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Assessment of heavy metals concentration in groundwater and their associated health risks near an industrial area

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Abstract

Background: Heavy metals (HMs) contamination from industrial wastewater is a major environmental problem that has been increasing in the past few years. The purpose of this study was to investigate the current status of HMs contamination in Bu-Ali industrial town, Hamedan, western Iran.

Methods: The concentration of 9 serious HMs (arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc) in groundwater samples was studied during spring 2017. In order to evaluate water quality for aquaculture and drinking purposes, heavy metal evaluation index (HEI), heavy metal pollution index (HPI), and contamination (Cd) indicator were calculated. Health risk of HMs was also calculated to assess the risk of cancer.

Results: The results showed that the mean concentration of the HMs according to the Cd index was as follows: Pb > Ni > Cr > Fe > Cd > As > Cu > Zn > Mn. The mean HEI and HPI values were 89.1 and 815.5, respectively. The results also showed that there was no relationship between the HMs concentration and cancer risk.

Conclusion: The concentration of the studied HMs in most samples was higher than the permissible limit for drinking water. The HEI and HPI values in high-risk samples were higher than the permissible limit of drinking water, therefore, there is high risk and limitation for aquatic life, but there is no risk of cancer.

Keywords: Groundwater, Drinking water, Heavy metals, Cities

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Introduction

Today, with limited water resources, less than one percent of available water resources are suitable for human consumption (1). Therefore, it is essential to protect water resources with proper management. Groundwater conservation, especially in arid and semi-arid regions, has particular economic importance. The rapid growth of population and urbanization over the past decades had a major impact on groundwater quality due to over-utilization and increased agricultural demand, domestic and industrial water supply. Excessive use of groundwater as a result of population growth has led to a reduction in these valuable resources (2). Given the growth of industries, more concerns are about negative impacts of industry on the quality of the subsurface environment. The discharge of industrial effluents leads to the infiltration of these pollutants into surface and groundwater, and subsequently, their contamination (3,4). Uncontrolled discharge of industrial and agricultural wastewater and infiltration of municipal wastewater leads to groundwater contamination (5). Based on the quality of groundwater in different regions, and with proper management, the use of water resources for drinking or agricultural purposes can be allocated (1). The presence of HMs in surface and groundwater is usually related to human industrial activities. The vertical movement of these contaminants in soil profile can lead to groundwater contamination (6). Management of water resources and monitoring water quality are the ways to achieve sustainable development. Several factors including climate, soil properties, groundwater flow through a variety of rocks, area topography, infiltration of saline water into coastal areas, human activities on land, etc have a significant impact on water quality (7). The importance of water quality in the human health is one of the issues that have recently attracted more attention. A study by Olajire and Imeokparia shows that in the developing countries, a high percentage of diseases (over 80%) are directly or indirectly related to the low quality of drinking water and unsanitary conditions (8). The study of groundwater quality has been focused by many researchers because hazardous substances such as HMs entering the groundwater, can enter the food chain, and ultimately, harm aquatic and human organisms (9). About 13%-30% of the total volume of freshwater in the hydrosphere is groundwater (10), which accounts for more than 50% of the world's population (11). The presence of HMs in the groundwater resources is a serious threat to public health. Because of the HMs biological stability and magnification, their contamination in aquatic environments has become a major global concern (12). Metals are naturally impermeable, intolerant, toxic, and biodegradable and can reside for thousands of years (13,14). In terms of risk, these toxic elements are divided into two categories: carcinogenic and non-carcinogenic, which can be calculated in terms of health risk assessment (15). The health risk assessment is an effective and efficient way to evaluate the relationship between the environment and human health that can quantify the risk of HMs (16). Muhammad et al investigated the health risk of HMs in local populations as a result of contaminated water consumption, and found that the main causes of pollution were geogenic processes and anthropogenic activities in the Kohistan region (17).

Some HMs are considered as essential elements for plant growth, that are harmful to human health if their concentration exceeds the permissible level for drinking water (18-20). Therefore, the evaluation and control of HMs in groundwater, which are used for drinking purposes, is of great importance for human health.

Many studies have been carried out on the contamination of HMs in soils, plants, surface water, and groundwater due to human activities (21-24).

Marbooti et al investigated HMs contamination of groundwater in the Behbahan plain, Southwest Iran, as well as its suitability for drinking purposes. According to their results, the concentration of Pb, As, Cd, and Se in this area was 33%, 13%, 56%, and 100% higher than the permissible limit presented by the WHO, respectively (25). In another study, the chemical quality of groundwater of Bushehr, south of Iran, was assessed. The results of analysis of the concentration of HMs in this study showed that the quality of water in this area was not suitable for drinking purposes (26). Barzegar et al investigated the concentration of HMs, such as Fe, Cr, Mn, Al, and As in the Tabriz plain aquifer. Their results show the concentrations of studied heavy metals in some of the groundwater samples exceed the maximum admissible concentration (MAC). (27).

Accurate tracking and monitoring of pollutants and HMs in groundwater will help us better understand the status of water pollution in industrial areas. Therefore, there is a need for sustainable management to prevent water contamination, which requires detailed knowledge of groundwater chemistry.

The present study was conducted to quantify the HMs pollution of groundwater in Hamedan-Bahar plain (western Iran), affected by Bu-Ali industrial town, as well as its suitability for drinking purposes. The importance of this subject is highlighted because groundwater supplies approximately 88% of the water consumed in Hamadan. In Hamedan-Bahar plain, groundwater is the only available and widely used source of drinking water for rural and urban areas, as well as for irrigation (28).

For this purpose, the concentrations of 9 important HMs (arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc) were investigated in 26 groundwater samples. The samples were taken up to a 4 km radius around the industrial town. Pollution indicators and health assessments were investigated to find out the current status of groundwater contamination by the HMs.

Materials and Methods

Study area

The study zone was Hamedan-Bahar plain, western Iran, under the influence of Bu-Ali industrial town (Figure 1), which is located at longitude 48°34' E and latitude 34°56' N. Hamedan-Bahar plain occupies about 880 km^2, with a mean altitude of 1775 m.a.s.l. The study area is semi-arid, and the annual average precipitation is approximately 300 mm, about 37% of which happens in winter. The annual potential evapotranspiration which exceeds the annual precipitation is about 1505 mm.

In this area, groundwater is used for several purposes, like drinking, agricultural, domestic, and industrial purposes. Geologically, Hamadan-Bahar plain is located on Sanandaj-Sirjan metamorphic zone (Hamedan Regional Water Authority, HRWA). The parent rocks are generally composed of limestone, calcareous shale, and granitic materials. The soil texture in this area is silty loam on average with clay less than 17% (Information Center of Ministry of Jahade-Agriculture of Hamadan, MOJAH).

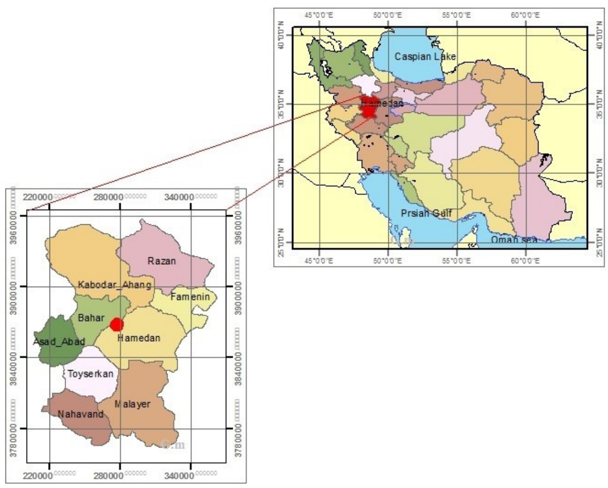

Figure 1. The location of Hamadan province in Iran indicated by the red point.

Sampling and water analysis

Water samples were obtained from 26 wells during spring 2017 (Figure 2). For this purpose, a buffer zone with 4 km diameter was supposed around the industrial town. The samples were collected from the wells inside the selected area. The places of wells were recorded using a global positioning system (GPS).

Before sampling, all the sample containers were rinsed with distilled water. Samples were collected to assess the concentration of HMs and protected by 1% nitric acid (HNO_3). The containers were held in icebox at 4°C and carried to the laboratory for analysis.

Electrical conductivity (EC), total dissolved solids (TDS), and pH were analyzed using the Hach Series Meters (HQ40D) in place. The concentrations of the HMs (i.e., As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn) in groundwater samples were measured by inductively coupled plasma-optical emission spectrometry (Varian E-710) in μgL^{-1}, detection limit. That is linearly calibrated from 10 to 100 μgL^{-1} with custom multi-element standards (SPEX CertiPrep, Inc., NJ, USA) before running the tests. The accuracy and precision of analyses were examined through running triplicate analysis on the samples. The comparative standard deviations for studied elements were found to be within ±2%.

Heavy metal evaluation index (HEI)

The HEI presents the overall quality of water based on the HMs concentrations (29,30), and is expressed as Eq. (1):

$$HEI = \sum_{i=1}^{n} \frac{H_c}{H_{mac}} \quad (1)$$

where H_c and H_{mac} are the observed amount and MAC of the *i*th parameter, respectively.

Heavy metal pollution index (HPI)

The HPI shows the quality of water in relation to the HMs concentrations (31,32). The proposed HPI is based on the weighted arithmetic quality mean method and is obtained in two basic steps: First, a grading scale is created for each selected parameter rendering weightage to the selected parameter (HMs), and secondly, the pollution parameter on which the index is based, is selected. Grading system is either an arbitrary value between 0 and 1, depending on the importance of exclusive quality attentions in a comparative way or it can be distinguished by making values inversely proportional to the recommended standard for the responsible parameter (33,34). In this equation, unit weightage (Wi) is derived as a value inversely proportional to the recommended standard (Si) of the responsible parameter. The HPI model suggested by Mohan et al is expressed as Eq. (2) (34):

$$HPI = \frac{\sum_{i=1}^{n} W_i \, Q_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

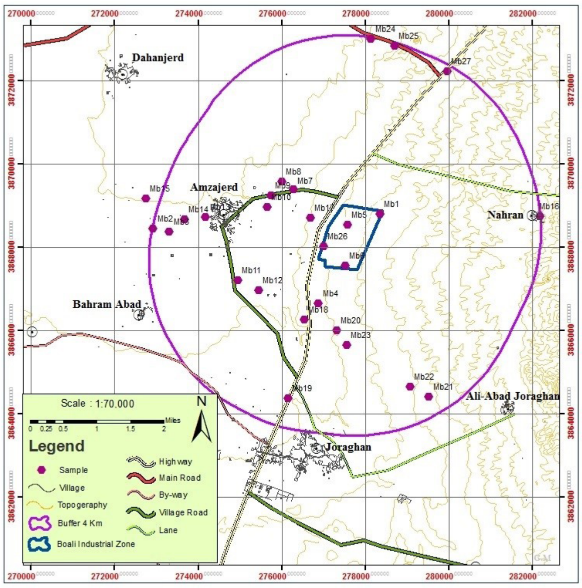

Figure 2. The location of water sampling points.

Where Qi is the sub-index of the *i*th parameter, Wi is the unit weightage of the *i*th parameter, and n is the number of parameters considered. The sub-index (Qi) of the parameter is computed by Eq. (3):

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \times 100 \quad (3)$$

Where M_i is the observed amount of HMs of the *i*th parameter, I_i is the perfection amount (the maximum favorable amount for drinking water) of the *i*th parameter, and S_i is the modulus value (the greatest allowed amount for drinking water) of the *i*th parameter. The sign (–) demonstrates the numerical difference of the two values, relinquishing the algebraic mark. The critical pollution index of HPI value for drinking water suggested by Prasad and Bose, is 100 (35).

Degree of contamination (DOC)

The contamination index (C_d) briefs the combined effects of various quality parameters considered adverse to homemade water (36) and is calculated using Eq. (4):

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

where $C_{fi} = (C_{Ai}/C_{Ni}) - 1$, C_{fi}, C_{Ai}, and C_{Ni} represent the contamination factor, analytical value, and upper allowed concentration of the *i*th component, respectively, and N denotes the "normative value". Here, C_{Ni} is considered as MAC.

Health risk assessment

Basically, the assessment of the health risk of each contaminant is estimated based on its risk level and is classified into two groups: carcinogenic and non-carcinogenic health risks. In this study, the possible carcinogenic health risk of HMs present in groundwater was assessed using Eq. (5) (37):

Health Risk = *ADD* × *CSF* (5)

where, *ADD* is the average daily dose of HMs in water via oral exposure in the study area (mg kg^{-1} day^{-1}) and *CSF* is cancer slope factor. A CSF is an upper bound, approximating a 95% confidence limit, on the increased cancer risk from a lifetime exposure to toxicant by ingestion, dermal or inhalation exposure route (38). People who are living near contaminated areas may be at risk from drinking water sources or contact of the mouth with hands contaminated with such water. In this study, the average daily dose for each of the toxic metals (As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn) ingested in the water bodies were calculated using Eq. (6) (37):

$$ADD = \frac{EPC \times IR \times AAF_{wo} \times EF \times ED \times 10^{-6}}{BW \times AT} \quad (6)$$

The equation parameters are described in Table 1. The CSF values are presented in Table 2.

The acceptable health risk is one in million (1× 10^{-6}), meaning that one person among one million people is likely to develop cancer due to drinking HMs-contaminated groundwater (39).

Results

Minimum, maximum, and average concentrations of several water quality parameters in the groundwater samples are shown in Table 3. The pH of the samples ranged from 6.61 to 7.84 while the average pH was 7.28 (Table 3), which corresponds to the WHO standard for drinking water. EC ranged from 0.575 to 1.218 dS m^{-1}. The Pearson's correlation (Table 4) indicates that EC had a strong correlation with TDS. The TDS quantities ranged from 291 to 827 mg L^{-1}, while the average TDS level was 479.4. According to the WHO report, there is no health risk associated with drinking water with a TDS below 1000 mg L^{-1} (40).

The mean concentrations of As, Cd, Cr, Cu, Fe, Pb, Mn,

Table 1. Parameters and input assumptions for exposure assessment of heavy metals through ingestion pathways

Parameter	Explanation	Unit	Value
EPC	Exposure point concentration of a metal in the drinking water	µg L^{-1}	-
IR	Water ingestion rate per unit time	L day^{-1}	2.2
AAF_{wo}	Oral-water adjustment factor	µg L^{-1}	0.001
EF	Exposure frequency	Events $year^{-1}$	365
ED	Exposure duration	Year	70
BW	Body weight	Kg	70
AT	Averaging time	Day	25550

Table 2. Toxicity values (CSF)

	As	Cd	Cr	Cu	Fe	Mn	Ni	pb	Zn
CSF (mg kg^{-1} day^{-1})	1.5	6.3	42	-	-	-	0.84	8.5	-
Ref	(7)	(7)	(7)				(7)	(59)	

Table 3. Minimum, maximum, and average concentrations of some water quality parameters in the groundwater samples

Water Quality Parameters	Units	Minimum Concentration	Maximum Concentration	Average
pH	-	6.61	7.84	7.28
EC	dS m^{-1}	0.575	1.218	0.949
TDS	mg L^{-1}	291.0	827.0	479.4
Heavy metal ions				
As	ppb	36.93	112.66	72.29
Cd	ppb	18.31	34.50	25.91
Cr	ppb	117.63	894.90	590.01
Cu	ppb	138.16	650.23	461.19
Fe	ppb	2829.63	7157.93	4965.04
Pb	ppb	359.03	3580.96	2026.23
Mn	ppb	120.93	409.42	269.08
Ni	ppb	98.76	757.93	525.43
Zn	ppb	173.50	1890.36	947.32

Table 4. Correlation coefficient between heavy metal concentration (ppb) and water quality parameters measured in the groundwater samples

	pH	EC	TDS	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
pH	1.00											
EC	-0.11	1.00										
TDS	-0.10	0.99**	1.00									
As	-0.20	0.00	-0.00	1.00								
Cd	- 0.13	0.06	0.07	0.49**	1.00							
Cr	0.13	-0.08	-0.12	0.76**	0.47**	1.00						
Cu	0.08	-0.08	-0.10	0.58**	0.37**	0.75**	1.00					
Fe	0.10	-0.07	-0.06	0.67**	0.35**	0.77**	0.76**	1.00				
Pb	0.03	0.01	0.04	0.70**	0.36**	0.67**	0.49**	0.53**	1.00			
Mn	-0.07	0.02	0.14	0.63**	0.63**	0.65**	0.49**	0.62**	0.58**	1.00		
Ni	-0.04	0.04	0.01	0.65**	0.56**	0.77**	0.69**	0.74**	0.57**	0.64**	1.00	
Zn	0.14	-0.09	-0.15	0.70**	0.51**	0.83**	0.66**	0.75**	0.66**	0.66**	0.65**	1.00

**Correlation is significant at 1% level of significance (two-tailed).

Ni, and Zn were 72.29, 25.9, 590.0, 461.2, 4965.0, 2026.2, 269.0, 525.4, and 947.3 ppb, respectively, which contain total 26 groundwater sampling points. According to the WHO guideline for drinking water, the highest permissible concentrations for As, Cd, Cr, Cu, Pb, and Ni are 10, 3, 50, 2000, and 70 ppb, respectively. For Fe, Mn, and Zn, a permissible limit concentration has not been established and none of health concern at levels found in drinking water for them. The concentrations of all studied HMs except Cu, in groundwater exceed the permissible levels for drinking water, therefore, such water is not suitable for drinking (40).

In a similar study by Obiri et al, the concentration of As, Cd, Hg, and Pb in water samples of Prestea Huni Valley District of Ghana was investigated. They reported that the concentrations of all HMs were higher than the WHO recommended permissible values for drinking water (37). The results of analysis of groundwater resources in Behbahan plain southwest Zagros demonstrated that the concentrations of Pb, As, Cd, and Se are 33, 13, 56, and 100% higher than the WHO recommended permissible levels, respectively (25).

Pollution indices

The quality of the groundwater samples was evaluated by measuring the concentration of the HMs in the samples (29). Figures 3-5 show the values of the HEI, HPI, and C_d in the studied samples. The results of the calculations of HEI, HPI, and C_d for one sample are demonstrated in Tables 5-7.

The HPI values ranged between 251.7 and 1202.1, with the average value of 815.5, which exceeds the critical index value of 100. The critical impurity index value over the overall pollution level should not be accepted (41). The HPI value was more than 100, indicating that the groundwater is contaminated with metals due to all mineralization, mining, and industrial activities near the study area (20).

The value of DOC (C_d) in the groundwater with an average value of 80.1 shows that the HMs concentrations in the groundwater samples were as follows: Pb > Ni > Cr > Fe > Cd > As > Cu > Zn > Mn.

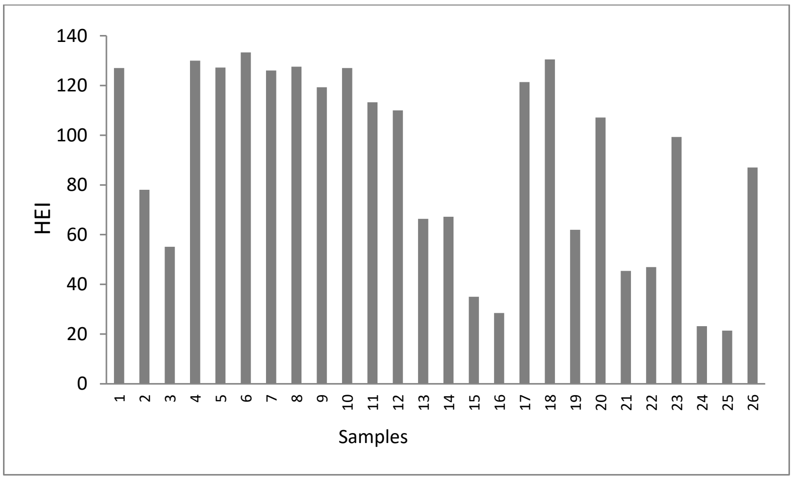

Figure 3. The HEI values for the studied groundwater samples.

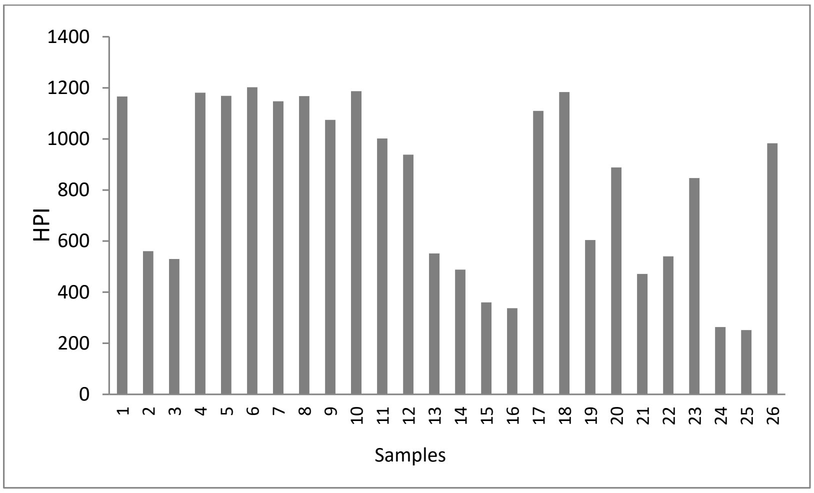

Figure 4. The HPI values for the studied groundwater samples.

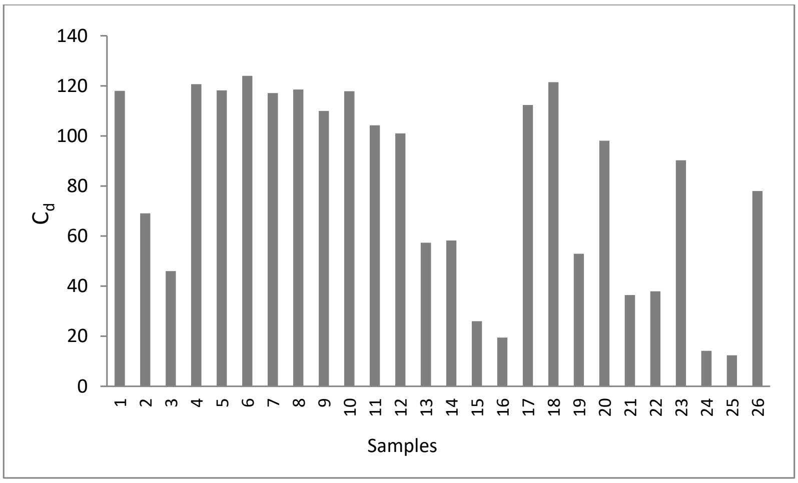

Figure 5. The C_d values for the studied groundwater samples.

The average values of health risk of all studied HMs are described in Table 8. The health risks of As, Cd, Cr, Ni and Pb were all below the maximum acceptable level (1×10^{-6}), therefore, there is no health risk (38,39).

Discussion

The optimum pH will change according to the composition of water and the nature of the ingredients in different water sources. According to the WHO guidelines for drinking water quality, it ranges usually between 6.5 and 8.5 (42).

In accordance with the WHO guidelines, the quality of water with a TDS level less than about 600 mg L^{-1} is commonly supposed to be desirable, but drinking water becomes significantly and increasingly undesirable at TDS levels higher than about 1000 mg L^{-1} (42). TDS in groundwater are basically because of inorganic salts and dissolved organic matter. The salts may be of geogenic origin from rock weathering or anthropogenic source such as urban runoff, sewage, industrial depletion, kind of materials used for water supply piping etc (43).

The ability of metals to move in the soil is affected by several soil properties. According to Campos, the treatment of HMs in soil depends on pH, texture, and amount of clay (44). Soil texture affects the amount of HMs as well as physicochemical properties and directly or indirectly controls the reactions occur on the surface of particles

Table 5. The results of HEI calculation for one of groundwater samples (example)

Heavy Metals	H_c (ppb)	H_{mac} (ppb)	H_c/H_{mac}
As	112.7	50	2.2
Cd	27.6	10	2.8
Cr	809.9	50	16.2
Cu	590.4	1000	0.6
Fe	5272.7	1000	5.3
Pb	3179.7	50	63.6
Mn	261.3	300	0.9
Ni	707.9	20	35.4
Zn	805.2	15000	0.04
HEI			$\Sigma = 127.04$

Table 6. The results of HPI calculation for one of groundwater samples (example)

Heavy Metals	M_i (ppb)	S_i (ppb)	I_i (ppb)*	W_i	Q_i	$W_i \times Q_i$
As	112.7	50	-	0.02	225.4	4.9
Cd	27.6	10	-	0.1	276.0	27.6
Cr	809.9	50	-	0.02	1619.8	32.4
Cu	590.4	1500	50	0.0007	37.3	0.03
Fe	5272.7	1000	300	0.001	710.3	0.6
Pb	3179.7	50	-	0.02	6359.4	127.2
Mn	261.3	300	100	0.002	80.6	0.2
Ni	707.9	70	-	0.009	1011.3	9.0
Zn	805.2	15000	5000	0.00007	42.0	0.003
				Σ = 0.16		Σ = 202.0
						HPI = 12625

*There are no desirable limits for As, Cd, Cr, Pb, and Ni according to the WHO guideline; hence, the optimal values were set equal to zero.

(45,46). The pH of the soils in the studied area ranged between 6.8 and 7.2, which was rated slightly acidic and increases the mobility of HMs (47-49). Considering the soil texture and low percentage of clay in the soil samples of the studied area, it is revealed that the groundwater may be contaminated due to HMs movement. De Matos et al stated that the low levels of HMs in groundwater could be due to the presence of high percentage of clay in the soil, which have strong adsorptive sites for metals, and as a result, decrease their movement (47).

The mean concentrations of HMs in the groundwater samples were as follows: Fe > Pb > Zn > Cr > Ni > Cu > Mn > As > Cd. According to the results, the concentrations of HMs such as Cu, Mn, and Zn were well below the WHO recommended permissible levels for drinking water. The concentrations of As, Cd, Cr, Fe, Pb, and Ni were higher than the WHO recommended value for drinking water (42).

Table 9 presents the concentration of HMs in groundwater reported by several researchers. It can be realized that the concentrations of HMs obtained in the present study are consistent with those represented by other researchers.

Table 7. The results of DOC (C_d) calculation for one of groundwater samples (example)

Heavy Metals	C_{Ai} (ppb)	C_{Ni} (ppb)	C_{fi}
As	112.7	50	1.25
Cd	27.6	10	1.76
Cr	809.9	50	15.20
Cu	590.4	1000	-0.41
Fe	5272.7	1000	4.27
Pb	3179.7	50	62.59
Mn	261.3	300	-0.13
Ni	707.9	20	34.40
Zn	805.2	15000	-0.95
C_d			Σ = 117.99

The results of correlation analysis between HMs concentrations and pH, EC, and TDS in groundwater samples done to supplementary statistically prove for similar sources of pollution for samples. Pearson's correlation coefficients are presented in Table 4. The results demonstrated a strong correlation between HMs at $P<0.01$. This strong positive correlation between all studied HMs shows that they originate from the same source. Therefore, the accumulation of metals indicates that groundwater is more likely to be affected by the same sources, including chemical industry and municipal sewage or landfill leachate (54).

The HEI values ranged between 21.4 and 133.3, with the average value of 89.1. HEI examines the potential impact of HMs on human health leading to a rapid assessment of the overall quality of drinking water. Increasing the concentration of HMs higher than the MAC leads to a decrease in water quality. High HEI values can be caused by washing industrial waste from the soil as a result of anthropogenic activities (48). The proposed HEI criteria are as follows: Low (HEI <10), medium (HEI = 10–20), and high (HEI >20) (54). Based on the classification, the samples were within the high zone.

The C_d values in the groundwater samples ranged from 12.4 to 124.0, with a mean value of 80. According to the results reported by Edet and Offiong and Backman et al, C_d may be categorized into three classes: Low (C_d < 1), medium (C_d = 1–3), and high (C_d > 3). Based on the classification, all of the samples were within the high zone. The C_d indices indicate that the samples were heavily polluted (36,55).

The HPI was applied for better understanding of the pollution indices. It is a very helpful tool for evaluating the overall pollution of water considering HMs concentrations (41). Pollution of the HMs in the studied area could be due to leaching of these metals from the industries into the region. The HPI exceeded the critical metal pollution index of 100, which was suggested for drinking water by Prasad and Bose, knowing potentially hazardous effects

Table 8. Mean HRI values for studied heavy metals in the groundwater samples

	As	Cd	Cr	Cu	Fe	Mn	Ni	pb	Zn
Mean HRI	3.4E-09	5.1E-09	7.8E-07	-	-	-	1.4E-08	5.4E-07	-

Table 9. Heavy metals concentrations (ppb) in groundwater samples reported by other studies

Zn	Ni	Mn	Pb	Fe	Cu	As	Cd	Cr	Reference
39	315.6	23	63	42	51		9	50.8	(30)
1500.7	375.5		116.4	10488	2151.8		47.6	147.1	(42)
0.24-45.2		8-264	6-20	12-500	0.2-2.1		0.2-1.7	0.5-11.8	(32)
303.6		60.6	52.6		19.6	2	3.3	6	(48)
			215			9	484		(25)
66	-	105	4	627	85	-	3	-	(50)
211.16		166.2	3.8	541.6	8.4		0.41	7.2	(20)
		95	40	1390			22	53	(51)
120-980	3.6-9.7	130-340	2.6-10	3250-5080	1.8-6.8				(52)
1-7380		10-522	1-123	280-5880	1-272				(53)
173.5-1890	98.7-757.9	120.9-409.4	359-3580.9	2829.6-7158	138-650.2	37-112.6	18.3-34.5	117.6-895	This study

on the aquatic environment (35). The HPI values in the studied groundwater show that the samples are not suitable for drinking (Figure 4).

Since the weightage (W_i) assigned to Cu and Zn was very less in the weighing of the parameters (Table 4), it can be concluded that the concentration of these metals would not have a significant effect on the HPI assessment. On the other hand, As, Cd, Cr, and Pb were not allowed in drinking water, therefore, they were given high weightage (W_i) value in the HPI computation. Hence, the presence of a small amount of these elements in water reduces water quality and depicts great values in the HPI computation.

The problems related to heavy metal pollution are among the most important issues in environmental science. Daily consumption of drinking water containing these metals threat human health and can cause various types of cancer (56). The health risk associated with drinking water depends on the volume of water consumed and the weight of the individual. In this regard, health risk assessment associated with the average daily dose (ADD) was determined using the concentrations of As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn in the water used for drinking. Heavy metals (As, Cd, Cr, Pb, and Ni) can potentially pose a risk of cancer in humans (57,58). Therefore, prolonged exposure to HMs can lead to many types of cancers. For an HM, an ILCR less than 1×10^{-6} is considered as insignificant and the cancer risk can be neglected, while an ILCR above 1×10^{-4} is considered as harmful and the cancer risk is troublesome (57,59). Among studied HMs, As, Cd, Cr, Ni, and Pb had no cancer risk (mean HRI lower than 1×10^{-6}). Since Cu, Fe, Mn, and Zn are essential elements for human beings and abundant in nature, there is no health concern about drinking water containing these elements. Thus, the results of this study indicate that there is no cancer risk for residents through daily and long-term consumption of drinking water of the groundwater.

Mohammadi et al assessed carcinogenic and non-carcinogenic health risk of HMs in drinking water of Khorramabad, Iran, and concluded that the health risk for Pb, Cr, Cd, and Ni was higher than the permissible limit (1×10^{-6}) (58). Wongsasuluk et al also evaluated the HMs pollution in groundwater in Ubon Ratchathani province, Thailand, and reported that only the concentration of As was within the unacceptable cancer risk level (60). Kim et al accessed the health risk of uranium in Korean groundwater, and demonstrated that radiological risk was within acceptable ranges (61). In Nanjing, China, a study on six surface waters showed the carcinogenic value of $2.05–3.28 \times 10^{-4}$, which was higher than the acceptable limit (62).

Conclusion

The results of the present study showed that the HMs concentrations in most samples are generally higher than the permissible limits for drinking water, according to the WHO guideline. Among the HMs verified in the present study, the sequence of the mean concentrations of HMs was recorded to be as Pb > Ni > Cr > Fe > Cd > As > Cu > Zn > Mn, considering the C_d index.

The correlation analysis demonstrated good to strong positive correlations among all HMs, proposing that the HMs have the same origin and it can be attributed to the associated industries along with the neighbor wells. In the present study, the mean HPI of groundwater was 815.5, which is higher than the critical index value of 100, indicating that the groundwater in this area is contaminated with HMs. Similarly, the mean HEI value of the groundwater samples was 89.1. Also, the results of evaluation of the health risk index indicate that there is no cancer risk for residents through daily and long-term consumption of such groundwater.

The results of the present study clearly illustrated that the contamination of groundwater with HMs was mainly due to industrial and anthropogenic activities.

Eventually, the study of soil and geological characteristics of the region and accurate identification and introduction of pollution sources are important goals that can be followed in future studies.

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Ethical issues
The authors hereby certify that all data collected during the research are as expressed in the manuscript, and no data from the study has been or will be published elsewhere separately.

Competing interests
The authors declare that they have no conflict of interests.

Authors' contributions
All authors contributed to data collection, analysis, and interpretation. All authors reviewed, refined, and approved the manuscript.

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