TUJNAS

Original Article

Thamar University Journal of Natural & Applied Sciences 8(2) (2023) 1 – 9

DOI: https://doi.org/10.59167/tujnas.v8i2.1710

Health Risk Assessment of Some Heavy Metals in Groundwater Samples in Rada'a City, Yemen

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Received: 5 August 2023. Revised (in revised form): 4 September 2023. Accepted 16 October 2023. Published 31 December 2023

Abstract

Groundwater is an important source of domestic drinking water supply, and groundwater quality assessment is necessary to reduce pollution to acceptable levels. Therefore, this study aims to determine the concentrations of heavy metals (HM) (Cr, Cd, Cu, Ni, Mn, Fe, and Zn) in the groundwater of Rada'a City and to evaluate the health risk. Groundwater samples were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES). The following average concentrations (mg/l) were determined in the groundwater 0.01035, 0.01702, 0.043718, and 0.03652 for Cu, Ni, Mn, and Zn were concentration values lower than the World Health Organization acceptable limit (WHO) 2, 0,07, 0.4, and 4 for Cu, Ni, Mn, and Zn, respectively. Still, at some locations in the study area, concentration values were found to be above the acceptable limit of 0.3 (mg/l) for Fe, the average concentrations were 0.42567 (mg/l). Based on the HM concentrations, the health risk was classified as non-carcinogenic. The health risk indices (HRI) were < 1 for all HMs in the groundwater samples, indicating no health risk. In addition, a high carcinogenic risk (Probability of Cancer Risk, PCR) of 4.42×10^{-4} on average was found from drinking water consumption, while the acceptable range for cancer risk is $\leq 1 \times 10^{-6}$ to 1×10^{-4}.

Keywords: Groundwater; Heavy Metals; Rada'a; Health Risk, ICP-OES

1. Introduction

Groundwater plays an important role in water supply for drinking, agriculture, industry, and households [1]. Groundwater may be contaminated with heavy metals (HM), either by anthropogenic (e.g., mining, wastewater, irrigation, industry, and agriculture) or natural resources (e.g., erosion of rock layers and volcanic eruptions) [2,3]. Therefore, groundwater has become a serious global problem [4]. HM enters our bodies through the water we drink, the air we breathe, and the food we eat, so its contamination of water, air, or food poses a potential threat to human health [5]. High molecular weight substances are elements with an atomic mass greater than 20, have metallic properties, and a density greater than 5 g/cm^3, so they are at least five times denser than water (1 g/cm^3), cannot be metabolized by the body, and are stable and bioaccumulative [6,7,8]. High molecular weight metals such as copper and zinc are essential elements for the normal growth and function of living organisms, while high concentrations of other metals such as cadmium, lead, chromium, arsenic, and manganese are highly toxic to humans and aquatic life [9,10]. These metals are not degradable and are stored in the human body, including fatty and nervous tissues. Their toxicity depends on the dose accumulated in cells [11].

Nowadays, pollution by HMS contaminants is one of the most important environmental problems due to their high toxicity and negative effects on human health. According to the report published by the World Health Organization. Drinking water with high concentrations of HMs has the potential to cause critical diseases such as cancer [12].

In the current study, the concentrations of heavy metals (Cr, Cd, Cu, Ni, Mn, Fe, and Zn) in the groundwater of Rada'a City were determined and the health risk was evaluated. Groundwater samples were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES).

2. Materials and Methods

2.1 Sampling Area

Rada'a City is the largest city in Al-Baida'a governorate and has a population of 56,383 according to the 2004 census. It is located at 14 º 24´ N 45 º 50 ´ E, southeast of the capital Sana'a, and has an average elevation of 2.25 km above sea level. Rada'a has a semi-arid climate with significant temperature variations between summer and winter. The sampling sites are listed in Table 1 and Figure 1. Physicochemical parameters and the concentration of HM were measured at 10 wells.

2.2 Sample Collection and Preparation

Samples were collected in December 2019 at various locations in separate polyethylene bottles for measurement of selected HMs (Cr, Cd, Cu, Ni, Mn, Fe, and Zn). Approximately 2 ml of 65% HNO_3 was added to prevent precipitation of the metals. The samples were then labeled, sealed, and transported to the laboratory, where they were stored in a cooler at a suitable temperature of 4 °C. The samples were then stored in a refrigerator at 4 °C until the analysis was completed [6,15,16].

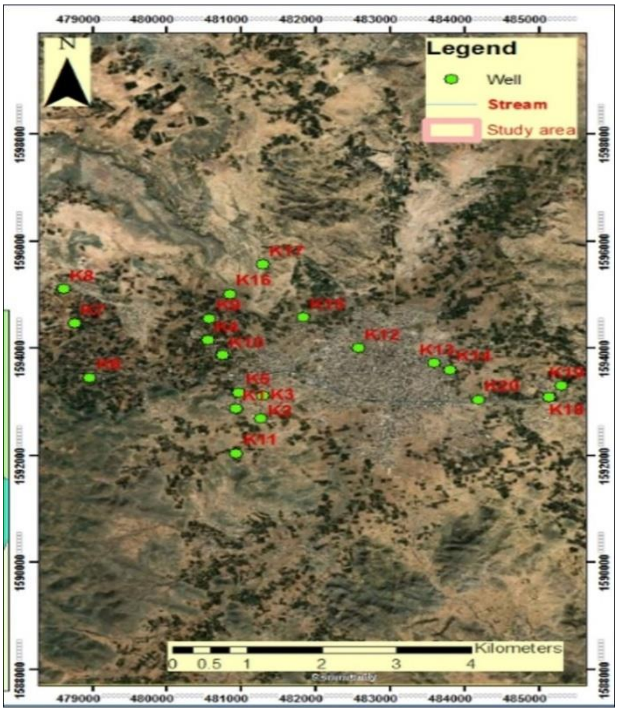

Figure 1: Map of well water sampling sites.

Table 1: Locations of Sampling Sites.

Area	Code of sample	Latitude	Longitude
Alhugah	K1	14°24 `29``	44°49`23``
Almuslaa	K3	14°24 `37``	44°49`35``
Althybanaa	K4	14°25 `11``	44°49`10``
Aljaf	K6	14°24 `48``	44°48`17``
Waddi-Alkath	K8	14°25 `42``	44°49`05``
Alashaa	K9	14°25 `24``	44°49`11``
Alqusier	K12	14°25 `06``	44°50`18``
Alsafaa	K15	14°25 `25``	44°49`53``
Alkhathra	K17	14°25 `57``	44°49`35``
Kaa Rada'a	K18	14°24 `34``	44°51`11``

2.3 Measurement Technique

In this study, inductively coupled plasma optical emission spectrometry (ICP-OES) fabricated (VISTAMPX CCD simultaneous ICP - OES, VARIAN SPS model (EL 05063632) with argon (99.99%) as carrier gas was used to determine 7 elements in the groundwater samples. From the standard raw solution, the samples were treated with ICP-OES equipment at the maximum wavelength of each of the elements in which the standard treatment of the standard solution and form as testing the samples analyzed.

2.4 Measurement of water physicochemical parameters

Physicochemical parameters such as pH, electrical conductivity (EC) in micro-Siemens per cm (μS/cm), total dissolved solids (TDS) in (mg /l), and temperature (T) in °C of the samples were measured on-site using a portable pH meter. 0.5 L of the water sample was used to determine the physicochemical parameters, TDS, T, and EC [17]. The techniques used for using a portable multiparameter meter, model EC59, CE. The pH was measured using the pocket pH meter, model 107, CE. Measurements were taken three times and the average was recorded.

2.5 HMs Health Risk Assessment

In recent years, health risk assessment of the carcinogenic and non-carcinogenic effects of heavy metals in the human body has been conducted using methods adopted by the US Environmental Protection Agency (USEPA) in 2004. Health risk indices (HRI), hazard indices (HI) and probability of cancer risk (PCR) have been studied by many researchers [8,18].

2.5.1 Chronic daily intake (CDI) indices

Heavy metals enter the human body via several routes, including ingestion, skin contact, and inhalation, but compared to oral intake, all other routes are negligible. The CDI risks arising from the ingestion of a single trace element are calculated for the adult population as follows [19,20]:

$$CDI = \frac{A_w \times IRW \times EF \times ED}{BW \times AT} \quad (1)$$

where CDI is the chronic daily intake, also referred to as the exposure dose (mg/(kg. Day); Aw represents HM concentration in water (mg/l); IRW represents water intake rate (IRW equals 2l for adults); EF is used to denote exposure frequency (EF equals 365 days per year); ED represents exposure duration (adults ED = 70 years); BW is body weight (equals 70 kg for adults); AT represents average exposure duration (equals 25,550 days).

2.5.2 Non-Carcinogenic Health Risk Assessment

The health risk indices (HRI) of a single element in each sample are evaluated [3,18,21,22]:

$$HRI = CDI/RfD \quad (2)$$

where RfD represents the reference dose of a particular element (mg/kg/day). The RfD equivalent for the heavy metals is 0.7 (Fe), 0.3 (Zn), 1.5 (Cr), 0.046 (Mn), 0.04 (Cu), 0.001 (Cd), and 0.02 (Ni) [20,23]. Whereas: HRI1 indicates no significant health risks; HRI ≥ 1 indicates significant health risks, which increase with increasing value of HRI [24]. The final value for the evaluation of noncarcinogenic risk is the hazard index (HI), which is the sum of the HRI values in each sample [25,26]:

$$HI = \sum HQ = HQ_{Cr} + HQ_{Cd} + HQ_{Cu} + HQ_{Mn} + HQ_{Ni} + HQ_{Fe} + HQ_{Zn} \quad (3)$$

HI is greater than one (HI ≥ 1), it means that the non-carcinogenic health risk of ingesting a particular element is above the permissible limits, while HI < 1 means that they are below the permissible limits [20].

2.5.3 Carcinogenic Health Risk Assessment.

The probability of cancer risk (PCR) for groundwater resources was estimated as an individual's incremental lifetime risk of developing cancer from exposure to a potential carcinogen. The PCR for each carcinogenic metal is calculated as follows [27,28]:

$$PCR = CDI \times CSF \quad (4)$$

where CDI was calculated using equation (1) and CSF is the cancer slope coefficient (mg/(kg. Day)) [29]. The acceptable health risk threshold is one in a million (1×10^{-6}), which means that one person in a million is likely to develop cancer if they drink well water contaminated with HMs [30]. However, it has been reported that a risk in the range of 1×10^{-6} to 1×10^{-4} is usually considered acceptable [31,32]. In this study, the CSF values used to calculate the PCR of heavy metals (carcinogens) are as follows: Cr (0.05), Cd (0.38), and Ni (0.91) [20].

3. Result and Discussion

3.1 Physicochemical parameter analysis

The results of the physicochemical parameters measured for the well water samples are shown in Table 2. The temperature varied from 25.3 to 36.3 °C with an average value of 30.17 °C from the 10 sites. T above the permissible limits of WHO. High water temperature promotes the growth of microorganisms and can exacerbate problems related to taste, odor, color, and corrosion. In addition, contaminants may become more toxic at higher temperatures, which could be due to the increase in their water solubility [33,34]. The pH ranged from 6.5 to 7.3 with an average value of 6.8 from the 10 sites. From this, it can be seen that all well water samples have pH values within the recommended WHO. High temperature and low pH can lead to increased toxicity of metals and radionuclides in the water. The chemical and biogeochemical processes that lead to a decrease in pH favor the dissolution of radionuclides and heavy metals into the water system at high concentrations [33]. The TDS content of the well water also varied from 422 to 895 mg/l, with the average value of the 10 sites being 578.9 mg/l. From the results, all well water samples had a TDS content that was within the minimum value of 600 mg/l recommended by WHO [35]. TDS concentrations in water vary considerably in different geological regions due to differences in mineral solubility [33]. Electrical conductivity (EC) is related to the concentrations of ions that can conduct electric current. Therefore, EC represents an estimate of TDS [34]. EC ranged from 839 to 1785 µs/cm with an average value of 1152 µS/cm for the 10 sites.

3.2 Heavy Metals Concentration analysis

Surmont of HM concentration, as shown in Table 3, while the concentration of cadmium (Cd) and Cr were below the detection limit (ICP - OE). The detection limit for Cd was 0.05 mg/l, which may be higher than the respective allowable limits (0.003 mg/l) in all samples. Cd causes skeletal disorders, liver damage, cardiovascular disease, dysfunction of the sex glands, and disturbs mineral balance in the body. Chronic Cd exposure can cause harmful effects such as lung cancer, proliferative lesions of the prostate, bone fractures, renal dysfunction, and hypertension [7]. In this study, the method detection limit for Cr in all samples was 0.07 mg/l, which may be lower than the respective permissible limits (0.05 mg/l). High concentrations of chromium (Cr) may be responsible for non-cancerous health risks such as neurological disorders, headache, and liver disease [7]. In general, the order of average concentration of selected metals in groundwater samples was Fe, Mn, Zn, Ni, and Cu in the vicinity of the study area.

Table 2: The physicochemical parameters.

No	Location of Sampling	T (˚C)	pH	TDS (mg/l)	EC (µS/cm)
1	Alhugah	33.7	7.0	422	839
2	Almuslaa	35	6.7	507	1013
3	Althybanaa	28.5	6.5	700	1387
4	Aljaf	36.3	7.3	432	867
5	Waddi-Alkath	26	6.7	497	994
6	Alashaa	26.4	6.8	686	1344
7	Alqusier	25.3	6.8	492	987
8	Alsafaa	22. 7	6.8	895	1785
9	Alkhathra	25.0	6.8	766	1532
10	Kaa Rada'a	24.7	7.1	385	774
Min		**25.3**	**6.5**	**422**	**839**
Max		**36.3**	**7.3**	**895**	**1785**
SD		**4.681**	**0.237**	**165.5**	**325.9**
Average		**30.17**	**6.825**	**578.9**	**1152**
Permissible limits WHO		**25**	**6.5 – 8.5**	**600 – 1000**	**1000 – 1200**

The concentration of copper (Cu) in the drinking water samples ranged from 0.00767 to 0.01372 mg/l, with an average of 0.01035 ± 0.00221 mg/l, as shown in Figure 2. Cu in very high concentrations is toxic and can cause vomiting, diarrhea, loss of strength, and liver cirrhosis. The water turns blue-green when the corroded copper dissolves from inside the pipes and appears as a precipitate in the water [36]. The concentration of nickel (Ni) in drinking water samples ranges from 0.00694 to 0.05821 mg/l, with an average concentration of 0.01702 ± 0.01497 mg/l, as shown in Figure 3. (Ni) is a metal that is widely distributed on the earth's surface. This metal is present in food and drinking water as a result of natural and anthropogenic activities. Ni has a biological function but is toxic in larger amounts; nickel salts cause allergies and even cancer [11].

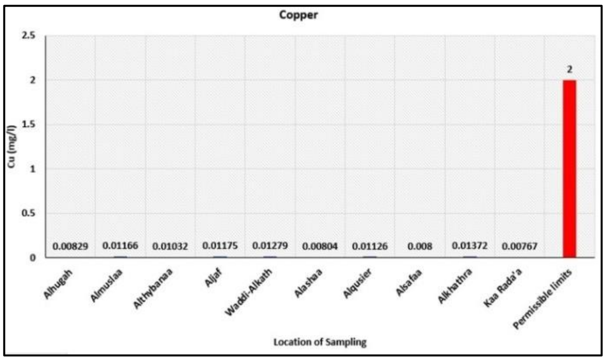

Figure 2: Copper concentrations in location of samples.

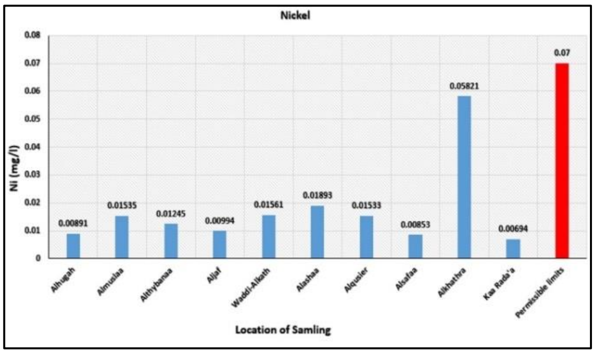

Figure 3: Nickel concentrations in location of samples.

Iron deficiency causes a disease called "anemia", and prolonged consumption of drinking water with high iron concentration can lead to a liver disease called hemosiderosis [37]. It can cause a metallic taste in drinking water, and exposure to high Fe concentrations has adverse effects on target organs such as the liver, cardiovascular system, and kidneys [36]. In the studied locations, the concentration of iron (Fe) in drinking water samples ranged from 0.00602 mg/l to 1.6778 mg/l, with an average value of 0.42567 ± 0.55929 mg/l. As can be seen in Figure 4, Fe concentration in Amuslan, Althybanaa, and Aljafand Alkhathra localities is above the respective permissible limits, which is probably due to the corrosion of steel and cast-iron pipes during water distribution [35].

Mn concentration in drinking water samples ranged from (below detection limit) BDL mg/l to 0.07692 mg/l, with an average of 0.0440 ± 0.0271 mg/l, as shown in Figure 5. The Mn concentration is below the respective permissible limits in all samples. The concentration of zinc (Zn) in the drinking water samples ranged from 0.00181 mg to 0.08524 mg/l, with an average concentration of 0.03652 ± 0.02579 mg/l. As can be seen in Figure 6, the Zn concentration in all samples is below the respective permissible limits. Zn is an important trace element that plays a crucial role in the physiological and metabolic processes of many organisms. Nevertheless, higher concentrations of zinc can be toxic to organisms [6].

3.3 Health Risk Assessment from Heavy Metals Concentration

3.3.1 Chronic daily intake (CDI) indices analysis

The heavy metals CDI were found in the order Fe > Mn > Zn > Ni > Cu by consuming well water. However, CDI levels for Fe, Mn, Zn, Ni, and Cu in all samples were below the respective RfD limit established by the USEPA.

The lowest observed Cu CDI mg/(kg. Day) was 0.000219, while the highest observed Cu CDI mg/(kg. Day) was 0.00039 with an average of 0.000293 ± 0.00006 mg/(kg. Day), The range of Ni for (CDI mg/(kg. Day)) was from 0.000198 to 0.00166, with an average of 0.000486 ± 0.000427 mg/(kg. Day) by drinking water consumption, as shown in Table 4. The lowest observed Mn CDI value was 0.00074 mg / (kg. Day), while the highest observed Mn CDI value was 0.0022 mg/(kg. Day) with an average of 0.00125 ± 0.00077 mg / (kg. Day) by consumption of drinking water. The range for Fe (CDI mg / (kg. Day)) was from 0.000302 to 0.0479, with an average of 0.01231 ± 0.015848 mg/(kg. Day) by consumption of drinking water. The lowest observed Zn-CDI mg/(kg. Day) was 0.00005, while the highest observed Zn-CDI was 0.00251 mg/(kg. Day) with an average of 0.00105 ± 0.000753 mg/(kg. Day) by consumption of drinking water.

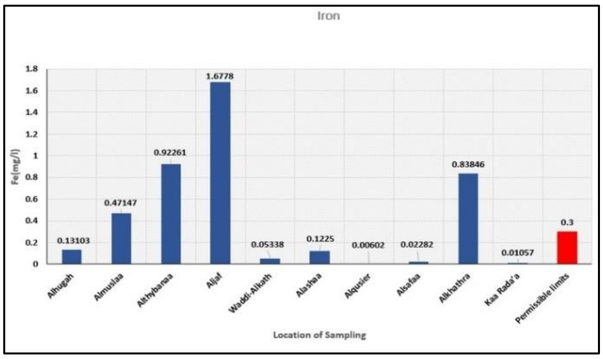

Figure 4: Iron concentrations in location of samples.

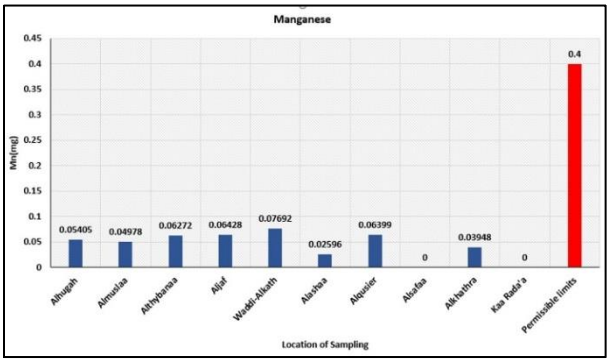

Figure 5: Manganese concentrations in location of samples.

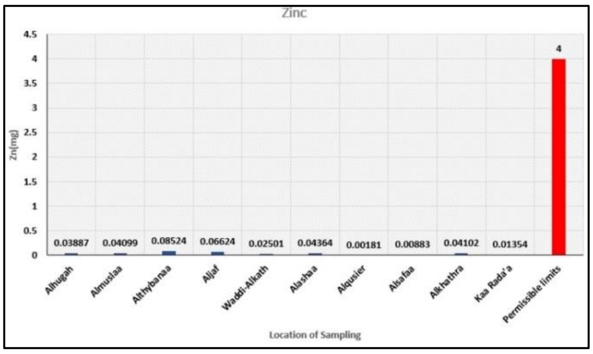

Figure 6: Zinc concentrations in location of samples.

3.3.2. Non-Carcinogenic Health Risk Assessment

As shown in Table 5, HRIs were found in the order of Mn, Ni, Fe, Cu, and Zn. The HRIs for all heavy metals indicate that there is no risk to the local population, indicating a low concentration of heavy metals. As can be seen in Table 5, the HRI for Mn, Fe, Cu, and Zn are less than 1 for all samples, indicating that there is no potential health risk from the concentration of heavy metals in drinking water. Compared with [36], the HRI of Fe, Ni, Cu, Mn, and Zn tended to be higher than the values reported for drinking water in this work and in [3,38]. To evaluate the total potential health risk posed by more than one heavy metal, the Hazard Index (HI) was used. (HI) is the sum of all health risk indices (HRI) calculated for individual heavy metals as shown in Figure 7. In Figure 7, all selected heavy metals were found in each sample, HI was lower than 1 which means that they are below their respective acceptable limits in all samples. There is no non-carcinogenic risk. There is no potential health risk from HM concentration due to the consumption of drinking water in the study area. As shown in Table 5, HRI were found in the order of Mn > Ni > Fe > Cu > Zn. The HRI for all heavy metals indicates that there is no risk to the local population, indicating low concentration of heavy metals. As can be seen in Table 5, the HRI for Mn, Fe, Cu and Zn in all samples are below < 1, indicating that there is no potential health risk from the concentration of heavy metals in drinking water. Compared to [36], the HRI of Fe, Ni, Cu, Mn and Zn tended to be higher than the values reported for drinking water in this work and in [3, 38].

Table 4: Chronic daily intakes (CDI) (mg/kg per day) of trace elements through drinking water.

No.	Location of Sampling	Cr	Cd	Cu	Ni	Mn	Fe	Zn
1	Alhugah	NC	NC	0.00023	0.000254	0.00154	0.00374	0.00111
2	Almuslaa	NC	NC	0.00033	0.000438	0.00142	0.0135	0.00117
3	Althybanaa	NC	NC	0.00029	0.000356	0.00179	0.0264	0.00251
4	Aljaf	NC	NC	0.00034	0.000284	0.00184	0.0479	0.00189
5	Waddi-Alkath	NC	NC	0.00036	0.000446	0.00220	0.00153	0.00071
6	Alashaa	NC	NC	0.00023	0.000541	0.00074	0.00350	0.00125
7	Alqusier	NC	NC	0.00032	0.000438	0.00183	0.00172	0.00005
8	Alsafaa	NC	NC	0.00023	0.000244	NC	0.000652	0.000252
9	Alkhathra	NC	NC	0.00039	0.00166	0.00113	0.0239	0.001172
10	Kaa Rada'a	NC	NC	0.00022	0.000198	NC	0.000302	0.000387
Min		**NC**	**NC**	**0.00022**	**0.000198**	**NC**	**0.000302**	**0.00005**
Max		**NC**	**NC**	**0.00039**	**0.00166**	**0.0022**	**0.0479**	**0.00251**
SD		**NC**	**NC**	**6.26E-05**	**0.000427**	**0.00077**	**0.01585**	**0.00075**
Average		**NC**	**NC**	**0.00029**	**0.000486**	**0.00125**	**0.01231**	**0.00105**
Permissible limits WHO		**1.5**	**0.001**	**0.04**	**0.02**	**0.046**	**0.7**	**0.3**

NC: Not Calculated, **SD:** Standard Deviation.

Table 5: Health risk indices (HRI) for different elements in the studied areas through drinking water.

No.	Location of Sampling	Cr	Ni	Mn	Fe	Zn
1	Alhugah	0.00575	0.0127	0.0335	0.00534	0.00370
2	Almuslaa	0.00825	0.0219	0.0039	0.0192	0.00390
3	Althybanaa	0.00725	0.0178	0.0389	0.0377	0.00837
4	Aljaf	0.00840	0.0142	0.0400	0.0684	0.00630
5	Waddi-Alkath	0.00900	0.0223	0.0478	0.00218	0.00273
6	Alashaa	0.00575	0.0270	0.0161	0.00500	0.00417
7	Alqusier	0.00800	0.0219	0.0398	0.00025	0.00017
8	Alsafaa	0.00575	0.0122	NC	0.00093	0.00084
9	Alkhathra	0.00975	0.0830	0.0246	0.0342	0.0039
10	Kaa Rada'a	0.00547	0.00990	NC	0.00043	0.00129
Min		**0.00547**	**0.0099**	**NC**	**0.00025**	**0.000173**
Max		**0.00975**	**0.083**	**0.0478**	**0.0684**	**0.00837**
SD		**0.00157**	**0.0213**	**0.0183**	**0.0228**	**0.0025**
Average		**0.007337**	**0.0243**	**0.0245**	**0.01736**	**0.0035**
Permissible limits WHO		**1**	**1**	**1**	**1**	**1**

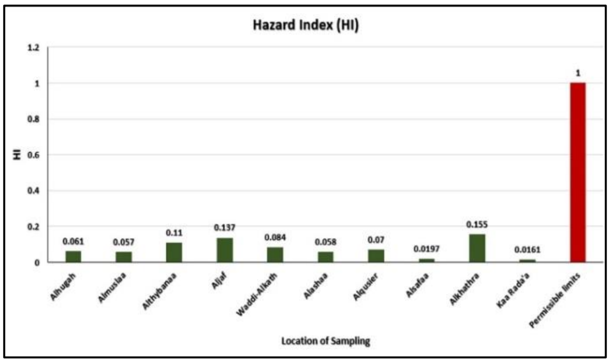

Figure 7: Hazard Index (HI) of HMs in location of samples.

3.3.3 Carcinogenic Health Risk Assessment

PCR calculated by drinking water and the results are shown in Figure (8). The probability of cancer risk of (Ni) for the adult population and based on the allowable range for cancer risk of ≤ 1×10^{-6} to 1×10^{-4} [31,32,39]. The lowest PCR was observed at 1.80×10^{-4}, while the highest PCR was observed at 1.51×10^{-3} with an average of $4.42 \times 10^{-4} \pm 4.42 \times 10^{-4}$ from drinking water consumption. Other works in similar found in values lower than those of the study [30] in Iran the PCR for HMs carcinogenic in this study were determined Cd (5.1×10^{-9}), Cr (7.8×10^{-7}) and Ni (1.4×10^{-8}).

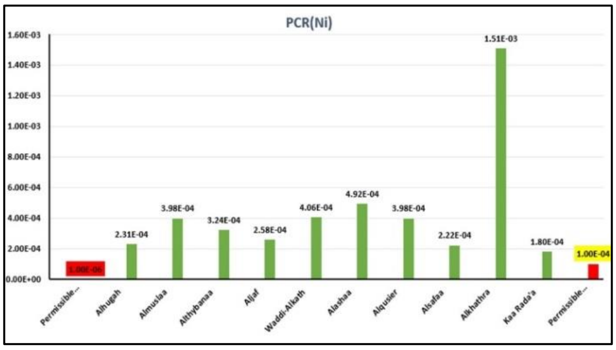

Figure 8: Hazard Index (PCR) of Ni in location of samples.

Table 6: Results of the Pearson correlation coefficient analysis between HMs (mg/l) and physicochemical parameters in the well water samples.

	T	PH	TDS	EC	Cu	Ni	Mn	Fe	Zn
T	1								
PH	0.3437	1							
TDS	-0.4851	**-0.6252**	1						
EC	-0.4881	**-0.6340**	**0.999**	1					
Cu	-0.1073	-0.1647	**0.579**	**0.5713**	1				
Ni	-0.1720	0.0401	**0.529**	**0.5097**	**0.6071**	1			
Mn	0.3819	-0.0069	0.127	0.1224	**0.6688**	0.0475	1		
Fe	0.0295	**-0.5639**	**0.795**	**0.7992**	0.4725	0.2181	0.3723	1	
Zn	**0.5931**	-0.3133	0.311	0.3121	0.2080	0.0808	0.4052	**0.7717**	**1**

The results obtained for HMs in water were compared with the studies of other researchers worldwide, as shown in Table 6. The lowest concentration of HMs was found in Egypt, Iran, and India (2017). Chin (2020) and Yemen (2016), the highest were found in Nigeria (2009 and 2017), India (2019), Iraq (2023), Libya (2022), and Saudi Arabia (2018), but the concentration of Zn was below the acceptable limit and in Yemen (Rada'a), the highest concentration of Fe was above the acceptable limit, but the concentration of Cu, Mn and Zn were below the acceptable limit.

3.4 Statistical Analysis

To evaluate the physical and chemical factors that may affect the source and mobility of HMs concentration in the well water of the study area, the relationship correlation was used to determine correlations between physicochemical parameters and HMs concentration [48]. Pearson correlation is used to determine linear correlations between different parameters and HMs as pairs in drinking water samples. Table 7 shows the Pearson correlation between heavy metals (Cu, Ni, Mn, Fe and Zn) and physicochemical parameters (temperature), PH, electrical conductivity (EC) and total dissolved solids (TDS) in groundwater. As showed a positive moderate correlation with T-Zn (0.5931). However, there was a weak correlation with the other elements. PH showed a negative moderate correlation with PH - TDS (0.6252), PH - EC (0.6340), and PH -Fe (0.5639). TDS showed positive strong correlation with TDS- EC (0.999) and moderate correlation with TDS — Cu (0.5792), TDS-Ni (0.5287) and strong correlation with TDS-Fe (0.79541).

Al loading in factor 1 showed positive correlation with Cu, Ni, Mn, Fe and Zn, indicating that these elements are directly derived from rock weathering [45]. EC showed positive moderate correlation with EC - Cu (0.5713), EC – Ni (0.5097) and strong correlation with EC — Fe (0.7992). Cu showed a positive moderate correlation with Cu -Ni (0.6071) and Cu — Mn (0.6687). Fe showed positive strong significant correlation with Fe — Zn (0.7717). These results can show that the elements measured in the present study have almost similar sources and the related sources can be associated with the geographical structure of the selected study area [30,45]. The pollution by HMs is significant due to weathering of rocks, fertilizers, and pesticides in the groundwater of the study area.

Table 6: Comparison of HMs concentration(mg/l) in groundwater with values taken from the open literature.

Country	Average concentration HMs in mg/ l							Reference
	Cr	Cd	Cu	Ni	Fe	Mn	Zn	
Nigeria	ND	ND	0.18	ND	0.71	ND	3.2	**[40]**
Yemen	ND	ND	ND	ND	0.01	0.005	ND	**[41]**
India	ND	ND	0.003	ND	0.051	0.227	0.342	**[42]**
Nigeria	ND	ND	0.17	ND	ND	0.43	ND	**[43]**
Iran	ND	ND	0.03	ND	ND	ND	0.04	**[15]**
Saudi Arabia	ND	ND	0.298	0.053	0.041	ND	ND	**[44]**
India	0.0369	0.0033	0.0527	0.0128	0.86426	0.1939	0.0877	**[45]**
Egypt	0.018	0.016	0.021	0.015	ND	ND	0,154	**[27]**
Iran	0.590	0.026	0.461	0.525	0.269	4.965	0.947	**[30]**
Iraq	0.055	0.0163	0.185	0.076	0.3	ND	0.45	**[46]**
China	0.68×10^{-3}	0.02×10^{-3}	0.57×10^{-3}	0.56×10^{-3}	0.63×10^{-3}	2.07×10^{-3}	0.79×10^{-3}	**[29]**
Libya	ND	ND	0.09	0.35	1.28	0.42	ND	**[47]**
Yemen	BDL	BDL	0.01035	0.01702	0.42567	0.00440	0.03682	**Present study**

ND: do not Detected, **BDL**: Below Detection Limits

4. Conclusion

Based on the results obtained in this study, the following were found:

1. The physicochemical parameters such as T were higher than the permissible limits of WHO, PH, TDS and EC were within the recommended WHO.
2. The average concentration of HMs in the water samples were Fe (0.426±0.559) Mn (0.044±0.026) Zn (0.036±0.026) Ni (0.017±0.0151) Cu (0.0103±0.002) mg/l, the concentrations of Cr, Cu, Mn, Ni and Zn were lower than the respective permissible limits in all the samples, but the concentration of Cd found was higher than the respective permissible limits.
3. In all samples, the concentration of Fe was higher than the respective permissible limits in four locations.
4. Non-carcinogenic health risk, while HRI and HI were lower than the permissible limits for the consumer (1), which means that there is no potential health risk from HM concentration in drinking water, but it can be concluded that the risks are not present, as possible exposure to HM through food and skin may also pose a risk.
5. Carcinogenic health risk, while the detected levels (PCR) in ten locations were higher than the safe levels, so there is a potential carcinogenic health risk from HM in drinking water. It is recommended to filter the water before using it as drinking water.
6. Correlation coefficient between HM concentrations and some physicochemical parameters as pairs in drinking water samples. Strong correlation with TDS — EC (0.999), TDS-Fe (0.79541), EC - Fe (0.79541), Fe — Zn (0.77174).
7. Therefore, this study recommends the government and other responsible agencies to:
   a) Implement appropriate drinking water treatment techniques that can reduce the current heavy metal levels,
   b) Educate the population to better storage of drinking water.
   c) Support the conduct of further studies on the health risks of the heavy metals Pb, As, Se, Co, and Hg to determine their contamination in air, rock, water, and soil samples.

Acknowledgments

The authors would like to thank the residents of the study area for their cooperation during the fieldwork, and we would like to thank all those who assisted us.

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