Bacteriological and Physico-chemical Qualities of Halabja Drinking Water

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Abstract

Water is crucial for all known forms of life without providing any calories or organic nutrients, while many people, especially in developing countries, may not be able to access pure and safe drinking water. They could lose their lives or become sick because waterborne diseases could contaminate the water, and when the chemical and/or physical properties of the water are not within the national and international standards. Thus, the present study aimed to evaluate water quality of the Halabja drinking water and Sirwan river. Halabja city is located to north of Iraq, north-east of the capital Baghdad. Every week of the year 2019, apart from official holidays, water samples were collected from each of river and several areas (4-10 sections) in Halabja for the bacteriological analysis, while chemical and physical water quality was monthly checked. The results showed no detectable waterborne pathogens in all drinking water samples. Additionally, values of pH, turbidity, total dissolved substances, and electrical conductivity of the purified water samples had ranges of 7.97–8.5, 0.02-0.8 NTU, 246–362 mg/L, and 383–566 μS/cm, respectively. The treated drinking water was free of Free Residual Chlorine (FRC) and nitrite. The amounts of chloride, sulfate, and nitrate varied during the year 2019, with ranges of 48.2- 73.8, 36-141.5, and 1-5 mg/L, respectively. The values of water hardness and Ca^{+2} and Mg^{+2} concentrations ranged 132- 344, 48–89.5, and 2.2-29.2 mg/L, respectively. Based on the results, values of all the above parameters were within the Iraqi and the World Health Organization (WHO) drinking water standards, although the value of water hardness and the concentration of Ca^{+2} were near the upper limits of the standards, which might cause harm to the human body.

Keywords: waterborne disease, microbial indicator, physico-chemical properties, drinking water quality, coliform bacteria, gastroenteritis

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الصفات البكتريولوجية والفيزيائية و الكيميائية لمحطة معالجة مياه الحلبجة

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الخلاصه

الماء ضروري لجميع أشكال الحياة المعروفة دون توفير أي سعرات حرارية أو مغذيات عضوية . في حين أن الكثير من الناس، وخاصة في البلدان النامية، لا يستطيعون الوصول إلى مياه الشرب النقية او الآمنة. وقد يفقدون حياتهم أو يمرضون لأن المياه قد تكون ملوثة بأمراض تنقلها المياه، ولأن الخصائص الكيميائية و الفيزيائية للمياه ليست ضمن المعايير الوطنية والدولية. وبالتالي ، هدفت الدراسة الحالية الى تقييم هذه الخصائص فى محطة معالجة مياه حلبجة ومياه نهر سيروان. في كل أسبوع من عام ٢٠١٩، ماعدا

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العطلة الرسمية، تم جمع عينات المياه من ٤-١٠ اقسام من مدينة حلبجة للتحليل البكتريولوجي، بينما تم فحص جودة المياه الكيميائية والفيزيائية شهريًا. أظهرت النتائج عدم وجود مسببات الأمراض المنقولة بالماء في جميع عينات مياه الشرب. بالإضافة إلى ذلك، تراوحت قيم الأس الهيدروجيني العكورة وإجمالي المواد الذائبة والتوصيل الكهربائي لعينات المياه النقية بين ٧.٩٧-٨.٥، ٠.٠٢-٠.٨، ٢٤٦-٣٦٢ ملغم / لتر و ٣٨٣-٥٦٦ مايكروسيمنز ١ / سم على التوالي. كانت مياه الشرب المعالجة خالية من كل من الكلور الحر المتبقي والنتريت. اختلفت كمية الكلوريد والكبريتات والنترات خلال عام ٢٠١٩ من ٤٨.٢ من ٤٨.٢- ٧٣.٨ ملغم /لتر، ٣٦-١٤١.٥ ملغم /لتر و ١-٥ ملغم /لتر على التوالي. اختلفت كمية تراوح تركيز عسر الماء، كالسيوم، مغنيسيوم ١٣٢-٣٤٤ ملغم /لتر، ٤٨-٨٩-٥ ملجم /لتر و ٢.٢ و ٢.٢-٢٩.٢ ملجم /لتر على التوالي. بناءً على النتائج، كانت جميع المعايير المذكورة أعلاه ضمن معايير مياه الشرب العراقية ومنظمة الصحة العالمية.على الرغم من أن تركيز عسرة الماء و الكالسيوم كانا قرب الحدود العليا للمعايير والتي من المحتمل أن يكون لها تأثير ضار على جسم الإنسان

Introduction

Water is an inorganic chemical substance that is essential for all known living organisms. Drinking water can compensate for any water loss and regulate all metabolic processes within the human body. Safe and pure drinking water is required for human health worldwide. Based on the United Nations International Children's Emergency Fund (UNICEF) (2004), safe drinking water has to be accessible to all people, while approximately 30% of the world population have safe drinking water [1, 2]. Many human diseases, such as diarrhoea and skin diseases, are water-related [3]. The high ratio of diarrhoea in developing countries is linked to unsafe water and poor hygiene. Waterborne diseases are caused by microscopic organisms, including viruses, parasites, and bacteria, that are ingested through water contaminated with human or animal faces or urine. A number of the most common waterborne diseases are diarrhoea, cholera, cryptosporidiosis, viral gastroenteritis, amebiasis, hepatitis, malarial fever, and typhoid fever [4]. Furthermore, water may contain an excessive amount of organic or inorganic materials that might have a detrimental effect on human and animal health.

The contamination of drinking water in urban water distribution systems is still continuously happening. Water is usually contaminated due to different causes, such as improper sanitation process, leakage of sewage water, and commercial, industrial, agricultural, and other human activities which affect water distribution networks [5]. Additionally, leakage and improper maintenance of drinking water distribution and chlorination systems can influence the quality of potable water. Supplied water could also be contaminated through the distribution pipes because of leakage [6]. These factors can pose remarkable challenges to the efforts of city authorities or governments to protect the water system from sources of microbiological and chemical contaminants. Within the developing world, particularly in rural and industrial areas, over three million people, predominantly among newborns and youngsters in poor communities, die per annum due to waterborne diarrheal diseases [7, 8]. In addition, it is estimated that water, poor sanitation, low-level hygiene education, poor supervision, and improper disinfection cause 4% of deaths and 5.7 % of the entire diseases occurring in the world [9]. Therefore, continuous analysis of water quality is required.

Different parts of the world, especially developed countries, perform regular assessment of drinking water quality. Many research studies have been performed to examine water quality worldwide [10, 11]. In Iraq, some studies were conducted to assess drinking water quality and any possibility of human health problems resulting from the consumption of unsafe water, especially in large cities like Baghdad where access to safe water may be a big challenge [12-14]. Similarly, in several other cities in Iraq, the quality of drinking water may not be regularly assessed. So far, there is no sufficient number of studies published on the physico-chemical and bacteriological quality of the water consumed by the population of Halabja, north Iraq. For this reason, it is important to test the water quality of both Sirwan River and

Halabja drinking water to determine their qualities in relation to both Iraqi and WHO standards.

Microbiological and physico-chemical parameters, including water content of fecal and total coliform bacteria, *Escherichia coli* (*E. coli*), nitrate, water turbidity, and others are normally accepted as critical drinking water quality parameters [1, 15]. The presence of *E. coli* and coliform bacteria in the water is assumed to be a definitive indicator of fecal pollution because these microorganisms are naturally occurring within the intestinal tract of humans and animals [16].

During this research article, the bacteriological, physical, and chemical parameters were used for the analysis of water quality of Sirwan River and/ or Halabja drinking water. These drinking water characteristics provide information on the quality of water consumed by the people living in the city of Halabja. These data might motivate other researchers to conduct more research on all sources of drinking water for Halabja and its surrounding rural area.

Materials and Methods
Study Area

The study was performed on the Halabja drinking water and Sirwan river water, located in Halabja city, Kurdistan region of Iraq. It is located 240 km north-east of the capital Baghdad and 14 km from the Iranian border. Geographically, the city is located between 35°11′11″N latitudes, 45°58′26″E longitude, and 900 m elevation above sea level. The population of the city is estimated to be 247,000. They fundamentally depend upon three sources of drinking water, which are Halabja drinking water, Water fall Ahmad Awa, and wells. Halabja drinking water provides approximately 75% of drinking water for the Halabja province. The water source of the Halabja drinking water is Sirwan River. This river is located in the south-west of Halabja city, 12 km from the city center (Figure **1**). Approximately 25,000 m^3/day of Sirwan river water are currently purified.

Figure 1-Map of the study sites, Halabja city, 2019. Samples were collected from both Halabja Drinking Water project and Halabja city cites.

Sample Collection

For bacteriological analysis, 248 purified water samples from drinking water of Halabja were collected almost every week from January to December 2019; sample collection was not performed in one week in each of July, August, and October, and in several weeks in March. In each week, treated water samples were analyzed from several area (4-10 sections) in Halabja. These parts of Halabja city were randomly chosen. For the next week, the samples were taken from some of these parts or from totally different parts of the city. Regarding the

physico-chemical analysis, water samples from both Halabja drinking water and Sirwan River were monthly collected, from January to December 2019. Analyzed water samples were compared to the Iraqi and WHO drinking water standards [1, 17]. A volume of 100-200ml of water was collected from each source. They were labelled and kept in an icebox during transportation and analysis. In the end, the samples were analyzed to determine the degree of contamination.

Bacteriological Analysis

This parameter is measured by the occurrence of a specific group of coliform bacterial indicators of water pollution. Fecal contamination is determined by the most important bacterial indicator *E. coli* [18]. The multi-tube method, or the Most Probable Number (MPN), was selected for the isolation, enumeration, and identification of coliform bacteria. MacConkey broth medium was used to culture bacteria. The cultures were incubated at 37°C for 24-48h. The number of tubes at each concentration of the inoculated samples showing acid and gas production was recorded. McCrady's probability tables were employed to determine the MPN of coliform bacteria in the samples of 100ml water from Halabja drinking water.

Physico-chemical Analysis

   Physico-chemical parameters were also analyzed following standard procedures [1]. Physico-chemical tests included the determination of turbidity using Eutech turbidity meter, pH using pH meter (Fisher Scientific XL 150), and conductivity using EC meter (Inolab-cond7110). The remaining water quality parameters, including the contents of total dissolved solids, chloride, FRC, calcium, magnesium, sulfate, nitrite, and nitrate, as well as total hardness, were determined following standard methods using an Orion aquamate 8000 spectrophotometer (Thermo Fisher).

Results and Discussion

   To examine the quality of water from Halabja water treatment pant and Sirwan River, some physico-chemical properties were examined. Along with these parameters, the microbial contamination including coliform bacteria and fecal *E. coli* were tested as they are important indicators of water quality [1]. Iraqi and WHO standards of these parameters are listed in **Table 1**.

Table 1-Iraqi and WHO drinking water standards of bacteriological and physico-chemical parameters.

Characteristic	Iraqi standards [17], Maximum Allowable Limit	WHO standards [1]
Natural Characteristics		
pH value	6.5-8.5	6.5-8.5
Turbidity, nephelometric turbidity units (NTU)	5	5
Condu tivity μS/cm	-	1500
Chemical Characteristics (mg/L)		
Total hardness (T.H)	500	500
Magnesium (Mg^{+2})	100	30
Calcium (Ca^{+2})	100	100
Nitrate (NO_3^{-1})	50	50
Nitrite (NO_2^{-1})	3	3
Sulfates (SO_4^{-2})	400	250
Chloride (Cl^-)	3 0	250
Total dissolved solids (TDS)	1000	600
FRC (Cl)	-	0.3-5
Biological Characteristics, Colony Forming Unit (CFU)		
Coliform bacteria	<1.1	0
E. coli	<1.1	0

Bacteriological Load of Drinking Water Source

A large area of the earth's surface is covered by surface water. The predominant water surfaces in rural areas of developing countries are rivers, pans, springs, and dams [19]. Open exposure of those water sources renders them vulnerable to contaminants that come from the environment [20]. The population of Halabja city, which mainly uses river water for drinking and food processing, might therefore be exposed to health risks, possibly arisen from contamination with coliform and *E. coli* bacteria. The presence of these microorganisms indicates that water could be contaminated by fecal matter and/ or other microbial pathogens. In this case, this water is not safe for drinking [21].

The microbial quality of drinking water can be monitored by investigating the coliform bacteria [20]. To decrease human health risks resulting from the consumption of contaminated water, suitable treatment processes need to be performed for the disinfection of water to become safe for drinking and usable in food processing [22]. The number of coliforms and *E. coli* should not exceed zero CFU per milliliter as a recommended standard [1]. It is recognized that the majority of the sporadic cases of intestinal illness might not be investigated or even detected, but they are recognized as being probably water-related. Several researchers have attempted to find diseases associated with waterborne microbes. It was found that these microbes might account for 33% of intestinal infections worldwide [8]. Thus, treatment of river water by utilizing disinfection substances is required.

In the current study, bacteriological analysis of water samples showed that all the tested samples had no indication of bacterial contamination (Table 2). All of the water samples were found to be negative or free-from coliform bacteria and *E. coli*. Hence, in all cases, bacterial counts were within the recommended levels set by the WHO [1]. This means that the quality of the water in Halabja drinking water was high, with no indication of fecal or other water contaminants. These data excluded any possibility of water contaminations that might come from the purification station until reaching the city center, main tanks, distribution pipes, and unhygienic handling of the water after chlorination. In addition, there was no evidence of an inadequate sewerage system along the treated water supply chain, nor leakages that could contaminate the water with bacteria.

The absence of coliform pathogens is due to applying liquefied chlorine gas to Sirwan river water in the treatment plant to disinfect and kill any microbial organism. FRC can protect the water against reinfection from the point of chlorination to the point of use. FRC levels in the chlorinated Sirwan river water was in the range of 0.4-0.94ml/L over the year 2019. This was less than the recommended level for piped water. Generally, the results suggest that the possibility of infection by microbes that cause severe diseases to humans, such as gastroenteritis, typhoid fever, hepatitis, and dysentery, might be low [23].

Table 2-Bacteriological parameters of Halabja drinking water. The samples were weekly collected in year 2019. However, the samples were not collected in one week during July, August and October, and several weeks in March.

Month	Weeks in a month	Number of replicates*	Coliform bacteria CFU/100ml	*E. coli* CFU/100ml
January	1	6	0	0
	2	6	0	0
	3	5	0	0
	4	6	0	0
February	1	3	0	0
	2	4	0	0
	3	4	0	0
	4	5	0	0
March	1	4	0	0
	4	5	0	0

Month				
April	1	4	0	0
	2	4	0	0
	3	7	0	0
	4	6	0	0
May	1	10	0	0
	2	5	0	0
	3	10	0	0
	4	10	0	0
June	1	10	0	0
	2	5	0	0
	3	4	0	0
	4	5	0	0
July	1	4	0	0
	3	8	0	0
	4	6	0	0
August	1	7	0	0
	3	5	0	0
	4	7	0	0
September	1	6	0	0
	2	7	0	0
	3	5	0	0
	4	7	0	0
October	1	8	0	0
	2	5	0	0
	3	5	0	0
November	1	5	0	0
	2	5	0	0
	3	5	0	0
	4	4	0	0
December	1	4	0	0
	2	5	0	0
	3	6	0	0
	4	6	0	0

* These parameters were weekly analysed. In each week, 4 to 10 replicates of water samples were collected for analysis from several areas (4-10 sections) in Halabja.   .

Physical-chemical Analyses

The results of the physical-chemical analyses of water from both the raw pre-treated Sirwan water and Halabja drinking water are presented in Figures 2 and 3. The monthly values of these parameters over the entire year of 2019 are presented. .

One of the essential parameters that is often employed to test water quality is pH. It affects both the physical and chemical properties of water. The pH value of water samples was within the range of 8.11–8.5 in the raw water and 7.97-8.5 in the treated water (Figure 2). This value is near to neutrality, and within the Iraqi and WHO recommended standard of 6.5–8.5 [1]. pH differences are probably due to geological conditions of types of water.

The turbidity of water was also assessed as one of the measurements of the quality of water. The desirable level of water turbidity is up to 5 NUT, s recommended by the WHO [1]. Turbidity values higher than 5 NUT might correlate with increasing pathogenic microorganisms, including coliform bacteria [24]. There was an enormous difference in turbidity of water within the untreated river water over the year 2019, ranging from 3.3 NTU in June to 57 NTU in September. However, the turbidity of the treated water was dramatically decreased to 0.02 NTU in October and November, but increased to 0.8 in April (Table 1). The turbidity value in the present study was found to be below the standards [1].

Electrical conductivity in aquatic environments is taken into account to be a crucial indicator of total dissolved solid substances to test the purity of water [25]. This parameter

essentially examines a number of dissolved salts, including potassium chloride and sodium chloride. Over the year 2019, the electrical conductivity in both types of water increased from 383μs in July to the highest level of 566μs in December. Although there was a variation in this parameter over the year, which could be due to agricultural activities, geological factors, and environmental factors, this value was also within the Iraqi and WHO standards [1, 17, 26].

Total dissolved solids measurement did not show dramatic differences in the Sirwan river and treated water samples. This might relate to the absence of any factor that would participate to make differences in this parameter in both types of water. Values of total dissolved solids were between 246 mg/L in late spring and at the beginning of summer to 362 mg/L at the beginning of winter. These values are below the maximum acceptable standard of 600 mg/L [1]. It is generally accepted that the flavor of drinking water is good when it contains 600 mg/L dissolved solids or lower. By increasing the solids to a level of 600 mg/L or higher, the water will not be suitable for drinking.
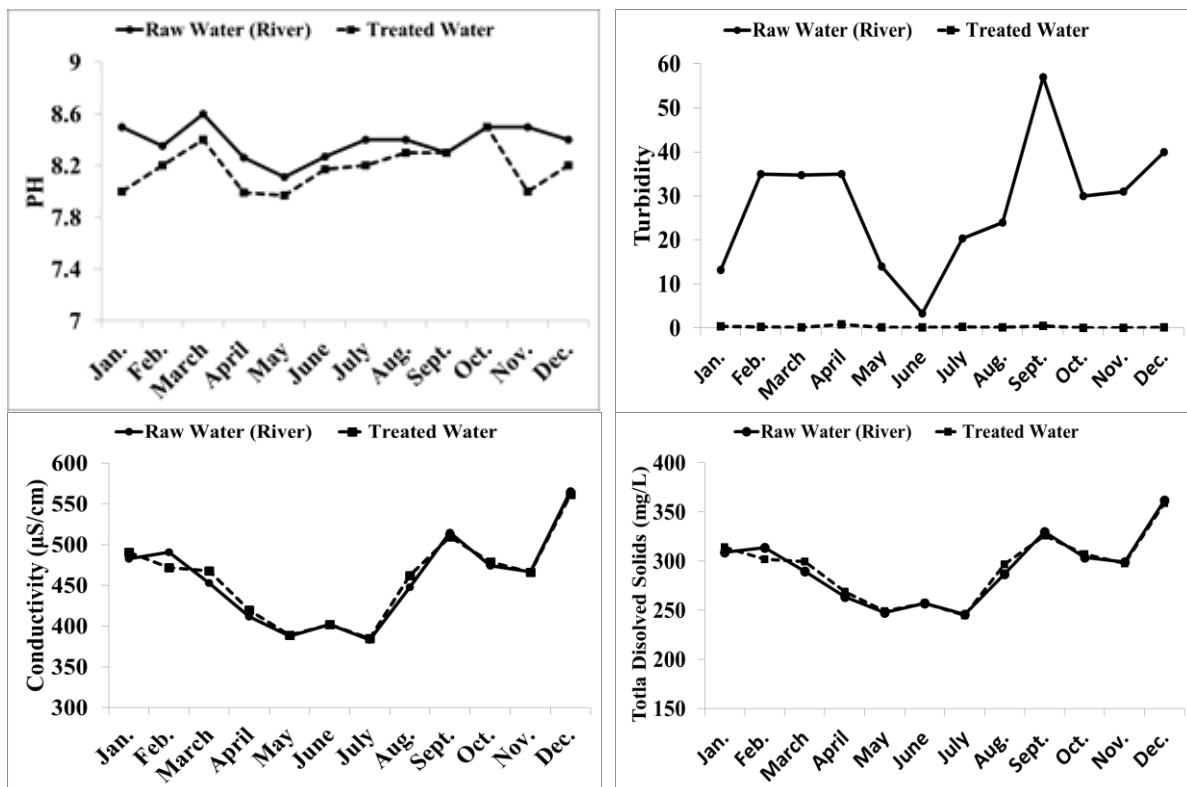

Figure 2- Distribution of the PH, Turbidity, Conductivity and Total Dissolved Solids values of physico-chemical parameters within the drinking water of Halabja and raw Sirwan river water over the entire year of 2019.

FRC levels of water samples from Sirwan river water and the treated water were 0.0 mg/L and 0.4 to 0.94, respectively (Figure 3). The quantity of this substance was lower than the maximum concentration determined by the WHO. Surface water bodies generally have a low concentration of chlorides compared to groundwater. This compound has an important role in metabolic and physiological processes within the human body. An excessive amount of chloride can damage metallic pipes and structures. According to WHO standards, the amount of chloride has to be less than 250 mg/l [1]. The concentration of chloride within Sirwan river was 31.2 to 65.3 mg/L and in the treated water was 48.2 to 73.8 mg/L. These values are permitted by both the Iraqi and WHO drinking water standards.

Hard water is a type of water that contains high minerals that are usually not detrimental to the human body. This water hardness is usually associated with the presenting of both

calcium and magnesium metal cations. Water hardness is principally quantified as calcium carbonate ($CaCO_3$). According to the WHO, the taste threshold for calcium ion is 100 mg/L and that for magnesium is possibly lower (Table 1). In some instances, consumers may tolerate water hardness to a level of 500 mg/L or more. In addition, water can be classified as soft (60–120 mg/L $CaCO_3$), moderately hard (120–180 mg/L $CaCO_3$), or very hard (over 180 mg/L $CaCO_3$) [1]. In the current study, the hardness of the treated water ranges from 132 mg/L in July to 344 mg/L in December. Similarly, this parameter in the Sirwan River ranged from 180 mg/L in March to 332 mg/L in January (**Figure 3**). Although these data are below the highest limit of WHO standards, water hardness in this study area was moderately hard to very hard. This might have adverse effects on the human body and/or the environment [27]. The health influences of hard water are due to the effects of dissolved salts, such as magnesium and calcium. There is probably a positive correlation between the amount of magnesium and calcium in water and food with blood pressure [27].

Calcium is the fifth most abundant element on the crust of the Earth and is essential for human bodies to function properly, especially cell physiology and bones. A proportion of 95% of calcium is stored within the teeth and bones of animals. Deficiency of this mineral in humans may cause health disorders, such as poor blood clotting and bone fracture. Similarly, exceeding the limit of this mineral might produce cardiovascular diseases [28]. Magnesium is the eighth most abundant element on Earth's crust and water. This is also important for a properly functioning human body. More than half of Mg^{+2} in humans is found in the bones and the remaining is in the muscles and tissues. The concentrations of Ca^{+2} and Mg^{+2} in the treated water were within the ranges of 48–89.5 mg/L and 2.2-29.2 mg/L, respectively. These were within the range of standards for concentrations of Ca^{+2} of 100 mg/ L and Mg^{+2} of 30-100 mg/ L. Nevertheless, the concentration of Ca^{+2} is close to the upper limits, which could be harmful to the human body [29]. The influence of water hardness on the kidney stone formation remains unclear, despite a weak correlation between water hardness and urinary calcium and magnesium is seen [27].

Nitrite typically has a lower level than nitrate in water bodies, which comes from the degradation of organic matter; especially, nitrite originates from the reduction of nitrate. Nitrate has a crucial effect on the quality of drinking water. Human or animal excreta, nitrogen fertilizers, and drainage of wastewater can increase the concentrations of these compounds, which can have health risks because of their toxicity. There was a variation in nitrate level over the year 2019 in the treated water, being approximately 1 mg/L in summer and increased to approximately 5 mg/L in autumn. Nevertheless, the value of this compound was largely lower than the recommended limits of 50mg/ L in drinking water [1]. Within the study area, results were free of nitrite due to the purification process of the river water. This process is vital because the standards have only permitted a maximum level of 3 mg/L nitrite. Exceeding this range might threaten the health of inhabitants.

Sulfate is especially obtained from the dissolution of sulphuric acid salts and is usually available in most types of water bodies. The concentration of sulfate in natural water is extremely low, while might be increased to several hundred milligrams per liter without serious negative impacts on human health. The highest permitted limit for sulfate in drinking water is 250 mg/L. Within the present study, the concentration of sulfate within the treated water was from 36 mg/L in September to 141.5 mg/L in December. This compound had an identical pattern in the river water, ranging from 28 to 84.3 mg/L. Both water types exhibit that the concentration of sulfate was within the standard limit and safe for human health.
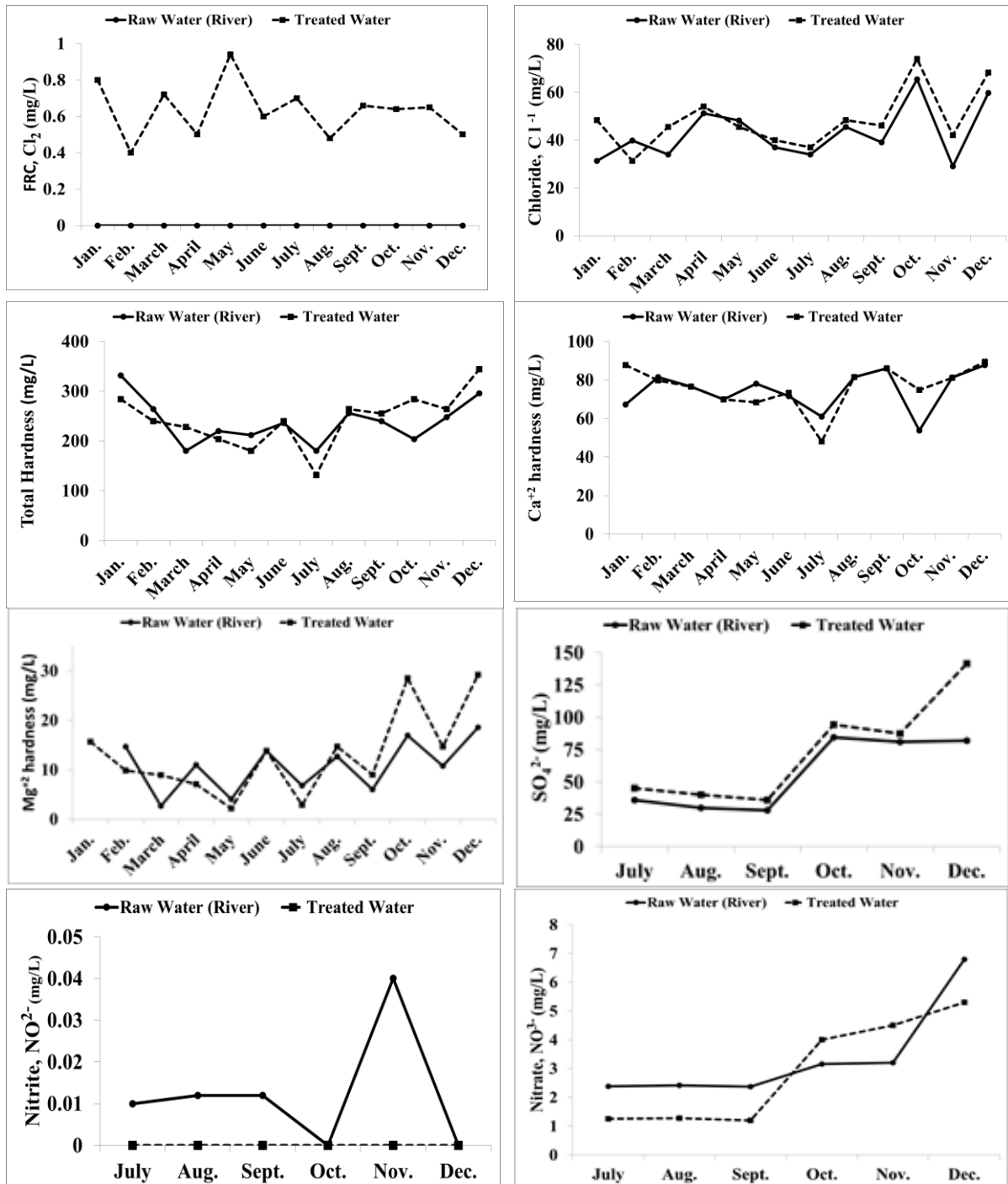
Figure 3-Distribution of chloride, Cl_2, Total hardness, Ca^{+2} hardness, Mg^{+2} hardness, SO_4^{2-}, Nitrate and nitrite in Halabja drinking water and Sirwan river raw water over the year 2019.

Conclusions

To conclude, this study indicates that the quality of the purification processes in the Halabja drinking water was good enough to purify the Sirwan river water to be suitable for drinking. Water samples were weekly or monthly studied in several sections of Halabja city. The data revealed that each of the bacteriological indicators and physico-chemical parameters was in a satisfactory status for drinking and use in food processing. The chlorination process was effective to disinfect the water and prevent the growth of waterborne pathogens. All parameters were within the limits of Iraqi and WHO drinking water standards. However, a number of these parameters, such as pH, total hardness, and Ca^{+2}, were near the upper limits

of standards, which could indicate a critical situation. Thus, a continuous assessment of Halabja drinking water should be performed and a similar study can be performed on the other sources of Halabja drinking water.

Conflict of Interest

The author confirms that there is no conflict of interest regarding the publication of this paper.

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