ASSESSMENT OF LEVELS OF SOME HEAVY ELEMENTS IN GROUNDWATER OF AL-HAWIJA DISTRICT AND STUDY THEIR HEALTH RISKS

Hassan Ibrahim Madeed1,Moafaq Anhab Saleh2
Hawija Education Department, General Directorate of Kirkuk Education
Department of Biology, College of Education for Pure Sciences, Tikrit University
Email Id: hasanmadeed@gmail.com

Abstract: The current study was conducted in the Department of Life Sciences/Faculty of Pure Science Education/University of Tikrit, from November 1, 2023, to April 1, 2024. To assess the quality of groundwater in Al-Hawija district, northern Iraq, water samples were collected from ten randomly selected wells in the study area, with one sample per site monthly, starting from January 2023 until December 2023. The concentrations of heavy elements in well water were determined, including Zinc (Zn), Cadmium (Cd), Nickel (Ni), and Iron (Fe). Health risks of drinking water in the study area were assessed using global mathematical models. The results were as follows: Zinc concentrations ranged from 0.041 to 1.251 mg/L, Cadmium concentrations ranged from 0.011 to 0.091 mg/L, Nickel concentrations ranged from 0.010 to 0.074 mg/L, while Iron concentrations ranged from 0.030 to 3.593 mg/L. It was found that there was an increase in the exposure rate to Iron and Zinc due to their high concentrations in water. The health risk quotient for the studied elements was less than 1, except for the health risk quotient for Cadmium concentrations in dermal contact in adults, which reached a true value of 1, and the health risk index for Cadmium in adults which reached 1.007. The rest of the results indicated no adverse health effects for these elements in both adults and children. The results showed a carcinogenic health risk for Cadmium of medium type through ingestion and dermal contact.
Keyword: heavy elements, groundwater, health risks.

Introduction

There are two types of water sources on our planet: the first is water available in oceans, rivers, lakes, and ponds, referred to as surface water, which serves as habitat for many plant and animal species that rely not only on quantity but also on the quality of water to survive. The other type is groundwater stored beneath the Earth's surface, nourishing our rivers and oceans and constituting the majority of drinking water supplies worldwide. All these resources are essential for life on Earth (Kilic, 2021).Groundwater is used to provide industrial and domestic water as well as for irrigation purposes worldwide. However, several factors affect the quality of groundwater, such as the flow of chemicals used in agriculture, industrial and domestic waste, geological formation, land use practices, leakage rates, and rainfall patterns (APHA, 2005). The demand for freshwater is witnessing a significant increase due to inflation in industrial activities and population growth (Dohare *et al*., 2014). The World Health Organization reports that about 80% of human diseases are water-related (Kavitha and Elangovan, 2010). Suresh and Kottureshwara (2009) affirmed that water quality is deteriorating due to pollution from human activities. Groundwater is considered the safest type of water source for domestic and drinking purposes.The rapid urbanization and intense human activities in cities have led to the emergence of a variety of environmental pollutants through chemical emissions rich in heavy metals (Wei and Yang, 2010). Soil and water serve as significant reservoirs for these pollutants, which are of great importance in environmental security. Pollution has become a major obstacle to regional development and human health in recent decades (Liang *et al*., 2017; Jiang *et al*., 2017), due to the environmental effects left by heavy elements in soil, water, sediments, air, and plants. This has increased the interest of official authorities and organizations concerned with reducing risks to human health (Soltani *et al*., 2015), as studies have shown a direct relationship between human activities and heavy metal pollution, leading to their accumulation in the environment (Taghavi *et al*., 2019).Many researchers have confirmed the negative effects of heavy metals on human health (Akortia *et al*., 2017), as these elements can enter the human body through ingestion, inhalation, and skin contact, accumulating therein, especially in children (Zheng *et al*., 2010). Although some heavy elements are necessary in the human body at low concentrations, their presence at high concentrations is considered a risk, as is the case for copper and zinc (Rizo *et al*., 2011), while others are not necessary for the body but have toxic effects even at low concentrations, such as cadmium and lead (Pragg and Ahmad, 2018).

The aim of the current study is to assess the levels of some heavy elements in several water wells in Al-Hawija district, western Kirkuk province, Iraq, and to study the health risks associated with these waters.

Materials and Methods

Study area: The current study was conducted in the Department of Life Sciences/Faculty of Pure Science Education/University of Tikrit, from November 1, 2023, to April 1, 2024. To assess the quality of groundwater in Al-Hawija district, located 60 km west of Kirkuk city, northern Iraq, ten wells were selected. These wells are utilized for irrigation of agricultural fields, watering livestock, and some domestic purposes.

Sample Collection: Water samples were collected from ten randomly selected wells in the study area, with one sample taken from each site monthly, starting from January 2023 until December 2023. The coordinates of the studied well locations were determined using Google Earth software, as shown in Table (1). Samples were taken between 8:00 AM and 10:00 AM after operating the well pump for several minutes. Samples were collected using non-transparent polyethylene bottles with a capacity of 500 ml. To preserve the water properties, samples were stored away from light and heat until necessary tests were conducted. Additionally, samples underwent filtration to remove particles and suspended solids using filter paper with a pore size of 0.45 micrometers. The filtered samples were then stored in a cooled container away from sunlight until they reached the laboratory for the required tests.

Table (1): Studied Wells with their Coordinates.

Well	Location (Village)	Coordinates (°)	
		N	E
First	Al-Azizia	35.336476	43.751839
Second	Suleiman AlGharb	35.363459	43.749369
Third	Al-Dawdah	35.343079	43.731279
Fourth	Tal Hussein	35.329571	43.716961
Fifth	Nafla	35.327820	43.758741
Sixth	Al Qasimia	35.358928	43.727046
Seventh	Alamenea 2	35.219909	43.713923
Eighth	Alamenea 1	35.373595	43.732917
Ninth	Al-Shalala	35.390718	43.704707
Tenth	Lzaga	35.384355	43.693926

Estimation of Heavy Elements in Water: The concentrations of heavy elements in water samples were estimated as outlined in (APHA, 2005), using Flame Atomic Absorption Spectroscopy (FAAS) equipment manufactured by Sens AAS GBC Scientific Equipment Dual, Australia. Through this equipment, the concentrations of heavy elements in well water were measured, including Zinc (Zn), Cadmium (Cd), Nickel (Ni), and Iron (Fe), as these metals are the most common in groundwater. The water samples underwent digestion by adding 1 ml of concentrated nitric acid per 50 ml of sample volume. When measuring the concentration of each element, its specific lamp was selected because each element has its own wavelength.

Assessment of The Health Risks of Drinking Water in The Study Area:

Daily Dose Average (DDA): It is defined as the daily dose rate per individual of heavy elements in water, determining the health risks resulting from exposure to them on human health. The daily dose is calculated for both children and adults for ingestion and dermal contact pathways of water (EPA, 2004), using the following equations:

$$ADD_{ing} = \frac{C * Ring * CF * EF * ED}{BW * AT}$$

$$ADD_{\mathrm{der}mal} = \frac{C * SA * CF * ET * K_p * EF * ED}{BW * AT}$$

Since:

ADDing represents the Average Daily Dose through drinking water.

ADDdermal represents the Average Daily Dose through dermal contact.

The rest of the equation parameters are described in Table (2).

Table (2): Values of the equation parameters for the Average Daily Dose of drinking water.

Factor	Definition	Units	Childs	Adults	Reference
C	Heavy metals concentration in water	µg kg^{-1}	-	-	This study
R_{ing}	Ingestion rate of water	mg day^{-1}	1	2	USEPA (2001)
EF	Exposure frequency	Days year^{-1}	350	350	
ED	Exposure duration	Years	6	30	
BW	Body weight of the exposed individual	Kg	15	60	
AT_{nc}	Average time for no carcinogens	Days	365 × ED	365 × ED	
AT_{ca}	Average time for carcinogens	Days	70 × 365	70 × 365	
CF	Conversion Factor	Unit less	1×10^{-3}	1×10^{-3}	
PEF	Particle emission factor	m^3 day^{-1}	1.32×10^9	1.32×10^9	
SA	Exposed skin surface area	cm^2	1800	5000	
ET	Exposures Time	Hour day^{-1}	1	0.58	
K_p	Dermal Permeability Coefficient	Unit less	Cd, Fe = ($1*10^{-3}$) Ni= ($2*10^{-4}$); Zn =($6*10^{-4}$)		

Hazard Quotient (HQ): The HQ represents a mathematical equation to calculate the ratio of the potential exposure to heavy elements to the reference exposure value allowed for that element from a single pathway without causing adverse health effects (EPA, 2004). The health hazard quotient for water samples was calculated according to the following equations:

$$HQ_{ing} = \frac{ADD_{ing}}{RfD_{ing}}$$

$$HQ_{dermal} = \frac{ADD_{dermal}}{RfD_{dermal}}$$

Since ADDing represents the Average Daily Dose through drinking water, and RfDing represents the Reference Dose for the element through ingestion, while ADDdermal represents the Average Daily Dose through dermal contact, and RfDdermal represents the Reference Dose for the element through dermal contact.

Hazard Index (HI): As for the Hazard Index (HI), it represents the sum of the hazard quotients for both ingestion and dermal contact pathways of water, calculated using the following equation:

$$HI = HQ_{ing} + HQ_{dermal}$$

Since HQing represents the health hazard quotient through ingestion, and HQdermal represents the health hazard quotient through dermal contact.

Cancer risk (CR): To assess the carcinogenic risk of heavy elements, a mathematical equation was developed by (USEPA, 2005). It is calculated by summing the product of the carcinogenic daily dose rate for each pathway by the slope factor of the element, as follows:

$$CR = ADD_{ing-ca} * SF_{ing} + ADD_{ing-ca} * SF_{dremal}$$

Since ADDca represents the carcinogenic daily dose rate and SF represents the slope factor for each exposure pathway.

Results and Discussion

Upon analyzing the results of the current study, we noticed the presence of high levels of some heavy metals in a few water samples. This may be attributed to variations in geological composition and differences in the depths of the wells studied, some of which are closer to sources of human pollution, as well as seasonal effects.

The concentration of zinc: The results in Table (3) showed significant differences between the concentrations of zinc within the well averages and study months. Observing the study month averages, the highest significant concentration of zinc reached 0.606 mg/L in January 2023, while the lowest concentration was 0.271 mg/L in March. In the well averages, the highest significant concentration of zinc was 0.789 mg/L at the first well, while the sixth well recorded the lowest concentration at 0.210 mg/L. The averages of interactions between wells and study months showed that the first and third wells achieved the highest concentrations of zinc during January 2023, reaching 1.251 mg/L for each, while the lowest concentrations were 0.041 mg/L at both the seventh well during February and the eighth well during January. The zinc concentrations obtained in the current study are relatively low compared to the established standards and previous studies. The World Health Organization (WHO, 1996) estimated the concentration of zinc at 3 mg/L as the maximum permissible limit in drinking water. Zinc is considered non-toxic when found in small concentrations and is beneficial for human health. Therefore, zinc has been given a minimum weight limit of 1 due to its minor effect on water quality assessment (APHA, 2005). The groundwater in the Al-Hawija district contains low levels of zinc according to the standards set by the World Health Organization, with zinc levels ranging from 0.041 to 1.251 mg/L, which is within the recommended limit by the World Health Organization. The main reason for zinc contamination in groundwater, according to Singh *et al.* (2022), is human activities such as municipal sewage discharges, industrial processes, and agricultural activities using minerals and weathering phenomena. Excessive zinc discharge leads to the pollution of surface water and subsurface environments, contributing to groundwater pollution. Human body muscles and bones contain approximately 90% of the zinc in acceptable quantities (Li and Zhang, 2010). Additionally, zinc is an essential mineral in these allowable quantities because it assists in protein production or synthesis, which is important for human health (Li and Zhang, 2010).

Table (3): Average concentrations of zinc (mg/L) for the ten wells during the study period and their averages.

Wells / Months	1	2	3	4	5	6	7	8	9	10	Months rate
January	1.251	0.142	1.251	0.595	0.998	0.192	0.293	0.041	0.251	1.049	0.606 a
February	0.847	1.049	0.293	0.394	0.897	0.092	0.041	0.092	0.192	0.051	0.395 j
March	0.332	0.304	0.314	0.259	0.286	0.276	0.257	0.161	0.229	0.293	0.271 l
April	0.806	0.414	0.724	0.496	0.097	0.196	0.186	0.554	0.462	0.616	0.455 f
May	0.895	0.373	0.872	0.525	0.103	0.207	0.197	0.445	0.513	0.684	0.481 e
June	0.716	0.355	0.653	0.437	0.153	0.189	0.292	0.468	0.503	0.547	0.431 g
July	0.884	0.395	0.689	0.539	0.189	0.246	0.351	0.577	0.553	0.676	0.510 b
August	0.797	0.481	1.013	0.461	0.165	0.253	0.325	0.462	0.458	0.596	0.501 c
September	0.817	0.421	0.803	0.49	0.173	0.235	0.331	0.514	0.516	0.621	0.492 d
October	0.716	0.289	0.633	0.468	0.146	0.241	0.259	0.451	0.465	0.437	0.411 i
November	0.692	0.259	0.422	0.401	0.144	0.205	0.251	0.379	0.449	0.371	0.357 k
December	0.709	0.322	0.558	0.271	0.179	0.185	0.221	0.588	0.654	0.601	0.429 h
Wells rate	0.789 a	0.400 f	0.685 b	0.445 d	0.294 h	0.210 j	0.250 i	0.394 g	0.437 e	0.545 c	

The values followed by the same letter do not differ significantly from each other.

Cadmium concentration: The results in Table (4) showed significant differences between the concentrations of cadmium within the well averages and study months. Observing the study month averages, the highest significant concentration of cadmium reached 0.059 mg/L in August 2023, while the lowest concentration was 0.036 mg/L in January. In the well averages, the highest significant concentration of cadmium was 0.070 mg/L at the tenth well, while the sixth well recorded the lowest concentration at 0.034 mg/L. The averages of interactions between wells and study months showed that the tenth well achieved the highest concentration of cadmium during August 2023, reaching 0.091 mg/L for each, while the fifth well recorded the lowest concentration at 0.011 mg/L during January. The concentrations recorded in this study exceeded the permissible limits according to the Iraqi standard specifications for drinking water for the year 2001, which set the maximum value at 0.003 mg/L.Cadmium has a wide range of adverse effects on humans when exceeded the permissible limits. For example, kidney damage, colorectal cancer, stomach cancer, and calcium metabolism disorders (WHO, 2017).

In a previous study, Myers *et al*. (2023) analyzed concentrations of cadmium, chromium, nitrogen, zinc, lead, and copper in 15 groundwater samples from various wells. They used water quality and health risk assessment indices to evaluate the suitability of water for domestic purposes and confirmed that the highest concentrations reached Cd (0.12 mg/L) and Cr (0.11 mg/L), exceeding their standards of 0.003 and 0.05 mg/L recommended by the World Health Organization for drinking water. The increase in cadmium concentrations may be partially attributed to improper disposal of discarded car batteries. According to Idrees *et al*. (2018), cadmium is a highly hazardous metal, even at low doses. It can accumulate in organs/tissues such as the kidneys, lungs, heart, and liver (Yu-Ting *et al*., 2022). Exposure to cadmium can lead to chronic kidney damage and failure (OSHA, 2013). Recently, it has been reported that cadmium disrupts calcium metabolism in the body, and high levels of cadmium exposure have been linked to prostate and lung cancer (Goodwill *et al*., 2019).

Table (4): Average concentrations of cadmium (mg/L) for the ten wells during the study period and their averages.

Wells / Months	1	2	3	4	5	6	7	8	9	10	Months rate
January	0.017	0.057	0.065	0.035	0.011	0.051	0.021	0.033	0.033	0.038	0.036 l
February	0.042	0.056	0.055	0.037	0.046	0.039	0.041	0.059	0.061	0.058	0.049 d
March	0.051	0.031	0.066	0.049	0.052	0.036	0.014	0.044	0.053	0.063	0.046 g
April	0.036	0.041	0.036	0.048	0.045	0.025	0.042	0.049	0.053	0.062	0.044 i
May	0.041	0.034	0.025	0.033	0.041	0.01	0.046	0.034	0.048	0.069	0.038 k
June	0.044	0.053	0.031	0.048	0.053	0.033	0.051	0.049	0.057	0.076	0.050 c
July	0.048	0.061	0.031	0.041	0.059	0.038	0.056	0.052	0.073	0.083	0.054 b
August	0.053	0.054	0.036	0.047	0.065	0.041	0.061	0.057	0.081	0.091	0.059 a
September	0.047	0.046	0.038	0.041	0.053	0.037	0.056	0.039	0.059	0.064	0.048 f
October	0.039	0.055	0.036	0.033	0.053	0.034	0.051	0.045	0.055	0.084	0.049 e
November	0.034	0.053	0.028	0.023	0.041	0.029	0.054	0.049	0.058	0.083	0.045 h
December	0.023	0.045	0.019	0.029	0.043	0.031	0.059	0.043	0.043	0.065	0.04 j
Wells rate	0.040 g	0.049 c	0.039 h	0.039 i	0.047 d	0.034 j	0.046 f	0.046 e	0.056 b	0.070 a	

The values followed by the same letter do not differ significantly from each other.

Nickel concentration: The results in Table (5) indicated significant differences between the concentrations of nickel within the well averages and study months. From the study month averages, the highest significant concentration of nickel reached 0.053 mg/L in January 2023, while the lowest concentration was 0.023 mg/L in March. In the well averages, the highest significant concentration of nickel was 0.043 mg/L at the second well, while the ninth well recorded the lowest concentration at 0.024 mg/L. The averages of interactions between wells and study months showed that the second well achieved the highest concentrations of nickel during December 2023, reaching 0.074 mg/L for each, while the lowest concentrations were 0.010 mg/L at both the second well during March and the fourth well during December, and the sixth well during both March and December, and the ninth well during November. The nickel concentrations obtained in this study were close to the safe limits, as the World Health Organization estimated the concentration of 0.07 mg/L as the maximum permissible limit for nickel in drinking water (WHO, 1996), and it was found that the second well during December and the sixth well during January exceeded the standard limits.Nickel pollution in groundwater arises from the weathering of mafic and ultramafic rocks, mineral dissolution, water-rock interactions, as well as the interplay between human and geological influences (Rashid *et al*., 2023). Generally, mixed sources such as mineral leaching, mafic rocks (Marieni *et al*., 2020), agricultura chemicals, industrial waste, electroplating, and coal combustion play significant roles in groundwater pollution (Deng *et al*., 2020).

Table (5): Average concentrations of nickel (mg/L) for the ten wells during the study period and their averages.

Wells / Months	1	2	3	4	5	6	7	8	9	10	Months rate
January	0.041	0.041	0.057	0.048	0.063	0.071	0.055	0.048	0.062	0.042	0.053 a
February	0.013	0.022	0.044	0.049	0.021	0.021	0.032	0.038	0.016	0.014	0.027 j
March	0.016	0.010	0.032	0.043	0.024	0.010	0.021	0.031	0.022	0.016	0.023 k
April	0.022	0.048	0.034	0.039	0.043	0.025	0.032	0.029	0.021	0.041	0.033 e
May	0.025	0.051	0.039	0.039	0.045	0.031	0.033	0.029	0.021	0.049	0.036 b
June	0.025	0.049	0.038	0.039	0.053	0.023	0.031	0.040	0.025	0.039	0.036 b
July	0.027	0.051	0.033	0.026	0.036	0.024	0.034	0.043	0.023	0.042	0.034 d
August	0.031	0.046	0.037	0.021	0.033	0.027	0.031	0.047	0.028	0.056	0.036 c
September	0.024	0.042	0.032	0.019	0.035	0.034	0.027	0.053	0.022	0.044	0.033 f
October	0.022	0.034	0.039	0.027	0.031	0.029	0.025	0.051	0.019	0.041	0.032 h
November	0.025	0.045	0.036	0.027	0.037	0.029	0.031	0.044	0.010	0.044	0.033 g
December	0.025	0.074	0.036	0.010	0.037	0.010	0.019	0.039	0.023	0.029	0.030 i
Wells rate	**0.025 h**	**0.043 a**	**0.038 d**	**0.032 e**	**0.038 c**	**0.028 g**	**0.031f**	**0.041 b**	**0.024 i**	**0.038 d**	

The values followed by the same letter do not differ significantly from each other.

Iron concentration: The results in Table (6) indicated significant differences between the concentrations of iron within the well averages and study months. From the study month averages, the highest significant concentration of iron reached 2.657 mg/L in August 2023, while the lowest concentration was 0.071 mg/L in April. In the well averages, the highest significant concentration of iron was 2.289 mg/L at the seventh well, while the second well recorded the lowest concentration at 2.010 mg/L. The averages of interactions between wells and study months showed that the fifth well during November 2023 achieved the highest concentration of iron, reaching 3.593 mg/L for each, while the lowest concentration was 0.030 mg/L at the fifth well during April. The maximum permissible limit for iron concentration and the acceptable level set

Table (6): Average concentrations of iron (mg/L) for the ten wells during the study period and their averages.

Wells / Months	1	2	3	4	5	6	7	8	9	10	Months rate
January	2.128	2.155	2.671	2.121	2.176	2.521	2.189	2.079	2.431	2.465	2.294 f
February	2.251	2.541	2.508	2.336	2.376	2.528	2.568	2.323	2.482	2.495	2.441 d
March	2.775	2.201	2.117	2.128	2.611	1.294	2.216	1.954	2.152	2.827	2.228 i
April	0.060	0.040	0.090	0.060	0.030	0.070	0.060	0.080	0.110	0.110	0.071 l
May	2.144	2.358	2.334	1.814	1.961	2.091	2.114	2.418	1.999	2.187	2.142 k
June	2.389	2.515	2.489	2.267	1.763	2.394	2.254	3.216	2.552	2.333	2.417 e
July	2.089	2.201	2.626	2.778	1.965	2.094	2.329	2.181	2.232	2.097	2.259 g
August	2.327	2.451	3.211	2.737	2.417	2.629	3.074	2.429	2.955	2.336	2.657 a
September	2.341	2.175	2.521	2.332	2.431	2.644	2.699	2.442	2.725	2.349	2.466 b
October	2.135	1.888	1.734	1.959	2.493	2.611	2.968	1.924	2.487	2.144	2.234 h
November	2.254	1.699	1.831	2.586	3.593	2.348	2.671	3.414	2.238	1.929	2.456 c
December	2.005	1.893	2.933	2.172	2.198	2.181	2.331	2.312	2.214	1.954	2.219 j
Wells rate	2.075 i	2.010 j	2.255 b	2.108 g	2.168 e	2.117 f	2.289 a	2.231 c	2.215 d	2.102 h	

The values followed by the same letter do not differ significantly from each other.by the World Health Organization (2011) in groundwater samples is 1.0 mg/L, and thus we find that all samples exceeded this level except for the readings in April for all wells. Groundwater samples in the study area were found to be contaminated with iron, as they all contained significantly higher concentrations than the standard limits, and the seasonal levels were also higher in dry seasons than in rainy seasons. Iron in groundwater can originate from natural sources such as minerals in sediments and rocks, or from mining, industrial waste, and mineral weathering in the surrounding soil (Kumar and Kumar, 2012).

Assessment of Health Risks Associated with the Use of Studied Drinking Water

Exposure through drinking water and skin contact with water contaminated with heavy metals leads to several health risks; therefore, its use should be investigated. Exposure to these toxic metals in humans can cause non-carcinogenic and carcinogenic health effects, including increased cancer cases, eye deformities, and neurological and behavioral disorders (Tirkey *et al*., 2017).

Average Daily Dose (ADD): Ingestion and dermal contact are the two main routes through which humans are exposed to pollutants such as heavy metals in water (USEPA, 2005).

Table (7) shows the results of estimating the average daily dose of heavy elements in drinking water, indicating an increase in exposure to iron and zinc due to their high concentrations in the water. Overall, exposure levels varied between ingestion and dermal contact, with the effect of ingestion attributed to consuming large quantities of the studied well water, as the absorption factor in the stomach is much higher than that in the skin.

Table (7): Values of the average daily dose of heavy elements through drinking water in the study area ($\times 10^{-3}$).

Heavy metals	ADD injection		ADD dermal	
	Childs	Adults	Childs	Adults
Zn	0.03	0.07	0.03	0.06
Cd	0.003	0.007	0.005	0.01
Ni	0.002	0.005	0.0007	0.002
Fe	0.1	0.3	0.2	0.5

Hazard Quotient (HQ) and Hazard Index (HI): The results of Table (8) indicate that the health hazard quotient for the studied water samples showed that all the studied heavy elements were less than 1, except for the health hazard quotient for the concentrations of cadmium in the case of dermal contact in adults, which was one true value, and the hazard index for cadmium in adults, which was 1.007. The rest of the results suggest that there were no adverse health effects for those elements in both adults and children.These results are consistent with those published by the Australian Environmental Protection Agency, which stated that the HI values for As, Cd, and Cr are high, indicating that these metals deserve special health attention (Saha *et al*., 2017). Myers *et al*. (2023) also studied the health risks of groundwater in Ghana and mentioned that the HI for children was higher than that for adults, meaning that children are more susceptible to potential non-carcinogenic risks from heavy metals when consuming and using groundwater. Damage to the nervous system, blood cells, and intelligence quotient are potential non-carcinogenic health effects in infants (WHO, 2008); Centers for Disease Control (Hong *et al*., 2014). Potential non-carcinogenic health effects observable in adults include neurological disorders, decreased kidney function, female infertility, high blood pressure, and cataract formation (Hong *et al*., 2014).

Table (8): Results of Hazard Quotient and Hazard Index for water samples in the study area.

Heavy metals	HQ injection		HQ dermal		HI	
	Childs	Adults	Childs	Adults	Childs	Adult
Zn	0.0001	0.0002	0.0005	0.001	0.0006	0.0012
Cd	0.003	0.007	0.5	1	0.503	1.007
Ni	0.0001	0.0003	0.0001	0.0004	0.0002	0.0007
Fe	0.002	0.005	0.003	0.009	0.005	0.014

Cancer risk (CR): Repetitive exposure to certain heavy elements may pose a carcinogenic health risk to the human body. Therefore, the US Environmental Protection Agency (USEPA) typically recommends that CR values below 10^{-6} can be considered negligible, while CR values above 10^{-4} are harmful to humans, indicating a carcinogenic health risk. CR values ranging from 10^{-6} to 10^{-4} indicate an intermediate carcinogenic health risk.The results of the carcinogenic risk in the studied water samples, as shown in Table (9), indicate a medium-level carcinogenic health risk for cadmium, with values ranging from 10^{-6} to 10^{-4} for both children and adults in terms of ingestion and dermal contact, as well as in the overall risk category. This could be attributed to its concentration rate in the drinking water of the study area, which was measured at 0.046 mg/L. Cadmium is described as non-essential to the human body and toxic and carcinogenic even at very low concentrations. As for the nickel risk, it appears that there is no carcinogenic health risk for both children and adults, as its values were below 10^{-6}.

Table (9): Results of carcinogenic risk for water samples in the study area ($\times 10^{-4}$).

Heavy metal s	CR ing		CR dermal		∑CR	
	Childs	Adults	Childs	Adults	Childs	Adults
Cd	0.030 5	0.0549	0.030 5	0.0549	0.061	0.1098
Ni	0.000 6	0.0008 4	0.000 6	0.0008 4	0.001 2	0.0016 8

When comparing these results with the study conducted by Myers *et al*. (2023), it is evident that cadmium contributed significantly to the overall cancer risk, with adults being more susceptible to cancer risk than children. For instance, the results reveal that 9 out of 10,000 adults are potentially affected by carcinogenic risk, while 6 out of 10,000 children may be susceptible to carcinogenic risk. Li *et al*. (2017) confirmed that the reason behind the lower cancer risk among children compared to adults could partially be attributed to the shorter duration of exposure for children.

Conclusion: The recorded concentrations of heavy elements in this study were within safe limits for zinc and nickel, while cadmium and iron exceeded the established standard limits. There was an increase in exposure to iron and zinc due to their high concentrations in the water. The health risk quotient for the studied elements was less than 1, except for the health risk quotient for cadmium concentrations in dermal contact among adults, which was exactly 1, and the hazard index for cadmium in adults, which was 1.007. The rest of the results indicate no adverse health effects for those elements in both adult and children categories. The results show a medium-level carcinogenic health risk for cadmium through ingestion and dermal contact.

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