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Heavy Metals Contamination Assessment Using Pollution Indices for Spring Water in Barwari Bala Villages, Duhok, Kurdistan Region-Iraq

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ABSTRACT

Regular quality monitoring of drinking water resources is crucial for ensuring a safe drinking water supply for various users. Thus, this study was carried out to assess water safety for human drinking in terms of heavy metal content using pollution indices for spring water in Barwari Bala Villages located in Duhok City, Kurdistan Region of Iraq. Six spring water samples were collected at 10 to 15 day intervals from 10 areas during the summer of 2023. All 60 samples were analyzed in the laboratory to evaluate heavy metal concentrations, including manganese (Mn), chromium (Cr), iron (Fe), zinc (Zn), copper (Cu), cadmium (Cd), and lead (Pb). The overall quality of water was then assessed by utilizing pollution indices, including the degree of contamination (Cd), the heavy metal evaluation index (HEI), and the heavy metal pollution index (HPI). The results revealed that the concentrations of all the selected heavy metals found in spring water samples were lower than the permissible limits based on Iraqi standards, except for Pb in sites SW1 (Kyle Baze), SW2 (Kani Mazne), and SW8 (Derishke), which had higher concentrations of Pb depending on the prescribed limits (10 µg/L). According to metal pollution indices, the values of all the indices were lower than their critical ranges of contamination, indicating that the water of every site was safe for drinking. However, greater concentrations of Pb in spring water at sites SW1, SW2, and SW8 might have an adverse impact on human consumption in the long term. Thus, the treatment of spring water at these sites before utilization is highly recommended to ensure safe water for consumption. Further research is needed to determine the causes and contributing factors behind the rising lead (Pb) levels observed at those locations, as well as to develop appropriate treatment strategies to mitigate contamination.

1. INTRODUCTION

Water is considered one of the most valuable natural resources as it is necessary for all life forms and vital for various human activities. In recent years, freshwater demand has dramatically increased due to rapid growth in the human population (Alobaidy et al., 2010; Saleh et al., 2022). However, with the ever-increasing demand for water and the impact of various anthropogenic activities and climate change, the quality of water resources is under constant threat (Ameen, 2019; Poudel and Duex, 2017). Moreover, many nations, particularly developing countries, have faced a scarcity in freshwater resources because of climate change (Postel, 2000). For a healthy lifestyle and a sufficient supply of clean drinking water, it becomes crucial to assess and monitor water quality effectively.

Groundwater springs are considered vital lifelines for millions of mountain people around the world, providing the main supply of household water and local food security (Gurung et al., 2019; Hosseinifard and Mirzaei Aminiyan, 2015). In recent years, from the important issues that the environment has been facing is the contamination of water

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resources. The quality of groundwater and spring water is generally good; however, it is affected by many factors. Agricultural practices, urbanization, industrial activities, climate change, and remnants of war are considered significant threats to the quality of water (Li et al., 2021; Patil et al., 2022; Swain, 2024). It has been stated that the pollution of groundwater by pollutants such as heavy metals, pesticides, hydrocarbons, trace organic contaminants, microplastics, nanoparticles, and other emerging pollutants has a serious impact on human health and the quality of water, making it extremely important to assess and understand the quality of water (Li, 2020; Tran et al., 2023; Wang et al., 2023; Badar et al., 2024).

One of the effective approaches for assessing heavy metal contamination in aquatic systems is through the application of heavy metal pollution indices (Ameen et al., 2019; Kamali Maskooni et al., 2020; Majeed and Ibraheem, 2024). These indicators are considered very important tools for water quality assessment, as they provide a summarized numerical value or rating that represents the water quality based on multiple water quality parameters (Ameen et al., 2019; Prasad Ahirvar et al., 2023; Shigut et al., 2017). Moreover, water quality indices facilitate the interpretation and communication of water quality information to policymakers, water resource managers, and the general public (Banda and Kumarasamy, 2020; Lukhabi et al., 2023). Consequently, various water quality and pollution indexes have been proposed and accepted globally. The most widely used indices for such purposes include the heavy metal evaluation index (HEI), the heavy metal pollution index (HPI), and the degree of contamination (Cd) (Backman et al., 1998; Brown et al., 1970; Edet and Offiong, 2002; Raja et al., 2021; Shigut et al., 2017; Terry and Stone, 2002).

Numerous studies across the globe have used these indices to evaluate the quality of water. For instance, in Damascus, Syria, researchers found that 74% of groundwater samples have an HPI lower than the mean value of 8.58. Whereas 26% of the samples exceed this mean and only one sample reaches the limit of low pollution by heavy metal (Abou Zakhem and Hafez, 2015). The same study reported that high HPI values are concentrated in the southeastern to central parts of Damascus, especially in the northeast, due to industrial, agricultural, and urban activities, as well as heavy metal leaching from a sewage treatment station. Similarly, a study in Iraq's Maysan Province found values below the critical threshold of 100, indicating minimal pollution, though with localized risks due to industrial and agricultural activities (Jazza et al., 2022). Conversely, the Shatt Al-Arab River, Basrah-Iraq, exhibited HPI values ranging from 130.41 to 196.97, far exceeding safe limits (100), pointing to severe pollution from industrial and human activities (Al-Hejuje et al., 2017).

The vast majority of rural people in the Kurdistan Region of Iraq use groundwater and spring water for drinking without any type of treatment. The necessity of the identification and elimination of heavy metals from spring water cannot be understated because the water from these springs is utilized for a variety of purposes, including providing drinking water to villages and for agricultural purposes. Thus, the quality evaluation of spring water is needed to supply clean drinking water for any purpose. Although Ameen (2019) researched to assess the water quality in these springs for drinking, only the major elements were taken into account in this study, and heavy metal elements were not examined. To the best of the researchers' knowledge, no research has yet been undertaken using pollution indicators to assess the quality of spring water in this location; therefore, some form of indication of their concentration and variation ranges is needed to more correctly examine the quality of water. The current study was, therefore, aimed at evaluating the drinking water contamination by heavy metals and presenting the use of pollution indices as a possible monitoring tool for the drinking water quality of springs existing in Barwari Bala villages in the Amedi district in the Kurdistan Region of Iraq.

2. METHODOLOGY

2.1 Study area

This study was conducted in the ten villages of the Barwary Bala Region, located in the northern part of the Kurdistan Region of Iraq, alongside the Iraq-Turkey border. This area is roughly 100 kilometers from Duhok City. It lies at 37°10'03" N and 37°16'11" N latitudes and 43°10'08" E and 43°29'46" E longitudes. The region has a mountainous topography and a semiarid climate, which is distinguished by a dry and hot summer as well as a wet and cold winter that typically includes snow and higher rainfall. The geology of the region is completely of sedimentary origin and is made primarily of limestone (Ameen, 2019). It receives an annual rainfall of between 760 mm and 950 mm. Springs from ten villages were identified in the study. The main springs from each village were selected for investigation in case the villages have more than one spring. The symbols, names, and geographical locations of the selected springs are presented in Figure 1 and Table 1.

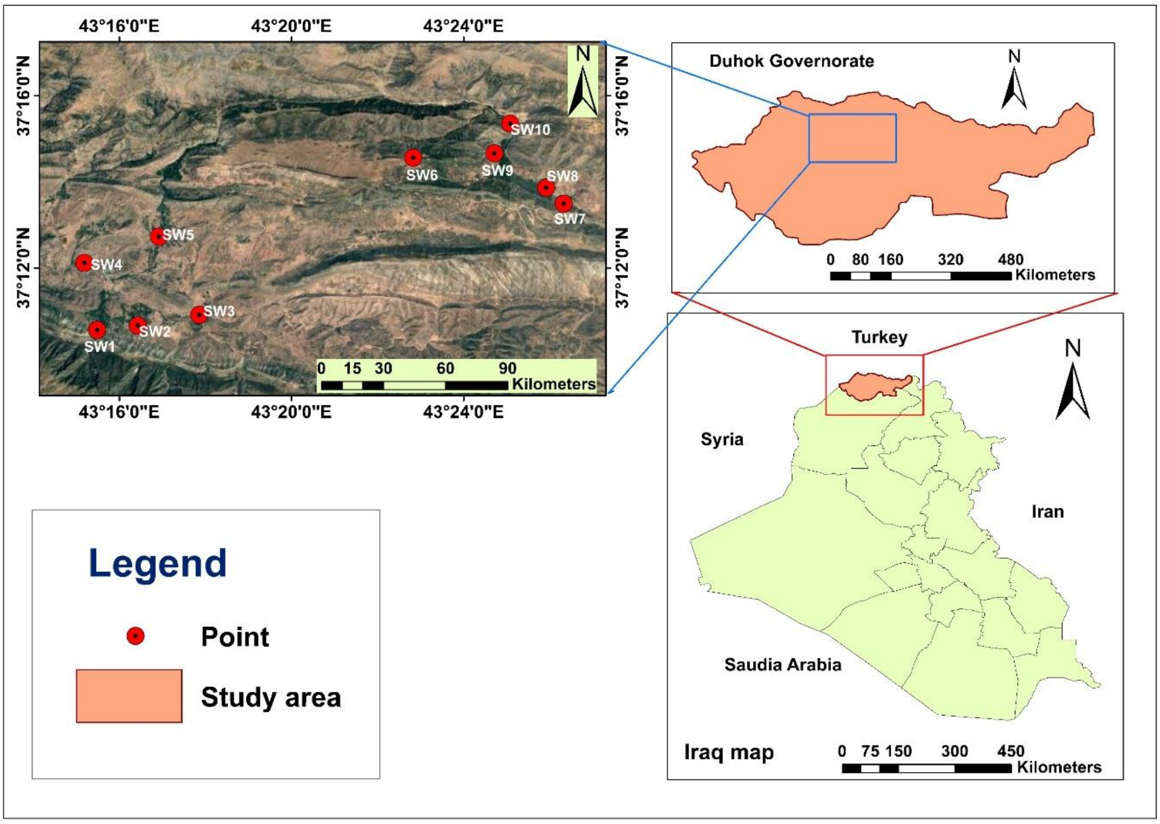

Figure 1. The study area and sample locations are shown on a map of Iraq with a satellite picture

Table 1. The symbol, names, and geographic location of the investigated water springs

Location	Sample symbol	Latitude	Longitude
Kyle Baze	SW1	37°10′31.29″N	43°15′28.78″E
Kani Mazne	SW2	37°10′39.73″N	43°16′26.10″E
Miska	SW3	37°10′54.36″N	43°17′50.88″E
Xshxasha	SW4	37°12′06.3″N	43°15′11.44″E
Beqolke	SW5	37°12′44.13″N	43°16′54.83″E
Bnavi	SW6	37°14′33.55″N	43°22′50.46″E
Kani Mase	SW7	37°13′29.3″N	43°26′18.86″E
Derishke	SW8	37°13′51.57″N	43°25′54.93″E
Maye	SW9	37°14'38.33"N	43°24'40.85"E
Bedhi	SW10	37°15′10.07″N	43°25′08.26″E

2.2 Sample collection and analysis

Spring water samples were obtained during the summer season of 2023 from June to October, as during this period, most of the people visit their villages and return to their original homes in cities during the winter. In the present study, six water samples were taken from each area at intervals of 10 to 15 days using stopper-fitted polyethylene bottles with a 450 mL capacity. Before collection, the sample collecting bottles were washed with distilled water multiple times and then with spring water. To reduce the precipitation and heavy metals adsorption, samples were then acidified with 5 mL of concentrated HNO_3 (50%) to a pH below 2 in accordance with national standard procedures (Rice et al., 2012). The obtained water samples were transported to the lab and stored at 4°C for further examination. All water samples were then analyzed to determine the concentrations of the following heavy metals manganese (Mn), chromium (Cr), iron (Fe), zinc (Zn), copper (Cu), Cadmium (Cd), and lead (Pb) by using the GBC Atomic Absorption Spectrophotometer (A.A.S.), Model 932 AA, Australia.

2.3 Pollution evaluation methods

Water pollution by heavy metals is typically estimated by heavy metal pollution or contamination indices. Various pollution indices are available worldwide for this purpose, and the three documented indexes used in the present research are the heavy metal pollution index (HPI), degree of contamination (C_d), and heavy metal evaluation index (HEI). These indices are calculated to assess the quality of drinking water concerning the content of heavy metals (Brraich and Jangu, 2015).

2.3.1 Heavy metal pollution index (HPI) calculation

This index, which indicates the collective effect of various heavy metals on the water quality, can be evaluated by employing the weighted arithmetic index technique applied by Brown et al. (1970) after minor adjustments. HPI is a rating technique that indicates the combined impact of several heavy metals on the water quality generally. This rating method is an arbitrarily chosen value between zero and one, and its selection relies on the relative significance of specific quality factors and is inversely proportional to the proposed rating standard (S_x) for each parameter (Prasad and Bose, 2001; Reza and Singh, 2010). In this research, HPI calculations were performed on seven important heavy metals, as shown in Table 2. The Iraqi Standard (COSQC, 2001) and WHO (2017) standards have been deployed to assess the samples in terms of water quality. The HPI was calculated based on the relative importance and its significant role on the overall quality of water, each of the chosen heavy metal parameters has been allocated a weight (W_x). As mentioned previously, the rating is a number between 0 and 1, representing the importance of selected heavy metals, and it is inversely proportional to the approved standards (S_x) for each heavy metal (Table 2). The unit weight (W_x) can be measured utilizing the following formula:

$$W_x = K/S_x \quad (1)$$

Where; W_x refers to the unit weightage of the parameters, S_x refers to the dependent standards, and K refers to the constant of proportionality, which was considered one in the current study. Then, the concentration of measured values for each parameter (Mv) was divided by its corresponding standard to get a quality rating score (Q_n) or sub-index, which was then multiplied by 100 as follows:

$$Q_n = M_V/S_x \times 100 \quad (2)$$

Where; M_v=the measured value of heavy metal of the ^{it}h parameter; S_x=the standards value for the ^{i}th parameter. Finally, utilizing the formula (Mohan et al., 1996; Prasad and Bose, 2001), the HPI for every sample was calculated as follows:

$$HPI = \frac{\sum_{i=1}^{n} W_x Q_n}{\sum_{i=1}^{n} W_x} \quad (3)$$

Where; Q_n=the quality rating of the ^{n}th water quality parameter; W_x=the unit weightage of the ^{i}th parameter; n= the number of parameters considered. Typically, the critical contamination indicator of the HPI value for water for drinking is 100 (Prasad and Bose, 2001). The value of HPI<100 represents low pollution by heavy metals. If the HPI value is greater than 100, it indicates that the water is not drinkable (Edet and Offiong, 2002; Mohan et al., 1996; Prasad and Bose, 2001).

2.3.2 Degree of contamination (C_d)

The degree of contamination (C_d) quantifies the combined harmful impacts of C_d based on numerous parameters that are thought to be possibly dangerous for drinking water (Backman et al., 1998). C_d is a sum of the pollution influences of the different parameters that surpass their admissible values and is calculated as follows:

$$C_d = \sum_{i=1}^{n} C_{fi} \quad (4)$$

$$C_{fi} = \frac{C_i}{C_n} - 1 \quad (5)$$

Where; C_{fi}, C_i, and C_n refer to contamination factor, measured value, and upper permissible concentration of the ^{i}th component or parameter, respectively. For the current study, C_n was considered as the maximum permissible limit (MPL), as shown in Table 2. The C_d values, which describe the degree of contamination (Backman et al., 1998; Edet and Offiong, 2002), are divided into three groups: low (C_d<1), medium (1<C_d<3), and high (C_d>3).

Table 2. Unit weight of individual heavy metals with recommended standards (µg/L) used for index calculation

Heavy metals	Unit	(WHO, 2017) Drinking water (Gv)[a]	Iraqi standards (COSQC, 2001) (MPL)[b] (S_x)	Units weight (W_x)
Cr	µg/L	50	50[c]	0.020
Mn	µg/L	400	100[c]	0.010
Fe	µg/L	-	300[c]	0.003
Cu	µg/L	2,000	1,000[c]	0.001
Zn	µg/L	-	3,000[c]	0.000
Pb	µg/L	10	10[c]	0.100
Cd	µg/L	3	3[c]	0.333
				$\Sigma W_i = 0.468$

(Gv)[a]=Guideline value; (MPL)[b]=Maximum permissible limit, [c] depended standards.

2.3.3 Heavy metal evaluation index (HEI)

Similar to the HPI, the HEI measures the water quality in terms of heavy metals (Edet and Offiong, 2002). According to Mohan et al. (1996), the following equation is used to determine the HEI:

$$\mathrm{HEI} = \sum_{i=0}^{n} \frac{H_C}{H_{max}} \tag{6}$$

Where; H_c and H_{mac} stand for both the measured value and the maximum admissible concentration (MAC) of the ^{i}th parameter. According to Edet and Offiong (2002) procedure, HEI is divided into three categories: low (HEI<10), middle (10<HEI<20), and high (HEI>20).

2.4 Statistical analysis

A one-way ANOVA following the GLM procedure was used for measuring the significant differences in the selected heavy metals among the studied sites. The significant differences in heavy metal means were found by Tukey's HSD (Honestly Significant Difference) test at p<0.05. One sample t-test (right-tailed t-test) was used to determine if the measured values were greater than the recommended standards. Minitab software version 18 was used to analyze the Data of the research.

3. RESULTS AND DISCUSSION

3.1 Sidewise distribution of heavy metals and their comparison to standards

The statistical results [mean±standard error (SE) and p-values] of measured heavy metals in the collected spring water samples at 10 sites and Iraq water quality standards are provided in Table 3.

Chromium (Cr) is one of the elements that is widely distrusted in the earth's crust and can exist in forms (valences) of +2 to +6 (WHO, 2017). The sources of Cr in water could be natural or anthropogenic (Bhardwaj et al., 2017). Chromium (III) is considered an essential nutrient for humans, according to the World Health Organization (WHO, 2017). Chromium, a toxicological and carcinogenic substance, can be a reason for dermatitis and skin ulcers (Saha and Paul, 2016). However, the results showed that the chromium (Cr) concentration in water samples ranged from 0.12 to 2.81 µg/L. It was observed that the concertation of Cr was significantly (p<0.001) varied among the studied sites. Significantly higher concentrations of Cr were found at sites SW3, SW7, and SW8, followed by sites SW1, SW2, SW6, and SW10, while concentrations of Cr were found at the rest of the sites (Table 3). These differences in the concentration of heavy metals among the studied locations could be due to the differences in the lithological structure of these locations or some of these sites may contain potentially contaminated sources such as residential wastewater, septic tank effluent, and fertilizers. However, the concentration of Cr in every sample was lower than the maximum acceptable value (50 µg/L) of Iraq's standards (COSQC, 2001) for drinking.

Iron (Fe) and manganese (Mn) are considered from important substances that the human body needs in small amounts because of their crucial roles in the formation of hemoglobin and cell function (Gautam et al., 2014). Although Fe and Mn are necessary for enzyme function, their undesirable concentrations in drinking water might be harmful to human health (Gautam et al., 2014; Saha and Paul, 2016). Iron is among the most prevalent metals in the crust of the earth. Mn is also present in the earth's crust, however, in smaller proportions. According to Ameen et al. (2019), there are several ways for these two elements to get into the water, including the weathering of rocks, leachate from landfills, wastewater from the metal industries, and agricultural runoff, including pesticides and fertilizers. Nevertheless, in the current investigation, the concentration of iron was from 17.12 to 96.5 µg/L (Table 3). The study showed a significant difference ($p<0.001$) in the concentration of Fe among the tested sites. The Fe concentration was significantly greater at site SW4, followed by sites SW2, SW3, SW7, SW8, and SW10, and the Fe concentration was significantly lower at site SW5, followed by sites SW1, SW6, and SW9. Furthermore, Mn concentrations also ranged from 2.15 to 3.22 µg/L. Higher concentrations of Fe were observed in the samples from SW4, SW5, SW7, and SW8, while the rest of the sites had a lower concentration of Mn. These variations in the concentrations of Fe and Mn (as discussed previously) might be related to the variation in geological rocks or a certain anthropogenic source, e.g., domestic effluents, irrigation discharge, and sewage effluent. Although no health-based guideline value is proposed for Fe and Mn in drinking water, according to Iraq's standards (COSQC, 2001), the concentrations of Mn and Fe in all spring water samples were documented to be beneath the established thresholds.

Copper (Cu) is another essential trace metal that is required by biological systems to activate certain enzymes and facilitate bone repair, but in larger quantities, it may have negative effects on human health, particularly infants (Gautam et al., 2014; WHO, 2017). The presence of copper in spring water can be influenced by geological factors and the surrounding environment. However, as illustrated in Table 3 the Cu value in the tested spring water samples varied from 6.06 and 77.28 µg/L. The Cu concentrations also varied according to the various places, and higher concentrations were found at sites SW4 and SW6, followed by sites SW9 and SW10, and a lower value was found at site SW3. The value of Cu in water samples was lower than the prescribed limit (1,000 µg/L) depending on the described standard (COSQC, 2001).

Zinc (Zn) is regarded as an important element for human nutrition, however, higher levels of zinc might be unhealthy (WHO, 2017). Zinc toxicity at excessive doses results in vomiting and nausea in children (Gautam et al., 2014), even though WHO (2017) has not established a health-based guideline value for this element in drinking water. Zinc can enter spring water naturally from geological rocks and through human activities such as the application of zinc-containing fertilizers or pesticides (Ameen et al., 2019; Gautam et al., 2014). However, the analyzed data revealed there was a significant difference ($p<0.001$) in Zn concentrations among the studied sites. Sites SW8 and SW10 had the highest concentrations of Zn, followed by site SW9, and lower concentrations of Zn were recorded at sites SW1 and SW5 (Table 3). The ranges of Zn detected in spring water samples were significantly lower ($p<0.001$) than the maximum permissible limits (3,000 µg/L) of Iraqi standards (COSQC, 2001).

Lead (Pb) is considered a non-beneficial element and has no nutritional value for living things; instead, it has been classified as a toxic metal (Gautam et al., 2014; WHO, 2017). Nevertheless, the Pb concentrations found in the water samples analyzed in the present study were in the range of 5.14 to 16.9 µg/L. A significant effect was recorded ($p<0.001$) on the concentration of Pb in spring water samples analyzed in the current study (Table 3). This effect showed that there were significantly greater concentrations of Pb at sites SW1 and SW8, followed by SW2 and SW4, while there were significantly lower concentrations of Pb at sites SW3 and SW6. The values of Pb in all tested samples were significantly lower than the acceptable limits (10 µg/L) according to Iraqi standards (COSQC, 2001), except for sites SW1, SW2, and SW8, where the concentrations of this metal were greater than the acceptable limits. The higher concentration of Pb in sites SW1, SW2, and SW8 could be due to the higher population and higher human activities in these areas. Thus, serious measures need to be considered in these areas, including the careful application of agricultural inputs as well as the use of wastewater and sewage sludge in agriculture. Additionally, Pb concentration in water may also depend on the period in which the water has been in contact with the lead-containing materials (WHO, 2017).

Cadmium (Cd) metal, a hazardous trace metal that is thought to contribute to the development of cancer and cardiovascular disease, is thought to increase with age, particularly in the kidney (Saha and Paul, 2016; WHO, 2017). Cadmium enters the water system through wastewater (Terry and Stone, 2002). Cadmium may also enter water bodies through the application of phosphate fertilizer or insecticide (Kubier et al., 2019). Nevertheless, interestingly, no concentrations of Cd were detected in the spring water samples collected in the current study.

Table 3. Mean±SE values of the studied heavy metals measured in spring water at the studied sites (μg/L)

Locations	Cr	Mn	Fe	Cu	Zn	Pb	Cd
SW1	1.42±0.03[cd]	2.15±0.08[f]	60.43±2.99[cd]	19.66±5.25[ef]	8.95±0.64[e]	15.35±0.58[ab]*	0.00
SW2	1.65±0.08[c]	2.47±0.12[def]	76.35±3.19[b]	19.46±0.22[f]	62.00±6.22[d]	12.72±0.95[bc]*	0.00
SW3	2.45±0.08[ab]	2.68±0.17[cde]	78.86±2.37[b]	11.40±2.32[fg]	85.61±14.4[cd]	6.83±0.23[ef]	0.00
SW4	0.62±0.02[ef]	3.03±0.08[abc]	96.50±0.56[a]	71.41±1.45[a]	83.44±0.02[cd]	10.13±0.44[cd]	0.00
SW5	0.12±0.01[f]	3.22±0.09[a]	17.12±0.36[e]	6.06±0.15[g]	8.40±0.02[e]	8.16±0.47[de]	0.00
SW6	1.86±0.13[cb]	2.25±0.04[ef]	48.54±1.45[d]	77.28±1.77[a]	94.65±0.17[c]	5.14±0.37[f]	0.00
SW7	2.81±0.33[a]	2.83±0.06[a-d]	76.13±2.60[b]	29.45±1.04[de]	106.35±1.84[c]	9.28±0.69[de]	0.00
SW8	2.53±0.29[ab]	3.13±0.12[ab]	78.58±4.11[b]	32.84±0.34[cd]	171.37±2.26[a]	16.90±0.89[a]*	0.00
SW9	0.73±0.00[def]	2.55±0.08[def]	54.20±4.47[d]	50.00±0.80[b]	143.06±2.77[b]	7.67±0.31[def]	0.00
SW10	1.31±0.23[cde]	2.77±0.06[bcd]	72.39±4.00[bc]	40.65±2.07[bc]	175.27±1.08[a]	8.17±0.27[de]	0.00
p-values	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Iraqi standards (MPL)	50	100	300	1,000	3,000	10	3

Means in each column sharing different letters are significantly different at p<0.05.
Mean±SE denotes *=measured values are significantly higher than standards at p<0.05.
Mean±SE without *=measured values are significantly lower than the standards (p<0.05.

3.2 Metal pollution indices

Pollution indices have been applied in the current study to assess the overall quality of spring water samples, such as HPI, Cd, and HEI, based on the measured concentrations of the nominated metals (Cr, Fe, Mn, Zn, Cu, Pb, and Cd). The calculation of heavy metal pollution indices in water samples is the most commonly used technique for water quality testing because it demonstrates the combined impact of individual heavy metals on the overall water quality (Ameen et al., 2019; Reza and Singh, 2010). However, the summarized values of pollution indices (HPI, Cd, and HEI) used in the current study of water samples for each site are presented in Table 4. The values of the indices HPI, Cd, and HEI calculated for all spring water samples ranged from 11.32 to 36.56, 6.16 to -4.88, and 0.84 to 2.12, respectively (Table 4). Depending on the values of the HPI, all of the examined spring water samples were below the threshold for contamination index value of 100 and not polluted critically with respect to the heavy metals used in the present study. The results of the Cd measured for all the studied spring water samples belong to a low degree of contamination (Cd<1). The HEI index also showed that all the analyzed water samples belonged to the low-heavy metal class (HEI<10). Comparing pollution indices among different studied sites, it was observed that the values of all the used indices were greater at site SW8, followed by sites SW1 and SW2, whereas the lower values of these indices were observed at site SW6, followed by sites SW3 and SW9 (Table 4). Higher values of indices at the latter sites might be due to the elevated concentration of Pb detected in the sites as well as the higher unit weight (W_x) given to this parameter.

Comparing to previous studies, Issa and Alshatteri (2018) recorded lower HPI than the threshold value, ranging from 24.564 to 54.986 during their study on surface and groundwater in different sites of the Garmian Area, Kurdistan Region of Iraq. However, in some sites, they observed higher HEI than the critical value (HEI>2.45). The maximum value recorded in site 8 (Kalar drinking water project) was 8.441. The results of Jazza et al. (2022) study also recorded lower HPI than the critical polluted value, which was done in Misan Province of Iraq on samples collected from different sites of treating water for drinking. According to Khalid et al. (2020), the results are in agreement with the current research in terms of HPI and HEI, which were below the threshold values with the averages 54.442 and 0.221 respectively. The study was done in Erbil City, Kurdistan Region of Iraq, to evaluate the drinking water quality in schools selected randomly. In addition, more recent studies around the Kurdistan Region of Iraq (North of Iraq) on evaluating the quality of drinking water with heavy metal contaminations such as Salih et al. (2015), Salim et al. (2017), Majid et al. (2018), and Ameen et al. (2019) recorded the results lower than threshold values which agreed with the current study results.

Table 4. Summarized values of metal pollution indices in spring water samples for all the studied sites

Locations	HPI		Cd		HEI	
	Value	Critical pollution category	Value	Degree of pollution	Value	Degree of pollution
SW1	33.11	Not polluted	-5.19	Low	1.81	Low
SW2	27.54	Not polluted	-5.38	Low	1.62	Low
SW3	15.05	Not polluted	-5.94	Low	1.06	Low
SW4	22.00	Not polluted	-5.52	Low	1.48	Low
SW5	17.55	Not polluted	-6.08	Low	0.92	Low
SW6	11.32	Not polluted	-6.16	Low	0.84	Low
SW7	20.31	Not polluted	-5.67	Low	1.33	Low
SW8	36.56	Not polluted	-4.88	Low	2.12	Low
SW9	16.64	Not polluted	-5.91	Low	1.09	Low
SW10	17.82	Not polluted	-5.79	Low	1.21	Low

4. CONCLUSION

Based on the findings of the current research, it can be concluded that the values of heavy metals and pollution indices measured in spring water samples varied from region to region. The results of the metal pollution indices also concluded that the quality of the spring water samples collected in the present study is safe for drinking purposes, as all the calculated pollution indices were lower than critical levels of contamination according to metal pollution indices. Moreover, based on individual heavy metal parameters, the concentration of all the selected heavy metals detected in spring water samples was lower than the maximum permissible limits according to Iraqi standards, except for Pb in sites SW1, SW2, and SW8, where the concentration of Pb in these sites was higher than the permissible limits. The higher lead concentrations in these locations might be a sign of leakage of this metal from anthropogenic activity that should be controlled. Nevertheless, care should be taken by the people of this area when utilizing the water from these springs. Furthermore, it is highly recommended that water be treated or filtered before utilization to ensure safe drinking water.

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