Academic Science Journal

Physico-chemical and Microbiological (Bacteria and Protozoa) Assessment of Halabja Drinking Water, Kurdistan, Iraq

Hazhar Jalal Ali[2], Muhammed S. Rasheed[2], Othman Abdulrahman Mohammed[1,2], Abdullah Ahmed Hama[3,4], Sardar Muhamad Wali[4], Fatima Mahmud Ali[4], Azad Faruq Fathala[5], Zakarya M. Salih[5]

[1]Medical Laboratory Science Department, Halabja Technical College of Applied Sciences and Research Center/ Sulaimani Polytechnic University, Kurdistan-Iraq

[2]Food Science and Quality Control Department, Halabja Technical College of Applied Sciences and Research Center/ Sulaimani Polytechnic University, Kurdistan-Iraq

[3] Medical Laboratory Department, College of Health & Medical Technology and Research Center/ Sulaimani Polytechnic University, Kurdistan-Iraq

[4]Medical Laboratory Science, College of Health Science/ University of Human Development, Kurdistan-Iraq

[5]Halabja water Treatment Project

muhammed.rasheed@spu.edu.iq

Received: 1 May 2023 **Accepted: 15 July 2023**

DOI: https://doi.org/10.24237/ASJ.01.03.769H

Abstract

Drinking water has directly related to human health so, it must have high quality; free from any constituents harmful to human health such as microorganisms, minerals, and organic substances. Most water born outbreaks due to inadequate sanitation and contamination of drinking water with bacteria and protozoa, which cause global health problems, so the drinking water must be monitored every month. The current research expected to evaluate the consumption water for the microbiological and chemical pollutant of Halabja. In diffirent sources of drinking water samples were collected and they subjected for physical, chemical and microbiological examination each season. The consequences of the current research indicated that Halabja Drinking water was free from waterborne microbial pathogenes. Furthermore, the highest values of the following parameters were found in autumn, although they were within international standards; total dissolved solids (382mg/I), Cl- concentration (103 mg/I), free chloride (0.58mg/I), Ec (595µS/cm), Mg^{+2} (103mg/I) and total hardness (392 mg/I). Therefore this water canbeused for drinking and daily work, while the sources of Halabja drinking water need treatment and management regularly and it should be monitored systematically.

Keywords: Drinking water, Physio-chemical, Microbiologocal, Assessmnet, Halabja

التقييم الفيزو-كيميائي والميكروبيولوجي (البكتيريا والبروتوزوا) لمياه الشرب في حلبجة / كوردستان – العراق

هەژار جلال علي[٢]، محمد سعيد رشيد[٢]، عثمان عبدالرحمن محمد[١،٢] ، عبد الله أحمد حمه[٣،٤]، سردار محمد والي[٤]، فاطمة محمود علي[٤]، آزاد فاروق فتح الله[٥] و زكريا محمد صالح[٥]

قسم علوم المختبرات الطبية، كلية حلبجة التقنية للعلوم التطبيقية ومركز البحوث/ جامعة التقنية السليمانية، كردستان العراق

قسم علوم الأغذية والسيطرة النوعيه، كلية حلبجة التقنية للعلوم التطبيقية ومركز الأبحاث/جامعة التقنية السليمانية، كردستان العراق

قسم المختبرات الطبية ، كلية الصحة والتكنولوجيا الطبية ومركز البحوث / جامعة التقنية السليمانية، كردستان العراق

علوم المختبرات الطبية، كلية العلوم الصحية / جامعة التنمية البشرية ، كردستان العراق

المشروع المعالجة مياه حلبجة

الخلاصة

ترتبط مياه الشرب ارتباطًا مباشرًا بصحة الإنسان ، لذا يجب أن تكون ذات جودة عالية ؛ خالية من أي مكونات ضارة بصحة الإنسان مثل الكائنات الحية الدقيقة والمعادن والمواد العضوية. تفشي معظم الأمراض الناتجة عن المياه بسبب عدم كفاية الصرف الصحي وتلوث مياه الشرب بمسببات الأمراض (البكتيريا والطفيليات الأولية) ، والتي تسبب مشاكل صحية عالمية ، لذلك يجب مراقبة مياه الشرب شهريًا. وتوقع البحث الحالي تقييم استهلاك المياه للملوثات الميكروبيولوجية والكيميائية في حلبجة. تم جمع عينات مياه الشرب من مصادر مختلفة واخضاعها للفحص الفيزيائي والكيميائي والميكروبيولوجي كل موسم. أشارت نتائج البحث الحالي إلى أن مياه الشرب في حلبجة خالية من الملوثات وستستخدم للشرب وللعمل اليومي ،علاوة على ذلك ، تم العثور على أعلى قيم للبارامترات التالية في الخريف ، على الرغم من أنها كانت ضمن المعايير الدولية ؛ إجمالي المواد الصلبة الذائبة (382 مجم / لتر) ، تركيز الكلور (103 مجم / لتر) ، الكلوريد الحر (0.58 مجم / لتر) ، EC (595 ميكرو ثانية / سم) ،المغنسيوم (103 مجم / لتر) والصلابة الكلية (392 مجم / لتر). لذلك يمكن استخدام هذه المياه للشرب وللعمل اليومي ، أما مصادر مياه الشرب في حلبجة فتحتاج للمعالجة والإدارة بشكل منتظم ويجب مراقبتها بشكل منهجي. بينما مصادر مياه الشرب في حلبجة تحتاج إلى معالجة وإدارة بشكل منتظم ويجب مراقبتها بشكل منهجي.

الكلمات المفتاحية: مياه الشرب ، الكيمياء الفيزيائية ، الميكروبيولوجية ، التقييم ، حلبجة

Introduction

Water is a valuable source that is essential for all living organisms for its required for the identifiable for body fucnctions. It sustains life, and health, and preserves the environment [1]. Drinking water must have the best quality; be free from any constituents harmful to human health including organic constituents, viruses, minerals, and bacteria [2]. The safe water shortage, poor hygiene, and inadequate sanitation is the important cause of waterborne illnesses which are the major cause of death in children. waterborne illnesses are increase throughout the direct intake of polluted water by pathogenic microbes [3]. It is assessed that a half million children's death occurs annually due to diarrheal disease worldwide and more than five million people die because of unclean drinking water, the majority of developing countries [4]. The drinking water may be contaminated in different stages, including source, distribution, transport, or handling in the household. Improper protection of water collection and storage containers, inadequate sanitation process, the problem of sewage water, and the effects of commercial and industrial are factors of water contamination [5]. Therefore, complete assessments of water quality require the correct safety of the water provide from pollution and consistent investigation of the sources of water, this is to minimize water-caused illness. Continued investigation of the quality of water analysis depending on the detection of pathogenic microorganisms is important for the water hygienic condition. In addition, the assessment of physical and chemical characteristics including pH, nitrate, temperature, turbidity and others are also essential parameters for drinking water [6]. In Iraq, some studies were conducted regarding the assessment of the suitability of water for drinking, for example, a study in Hilla city, in 2011, found that at the houses use level, the water was unacceptable for drinking [7], and another research in Baghdad, in 2017, established found that the level of Total Dissolved Solids (TDS) in water exceed the standard range and the sulfate content was moderately high in water and varied between 200 and 330 mg L^{-1} [8]. Moreover, another study in Baghdad, in 2017, indicated that incompetent sanitization processes in the all studied stations which studied were responsible for the high level of pathogenic microorganisms in drinking water [9]. There are two main sources of drinking water in Halabja city; Ahmed Awa (spring water) source and several deep wells source. These two sources are pumped to storage tanks and where it treated with chlorine for disinfection and distributed through the water network to the household [10]. Thus, this study aimed to determine the quality of drinking water in Halabje city and identify physical, chemical, and physival properties of the studied drinking water.

Materials and Methods

Study location

The current research conducted on the Halabja drinking water station which take water from Sirwan river. The area is located between 35°11′11″ N latitudes and 45°58′26″E longitude. It is located 240 km northeast of the capital Baghdad, near the Iranian border. Its population generally relies on different sources of drinking water, which include Ahmad Awa Lake, wells, and, water from the Halabja Drinking Water Project. About three-quarters of Halabja's drinking water are supplied by the Halabja Drinking Water Project, which is sourced from the Sirwan River. This river extends from east to southwest of Halabja about 12 km far from the Halabje city as shown in (Figure 1).

Figure 1: Map of the study area. Samples were collected from both the Halabja Drinking Water project and Halabja city [16].

Sample Collection

All sampling sites were either within Halabja city or the Sirwan River. From total sampling points, 130 water samples were collected from January to December 2020 for the physico-chemical analysis and 200 for the biological analysis. Samples were performed randomly at different points where the two main catchment basins (NDR1 and NDR2), the Sirwan River, and the household water distribution network before entering the roof tank.

Water sampling was conducting two weeks in March and May, and one week in January, June, July, August and December. But, in April sampling was not collected. About 300-350 mL of water in each of selected point were coleected and then labeled and stored in ice-box and then transported to the laboratory of Halabja water project for further analysis. The results were compared to the Iraqi and WHO drinking water standards to dermine the quality of water.

Physiochemical Analysis

At the laboratoty of Halabja water project. The pH value was measured using pH meter (Fisher Scientific XL 150), turbidity measurement was done using a Eutech turbidity meter, and conductivity was measured through an EC meter (Inolab-cond7110). The total dissolved solids, chloride, free chlorine, residual aluminum, calcium, magnesium, manganese, sulfate, iron, nitrate, total alkalinity, as well as total hardness determination, were conducted using a spectrophotometer (Orion aquamate 8000, Thermo Fisher)

Microbial Analysis

Water pollution by bacteria was determined by the presence of a particular set of coliform bacterial indicators. The *E. Coli* indicator was used for determining fecal contamination. It was isolated and enumerated by the Most Probable Number (MPN) or multi-tube procedure. The water samples were diluted serially and inoculated a in MacConkey broth medium, and the all culture samples were incubated at 37 $^{\circ}$C for 24-48 h. The presence of acid and gas production was recorded in the tube. The Most Probable Number of coliform bacteria in the samples of 100 mL of drinking water was determined by McCrady's probability tables.

Results

To identify if the Halabja drinking water provided to the Halabja community is safe for drinking, the biological and Physio-chemical investigation of water samples have to be accomplished. The physiochemical characteristics of each river (Sirwan river) and treated water (Halabja drinking water) were assessed. In addition to these essential parameters, the bacterial indicators of fecal contamination in drinking water including fecal *E. coli* and coliform bacteria were tested [11].

Bacteriological Load of Halabja Drinking Water

Water potability can be assessed by one of the crucial parameters. This is evaluated by the availability of microbial indicator pollutants, including total bacteria and fecal coliform bacteria. Total germ is all of the various bacterial species in drinking water. It presents the quality of water without finding out the origin of the water contamination [12]. Water might also be contaminated by fecal contaminated *E. coli* [13]. These parameters are usually applied to assess the ratio of water contamination.

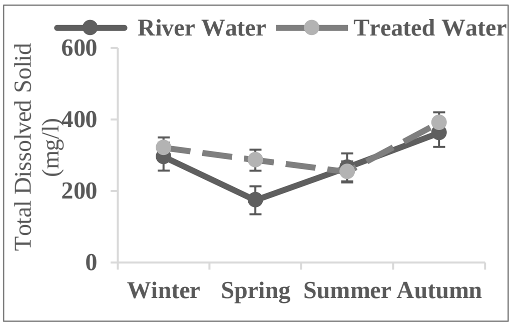
No bacterial counts, and protozoan pollutants were detected in Halabja drinking water for all seasons in 2020 (Table 1). Thus, the number of bacterial indicators in all tested samples were at the permitted level, which is set by WHO and free from fecal coliform bacteria [11]. This indicates that the efficiency of the treatment procedure was enough to kill pathogenic bacteria. Thus, this water was suitable for drinking, and no indication of either human or animal fecal contamination. Bacterial water analysis needs to be continuous. Therefore, at any time this water might be contaminated with any of the purification areas, main tanks, and pipes in the city. In addition, contamination from sewerage leakage systems causes human health problem.

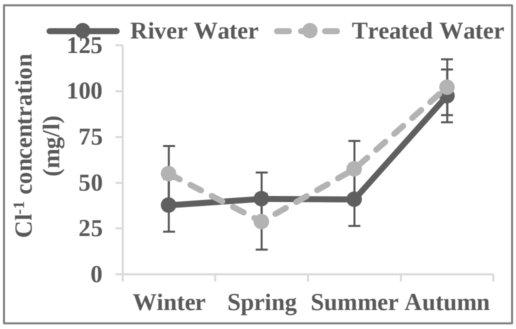
Physiochemical characters of the river and Halabja drinking water

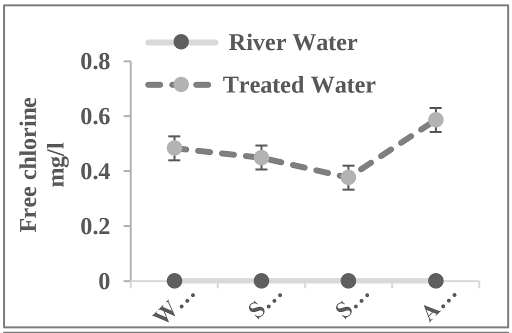
Physical-chemical characters of the river and Halabja drinking water

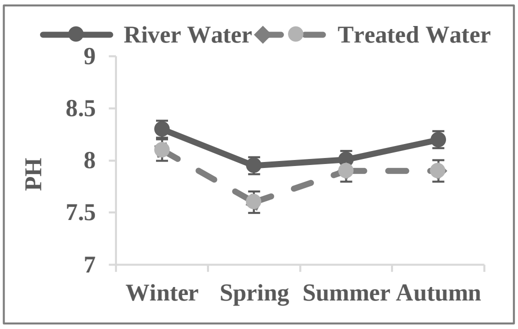
are shown in the following (Figure 1and Table 1). The data are mean of 4-5 replication per season over 2020. Different types of organic and inorganic minerals. For instance, magnesium, calcium, potassium, bicarbonates, etc. make unfavorable color and taste of water. Drinking water's **total dissolved solids (TDS)** come from different sources, including industrial wastewater sewage. For this reason, TDS can be used as one of the crucial parameters for measuring the purity of water. TDS maximum concentration was over 300 (mg/l) in both water types in autumn, while the lowest level of drinking water in summer was less than 300 (mg/l), but for river water, less than 200 (mg/l) was observed during spring. Drinking water TDS was in the allowed level.The main source of **chloride** is sourced from the break-up of salts including NaCl and HCl added to seawater and sewage, etc. The concentration of this compound is normally high in groundwater as compared to surface water. This chemical substance has an important role in the human body's metabolic activities. Metal pipes can be damaged by excessive amounts of chloride as well as harm plant growth. Maximum chloride concentration values in the river and the drinking water were over 80 (mg/l) during autumn. The concentration of this chemical parameter was in the WHO guideline permissions over the studied year (250 mg/l). In addition, the river water was free from **free chlorine**. However, after treating this water, some amount of free chloride was remaining in the drinking water (~ 0.5mg/l). The concentration of this element was lower than the permisable level which designed by the WHO. The **pH** of pure water is referring to the measure of the concentration of hydrogen ions in water. pH is normally ranged from 6 to 8.5. pH values of all water samples in different seasons were in the allowed range of 6.5-8.5 based on WHO guidelines [11]. The maximal level of this parameter was in winter whereas the lowest level was in spring. Alkalinity is the availability at least of one or more of the following ions in water; carbonates, hydroxides, and bicarbonates. Not much concentration of alkalinity is required to inhibit the corrosive effects of acidity. Besides this, high quantities might have some side effects. Results show that there were no remarkable differences in **total alkalinity** in both water types over 2020. The lowest level was in summer below 200ppm to around 220ppm in most of the rest time of the year. This value is entirely satisfactory based on the international water quality guideline values. The total alkalinity of all of the samples were within the allowed range [14]. Thus, these values probably do not cause human health-related problems.

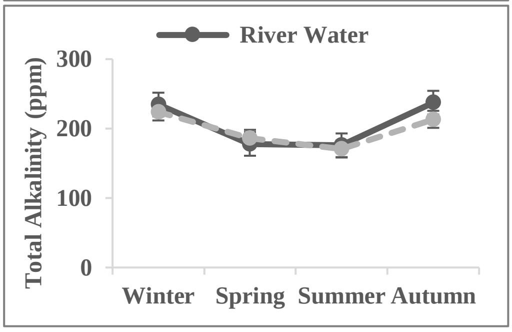
Academic Science Journal

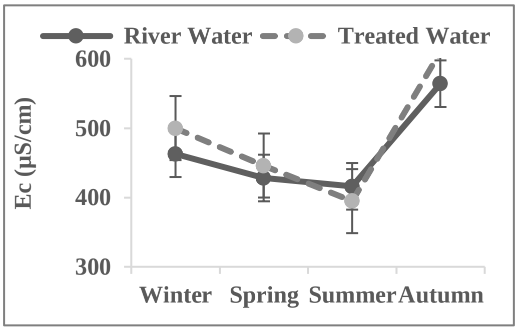


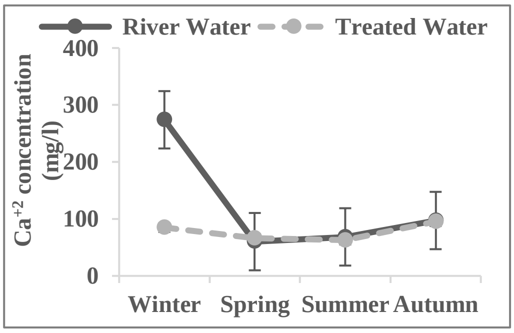


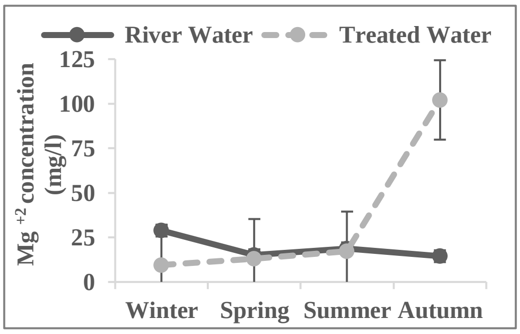


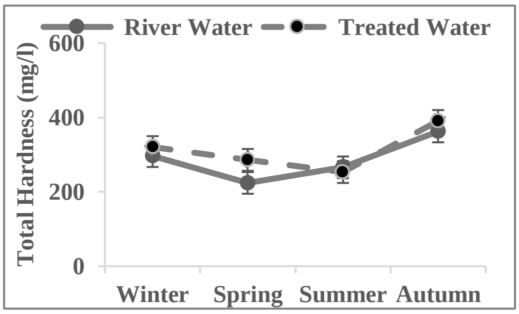


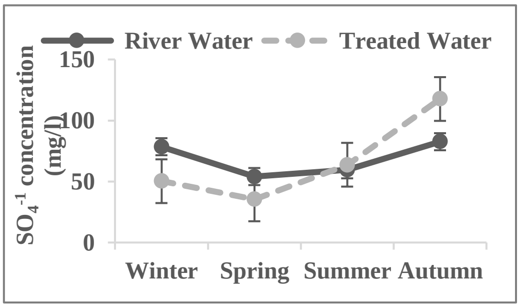












Academic Science Journal

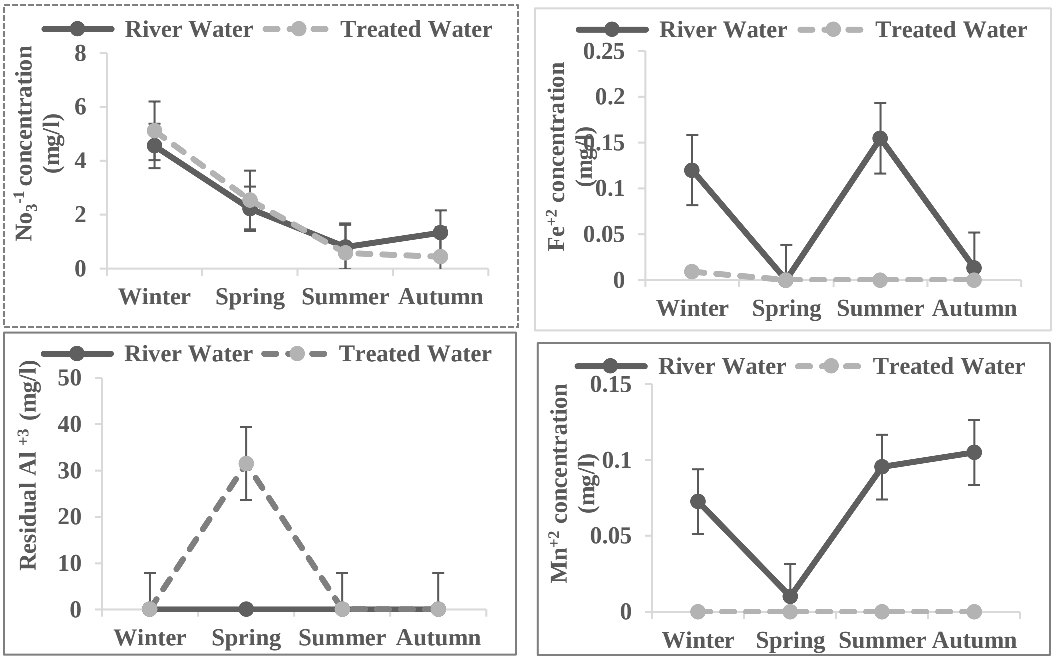


Figure 2: Distribution of River Water (Sirwan river) and Treated Water (Halabja drinking water) over all seasons of 2020. Error bars are mean of 4-5 replications. Water samples were monthly collected from both types of water apart from in March of 2020 due to the pandemic COVID-19.

Table 1: The measuered physiochemical and biological properties of studied source of drinking water for Halabja city

Properties	Source of water	Season				Bacteria
		Winter	Spring	Summer	Autumn	
pH	**River Water**	8.3±0.79	7.95±0.07	8.01±0.12	8.2±0.1	0
	Treated Water	8.1 0.53	7.6±0.28	7.9±0.2	7.90±0.1	0
Ec (µS m^{-1})	**River Water**	463±29.56	428±1.41	416±63.21	564±88.9	0
	Treated Water	500±44.8	446±15.6	394.7±83.4	610.3±20.7	0
TDS (mg L^{-1})	**River Water**	296±18.7	224±70.7	266±40.15	362.3±54.4	0
	Treated Water	320.3±28.6	286±8.49	253.3±54.3	390.7±13.4	0
T. Alkaline (mg L^{-1})	**River Water**	234.7±36.1	178±2.83	176±21.2	237.3±30.3	0
	Treated Water	224±14.4	186±19.8	170.7±8.33	213.3±24.4	0
Free Chlorine (mg L^{-1})	**River Water**	0±0.00	0±0.00	0±0.00	0±0.00	0

	Treated Water	0.48±0.08	0.45±0.64	0.38±0.42	0.58±0.51	0
Residual Al^{+3} (mg L^{-1})	**River Water**	0±0.00	0±0.00	0±0.00	0±0.00	0
	Treated Water	0.033±0.06	31.5±44.5	0.036±0.03	0±0.100	0
T. Hardness (mg L^{-1})	**River Water**	274±50.5	212±16.9	250±36.06	302.7±26.6	0
	Treated Water	284±360	218±14.14	245.7±38.8	298.7±60.0	0
Ca^{+2} (mg L^{-1})	**River Water**	72.8±22.19	60.1±0.14	68.4±8.15	97.2±25.0	0
	Treated Water	84.8±2.91	65.7±5.49	62.82±7.5	95.2±16.3	0
Mg^{+2} (mg L^{-1})	**River Water**	28.8±21.6	15.0±3.99	18.9±12.2	14.46±8.73	0
	Treated Water	9.52±5.34	13.0±6.82	19.91±9.84	14.7±12.4	0
Cl-1 (mg L^{-1})	**River Water**	37.7±16.9	41.2±14.7	40.8±6.01	97.4±25.4	0
	Treated Water	54.8±27.7	28.7±35.78	57.6±16.8	102.1±47.3	0
NO_3^{-1} (mg L^{-1})	**River Water**	4.55±4.03	2.21±1.68	0.8±1.13	1.33±0.75	0
	Treated Water	5.11±4.94	2.54±2.23	0.58±0.83	0.44±0.62	0
SO_4^{-2} (mg L^{-1})	**River Water**	78.5±61.5	54.0±21.6	59.6±33.1	82.6±50.9	0
	Treated Water	50.24±2.49	35.3±49.9	63.7±51.9	117.6±44.4	0
Mn^{+2} (mg L^{-1})	**River Water**	0.07±0.03	0.01±0.01	0.095±0.03	0.105±0.09	0
	Treated Water	0±0.00	0±0.00	0±0.00	0±0.00	0
Fe^{+2} (mg L^{-1})	**River Water**	0.12±0.17	0±0.00	0.154±0.13	0.013±0.02	0
	Treated Water	0.01±0.01	0±0.00	0±0.00	0±0.00	0

Electrical conductivity (EC) in water is mentioned as one of the crucial indicators for assessing total dissolved solid in water. EC of contaminated water is higher than in purified water. The EC of water is increased because of adding ions to the water. The EC of the drinking water ranges between 395 in the summer to 590 in autumn (µS /cm) which was within the Iraqi permisable value of this parameter (2000 microsiemens) for drinking water [9].

Calcium (Ca) is the main component of human bones and teeth (about 95%) and has essential roles in human cell physiology. It is one of the most prevalent element on the earth surface.

Non-standard level of this element in the human body has a detrimental effect on the physiology of the human body. For instance, exceeding the limit of calcium makes cardiovascular diseases and a high deficiency of this element in the body of humans might cause producing different diseases such as bone fracture, poor blood clotting, and rickets. In study areas, results show that the calcium concentration in the drinking water was 70 mg/l in spring and 95 mg/l in winter. Calcium quantity in winter was near the limit by WHO and may be deleterious to the human body. Magnesium is one of the natural water constituents and the 8th most abundant component on earth. Different organisms, including humans, require this element for the proper functioning of human body metabolisms. In study areas of drinking, water, magnesium was 9 mg/l in winter and 100 mg/l in autumn. The quantity of magnesium is below the Iraqi standards (100mg/l) over the year 2020 except in autumn. Such a high concentration somewhat affects the health of Halabja residents.

Water hardness ($CaCO_3$) is another basic water properties have to be assessed. Hard water contains numerous amount of minerals. If these minerals exceed their level from the permitted level, they will have an influence on human health. Soft water is the sort of water that contains a small amount of $CaCO_3$ (60–120 mg/l), whereas very hard water is containing more than 180 mg/l of $CaCO_3$ [11]. Current study, the drinking water hardness was 265 mg/l during summer, while it was 380 mg/l during autumn. The data had no major differences in the river water. A similar pattern was found in the hardness of the drinking water over the previous year 2019 [15].

Sulfuric acid is measured as the main source of sulfate (SO_4) in almost water source. In natural water, sulfate concentration is ranged from a few to several hundred mg per liter. It is known that this compound has no major negative influence on human health. In this investigation, the sulfate concentration in the drinking water was from 42 mg/l during spring to over 100 mg/l during autumn. The data show that the amount of sulfate in the drinking water was within the WHO standard limit (25mg/l).

Nitrate (NO_3) is another crucial disease-causing parameter of drinking water quality such as blue baby syndrome in children. Nitrate is sourced from industrial waste, cycle of nitrogen, etc.

The maximum allowed WHO level of drinking water nitrate is 10 mg/l. In the current study, nitrate values in the drinking water fall between 0.4mg/l in autumn to 5.1mg/l in winter, and the average value was 2.75 mg/l. These results show that the concentration of nitrate is acceptable and is not posing a threat of nitrate on human health.

Iron (Fe**)** is another essential element in assessing water quality. Soil leaching becomes contamination of surface water by iron and causes interring this element into underground water by water-rock interaction. Only a small amount of iron was found in the water (0.015 mg/l) in winter. This concentration is not exceeding to the WHO standard (0.3 mg/l). Furthermore, manganese (Mn) and iron behaved similarly. In fact, manganese was also free in the drinking water over 2020. Manganese is one of the important human micronutrients and can be taken from consumption of different sources of food.

Discussion

The growth of population and changes in lifestyle increased the water demand. Therfore, water quality has become of great concern [17]. Potable water without adverse health effects; has be free from microbes, viruses, parasites minerals, and organic substances; and free of disagreeable polution, such as color, taste, turbidity, and odor and is aesthetically acceptable [18, 2]. In many countries, especially in underdeveloped nations, it has been a major issue which the highest quality water sources were required for drinking purposes [19]. Many investigations have been carry out to analyze water condition and regular monitoring of the water [20, 21].

Control and detection of waterborne diseases depend on the microbiological analysis of drinking water and for this purpose total bacteria and fecal Coliforms were performed to analyse the microbial quality of the samples and the microscopical examination directly and or indirectly (sedimentation and flotation) techniques will be useful. Microbiologically there was no bacterial and parasitic water pollutant in the Halabja drinking water sources for the four seasons in 2020. The coliforms and *E. coli* bacterial contaminants of water samples were at the permission level according to the WHO and also most samples were free from fecal coliform bacteria [11]. A similar finding by Mohammed [15] showed that the Halabja drinking water was free from microbial contamination and also was within the WHO recommended levels [11]. These data indicate that the efficiency of the treatment procedure was enough to kill pathogenic bacteria. Thus, this water was suitable for drinking, and no indication of either human or animal fecal contamination.

Using liquefied chlorine gas to disinfect Sirwan river water can kill any microbial organism and this may be the reason for the absence of coliform pathogens also use of free residual chlorine (FRC) can inhibit the re-contamination of the water [11]. However [8], indicate that the coliform bacteria were found in drinking water in capital of Iraq, this indicates the possibility of water contamination by fecal matter [22]. Water treatment processes or contamination during the distribution system are potential sources of coliform bacteria in water supplies [23].

Chemical constituents and their concentrations are guideline values for drinking water that they have no detectable harmful effect on human. Drinking water TDS can be used as one of the crucial parameters for measuring the purity of water. As observed in figure 1, TDS maximum concentration was over 300 (mg/l) in both water types in autumn, while the lowest level was less than 300 (mg/l) in the samples in summer, but less than 200 (mg/l) in the untreated water in spring.

Total dissolved solids were no much differences in the both water samples. This is agreement with finding which was done by Mohammed [15]. The values are below the maximum permitted level of 600 mg/L [15]. So both studies show that water is suitable for drinking because it contains less than 600 mg/L dissolved solids. Water contained high level of TDS is not acceptable and may have high level of microbes [24]. In additon, this may cause excessive scales in water pipes and household appliances [11]. Different geological areas contain various amount of TDS due to solubility of minerals are varies [8].

Chloride concentration was in the WHO guideline permissions over the studied year (250 mg/l). However, after treating the water, some amount of free chloride was remaining in the drinking water, but the concentration of free chloride was within the permitted level of WHO. In 2019, the relatively same result was recorded, the concentration of chloride within both types Sirwan river and in the treated water were was 31.2 to 65.3 mg/L and 48.2 to 73.8 mg/L, respectively [15]. Another study which was done for tap water in Baghdad city, the chloride level was also within the accepted WHO limits [8]. This may be due to better water treatment techniques.

The water pH is another crucial water quality indices. It affects both the physico-chemical properties of water. pH of water samples in different seasons were in the allowed ranges of 6.5-8.5 based on WHO guidelines [11]. Maximal level of this parameter was in winter, whereas the lowest level was in spring. In the study done by [10] on the drinking water of Halabja City, the pH values for all wells and houses were within the WHO limit except for three wells whose pH was between (6.3-6.4). In another study done by Mohammed, he observed that the pH of samples was near to 7 and within the Iraqi and WHO recommended standards [15]. Both these studies agree with ours. But disagree with our study, the pH of drinking water in Hilla City ranged from 6.9 to 7.5 [7]. Also in another study on the tap water in Baghdad city, pH values ranged from 7.5 to 8.6, and was indicated that water was alkaline (pH >7). The differences in pH value may refer to different types of collecting water and geological conditions of types of water [24].

The electrical conductivity (EC) of the water may affect on its taste [24]. A high level of EC generally means water has high degree of salinity [11]. In our work, the electrical conductivity of the drinking water ranges between 395 in the summer to 590 in autumn (microsiemens/cm) and this is in the permitted level of Iraqi [9]. This was matched with other work done on Halabja drinking water over the year 2019 [15], but in a study which was done in Jaffna Peninsula, Sri Lanka, EC contents were within the acceptable level of SLS [2].

The water hardness ($CaCO_3$) indicated by the precipitation of soap scum and scale deposition [8]. Hard water usually contains a high amount of minerals that influence human health. In this study, the hardness of water samples ranges from 265 mg/l in summer to 380 mg/l in autumn. This data had no major differences in the river water. A similar pattern was found in the hardness of the drinking water over the previous year 2019 [15]. In dissimilar findings, this parameter in Baghdad drinking water was less than recommended [7].

Mineral analysis in our study showed that each calcium, sulfate, nitrate, manganese, and iron in the drinking water were within the WHO standard limit. Only the quantity of magnesium was below the Iraqi standards (100 mg/l) over the year 2020 except in autumn. In some instances, the concentration of some of these minerals such as calcium, magnesium, sulfate, and chloride were within normal recommended limits, and nitrate levels showed variation over the year 2019 in the drinking water, even so, this value was within the recommended limits [15].

Conclusions

This study concludes that Halabja drinking water in all seasons of 2020, was clear and suitable for drinking. May be this refers to a good purification process with good monitoring by those concerned. Microbiological analysis revealed that there were no bacterial and protozoan contaminants found in the water. The physico-chemical qualities of each river water (Sirwan and Ahmed Awa rivers) and treated water (Halabja drinking water) were assessed, and nearly all chemical constituents and their concentrations were within WHO standard limits. TDS of the drinking water were in the permissible value in both water types in autumn, with the lowest level in the drinking water in summer and less than 200 (mg/l) in the river water in spring. The chloride concentration of drinking water samples and pH of all rivers and drinking water in different seasons were in the allowed ranges based on WHO guidelines. EC of the drinking water was within the Iraqi acceptable level, the hardness of the drinking water is from 265 mg/l in summer to 380 mg/l in autumn with no major differences in the river water. Calcium, sulfate, nitrate, manganese, and iron in the drinking water were within the WHO standard limit. Only the quantity of magnesium was below the Iraqi standards over the year 2020 except in autumn. Thus, Halabja drinking water and sources of all Kurdistan drinking water should be under continuous study and assessment.

Conflict of Interest

The authors declare that they have no conflict of interest

Acknowledgment

We Thank Halabja Drinking Water Project for thier help with sample collection

References

1. Bekele, M., Dananto, M., & Tadele, D. (2018). Assessment of Physico-Chemical and Bacteriological Quality of Drinking Water at the Source, Storage, Point-of-Use, Dry and Wet Season in Damot Sore Woreda, Southern Regional State, Ethiopia.
2. Sasikaran, S., Sritharan, K., Balakumar, S., & Arasaratnam, V. (2012). Physical, chemical and microbial analysis of bottled drinking water.
3. El-Sheekh, M. M., & Hamoud, M. M. (2021). Phycological and bacteriological assessment of drinking water in schools of Tanta city, Egypt. *Water Science and Technology*, *84*(10-11), 3018-3039.
4. Ondieki, J. K., Akunga, D. N., Warutere, P. N., & Kenyanya, O. (2021). Bacteriological and physico-chemical quality of household drinking water in Kisii Town, Kisii County, Kenya. *Heliyon*, *7*(5), e06937.
5. Tabor, M., Kibret, M., & Abera, B. (2011). Bacteriological and physicochemical quality of drinking water and hygiene-sanitation practices of the consumers in Bahir Dar city, Ethiopia. *Ethiopian journal of health sciences*, *21*(1), 19-26.
6. El Sayed, S. M., Hegab, M. H., Mola, H. R., Ahmed, N. M., & Goher, M. E. (2020). An integrated water quality assessment of Damietta and Rosetta branches (Nile River, Egypt) using chemical and biological indices. *Environmental monitoring and assessment*, *192*, 1-16.
7. Naji, H. F., Tawfiq, N. M., & Kuder, A. A. A. (2011). Bacteriological and Physiochemical Analysis of Drinking Water in Hilla City, Iraq. *Euphrates Journal of Agriculture Science*, *3*(9), 128-133.
8. AL-Dulaimi, G. A., & Younes, M. K. (2017). Assessment of potable water quality in Baghdad City, Iraq. *Air, Soil and Water Research*, *10*, 1178622117733441.
9. Al-Bayatti, K. K., Al-Arajy, K. H., & Al-Nuaemy, S. H. (2012). Bacteriological and physicochemical studies on Tigris River near the water purification stations within Baghdad Province. *Journal of Environmental and Public Health*, *2012*.
10. OKasem, A., A Salih, F., F Othman, N., & H Abdullah, T. (2015). Assessment of the quality of drinking water of Halabja City-Iraqi Kurdistan. *Kirkuk University Journal-Scientific Studies*, *10*(3), 259-272.
11. World Health Organization, & WHO. (2004). *Guidelines for drinking-water quality* (Vol. 1). World Health Organization.
12. Steele, A., Clarke, B., & Watkins, O. (2008). Impact of jerry can disinfection in a camp environment–experiences in an IDP camp in Northern Uganda. *Journal of water and health*, *6*(4), 559-564.

13. Edberg, S. C. L., Rice, E. W., Karlin, R. J., & Allen, M. J. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Journal of applied microbiology*, *88*(S1), 106S-116S.
14. Sohel, K. M. A., Chowdhury, M. A. I., & Ahmed, M. F. (2003). Surface water quality in and around Dhaka City. *Journal of Water Supply: Research and Technology—AQUA*, *52*(2), 141-153.
15. Mohammed, O. A. (2021). Bacteriological and Physico-chemical Qualities of Halabja Drinking Water. *Iraqi Journal of Science*, 3816-3826.
16. Abed, K. F., & Alwakeel, S. S. (2007). Mineral and microbial contents of bottled and tap water in Riyadh, Saudi Arabia. *Middle East J Sci Res*, *2*(3-4), 151-6.
17. Rahmanian, N., Ali, S. H. B., Homayoonfard, M., Ali, N. J., Rehan, M., Sadef, Y., & Nizami, A. S. (2015). Analysis of physiochemical parameters to evaluate the drinking water quality in the State of Perak, Malaysia. *Journal of Chemistry*, 1-10.
18. Gray, N. F. (1994). Drinking water quality: problems and solutions. John Wiley & Sons.
19. National Research Council. (1930). Summary Report: Drinking Water and Health.
20. Wen, X., Chen, F., Lin, Y., Zhu, H., Yuan, F., Kuang, D., ... & Yuan, Z. (2020). Microbial indicators and their use for monitoring drinking water quality—A review. *Sustainability*, *12*(6), 2249.
21. Mulamattathil, S. G., Bezuidenhout, C., & Mbewe, M. (2015). Analysis of physico-chemical and bacteriological quality of drinking water in Mafikeng, South Africa. Journal of water and health, 13(4), 1143-1152.
22. Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS medicine*, *11*(5), e1001644.
23. Prasai, T., Lekhak, B., Joshi, D. R., & Baral, M. P. (2007). Microbiological analysis of drinking water of Kathmandu Valley. *Scientific world*, *5*(5), 112-114.
24. Medema, G. J., Payment, P., Dufour, A., Robertson, W., Waite, M., Hunter, P., ... & Andersson, Y. (2003). Safe drinking water: an ongoing challenge. *Assessing Microbial Safety of Drinking Water*, 11.
25. Pradeep, J. K. (1998). Hydrogeology and Quality of Ground Water around Hirapur, District Sagar (M.P.). *Pollution Research*, 17 (1): 91-94.