO3/ L	200	1	0.030303
Total Hardness	mgCaCO3/L	200	2	0.060606
Calcium	mg/L	100	2	0.060606
Magnesium	mg/L	30	2	0.060606
Sodium	mg/L	200	1	0.030303
Potassium	mg/L	10	1	0.030303
Chloride	mg/L	250	2	0.060606
Nitrate	mg/L	50	5	0.151506
Sulfate	mg/L	250	4	0.121212
Total			**∑wi=33**	**∑Wi= 1**

3) The third step involved assigning a quality rating scale (Qi) for all parameters except pH by dividing their concentration in each water sample by their corresponding standard in accordance with the advice given by (WHO, 2006) and multiplying the result by 100:

$$Qi = \left[\frac{Ci}{Si}\right] \times 100 \qquad (2)$$

The following equation served as the foundation for calculating the pH quality rating (QpH), however

$$Qi\,pH = \left[\frac{Ci-Vi}{Si-Vi}\right] \times\ 100 \qquad (3)$$

Where Qi stands for the quality rating, Ci for the water quality parameter value acquired from the laboratory analysis, Si for the water quality parameter value obtained from the recommended WHO or Iraqi standard for the relevant parameter, and Vi for the ideal value, which is 7.0 for pH.

Equations 2 and 3 guarantee that Qi = 0 when a pollutant is completely absent from the water sample and Qi = 100 when the value of this parameter is just equal to its allowable value. Consequently, the more Qi is present, the more polluted the water is (Mohanty, 2004). Each chemical parameter's SI is first determined before it is used to calculate the WQI in the manner described below:

$$SI\,i = RW \times Qi \qquad (4)$$
$$WQI = \sum SI_I \qquad (5)$$

Table (2): Classification of water quality based on WQI value

Water Quality Index Level	Water Quality Status
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very Poor
>300	Unsuitable

2. 4 Efficiency (E%) Calculation

The efficiency (E%) of the water treatment units situated at tap water was calculated by estimating the WQI of the before and after treated water supplied using the following formula (Alobaidy et al., 2010):

$$E\,\% = \frac{[WQI\ of\ Raw\ water - WQI\ of\ Treated\ water]}{WQI\ of\ Raw\ water} \times 100$$

3. RESULTS and DISCUSSION

3.1 Water Quality Assessment

The descriptive assessment of annual mean values of thirteen physical and chemical parameters adopted in this study, including turbidity, pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, alkalinity, chloride, sodium, potassium, nitrate, sulfate, was carried out on the obtained dataset of drinking water quality from the studied water treatment plant in two stages (raw and treated) of the Greater Zab River analysis by General Directorate of Water &Sewerage Quality Assurance-Drinking Water Quality Control department were listed in (Tables 3, 4).

Turbidity develops naturally in surface water. Particulate substances in the water, such as clay, colloidal particles, and planktons, as well as the presence of other species, are the main causes of turbidity (Katz, 1985). As shown in (Tables 3, 4), turbidity of raw water was variable and ranged between (54.42 –210.4NTU) in 2010 and 2016 respectively. As a result, the raw water recorded values that were greater than the specified range advised by the WHO (> 5 NTU) and implied unsuitable water for direct consumption without pretreatment. After treatment at Ifraz-2, the turbidity of water samples ranged from (1.79 – 4.92 NTU), with the least value being recorded in 2011 and the highest value being reported in 2020. As a result, the treated water showed that all studied turbidity samples during the study periods were found to be below the limits recommended by (WHO, 2004) and safe for drinking. Furthermore, these findings agreed with those of (Toma, 2013; Hassan and Mahmood, 2018; Al-Ridah et al., 2020).

The pH value determines whether a solution or body of water is acidic or basic. pH is an important marker that may be used to evaluate the quality of the water and the level of contamination in water bodies (Ameen, 2019). The Greater-Zab River's pH values ranged from (7.10-7.90), whereas those of Ifraz-2 ranged from (7.35 to 8.12). pH findings (Tables 3, 4) revealed that all values (raw water and treated water) remained within recommended limits throughout the study period (WHO, 2004). According to this result, the water samples were neutral to alkaline (Alsaqqar et al., 2013). The current investigation was similar to studies reported by other such as (Toma, 2013).

Total Dissolved Solids (TDS) is a measurement of the amount of inorganic salts dissolved in water (Ntengwe, 2006, Shekha, 2016). TDS levels were observed for the Greater Zab-River (Tables 3, 4), ranging from 175.95 mg/L in 2010 to 226.83 mg/L in 2012, while values for treated water (Ifraz-2) ranged from 167.57 mg/L in 2021 to 232.09 mg/L in 2012. Total Dissolved Solids values were all within allowable limits for surface water and were deemed safe for drinking (WHO, 2004).

The electrical conductivity (EC) is a measure of ions or salinity that provides an estimate of the presence of specific ions, indicating the existence of high dissolved solids (Kayastha, 2015). The EC values ranged between (353.1 - 453.65 µS/cm) in (raw water) and (326.72 - 464.18 µS/cm) in (treated water) at Ifraz-2 (Tables 3, 4). The results revealed that the EC values of all water samples were within the WHO guideline value (1000 µS/cm), but exceeding these limits causes water to be corrosive (Tadesse et al., 2018). High EC values can occur as a result of human activities or soil surface runoff, which causes an increase in the dissolved salts in river water (Tyagi et al., 2013).

Total hardness is one of the measures that is commonly used to monitor water quality in various water systems across the world (WHO, 1996). Water with a high mineral content produced by total hardness won't be harmful to people's health (Ewaid et al., 2017). As shown in Tables (3, 4), the results of Total Hardness of most of the study periods revealed higher concentrations than the permissible limits recommended by WHO (200 mg $CaCO_3$/L), except for values 199.94, 199.55, and 190.11, recorded in 2010, 2014, and 2015 respectively in the (raw water) Greater-Zab River and values 120.66, 192.68, and 197.82, recorded in 2010, 2014, and 2015 respectively for (treated water) at Ifraz-2. As a result, Total hardness recorded high levels, ranging from hard to very hard water, as was mentioned in (Tables 3, 4). This could be due to the addition of calcium and magnesium salts, or it could be due to the source, geographical and soil properties of the collected area, various human activities, and climate conditions, all of which affect the hardness value in any water source (Cole, 1983).

Calcium and magnesium ions are present in all natural waters and are often cited as the causes of hardness (Bartram and Balance, 1996). Because of their direct association with the development of water hardness, calcium and magnesium are also significant factors for evaluating water quality. The types of rocks determine the quantities of these two elements in natural water. In low concentration, they are both necessary for maintaining human health. (Ameen, 2019). Generally, Ca^{+2} levels dominate over levels of Mg^{+2} in natural water systems (Hutchinson, 1957). The calcium and magnesium ion levels of both (raw and treated water) were shown in Tables (3, 4). The levels of calcium ions in raw water ranged from 46.33–66.71 mg/L and those in treated water ranged from (24.29–78.29 mg/L), respectively, while the levels of magnesium ions in raw water ranged from (11.83–38.51 mg/L) and those in treated water ranged from (10.84-27.95 mg/L). According to (WHO, 2004), the maximum permissible calcium level is 200 mg/L, and the maximum permissible magnesium level is 30 mg/L. As a result, in the current study, water samples from all studied years (raw water & treated water) fall within these limitations and are thus considered to be of good quality, with the exception of the high levels of magnesium observed in Greater Zab-River in 2019 as (38.5 mg/L) and in 2020 as (34.3 mg/L). This could be attributed to Erbil City's geological formation, which is primarily composed of limestone, and the solubility of calcite rock, which is prevalent in the research area and dissolves faster than dolomite (Chauhan and Singh, 2010).

Water's ability to neutralize acids is determined by its alkalinity. Sawyer and

McCarthy (1978) describe the bicarbonates as the major forms of alkalinity. As shown in Tables (3, 4), the mean values of alkalinity fluctuated from 149.49 – 390.6 mg $CaCO_3$/L of the Greater Zab River (raw water) and from 150.53 – 203.03 mg $CaCO_3$/L of treated water (Ifraz-2), respectively. The alkalinity results of both studied sites (raw and treated) revealed that all water samples were found to be below the permissible levels of 200 mg $CaCO_3$/L, with the exception of the values recorded higher values of 390.6 mg $CaCO_3$/L for raw water in 2019 and 203.03 mg $CaCO_3$/L in 2010 for treated water exceeding the permissible range (WHO, 2004). High alkalinity values indicate a high concentration of carbonate and bicarbonate ions as well as a direct relationship between EC and alkalinity. However, the alkalinity of surface water was reported to be related to the geology of the area by Thomaz et al. (1992).

Chloride is abundant in nature, mostly in the form of (NaCl), (KCL), and ($CaCl_2$) salts. It makes up around 0.05% of the lithosphere (Benain et al., 1993). The chloride concentrations of studied samples (Tables 3, 4) ranged from (7.04–13.5 mg/L) for raw water and from (6.90–109.16 mg/L) for treated water. The current study found no higher chloride concentrations than the WHO (2004) permissible limits (250 mg/L), indicating that they were still safe and suitable for drinking.

Sodium salts are highly soluble in water. Their ratio is generally 200 mg/L, whereas according to USEPA (2004), the health-based value is 20 mg/L. According to this ratio, the concentration for drinking purposes is Furthermore, the potassium cation is not abundant in water, and the ratio of K^{+2} to Na^{+2} is frequently 1:10 or 1:20 (Khopkar, 2004). For raw water from the Greater Zab River and Ifraz 2 (WTP), respectively, the mean concentrations of Na^{+2} in the current investigation ranged from 5.42 to 13.64 and 5.47 to 15.62 mg/L. In contrast, the levels of K^{+2} at the two study locations ranged from 0.89 to 8.25 mg/L and 0.87 to 5.48 mg/L, respectively. The concentrations of sodium and potassium were also found to be safe for locals to drink, falling within WHO guidelines of 200 mg/L for sodium and 10 mg/L for potassium.

The WHO limits the amount of nitrate in drinking water at 50 mg/L. (WHO, 2004). The findings showed that the Greater Zab River's nitrate concentrations ranged from 5.90 to 12.19 mg/L whereas those in Ifraz-2 (WTP) ranged from 3.86 to 9.71 mg/L. The current investigation's observed values, regardless of nitrate concentrations, indicated that the mean values of all study periods were within the WHO standard and safe for drinking use.

Although sulfate is one of the least toxic anions in water, high levels of sulfate may contribute to an unpleasant taste in water (APHA, 2005). During the study periods (Tables 3, 4), the low concentration of sulfate was 36.05 and 38.85 mg/L for raw water from the Greater Zab River and Ifraz-2, respectively, while the high concentration of sulfate was 93.035 and 90.92 mg/L for raw water from the Greater Zab River and Ifraz-2, respectively. Sulfate concentration was within the allowable limits (250 m/L) and thus safe for human consumption, according to WHO.

3.2 Water Quality Index (WQI)

The water quality index was calculated in this study to assess the overall quality status and suitability of drinking water in Erbil City, Kurdistan Region of Iraq. The physico-chemical parameters (turbidity, pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, alkalinity, chloride, sodium, potassium, nitrate, and sulfate) were monitored for the calculation of WQI from 2010 to 2021 by using the assigned weighted arithmetic index WQI method. Table 5 shows the WQIs calculated during the study period for the two studied stations (raw and treated).

The calculated WQI for raw water (Greater Zab River) ranged from (140.532) in 2010 to (422.455) in 2016, while the calculated WQI for treated water plant (Ifraz-2) ranged from (44.197) in 2010 to (69.118) in 2018. Based on these WQI values (Table 5), Greater Zab River water was classified as "Poor," "Very Poor," and "Unsuitable" for drinking purposes during the study period (2010-2021). The Greater-Zab River's poor or very poor or unsuitable water quality could be attributed to an untreated household pollutant disposal site, which discharged directly into the river via wastewater streams and effluent (Reza and Sing, 2010; Bapeer et al., 2006; Shareef and Muhamad, 2008). Furthermore, the high WQI value obtained as a result of the high concentrations of turbidity, total hardness, alkalinity, and magnesium can be attributed to the various human activities occurring on the river bank (Al Saqqar et al., 2013). Turbidity varies with land use and river hydrology, and runoff from surrounding areas reveals higher levels of turbidity in river water. The turbidity of river water will increase as surface runoff increases (Huey and Meyer, 2010). However, the region's recent dryness may be to blame for the clearly visible decline in WQI, particularly in the upstream station where there is not a significant interaction between the effects of dryness and those of human activity (Khudair, 2013; Nanakely et al., 2016). As a result, regardless of the water of the Greater Zab River during the studied periods, all WQI values indicate polluted waters and are unacceptable for potable purposes, implying unsuitable water for drinking purposes without pretreatment, including the filtration process.

The results of computed WQI for treated water plant (Ifraz-2) as shown in (Table 5) were classified as "Excellent" and "Good but (not excellent)" during all studied periods. The "Good" classification was observed especially in the years 2012, 2014, 2015, 2018, 2020, and 2021. This could be due to insufficient treatment systems, inadequate water quality monitoring, and contamination at various interconnections (WHO, 2011). However, it should be noted that the turbidity is the most crucial factor in determining the WQI rating. Exceeding drinking water standards may be caused by insufficient filtration during water treatment (Nduka et al., 2008) or by the mobilization of sediments, mineral precipitates, or biomass within the water supply network (UNICEF, 2008). The water registered a "good" quality, which implied simple treatment is necessary, even adequate filtration of the water before human consumption, regardless of the good quality. Additionally, the treated water was rated "Excellent" primarily because of its low chemical parameter values, which reduced its overall impact on the quality of the drinking water (Akter et al., 2016). Based on WQI, it is clear that the water treatment plant (Ifeaz-2) in the current study area was of acceptable quality and fit for human consumption.

3.3 Water Treatment Plant Efficiency

The WQI of the supplied raw water and treated (Ifraz 2) water was calculated using the following formula to determine the Efficiency (E%) of the water treatment plants located at the Greater Zab River:

$$E\ \% = \frac{[WQI\ of\ Raw\ water - WQI\ of\ Treated\ water]}{WQI\ of\ Raw\ water} \times 100$$

Table 6 shows the efficiency of Erbil City's water treatment plant. According to Tables (5, 6), the (raw water) quality was poor, very poor, and unsuitable throughout the entire study period, as the efficiency of WTP (Ifraz-2) ranged from (61.75 to 89.49) during the entire study period. This means that the efficiency of WTP (Ifraz-2) in Erbil City was recorded more efficient "very good" in 2016 (89.49) as compared to other years, while it was recorded less efficient "good" (61.75) in 2018. This variation may result from the type of water source, the treatment plant's layout, and the local runoff conditions (Ezzat, 2018). Furthermore, the quality of treated water decreased along the river due to poor raw water quality and low water efficiency (E%) at the treatment plant (Al-Ridah et al., 2020). Strict measures should be implemented to control the levels of pollutants discharged into the greater Zab River from various types of point and nonpoint sources (Alobaidy et al., 2010), and much more attention should be paid to these parameters in the context of not meeting the permissible drinking water limits.

4. CONCLUSIONS

It can be concluded from the current study that WQI showed that the quality of the raw water (Greater Zab River) is generally "poor," "very poor," and "unsuitable". Additionally, the water quality index (WQI) of the treated water (WTP

Ifraz-2) revealed that the drinking water quality is generally "Good" or "Excellent" in some years. The results of the efficiency (E%) of (WTP Ifraz-2) ranged from 61.75 to 89.49 in the whole period of study in Erbil City. This indicated that the WTP Ifraz-2 was more efficient and "Very Good" in the year 2016 as compared to other years and suitable for drinking purposes. The performance of WTPs in the studied area must be improved.

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CONFLICT OF INTEREST

There are no conflicts of interest declared by the author.

Table 3: Mean physicochemical properties of water samples collected from the Greater-Zab River (raw water) and the Ifraz-2 water treatment plant (treated water) during the study period (2010-2015).

Year / Parameter	Units	Water sample	2010	2011	2012	2013	2014	2015	WHO
Turbidity	NTU	**Raw**	54.4	92.2	154.7	139.8	123.3	204.4	**5**
		Treated	2.4	1.7	2.5	2.4	4.4	3.0	
pH	-	**Raw**	7.6	7.4	7.5	7.6	7.7	7.9	**6.5-8.5**
		Treated	7.5	7.5	7.5	7.5	7.8	7.9	
TDS	µS/cm	**Raw**	175.95	203.08	226.83	187.7	190.08	200.36	**1000**
		Treated	205.62	221.06	232.09	177.77	188.04	207.63	
EC	mg/L	**Raw**	388.91	401.47	453.65	375.41	380.16	400.72	**500**
		Treated	411.23	442.11	464.18	355.55	376.08	415.21	
T. Hardness	mg/L	**Raw**	199.94	**204.56**	**209.51**	**216.86**	199.59	190.11	**200**
		Treated	120.66	**229.74**	**213.18**	**215.43**	192.68	197.82	
Calcium	mgCaCO$_3$/L	**Raw**	59.18	48.00	62.17	64.03	60.11	47.16	**100**
		Treated	24.97	54.50	62.48	63.62	59.00	49.37	
Magnesium	mgCaCO$_3$/L	**Raw**	12.47	20.29	12.97	13.36	11.83	17.32	**30**
		Treated	15.30	22.43	13.67	13.79	10.84	17.85	
Alkalinity	mgCaCO$_3$/L	**Raw**	161.47	162.97	154.49	169.34	149.49	185.5	**200**
		Treated	**203.03**	171.03	150.53	160.99	158.4	191.21	
Chloride	mg/L	**Raw**	11.81	7.048	11.06	7.79	8.70	12.94	**250**
		Treated	109.16	8.20	8.96	7.94	6.90	14.78	
Sodium	mg/L	**Raw**	8.85	6.02	7.06	6.29	10.32	11.61	**200**
		Treated	5.47	5.68	6.33	6.62	9.67	7.00	
Potassium	mg/L	**Raw**	0.8938	1.0722	1.2379	1.8686	8.25	1.83	**10**
		Treated	1.10	0.91	0.87	1.20	1.34	5.48	
Nitrate	mg/L	**Raw**	6.53	12.19	11.14	8.97	5.90	6.44	**50**
		Treated	3.86	6.09	9.71	7.9	4.45	4.72	
Sulfate	mg/L	**Raw**	57.04	53.787	93.03	63.62	64.65	50.58	**250**
		Treated	58.93	55.52	90.92	51.81	38.85	39.04	

Table 4: Mean physicochemical properties of water samples collected from the Greater-Zab River (raw water) and the Ifraz-2 water treatment plant (treated water) during the study period (2016-2021). (Continued)

Year / Parameter	Units	Water sample	2016	2017	2018	2019	2020	2021	WHO
Turbidity	NTU	**Raw**	210.4	63.3	78.2	82.1	71.6	113.2	**5**

		Treated	3.3	2.6	3.3	4.1	4.9	3.9	
pH	-	**Raw**	7.4	7.4	7.3	7.1	7.2	7.5	**6.5-8.5**
		Treated	7.4	7.4	8.1	7.3	7.4	7.6	
TDS	µS/cm	**Raw**	204.10	203.15	201.21	176.55	222.36	196.91	**1000**
		Treated	203.58	204.71	211.08	192.74	199.29	167.57	
EC	mg/L	**Raw**	408.2	410.79	402.42	353.1	437.57	393.82	**500**
		Treated	407.16	409.43	422.17	385.49	413.86	326.72	
T. Hardness	mg/L	**Raw**	**228.20**	**259.54**	**217.42**	**303.85**	**307.86**	**241.03**	**200**
		Treated	**221.39**	**308.30**	**313.56**	**269.24**	**283.36**	**248.17**	
Calcium	mgCaCO$_3$/L	**Raw**	56.85	64.79	46.33	57.35	66.71	60.14	**100**
		Treated	55.55	77.20	78.29	67.13	70.57	62.02	
Magnesium	mgCaCO$_3$/L	**Raw**	20.65	23.41	24.38	**38.51**	**34.34**	21.91	**30**
		Treated	20.11	27.67	27.95	25.34	26.73	23.27	
Alkalinity	mgCaCO$_3$/L	**Raw**	176.70	177.75	167.54	**390.6**	193.36	197.28	**200**
		Treated	170.28	181.36	193.83	192.26	187.43	182	
Chloride	mg/L	**Raw**	13.5	11.41	9.83	10.55	11.57	10.06	**250**
		Treated	13.31	13.59	16.35	13.59	13.42	10.48	
Sodium	mg/L	**Raw**	6.72	5.42	6.08	9.4	13.64	10.31	**200**
		Treated	6.41	6.19	8.00	15.62	11.07	10.33	
Potassium	mg/L	**Raw**	1.01	1.08	1.25	1.12	1.32	1.06	**10**
		Treated	0.89	0.91	1.07	1.27	1.07	1.06	
Nitrate	mg/L	**Raw**	7.41	6.57	7.97	6.07	8.19	6.64	**50**
		Treated	5.18	4.52	7.86	5.65	5.5	5.05	
Sulfate	mg/L	**Raw**	50.5	59.39	45.83	36.05	47.929	56.694	**250**
		Treated	41.79	45.36	39.81	44.81	57.57	47.36	

Table 5: Shows the Water Quality Index (WQI) for the Greater Zab River and the Water Treatment Plant Ifraz-2.

Year **Water sample**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Greater-Zab River (Raw)	**140.532** Poor	**208.438** V. poor	**326.522** Unsuitable	**300.187** Unsuitable	**272.425** V. poor	**421.537** Unsuitable	**422.455** Unsuitable	**157.576** Poor	**180.710** Poor	**190.830** Poor	**174.307** Poor	**250.401** V. poor
WTP Ifraz -2 (Treated)	**44.197** Excellent	**47.706** Excellent	**50.116** Good	**46.503** Excellent	**53.256** Good	**56.932** Good	**44.377** Excellent	**49.320** Excellent	**69.118** Good	**48.173** Excellent	**53.277** Good	**51.554** Good

Table 6: Efficiency of the Water Treatment Plant (WTP) of Ifraz-2

Year **WTP**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
WTP Ifraz -2	68.55	77.11	84.65	84.50	80.45	86.49	**89.49**	68.70	61.75	74.75	69.43	79.41

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