Spring water quality assessment using water quality index in villages of Barwari Bala, Duhok, Kurdistan Region, Iraq

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Abstract

Periodic quality assessment of drinking water sources is necessary to guarantee the quality and security of water supply to people. Accordingly, this study assessed the drinking water quality of spring water of some villages located in Barwari Bala region of Duhok Governorate, Kurdistan region, Iraq, using the water quality index (WQI). To realize this objective, 120 spring water samples were collected from ten villages during the dry and wet seasons in 2018 and were analyzed for major physicochemical characteristics, including: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), pH, total dissolved solids (TDS), turbidity, total hardness (TH) and total alkalinity (TA). The results for pH, turbidity, sodium, potassium, chloride, sulfate and nitrate showed that the water samples at all the sampled springs were suitable for drinking and within permissible limits based on given standards. However, TDS, TA, calcium and magnesium exceeded the permissible limits at some sites. It was also observed that, except for SO_4^{2-} , at almost all the sites, the majority of parameters were significantly greater during the wet season compared to the dry season. With reference to all the parameters, the WQI values ranged from 10.76 to 18.13 during the dry season and from 17.10 to 20.45 during the wet season, indicating that all water samples are classified as having “excellent” water quality for drinking purposes. The calculation of WQI based on specific parameters, where values were close to or exceeded the maximum acceptable limits, showed that the water quality status of all water samples was “good” quality, except for sites S6 and S8, which were classified as “poor” quality and are not considered suitable for drinking purposes without treatment. Water from almost all the sampled spring sites can be considered as suitable for drinking purposes, although some parameters exceed permissible limits. Simple filtration treatment of the sampled spring water before use is desirable for ensuring good quality and security of the water supply to people of these areas.

Keywords Drinking water · Water quality assessment · Water quality index (WQI) · Spring water · Physicochemical parameters

Introduction

Water is considered as the most important and valuable natural resource on which all life on earth ultimately depends. Water plays an imperative role in the development of different sectors of the economy, including agriculture, cattle production, forestry, industrial electricity generation, fisheries, and other innovative activities (Bouslah et al. 2017; Tyagi et al. 2013). However, the continuous growth of the human population is increasing the demands for water, and

the sustainability of the freshwater supply is significantly threatened due to extensive depletion of groundwater, surface water contamination, and the effects of climate change (IPCC 2007; Poudel and Duex 2017). Consequently, numerous countries are facing serious water scarcity and poor water quality. Thus, information on water resources and their suitability for use is mandatory for spatial planning and sustainable development. This is of particular importance in arid and semiarid areas, where water resources are limited and the long-term average precipitation is decreasing (Barakat et al. 2018; Mishra and Singh 2010; Tallaksen and Van Lanen 2004).

Like other countries in arid and semiarid zones, Iraq experiences water shortages and has limited freshwater resources to meet the local population's water needs. In the

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Kurdistan region, the primary sources of water for human activities include groundwater, rivers, dams, ponds, hand-dug wells, and springs. The quality and quantity of these water sources vary depending on the geographic location and environmental factors, such as the chemical composition of the underlying rocks, precipitation inputs, soil formation, and the length of time that the water body has been trapped underground (Faniran et al. 2001; Van der Merwe 1962). These water bodies may be threatened further as a consequence of human development (Yogendra and Puttaiah 2008). Monitoring and conserving these important water sources is necessary for healthy living and an adequate supply of safe drinking water.

Over the past few decades, the water quality index (WQI) has been considered as an effective tool that provides information on the quality of water for use by concerned citizens and policymakers (Yisa et al. 2012) and has been utilized in surface and groundwater quality evaluation all over the world (Bora and Goswami 2017; Kaviarasan et al. 2016; Samantray et al. 2009). The WQI indicates the quality of water in terms of an index number which represents the overall quality of water in relation to specific standards for specific uses (Etim et al. 2013). WQI is defined as a rating reflecting the overall effect of various water quality parameters. The first WQI was proposed by Horton (1965), and subsequently, there have been improvements to the original technique. Accordingly, numerous WQIs have been formulated and approved around the world (Brown et al. 1970; Ganiyu et al. 2017; Reza and Singh 2010; Shigut et al. 2017), which vary in terms of statistical incorporation and translation of parameter values (Abbasi and Abbasi 2012; Alobaidy et al. 2010).

Springs are the primary source of water for drinking, agricultural, and domestic purposes in most villages in the Kurdistan region. Although spring water is considered inexpensive and of high-quality due to its filtration through the soil layers, the quality of this water source is based on certain physiochemical parameters. In the Kurdistan region, spring water is mainly used for drinking and rural domestic use; hence, it should be tested and compared against domestic water quality standards to ensure safe drinking water. WQIs have been applied worldwide and are used to assess the overall water quality within a particular region quickly and effectively (Abdulwahid 2013). However, in the Kurdistan region of Iraq, few studies have been conducted on spring water using WQIs. In addition, to the best of our knowledge, the spring water quality of many villages in the area was left unassessed. The present study, therefore, evaluates the drinking water quality and presents the application of the WQI as a possible tool for monitoring the quality of spring water in villages within the Barwari Bala area at Duhok Governorate, Kurdistan region, Iraq.

Materials and methods

Study area and sampling sites

In this study, water samples were collected from the springs in 10 villages within the Barwari Bala area. Barwari Bala is a region situated in the north of Iraq at a distance of about 105 km from Duhok and 584 km from Baghdad. The study area lies between the latitude 37°10'02"N and 37°16'10"N and longitudes 43°10'09"E and 43°29'45"E. The name and geographic coordinates of the investigated springs are presented in Fig. 1 and Table 1. The geography of the area is mountainous, and the climate is considered semiarid, characterized by hot, dry summers and cold, wet winters and is usually snowy with more rainfall in the north than in the central and southern parts. The area receives an annual rainfall of 750–900 mm. The major water sources are springs and rivers, and a great proportion of the population obtains water from springs for drinking and domestic purposes.

Sampling and sample analysis

A total of 120 water samples were collected from 10 different springs at two different sampling periods. Sampling was undertaken during the wet season (December–April), when the area had received sufficient rainfall to cause runoff, and during the dry season (July–October 2018), when the area had not received rainfall for some months. During each season, six water samples at 10–15-day intervals were collected from each spring. Stopper-fitted polyethylene bottles (capacity 500 mL) were used for collecting water samples. Prior to sampling, the bottles were triple-rinsed with distilled water. After sampling, the samples were transported to the Central Laboratory of College of Agriculture, University of Duhok, Kurdistan region, Iraq, and refrigerated at 4 °C for physicochemical analysis.

The samples were analyzed for pH, total dissolved solids (TDS), turbidity, total hardness, total alkalinity, Ca^{2+} , Mg^{2+} , K^+ , Na^+ , Cl^- , NO_3^- , and SO_4^{2-} in accordance with the procedures delineated in the standard methods described by Motsara and Roy (2008) and APHA (1995). Electrical conductivity (EC) and pH of each water sample were measured *in situ*. Table 2 shows the technical and methods used for the analysis of different parameters, along with the instruments and units used in this study.

WQI calculation

The WQI of all drinking water samples was assessed by applying the weighted arithmetic index method employed by Brown et al. (1972). The WQI is used to determine the

Fig. 1 Map of Iraq with a satellite image of the study area illustrating the sampling sites

Table 1 The name and geographic coordinates of the sample springs

Names of sampling sites	Sampling site codes	Latitude	Longitude
Kyle Baze	S1	37°10'31.28"N	43°15'28.76"E
Kani Mazne	S2	37°10'39.74"N	43°16'26.03"E
Miska	S3	37°10'54.37"N	43°17'50.87"E
Xshxasha	S4	37°12'06.5"N	43°15'11.42"E
Beqolke	S5	37°12'44.15"N	43°16'54.81"E
Bnavi	S6	37°14'33.58"N	43°22'50.45"E
Kani Mase	S7	37°13'29.2"N	43°26'18.88"E
Derishke	S8	37°13'51.59"N	43°25'54.9"E
Maye	S9	37°14'38.3"N	43°24'40.8"E
Bedhi	S10	37°15'10.06"N	43°25'08.29"E

composite effect of individual parameters on the overall quality of water. In essence, twelve important parameters were chosen for the WQI calculation. International standards were used to assess the quality of different water samples (See Table 3). However, where parameters were not set in international standards, other national standards were used. The calculation of WQI involves the following steps:

In the first step, the unit weight (W_n) for each water quality parameter has been calculated using the following formula:

$$W_n = K/S_n$$

where W_n is the unit weight and S_n is the recommended standard for an i th parameter (Table 4), while k is the constant of proportionality and it was calculated using the following equation:

$$K = 1/\Sigma(1/S_n)$$

In the second step, a quality rating score (Q_n) or subindex for all the parameters except pH was calculated by dividing the

concentration of each parameter by its respective standard. The result was then multiplied by 100 as follows:

$$Q_n = [(V_n - V_i)/(V_s - V_i)] \times 100$$

where V_n is the actual amount of n th parameter present, V_i is the ideal value of the parameter [$V_i=0$, except for pH($V_i=7$)], V_s is the recommended standard or permissible limit for the n th water quality parameter.

The above equation indicates that $Q_n=0$ when a pollutant is absent from the water sample and $Q_n=100$ when the value of this parameter is just equal to its recommended value. Hence, the higher the value of Q_n , the higher the level of contamination.

Finally, the overall WQI for each sample was calculated using the following equation:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n}$$

where Q_n referred to the quality rating of n th water quality parameter and W_n is the unit weight of n th water quality parameter.

The computed WQI values were then classified into five categories in order to determine the water quality status (WQS) as shown in Table 5.

Statistical analysis

Descriptive statistics, such as mean and standard deviation (SD), were calculated to describe the variation of each parameter. Paired T test was performed to determine if there are significant variations (at 95% confidence level) in the selected parameters between seasons. Prior to analysis, data were evaluated for normal distribution using the Kolmogorov–Smirnov normality test (if p value < 0.05 data considered non-normal). Long Logarithmic ($\log_{10}$) transformation was used where the data were non-normally distributed. All

Table 2 Water quality parameters, analytical methods, and instruments used for the current study

Parameters	Unit	Instruments/analytical methods used
pH		Digital pH meter (EcoScan pH 5 Palmtop pH meter)
Total dissolved solids (TDS)	mg/L	Conductivity meter (waterproof conductivity meter HI 9835)
Turbidity	NTU	Digital turbidity meter (HF Scientific 20016, micro 1000 IR laboratory turbidimeter)
Calcium (Ca^{+2})	mg/L	EDTA titrimetric method
Magnesium (Mg^{+2})	mg/L	EDTA titrimetric method
Sodium (Na^{+})	mg/L	Flame-photometric method (Jenway PFP7 clinical flame photometer)
Potassium (K^{+})	mg/L	Flame-photometric method (Jenway PFP7 clinical flame photometer)
Chloride (Cl^{-})	mg/L	AgNO_3 titrimetric method
Sulfate (SO_4^{-2})	mg/L	Barium sulfate turbidity (Spectrophotometer)
Nitrate (NO_3^{-})	mg/L	Steam distillation method (Kjeldahl)
Total hardness as CaCO_3	mg/L	EDTA titrimetric method

Table 3 National and international standards related to assessing the quality of spring water

Parameter	Unit	WHO (2017)	EPA (2018)	(Drinking Water Standard IQS:417 2001)	Turkish Legislation R.G. no. 23144a (Gazete 1997)
		Drinking water (Gv) ^a	Drinking water (MCL) ^b	(MPL) ^c	Bottled drinking water (MAC) ^d
pH		–	6.5–8.5 ^e	6.5–8.5	5.5–8.5
Turbidity	NTU	–		5 ^e	5
TDS	mg/L	–	500 ^e	1000	–
Ca ²⁺	mg/L	–	–	75 ^e	100
Mg ²⁺	mg/L	–	–	50 ^e	50
Cl [–]	mg/L	–	250 ^g	250	250
Na ⁺	mg/L	–	–	200 ^e	175
K ⁺	mg/L	–	–	–	12 ^e
SO ₄ ^{2–}	mg/L	–	250 ^e	250	250
NO ₃ [–]	mg/L	50 ^e	44	50	45
Total alkalinity CaCO ₃	(mg/L)	–	–	200 ^e	–
Total hardness CaCO ₃	mg/L	–	–	500 ^e	–

WHO World Health Organization, EPA US Environmental Protection Agency

^aGuideline value

^bMaximum contaminant level

^cMaximum permissible limits

^dMaximum admissible concentration

^edependent values for comparison and water quality assessment

Table 4 Recommended Standards for drinking water quality and unit weight of individual parameters

NTU	Parameters	Recommended water quality standards (S _n)	Units weight (W _n)
pH		6.5–8.5	0.247
Turbidity	NTU	5	0.420
Total dissolved solid	(mg/L)	500	0.004
Calcium	(mg/L)	75	0.028
Magnesium	(mg/L)	50	0.042
Chloride	(mg/L)	250	0.008
Sodium	(mg/L)	200	0.011
Potassium	(mg/L)	12	0.175
Sulfate	(mg/L)	250	0.008
Nitrate	(mg/L)	50	0.042
Total alkalinity	CaCO ₃ (mg/L)	200	0.011
Total hardness	CaCO ₃ (mg/L)	500	0.004
			1.001

statistical analyses were conducted using the Minitab software package 17.

Results and discussion

The relative abundance of major dissolved chemical constituents in water is dependent upon weathering process, type of geological rock (Singh and Hasnain 1999), and inputs from anthropogenic activities. The physicochemical analysis is used for detecting the levels of these dissolved constituents in water (Barakat et al. 2018). Accordingly, in the current study, the collected samples from spring water in different villages in the Barwari Bala region were analyzed for 12 physicochemical parameters. The summary of the results derived from descriptive statistics [Mean ± SD] for measured variables at 10 sample points during dry and wet seasons and the suggested standards are shown in Tables 6 and 7. In addition, the paired *t* test analysis results for seasonal variation

Table 5 WQI ranges, status, and possible use of the water sample (Brown et al. 1972)

WQI	Water quality status	Possible use
0–25	Excellent	Drinking, irrigation, and industrial
26–50	Good	Drinking, irrigation, and industrial
51–75	Poor	Irrigation and industrial
76–100	Very poor	Irrigation
More than 100	Unsuitable for drinking	Proper treatment required before use

Table 6 Mean $\pm$ SD values of the studied parameters of each sampling site during the dry season

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Water quality standards
pH	7.14 $\pm$ 0.007	7.24 $\pm$ 0.01	7.30 $\pm$ 0.003	7.43 $\pm$ 0.03	6.97 $\pm$ 0.04	6.97 $\pm$ 0.007	7.18 $\pm$ 0.013	7.12 $\pm$ 0.007	6.95 $\pm$ 0.04	7.34 $\pm$ 0.003	6.5–8.5
Turbidity	0.05 $\pm$ 0.003	0.03 $\pm$ 0.003	0.03 $\pm$ 0.002	0.03 $\pm$ 0.003	0.06 $\pm$ 0.003	0.03 $\pm$ 0.003	0.03 $\pm$ 0.003	0.04 $\pm$ 0.003	0.04 $\pm$ 0.003	0.03 $\pm$ 0.003	5
TDS	392.1 $\pm$ 1.66	445.4 $\pm$ 0.33	461.9 $\pm$ 0.66	473.3 $\pm$ 0.99	526.7 $\pm$ 1.33	449.1 $\pm$ 2.32	518.4 $\pm$ 0.33	538.6 $\pm$ 0.33	506.4 $\pm$ 0.34	466.0 $\pm$ 1.70	500
Chloride	15.71 $\pm$ 1.18	16.24 $\pm$ 1.18	19.79 $\pm$ 1.18	19.8 $\pm$ 1.18	23.3 $\pm$ 1.18	17.48 $\pm$ 1.18	19.26 $\pm$ 1.18	22.81 $\pm$ 1.18	20.95 $\pm$ 1.80	18.1 $\pm$ 1.20	250
Sulfate	79.24 $\pm$ 1.62	102.9 $\pm$ 7.90	98.03 $\pm$ 1.07	81.30 $\pm$ 4.42	85.4 $\pm$ 4.73	78.48 $\pm$ 7.85	116.9 $\pm$ 7.99	105.2 $\pm$ 0.74	112.6 $\pm$ 1.36	132.2 $\pm$ 4.87	250
Calcium	75.40 $\pm$ 2.65	82.80 $\pm$ 5.31	53.70 $\pm$ 1.33	79.4 $\pm$ 2.65	90.4 $\pm$ 5.57	58.30 $\pm$ 1.32	85.70 $\pm$ 1.33	87.4 $\pm$ 2.65	90.4 $\pm$ 1.36	90.4 $\pm$ 1.36	75
Magnesium	28.14 $\pm$ 2.39	34.68 $\pm$ 4.78	46.26 $\pm$ 2.39	30.18 $\pm$ 0.80	40.97 $\pm$ 6.63	41.2 $\pm$ 0.001	51.06 $\pm$ 2.39	41.1 $\pm$ 3.98	40.80 $\pm$ 4.07	40.97 $\pm$ 0.31	50
Sodium	0.93 $\pm$ 0.003	1.86 $\pm$ 0.007	2.79 $\pm$ 0.007	6.62 $\pm$ 0.07	3.76 $\pm$ 0.03	1.04 $\pm$ 0.03	2.79 $\pm$ 0.003	3.82 $\pm$ 0.07	1.86 $\pm$ 0.003	0.93 $\pm$ 0.003	200
Potassium	0.74 $\pm$ 0.003	0.64 $\pm$ 0.007	0.90 $\pm$ 0.007	1.79 $\pm$ 0.007	0.90 $\pm$ 0.003	3.55 $\pm$ 0.003	1.77 $\pm$ 0.007	1.52 $\pm$ 0.20	0.93 $\pm$ 0.002	0.90 $\pm$ 0.007	12
Nitrate	3.17 $\pm$ 0.041	2.50 $\pm$ 0.082	2.62 $\pm$ 0.082	2.67 $\pm$ 0.04	2.18 $\pm$ 0.04	2.43 $\pm$ 0.04	2.67 $\pm$ 0.04	2.55 $\pm$ 0.04	2.55 $\pm$ 0.042	2.43 $\pm$ 0.04	50
TA	243.6 $\pm$ 4.97	259.7 $\pm$ 3.65	272.1 $\pm$ 6.96	270.1 $\pm$ 11.61	317.1 $\pm$ 1.66	263.5 $\pm$ 4.31	316.4 $\pm$ 4.97	298.6 $\pm$ 4.97	317.0 $\pm$ 1.70	272.0 $\pm$ 1.70	200
TH	304.4 $\pm$ 3.21	349.9 $\pm$ 6.41	324.8 $\pm$ 13.16	322.8 $\pm$ 3.35	396.6 $\pm$ 6.37	313.9 $\pm$ 3.32	424.6 $\pm$ 13.2	387.8 $\pm$ 23.0	394.1 $\pm$ 13.4	394.1 $\pm$ 3.39	500

All the parameters are in mg/L except pH and turbidity (NTU)

Table 7 Mean $\pm$ SD values of the studied parameters of each sampling site during the wet season

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Water quality standards
pH	7.52 $\pm$ 0.023	7.36 $\pm$ 0.02	7.42 $\pm$ 0.02	7.36 $\pm$ 0.03	7.25 $\pm$ 0.004	7.36 $\pm$ 0.027	7.46 $\pm$ 0.02	7.33 $\pm$ 0.02	7.33 $\pm$ 0.008	7.38 $\pm$ 0.04	6.5–8.5
Turbidity	0.04 $\pm$ 0.004	0.03 $\pm$ 0.005	0.03 $\pm$ 0.01	0.02 $\pm$ 0.005	0.05 $\pm$ 0.007	0.03 $\pm$ 0.005	0.02 $\pm$ 0.004	0.03 $\pm$ 0.006	0.02 $\pm$ 0.002	0.02 $\pm$ 0.004	5
TDS	385.0 $\pm$ 11.7	412.7 $\pm$ 12.8	459.4 $\pm$ 1.98	467.5 $\pm$ 1.38	495.2 $\pm$ 1.7	452.5 $\pm$ 1.62	455.3 $\pm$ 2.93	535.6 $\pm$ 2.46	493.6 $\pm$ 1.59	458.4 $\pm$ 3.30	500
Chloride	32.19 $\pm$ 2.29	36.1 $\pm$ 2.43	34.81 $\pm$ 3.39	37.82 $\pm$ 3.11	24.3 $\pm$ 2.5	34.02 $\pm$ 2.08	36.08 $\pm$ 0.34	39.17 $\pm$ 1.15	25.38 $\pm$ 0.37	34.24 $\pm$ 1.31	250
Sulfate	27.27 $\pm$ 6.13	91.12 $\pm$ 2.48	61.85 $\pm$ 10.6	47.41 $\pm$ 7.49	28.0 $\pm$ 3.48	29.08 $\pm$ 4.36	93.83 $\pm$ 4.41	67.47 $\pm$ 18.0	116.4 $\pm$ 21.25	90.15 $\pm$ 7.17	250
Calcium	73.16 $\pm$ 2.94	78.49 $\pm$ 1.68	73.67 $\pm$ 1.97	75.02 $\pm$ 3.24	89.96 $\pm$ 5.4	82.84 $\pm$ 2.94	74.31 $\pm$ 3.93	86.58 $\pm$ 1.47	80.89 $\pm$ 3.97	80.18 $\pm$ 4.18	75
Magnesium	37.87 $\pm$ 2.38	38.45 $\pm$ 1.28	44.60 $\pm$ 2.67	43.25 $\pm$ 4.28	36.69 $\pm$ 0.9	33.44 $\pm$ 2.65	43.36 $\pm$ 1.55	53.97 $\pm$ 3.89	49.17 $\pm$ 3.89	42.77 $\pm$ 1.16	50
Sodium	2.95 $\pm$ 0.17	3.54 $\pm$ 0.19	7.76 $\pm$ 0.34	15.02 $\pm$ 0.17	9.02 $\pm$ 0.35	3.25 $\pm$ 0.29	5.74 $\pm$ 0.17	9.88 $\pm$ 0.34	3.12 $\pm$ 0.34	3.12 $\pm$ 0.34	200
Potassium	1.05 $\pm$ 0.16	1.28 $\pm$ 0.07	1.41 $\pm$ 0.18	2.93 $\pm$ 0.34	2.10 $\pm$ 0.33	3.78 $\pm$ 0.24	1.94 $\pm$ 0.16	2.04 $\pm$ 0.33	1.21 $\pm$ 0.33	1.21 $\pm$ 0.33	12
Nitrate	2.83 $\pm$ 0.15	2.91 $\pm$ 0.10	2.95 $\pm$ 0.09	2.54 $\pm$ 0.13	2.27 $\pm$ 0.10	3.14 $\pm$ 0.10	2.83 $\pm$ 0.18	3.14 $\pm$ 0.10	2.95 $\pm$ 0.21	2.52 $\pm$ 0.40	50
TA	305.9 $\pm$ 3.86	325.0 $\pm$ 5.4	320.1 $\pm$ 7.32	343.7 $\pm$ 5.6	368.0 $\pm$ 3.6	330.8 $\pm$ 5.85	338.1 $\pm$ 1.97	368.7 $\pm$ 4.93	370.3 $\pm$ 9.06	346.1 $\pm$ 2.60	200
TH	338.9 $\pm$ 6.39	354.7 $\pm$ 3.6	367.9 $\pm$ 8.83	365.8 $\pm$ 9.7	376.1 $\pm$ 9.9	344.9 $\pm$ 3.55	364.4 $\pm$ 3.74	438.8 $\pm$ 12.6	404.8 $\pm$ 7.19	376.7 $\pm$ 12.9	500

All the parameters are in mg/L except pH and turbidity (NTU)

Table 8 Paired *t* test analysis for determining seasonal variation in physicochemical parameters

Parameters	S1			S2			S3			S4			S5		
	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference
pH	-0.41, -0.35	-0.378**	-0.14, -0.09	-0.12**	-0.12**	-0.15, -0.10	-0.13**	-0.13**	0.013, 0.13	0.07*	-0.32, -0.22	-0.27**	-0.32, -0.22	-0.27**	-0.32, -0.22
Turbidity	0.004, 0.01	0.009**	-0.01, 0.01	0.001	0.001	-0.003, 0.01	0.0005	0.0005	-0.004, 0.01	0.002	0.003, 0.014	0.009**	0.003, 0.014	0.009**	0.003, 0.014
TDS	-6.59, 20.75	7.08	19.24, 46.23	32.7**	32.7**	0.949, 3.862	2.41**	2.41**	3.85, 7.70	5.78**	28.4, 34.6	31.5**	28.4, 34.6	31.5**	28.4, 34.6
Chloride	-19.7, -13.3	-16.5**	-21.9, -17.8	-19.9**	-19.9**	-18.0, -12.1	-15.0**	-15.0**	-20.9, -15.1	-18.0**	-3.21, 1.25	-0.98	-3.21, 1.25	-0.98	-3.21, 1.25
Sulfate	44.81, 59.12	51.96**	2.92, 20.72	11.82*	11.82*	26.02, 46.34	36.18**	36.18**	22.99, 44.80	33.9**	49.74, 65.03	57.38**	49.74, 65.03	57.38**	49.74, 65.03
Magnesium	-10.7, -8.79	-9.73**	-8.73, 1.18	-3.77	-3.77	-3.17, 6.49	1.66	1.66	-16.8, -9.4	-13.1**	-1.05, 9.15	4.05	-1.05, 9.15	4.05	-1.05, 9.15
Calcium	0.502, 3.987	2.24*	-1.13, 9.75	4.31	4.31	-22.2, -17.7	-19.9**	-19.9**	3.18, 5.58	4.38**	-1.43, 4.52	1.54	-1.43, 4.52	1.54	-1.43, 4.52
Nitrate	0.167, 0.512	0.34**	-0.59, -0.24	-0.42**	-0.42**	-0.44, -0.22	-0.33**	-0.33**	-0.02, 0.28	0.13	-0.202, 0.014	-0.094	-0.202, 0.014	-0.094	-0.202, 0.014
Sodium	-2.20, -1.85	-2.03**	-1.88, -1.47	-1.68**	-1.68**	-5.31, -4.61	-4.97**	-4.97**	-8.60, -8.21	-8.40**	-5.60, -4.92	-5.26**	-5.60, -4.92	-5.26**	-5.60, -4.92
Potassium	-0.48, -0.13	-0.31**	-0.71, -0.57	-0.64**	-0.64**	-0.70, -0.32	-0.51**	-0.51**	-1.49, -0.78	-1.13**	-1.54, -0.86	-1.20**	-1.54, -0.86	-1.20**	-1.54, -0.86
TA	-69.3, -55.2	-62.3**	-69.9, -60.7	-65.3**	-65.3**	-61.9, -34.2	-48.1**	-48.1**	-89.7, -57.6	-73.6**	-55.2, -46.6	-50.9**	-55.2, -46.6	-50.9**	-55.2, -46.6
TH	-40.4, -28.6	-34.5**	-12.6, 3.01	-4.77	-4.77	-64.5, -21.7	-43.1**	-43.1**	-56.5, -29.4	-42.9**	3.69, 37.38	20.53**	3.69, 37.38	20.53**	3.69, 37.38

Parameters	S6			S7			S8			S9			S10		
	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference	95% CI for mean difference	Mean difference	95% CI for mean difference
pH	-0.42, -0.36	-0.39**	-0.30, -0.27	-0.28**	-0.28**	-0.231, -0.193	-0.21**	-0.21**	-0.42, -0.33	-0.37**	-0.083, -0.002	-0.04*	-0.083, -0.002	-0.04*	-0.083, -0.002
Turbidity	-0.005, 0.01	0.0008	-0.002, 0.01	0.002	0.002	-0.0001, 0.012	0.006	0.006	0.007, 0.015	0.011**	-0.002, 0.007	0.003	-0.002, 0.007	0.003	-0.002, 0.007
TDS	-4.91, -0.16	-2.54*	60.24, 66.07	63.16**	63.16**	0.666, 5.240	2.95*	2.95*	11.26, 14.25	12.76**	2.46, 12.78	7.62*	2.46, 12.78	7.62*	2.46, 12.78
Chloride	-19.8, -13.3	-16.5**	-17.9, -15.8	-16.8**	-16.8**	-18.46, -14.26	-16.36**	-16.36**	-6.33, -2.55	-4.44**	-18.7, -13.6	-16.1**	-18.7, -13.6	-16.1**	-18.7, -13.6
Sulfate	38.29, 60.50	49.4**	18.10, 28.08	23.09**	23.09**	18.22, 57.39	37.80**	37.80**	-25.81, 18.23	-3.79	29.86, 54.2	42.06**	29.86, 54.2	42.06**	29.86, 54.2
Magnesium	-27.9, -21.2	-24.5**	8.52, 14.25	11.4**	11.4**	-0.913, 2.557	0.822	0.822	4.32, 14.71	9.51**	4.52, 15.92	10.22**	4.52, 15.92	10.22**	4.52, 15.92
Calcium	4.82, 10.70	7.76**	3.62, 11.78	7.70**	7.70**	-21.02, -4.73	-12.87*	-12.87*	-15.38, -1.37	-8.37*	-3.29, -0.33	-1.81*	-3.29, -0.33	-1.81*	-3.29, -0.33
Nitrate	-2.52, -1.89	-2.21**	-3.13, -2.77	-2.95**	-2.95**	-6.43, -5.70	-6.07**	-6.07**	-1.62, -0.90	-1.26**	-2.55, -1.83	-2.19**	-2.55, -1.83	-2.19**	-2.55, -1.83
Sodium	-0.48, 0.024	-0.23	-0.34, 0.001	-0.171	-0.171	-1.05, 0.02	-0.51	-0.51	-0.652, 0.091	-0.28	-0.643, 0.033	-0.305	-0.643, 0.033	-0.305	-0.643, 0.033
Potassium	-0.82, -0.61	-0.71**	-0.37, 0.060	-0.156	-0.156	-0.718, -0.462	-0.59**	-0.59**	-0.63, -0.17	-0.40**	-0.491, 0.309	-0.091	-0.491, 0.309	-0.091	-0.491, 0.309
TA	-75.6, -59.1	-67.3**	-28.5, -14.9	-21.7**	-21.7**	-79.56, -60.54	-70.1**	-70.1**	-62.96, -43.6	-53.3**	-76.7, -71.5	-74.1**	-76.7, -71.5	-74.1**	-76.7, -71.5
TH	-36.2, -25.9	-31.0**	49.44, 70.95	60.2**	60.2**	-88.1, -13.9	-51.0*	-51.0*	-26.77, 5.33	-10.72	0.46, 34.40	17.43**	0.46, 34.40	17.43**	0.46, 34.40

Differences between means were calculated by subtracting values during the wet season from values during the dry season

*Mean difference significant at $p < 0.05$ **Mean difference significant at $p < 0.01$

in physicochemical parameters (at 95% probability levels) are given in Table 8.

Physicochemical parameters

pH refers to the degree of acidity or alkalinity of a solution or water. pH is a crucial indicator that can be used for assessing water quality and degree of contamination in water bodies. The results of pH values in all the sampling sites in both seasons ranged from 7.52 at S1 to 6.5 at S9. On this basis, all the water samples were almost neutral to slightly alkaline. These values aligned with the findings of other researchers (Al-Jiburi and Al-Basrawi 2015; Barakat et al. 2018) who reported that the pH of water sources in the area are characterized by a shift toward the alkaline side of neutrality; this might be due to the geological composition of the region, which consists largely of calcium carbonate (CaCO_3) (Al-Jiburi and Al-Basrawi 2015). The pH values in all the study sites were within an acceptable range (6.5–8.5) for both dry and wet seasons. The pH values, except for site S4, were significantly greater during wet season than during dry season ($p < 0.05$).

Turbidity is another indicator of water quality. Turbidity measures the relative clarity of the water by the presence of organic and mineral suspended particles and color producing substances (Shigut et al. 2017). The mean turbidity readings of the samples at all sampling sites and in both seasons were in the range of 0.02 to 0.06 Nephelometric Turbidity Units (NTU). Turbidity levels are very low compared to results of other studies (Al-Jiburi and Al-Basrawi 2015; Barakat et al. 2018; Shigut et al. 2017), and the results were far below the permissible level (5NTU) suggested by Iraqi and international standards for drinking water. According to (Barakat et al. 2018), “the higher levels of turbidity caused by suspended solid particles are due to fast transport pathway connecting potentially contaminated surface water with the aquifer.” The low turbidity values obtained in the present study could indicate an absence of such contamination transport pathways. Seasonally, paired *t* test results revealed that there was no statistically significant difference ($p > 0.05$) between the dry and wet seasons in terms of turbidity in most of the water samples, with exception of site S1 and site S5.

TDS, which is a measure of the salinity of groundwater, is also frequently used as a useful parameter for evaluating the quality of water and for classifying drinking and irrigation water (Barakat et al. 2018). TDS is usually estimated by electrical conductivity (EC) and there is a strong relationship between EC and TDS. EC refers to the direct measure of TDS (Abdulwahid 2013). According to Barakat et al. (2018), “the concentration of dissolved chemical substances and mineral contamination in water are controlled by the level of EC of the water.” The TDS ranged from 385 mg/L

at site S1 during the wet season to 538.6 mg/L at site S8 during the dry season. During the dry season, the TDS at sites S5, S7, S8, and S9 exceeded the maximum contaminant level (500 mg/L) based on the EPA standards (EPA 2018), while during the wet season, only site S8 exceeded the EPA maximum contaminant level. A similar result was obtained by Abdulwahid (2013) and Idoko and Oklo (2012). These higher TDS values could be due to the natural weathering of certain sedimentary rocks or a certain anthropogenic source, e.g., irrigation discharge, domestic effluents, and sewage effluent. The TDS values in most sampled sites were significantly higher in the wet season ($p < 0.05$) compared to the dry season, except at sites S5 and S10.

Chloride is one of the important water quality indicators and is widely found in nature in the form of salts of sodium (NaCl), potassium (KCl), and calcium (CaCl_2). There are numerous natural and anthropogenic factors that contribute to chloride levels in groundwater, including geological weathering, leaching from rocks, domestic effluent, irrigation discharge, agricultural use, etc. (Barakat et al. 2018). In the present investigation, the values of Cl^- ranged from 15.71 to 23.3 mg/L during the dry season and 24.32 to 39.17 mg/L during the wet season. These variations could be due to the variations in geology, rainfall, dissolution of fluid inclusions, Cl^- bearing minerals at these sites, or the existence of potentially polluted sources, such as domestic effluent, fertilizers, and septic tank effluent. The results revealed that chloride values in water samples during wet and dry seasons were all within the permissible limit (250 mg/L) for drinking water according to the EPA standards (EPA 2018). Chloride values in all spring water samples were found to be significantly greater during wet season than during dry season ($p < 0.05$). A possible explanation of the higher levels of Cl^- during the rainy season is that the Cl^- ion may be carried by rainwater into the groundwater.

Sulfate (SO_4^{2-}) is another important chemical parameter for water quality and has an influence on the taste and odor of drinking water (Bouslah et al. 2017). Water containing higher levels of SO_4^{2-} could have a noticeable taste and might cause a laxative effect in unaccustomed consumers (WHO 2017). SO_4^{2-} in the aquifer system is derived primarily from weathering of two major forms of SO_4^{2-} containing rocks, namely pyrite and gypsum, in addition to the inputs from anthropogenic activities (Ziani et al. 2017). SO_4^{2-} values of the sampled spring water for dry and wet seasons ranged from 79.24 to 116.9 mg/L and 27.27 to 116.4 mg/L, respectively. The lowest values of SO_4^{2-} were observed at the same site (S1) during both seasons. SO_4^{2-} values were relatively high but within the permissible limit (250 mg/L) recommended by the EPA for drinking water (EPA 2018). The results align with the results of previous studies in the Kurdistan region. Abdulwahid (2013) and Ahmad (2014) note that Kurdistan region inland waters generally contain

a significant amount of SO_4^{2-} . This is due to the presence of gypsum-rich sedimentary rock and a shallow aquifer, which result in much higher sulfate values than other in other parts of the world (Abdulwahid 2013). On the other hand, it was found the SO_4^{2-} values at all most all water sampling sites were significantly higher ($p < 0.05$) during the dry season than the wet season. The lower concentration of SO_4^{2-} in the wet season may reflect the dilution of groundwater by rainwater.

Calcium and magnesium are also important parameters for assessing water quality because of their direct relationship with the development of water hardness. The concentrations of these two elements in natural water depend upon the type of rocks. They are both essential to human health in limited amounts. In the current study, the values of Ca^{2+} ranged from 40.97 to 90.4 mg/L during the dry season and 73.16 to 89.96 mg/L during the wet season. Except for sites S3, S5, and S6, the values of Ca^{2+} at all the studied sites were greater than the permissible limit (75 mg/L) as per Iraqi standards (Drinking Water Standard IQS:417 2001). On the other hand, the Mg^{2+} values ranged from 28.14 to 51.06 mg/L during the dry season and 33.44 to 53.97 mg/L during the wet season. The results revealed that, except at site S7 during the dry season and site 8 during the wet season, the values of Mg^{2+} at all sampling sites did not exceed the permissible limit of 50 mg/L as per Iraqi standards (Drinking Water Standard IQS:417 2001). This variation in Ca^{2+} and Mg^{2+} levels might be related to the weathering of rocks and mineral content of each ion, such as sedimentary rocks, limestone, dolomite, gypsum, aragonite, the mineral of igneous rock, feldspars amphibole and pyroxene, and the pH value of each source (Hem 1985). Therefore, a simple physical treatment of the study spring water is preferable to minimize loads of these nutrients. In the present investigation, in general, it was also observed that the level of Ca^{2+} exceeded the level of Mg^{2+} ; this case could be attributed to the chemical properties of the soil and geological origin of water source (Toma et al. 2013). Except for sites S3 and S6, all sites had significantly a higher value of Ca^{2+} during the dry season than in the wet season, while half of the sampling sites showed significantly higher values of Mg^{2+} during the wet season ($p < 0.05$) than the dry season. The higher values of Ca^{2+} in the dry season may be due to the rapid ingress of rainwater, which reduces the dissolution of soil minerals and rocks (Al-Khashman 2008).

Sodium (Na^+) and potassium (K^+) are also widely used as important indicators for assessing water quality. Sodium is an essential nutrient needed by the human body for a number of functions such as muscle and nerve function, but an elevated concentration of Na^+ may cause a high chance of blood pressure and consequently increase the rate kidney failure (Batool et al. 2018). On the other hand, although no adverse health effects have been reported to be caused

by potassium intake through drinking water, it can cause an unpleasant taste and corrosion of pipes (Karavoltsov et al. 2008). Sodium in the aquifer system is mainly derived from the dissolution of salt minerals and silicate weathering (Ziani et al. 2017). In the present study, the values of Na^+ ranged from 0.93 to 6.62 mg/L during the dry season and 2.95 to 15.02 mg/L during the wet season. It was noticed that the minimum and maximum values of Na^+ have been recorded for both the dry and the wet seasons at the same sites (S1 and S4). The differences in Na^+ values could be related to the geological variation or rock mineral composition of these sites. On the other hand, K^+ values ranged from 0.64 to 3.55 mg/L during the dry season and 1.05 to 3.78 mg/L during the wet season. The minimum and maximum values of K^+ were also recorded for both dry and wet seasons at the same sites (S1 and S6). Again, this could be related to the geological variation or rock mineral composition at these sites. The Na^+ and K^+ concentrations from the study sites were lower than the permissible limits during both dry and wet seasons. In almost all water samples, the concentrations of K^+ were slightly lower than Na^+ . The K^+ is fixed by clay minerals and participates in the formation of secondary minerals, which could explain the low K^+ levels (Scheytt 1997). Concerning the seasonal variation, it was found that Na^+ values at almost all sites and K^+ at five sites were significantly higher ($p < 0.05$) during the wet season than the dry season.

Nitrate (NO_3^-) is another important parameter for assessing water quality. Nitrate is considered undesirable in drinking water as it can cause a number of health disorders, such as methemoglobinemia in infants, gastric cancer, goiter, birth malformations, and hypertension (Majumdar and Gupta 2000; Shigut et al. 2017). Natural concentrations of NO_3^- in groundwater are generally low, but concentrations increase as a result of anthropogenic activities, such as agricultural activities, and discharge of domestic effluent and septic tank effluent (Barakat et al. 2018). The NO_3^- concentrations in analyzed samples ranged from 2.18 to 3.17 mg/L during the dry season and 2.27 to 3.14 mg/L during the wet season. The NO_3^- values of all the spring water samples were far below the prescribed limit (50 mg/L) as per WHO standards (WHO 2017). Except for site S1, the NO_3^- concentration during the wet season was significantly higher ($p < 0.05$) than during the dry season. This data agreed with results of other researchers (Vilane and Dlamini 2016) who stated that “this difference in the means may be attributed to runoff driven nitrates from the surrounding areas, which accumulated during the dry period and deposited in the spring during the wet season.”

Total alkalinity (TA) refers to the capability of water to resist changes in pH. Carbonate and bicarbonate alkali substances represent the major forms of alkalinity in natural waters. Alkalinity testing is highly important for evaluating

water alkalinity changes due to anthropogenic disturbances (Barakat et al. 2018). The TA in the study area was mainly attributed to bicarbonate alkalinity, as reported by Abdulwahid (2013). TA values for the spring water samples in the study region ranged from 243.6 to 317 mg/L during the dry season and 305.9 to 370 mg/L during the wet season. Seasonal variation analyses revealed that virtually all sites have significantly higher values of TA during the wet season ($p < 0.05$) than during the dry season. The minimum and maximum values recorded for both dry and wet seasons occurred at the same sites (S1 and S9). According to Iraqi standards (Drinking Water Standard IQS:417 2001), the TA values of all spring water samples exceeded the permissible limit of 200 mg/L.

The total hardness (TH) is another essential indicator for assessing water quality for domestic, industrial, or agricultural purposes (Al-Jiburi and Al-Basrawi 2015). The development of hardness in water is primarily derived from dissolved alkaline earth metals, such as calcium and magnesium, with all other divalent cations also contributing to the concentration (Barakat et al. 2018). The rocks surrounding the water body are largely the source of TH, although some anthropogenic activity could contribute to varying concentrations (Bouslah et al. 2017). The TH values ranged from 304.4 to 424.6 mg/L during the dry season and 338.9 to 438.8 mg/L during the wet season, and the minimum and maximum values of TH were recorded at the same sites (S1 and S8). The TH values of all the water spring samples in the present study were below the permissible limit (500 mg/L) as per Iraqi standards (Drinking Water Standard IQS:417 2001), although the values were close to the allowable level. Higher values for TH were found in the work conducted by other researchers (Abdulwahid 2013; Barakat et al. 2018; Vilane and Dlamini 2016). Since the TH depends mainly on the geological context, the high values observed could

be related to the lithological nature of the aquifer formation which corresponds to Jurassic carbonate rocks of the mountains in the study area. At these TH levels, there could be adverse effects on human health in the long-term (Barakat et al. 2018). Therefore, a simple physical treatment of the study spring water is preferable to minimize hardness. There is significant seasonal variation in the TH values, and almost all of the sites showed significantly higher TH values during wet season than during dry season, except at sites S5, S7, and S10. This could be attributed to the solvent action of rainwater coming into contact with soil and rocks capable of dissolving calcium and magnesium and that promote water hardness (Vilane and Dlamini 2016).

Overall water quality indices

For evaluating the WQI of the sampled spring water, the weighted arithmetic index method (Brown et al. 1972) was used based on the measured values of the physicochemical parameters. The WQI is the most effective way to communicate water quality because it presents the overall water quality results, rather than the results for each separate parameter (Toma et al. 2013). The WQI values for all spring water samples for each season are presented in Table 9. In the present study, the WQI was calculated twice for each season, once for all parameters and once for specified parameters. Where parameters were close to or exceeded the maximum permissible limits, such as TDS, Ca^{2+} , Mg^{2+} , K^+ , SO_4^{2-} , TA, and TH, these parameters showed the maximum influence on the WQI.

The minimum and maximum values of WQI based on all parameters ranged from 10.76 to 18.13 during the dry season and 17.10 to 20.45 during the wet season, and these values indicate “excellent” class for drinking purposes. When applying WQI based on specified parameters, the WQI score

Table 9 WQI and classification for the sampled sites

Sites codes	Site name	Dry season				Wet season			
		All parameters		Specified parameters		All parameters		Specified parameters	
		WQI	Water quality	WQI	Water quality	WQI	Water quality	WQI	Water quality
S1	Kyle Baze	11.44	Excellent	30.81	Good	19.0	Excellent	35.8	Good
S2	Kani Mazne	13.79	Excellent	35.7	Good	17.25	Excellent	39.24	Good
S3	Miska	15.11	Excellent	35.33	Good	18.71	Excellent	40.9	Good
S4	Xshxasha	18.13	Excellent	38.45	Good	19.88	Excellent	49.1	Good
S5	Beqolke	11.17	Excellent	39.95	Good	17.10	Excellent	44.98	Good
S6	Bnavi	13.13	Excellent	48.12	Good	20.45	Excellent	51.11	Poor
S7	Kani Mase	16.46	Excellent	34.21	Good	20.15	Excellent	44.16	Good
S8	Derishke	14.25	Excellent	42.72	Good	19.85	Excellent	50.39	Poor
S9	Maye	10.76	Excellent	40.24	Good	18.04	Excellent	44.1	Good
S10	Bedhi	16.18	Excellent	39.38	Good	17.94	Excellent	41.0	Good

ranged from 30.81 to 48.12 for the dry season and 35.8 to 51.11 for wet season, and these values indicate “good” quality for drinking purposes, except at sites S6 and S8 during the wet season, which were classified as “poor” water quality and unsuitable for drinking purposes. The unsuitability of these two spring water samples could be due to the contact of rainwater with the sedimentary rock in the region leading to dissolution of ions into the aquifer or could be due to various anthropogenic activities, such as sewage disposal, waste disposal, agricultural activities, the presence of dirty drainage behind the spring water source, and anthropogenic pollution from the nearby dumpsite. However, these two sites with poor water quality could be suitable for drinking water purposes following a simple purification treatment, such as filtration.

Conclusion

The current study has been conducted to evaluate the quality of spring water based on several physicochemical parameters. Based on individual parameters, the majority of water samples were found to be suitable for drinking purposes and within permissible limits according to the chosen standard, except for a few samples, where TDS, TH, Ca^{2+} , Mg^{2+} , and TH were close to or exceeded the permissible limits of Iraqi standards, which indicates the water is not suitable for drinking without further treatment.

The overall WQI revealed that, by including all physicochemical parameters, all spring water samples were classified as “excellent” quality during both wet and dry seasons. When using parameters which have values close or exceeding the maximum acceptable limits, the water quality status was “good” quality for all water samples, except at two sites (S6 and S8), during the wet season which were classified as “poor” quality.

Based on the results of the present study, the current physicochemical parameters concentrations have no noticeable negative impacts on human health but could have negative impacts on human health in the long term, particularly where sites have higher values for some of the investigated parameters. Therefore, it is recommended that a simple physical treatment such as filtration of the study spring water is desirable to reduce nutrient loads and to ensure a better-quality water supply for the rural people. Furthermore, it is mandatory to regularly monitor these water sources in order to detect any changes in water quality parameters.

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