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Evaluation of potential health risks from Cd, Pb, Zn, and Fe in drinking water and groundwater sources in Sulaymaniyah City, Kurdistan Region of Iraq (KRI).

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ABSTRACT
Accessibility to a clean drinking water resource is vital for humanity. Sources of clean water need to be preserved well and local government authorities need to make sure that the clean water is delivered to community individuals without any contamination. This research aims to assess the health risks to humans associated with the concentrations of Cd, Pb, Zn, and Fe in drinking water samples from tap water and other sources within as Sulaymaniyah city. We analyzed key physicochemical parameters to assess risk and found that most drinking water sources met World Health Organization (WHO) standards. However, some samples indicated potential bioaccumulation risks of heavy metals, particularly high lead concentrations at site 31 G. Exposure assessment was evaluated for carcinogenic risk within the study area and the collected samples. The TTHQ (Total Target Hazard Quotient) level for children resulting from exposure exceeded that of adults. which indicates a higher risk for children. Lack of proper environmental monitoring of such risks may lead to irreversible outcomes, especially in sensitive community groups in the future.

***Keywords*:** heavy metals, water resources, health risks assessment and environmental health..

INTRODUCTION

Water is regarded as an essential resource in the ecosystem. The primary human need is clean drinking water access which is safe and has the essential element of a healthy life [1, 2, 3]. In Sulaymaniyah, the main sources of drinking water are tap water and groundwater.

Across the Kurdistan Region of Iraq (KRI), especially in Sulaymaniyah city, surface water is a major source of drinking water. Dukan river and Sarchnar channel are the main and the most important drinking water resource for Sulaymaniyah city, Groundwater serves as the primary source of drinking water for the entire city of Sulaymaniyah. The increasing demand for water in urban areas, driven by industrialization and population growth, is often addressed by supplementing the supply with groundwater or nearby surface water sources. However, this additional supply may lead to incomplete treatment processes, resulting in a substandard quality of drinking water [4]. In developing countries, groundwater is a vital water resource that supports domestic drinking needs, irrigation, and industrial activities (5; 6; 7; 8).

The Dukan reservoir, Sarchnar, and groundwater sources pose significant risks to human health due to contamination. Providing safe drinking water is essential for human survival, as it should not present any substantial risks to health [9].

Over the past few years, the quality of both surface water and groundwater supplies has faced increasing stress and threats, because of the rapid development of human society, urbanization, and industrial development. The majority of drinking water sources, such as surface water and groundwater, are at risk of heavy metal contamination resulting from both natural processes and human activities [2, 10]. Anthropogenic activities such as industrial operations, agriculture, commercial practices, and improper waste disposal are major contributors to the release of toxic contaminants and heavy metals into water systems [11; 12; 13; 14]. Additionally, geologic

Processes such as rock and mineral weathering, leaching, ionic exchanges, precipitation, and redox reactions also play a significant role in heavy metal pollution [15; 16; 17; 18]. So surface water and groundwater are contaminated by these resources and it becomes a significant problem, especially by heavy metals [7]. These pollutants not only pose environmental challenges but also pose significant threats to human health [5, 6]. In recent years, the evaluation of water contaminated with heavy metals (HMs) has become a key area of focus for environmental researchers [19; 2]. While heavy metals naturally present in the environment are typically harmless due to their minimal concentrations [20], elevated levels beyond recommended limits can pose serious risks. Humans may encounter heavy metals through diverse pathways, including consumption of food and drinking water, industrial emissions, and vehicular pollution [21]. Drinking water, in particular, is a significant source of heavy metal exposure, with concentrations typically measured in $\mu g.L^{-1}$. Due to their stability, toxicity, and ability to bioaccumulate, Heavy metals are identified as toxic contaminants that pose significant environmental risks. Epidemiological studies have highlighted the serious risks associated with exposure to HMs, emphasizing their non-biodegradable nature [22; 23].

Although certain heavy metals like Cu, Mn, Zn, Fe, and Ni are necessary in trace amounts for normal body growth and function [5; 6; 24; 25; 26; 27], excessive exposure through drinking water presents a serious risk to human health [2]. The accumulation of these metals in the body can lead to severe health issues, as many heavy metals are known carcinogens that contribute to various cancers and diseases [28; 29; 30]. Due to their tendency to bioaccumulate in the human body and their resistance to metabolism, toxic heavy metals present an imminent health hazard [31; 14].

Zinc (Zn), like other heavy metals, plays a vital role in maintaining normal body functions.

A deficiency in zinc can result in poor wound healing, reduced respiratory muscle performance, immune dysfunction, anorexia, diarrhoea, and hair loss [32]. However, excessive levels of zinc, particularly concentrations exceeding 0.8 mg/L [33], can lead to chronic health issues. These effects encompass cancer, birth defects, organ damage, neurological disorders, and immune system dysfunction [34; 35]. Iron (Fe) is also a notable concern because of its quick absorption in the digestive system. It can alter the taste of drinking water, and prolonged exposure to elevated iron levels can harm vital organs, including the liver, cardiovascular system, and kidneys [36]. Additionally, heavy metals like Cadmium (Cd) can interfere with essential nutrients like vitamins C and E by displacing them from their metabolically active sites, which leads to cellular toxicity [37; 38]. Both human and animal studies have shown that cadmium could potentially be carcinogenic to humans [39]. The USEPA has set the acceptable concentration of cadmium in drinking water at 0.003 mg/L [40]. Lead (Pb) is an extremely hazardous and cancer-causing metal that poses major health threats to humans. It can lead to long-term health problems, including hypertension, nerve damage, kidney dysfunction, and lung cancer. Prolonged exposure to elevated concentrations of lead can result in anaemia [41; 42]. One of the biochemical consequences of lead is its disruption of heme synthesis, leading to blood-related damage [34]. The USEPA has set a maximum allowable concentration of 0.015 mg/L for lead in drinking water [40].

The primary modes of heavy metal exposure include absorption, inhalation, and ingestion, with drinking water intake being the foremost source of exposure [43; 44; 45]. Compared to ingestion, the intake of heavy metals through inhalation is generally minimal.

The human health risk assessment model offers significant advantages over traditional drinking water standards, such as those recommended by the WHO. These models take into account variables such as age, body weight, metal concentration, exposure duration, and daily consumption [46]. Thus, assessing the human health risks, both carcinogenic and non-carcinogenic, associated with heavy metals like Cd and Pb in children and adults is essential. The hazard quotient (HQ) is a commonly used tool to analyze the health impacts of toxic metals by comparing exposure levels to the reference dose (RfD) [47]. Numerous studies have documented these risks by analyzing exposure scenarios involving contaminated water [19; 48; 49].

The objectives of this study are threefold: first, to determine the concentrations of selected physicochemical parameters and heavy metals (Cd, Pb, Zn, and Fe) in drinking water from different areas of Sulaymaniyah City; second, to compare these values with the drinking water standards recommended by national and international organizations, including the WHO; and third, to assess the potential human health risks posed by Cd, Pb, Zn, and Fe in surface and groundwater systems.

MATERIALS AND METHODS

1. 2.1 Study Area Description

The research was carried out in Sulaymaniyah Province, situated in the Kurdistan Region of Iraq, especially in and around the city of Sulaymaniyah (Figure 1).The tap water is a sources of surface water after being collected in the water projection and channelled over the city. There are other sources of water, such as well water, which is a source of groundwater. Both sources were used for drinking purposes.

1.2 Sampling and Analysis

Sample Collection: Water samples were collected for analysis over all Sulaymaniyah City to cover the optimal area of the city for both (Tap and Well) water, and without a home filtration system. Three replicate samples were collected from each sampling point in the study for both tap and well water, after sampling method directly laboratory measurement started for those parameters pH, EC, Turbidity, and heavy metals (Cd, Pb, Zn, and Fe). The measurements were performed at the College of Agricultural Engineering Science, Department of Natural Resources and at Anbar University. Temperature and pH were determined using a portable HANNA HI 8314 pH meter, following the method described by [50]. Electrical conductivity (EC) and total dissolved solids (TDS) were measured at 25°C with an EC meter (WTW, Multi197i) during sampling, as outlined in [50]. Turbidity was measured using a calibrated turbidity meter (WTW, Photo Flex/Turb 430), with results reported in nephelometric turbidity units (NTU), in accordance with the procedure described by [50]. Heavy metals run by (AAS) Atomic Absorption Spectroscopy GBC-Savanta, at University of Anbar-Iraq.

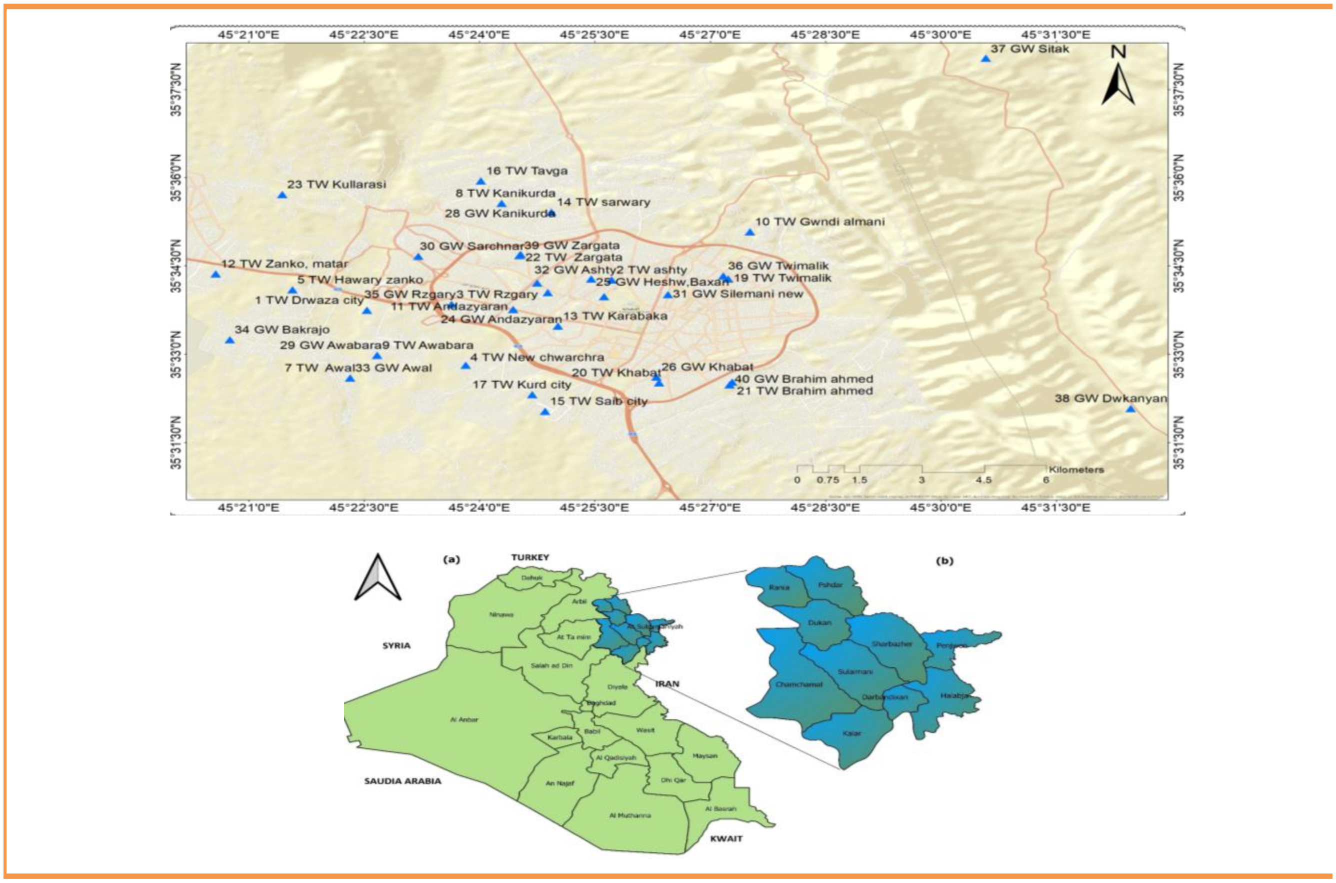


Figure 1: Iraq (a) and Sulaymaniyah city (b) map (c) Samples of drinking water

2.3 Heavy Metals Risk Assessment

2.3.1 Evaluation of Exposure

Heavy metals can enter the human body via multiple routes, including ingestion, inhalation, and skin absorption. However, the most significant route of exposure is oral intake, with other pathways contributing minimally [51; 52]. Risk assessment involves evaluating both hazard and exposure, and is defined as the process of estimating the probability of adverse health effects of a certain magnitude occurring over a specific time frame. The health risk assessment for each heavy metal typically involves quantifying the risk level, which is expressed in terms of carcinogenic or non-carcinogenic effects in the environment.

2.3.1.1 Assessment of Non-Carcinogenic Health Risks to Humans

To assess the non-carcinogenic risks to human health, we calculated the (TTHQ) and the (THQ) for each water sample. This process began with determining the (ADD) or (CDI). Based on these values, we estimated the THQ and TTHQ.

The risks linked to the consumption of individual trace elements were evaluated for both adult and child populations, utilizing the CDI or ADD criteria as outlined below:

$$ADD\ or\ CDI = \frac{C\ x\ IR\ x\ ED\ x\ EF}{BW\ x\ AT}\ x\ UF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

In this context, ADD refers to the mean daily dosage throughout the exposure period, measured in (mg/kg.day). The variable C represents the concentration of heavy metals in a drinking water sample (mg/L). IR stands for the ingestion rate of water, set at 3.45 L/day for adults and 2.0 L/day for children. BW refers to the average body weight, with 60 kg for adults and 25 kg for children. EF denotes the frequency of exposure, assumed to be 365 days per year. ED indicates the exposure duration, which is 70 years for adults and 10 years for children. AT calculates the average time, amounting to 25,550 days (70 years multiplied by 365 days/year for adults) and 3,650 days (10 years multiplied by 365 days/year for children). The factor UF equals 0.001 when using μg/L for heavy metals.

Target Hazard Quotient (THQ)

The non-carcinogenic health risks, expressed as (THQs), are determined by dividing the chronic daily intake (CDI) or (ADD) by the (RfD).

The non-carcinogenic risk associated with an individual element is evaluated using the following equation for the (THQ) (Eq. 2):

THQi=ADDi/ RFDi……………………………………………………………………………...…..2

The RfD represents the specific element ($mg \cdot kg^{-1} \cdot day^{-1}$). The RfD values for heavy metals are as follows: 0.001 $mg \cdot kg^{-1} \cdot day^{-1}$ for cadmium (Cd), 0.005 $mg \cdot kg^{-1} \cdot day^{-1}$ for lead (Pb), 0.0035 $mg \cdot kg^{-1} \cdot day^{-1}$ for zinc (Zn), and 0.7 $mg \cdot kg^{-1} \cdot day^{-1}$ for iron (Fe) [58], [59, 60].

Total Target Hazard Quotient (TTHQ)

The overall value for the non-carcinogenic risk assessment is represented by the hazard index (HI) or (TTHQ) [61], which is determined by summing the individual (THQ) values.

To assess the risk of a chemical mixture, the individual THQs are aggregated to calculate the (HI) or (TTHQ). Exposure to multiple metal contaminants may lead to cumulative effects. Therefore, the combined health effects risk from exposure to various metals is assessed by adding the THQ values of each metal, resulting in the (TTHQ), as shown in Equation (3). [62, 63, 64].

TTHQ or HI = ∑ THQi

TTHQ=THQ Cd+ THQ Pb + THQZn + THQ ……………………………………………..……3

According to [65, 66], If the Hazard Index (HI) is greater than 1, it suggests that the potential for adverse health effects from ingesting a specific element surpasses the safe limit. Conversely, An HI value of less than 1 indicates that the risk falls within safe limits. As a result, non-carcinogenic risk is classified into categories of negligible, low, medium, and high risk based on HI values [55, 58, 67, 68]. An HI greater than 1 indicates a possible threat to human health, highlighting the necessity for additional research [65]. As classified by [65], [58], and [69], the HI categories are as follows: Risk levels are categorized as negligible ($HI < 0.1$), low ($HI \geq 0.1$ but < 1), medium ($HI \geq 1$ but < 4), and high ($HI \geq 4$).

2.3.1.2 The excess lifetime cancer risk

Cadmium and lead are recognized as cancer-causing substances [2]. The cancer risk probability (PCR) related to consuming groundwater is evaluated based on the additional lifetime risk of an individual developing cancer due to exposure to a potential carcinogen [70]. The cancer-causing potential of these elements is determined using the following formula [51, 57]:

ELCRi = ADDi x CSFi ……………………………………………………………………….…4

ELCRi stands for Excess Lifetime Cancer Risk

ADD = (mg/kg/day) previously calculated using equation (1)

CSF = Cancer Slope Factor (mg/kg/day)

TELCR= ∑ ELCRi …………………………………………………………………………..…..5

(CSF), in $mg.kg^{-1}.day^{-1}$, is a key parameter in calculating cancer risk [59]. The Cancer Slope Factor (CSF) values for cadmium (Cd) and lead (Pb) are 0.380 and 0.0085, respectively [70, 69]. An acceptable probability of cancer risk (PCR) or excess lifetime cancer risk (ELCR) is $\leq 1 \times 10^{-6}$, which implies that, on average, the likelihood of one individual in 1,000,000 developing cancer due to carcinogen exposure is minimal [31, 71].

However, A cancer risk ranging from 1×10^{-6} to 1×10^{-4} is typically deemed acceptable [72, 70]. In this research, the estimated excess cancer risk was compared to the maximum risk threshold set by the USEPA, which is $\leq 1 \times 10^{-6}$ [73, 31].

2. Results and discussion

Table 1 presents an overview of the pH, (EC), turbidity, and levels of heavy metals in drinking tap water and groundwater gathered samples from various sites in Sulaymaniyah City (Figure 1). The pH directly affects human health and influences water quality parameters. Additionally, It is important to mention that elevated pH levels may result in a bitter taste in drinking water [74]. In the Sulaymaniyah area, the highest pH value (8.76) was recorded at site 38 in groundwater, This could be linked to the presence of sulfide mineralization beneath the surface. Conversely, The minimum pH value (7.07) was recorded in groundwater samples obtained from site 29. The findings show that both tap water and groundwater samples ranged from neutral to mildly alkaline. Importantly, the pH values of both were ranged from (6.5–8.5) established by the WHO, as shown in Table 1.

Electrical conductivity (EC) is a dependable measure of total salinity or the concentration of dissolved solids in water. Although it does not reveal the specific ionic composition, EC is a useful parameter for evaluating water's suitability for drinking and irrigation. For drinking water, the recommended EC level is below 750 µS/cm, with an acceptable range between 750 and 1500 µS/cm. The results revealed significant variations in EC values across different sampling sites for both tap water and groundwater. EC levels ranged from 318 to 1220 µS/cm, with an average value of 570 µS/cm. Tap water in all sites of Sulaymaniyah city has desirable EC (372 $\mu S.cm^{-1}$) for drinking water, while the EC in groundwater site number 26 has a higher value of EC (1220 $\mu S.cm^{-1}$), therefore these locations of groundwater samples were permissible for drinking (Table1).

Cadmium (Cd) is a highly toxic and non-essential element, and bio-persistent metal with harmful toxicological properties. In the supply water and groundwater samples, cadmium concentrations ranged from 0.0001 to 0.0043 mg/L (Table 1). The highest Cd concentration (0.0043 mg/L) was detected in groundwater samples collected from sites 36 and 37, likely due to the presence of cadmium-bearing bedrock in the Sulaymaniyah area.

The primary sources of Cd in groundwater in Sulaymaniyah City are likely anthropogenic, including industrial and municipal effluents. In contrast, the minimum cadmium (Cd) concentration (0.0001 mg/L) was detected in a tap water sample collected from site 3.

Cadmium(Cd):

Cadmium is a harmful and non-essential element, and a bio-persistent metal with severe toxicological properties. In this study, the levels of Cd in groundwater exceeded those in tap water samples, consistent with [75], who reported that groundwater generally contains higher Cd concentrations than surface water. Cd concentrations in this study varied between 0.0001 and 0.0043 mg/L (Table 1). The maximum concentration (0.0043 mg/L) was recorded in groundwater samples from sites 36 and 37, likely due to cadmium-bearing bedrock in the Sulaymaniyah area. Anthropogenic sources, such as industrial and municipal effluents, may also contribute to Cd contamination. The lowest cadmium concentration (0.0001 mg/L) was measured in tap water from site 3.

The mean Cd concentration reported by [55] (0.0457 μg/L) was lower than the concentrations detected in this study. Similarl, [76] found Cd concentrations varying from 0.005 to 0.051 mg/L in groundwater from the Kadava River Basin, which aligns with this study. [77] reported cadmium concentrations in drinking water varying from 0.00828 to 0.085 mg/L, with the minimum value agreeing with the findings of this study. Cadmium exposure poses significant health risks, which may include mucous membrane damage, vomiting, and diarrhoea in the short term, and kidney damage, bone disorders, and Itai-Itai disease with long-term exposure [78].

Lead (Pb):

Lead exposure can lead to cognitive issues, behavioural changes, anaemia, lung and stomach cancer, nerve and kidney damage, hypertension, asthma, abdominal pain, and irritability [79, 80, 41]. The average Pb concentration in tap water and groundwater samples was 0.0058 mg/L, spanning from 0.0008 to 0.0103 mg/L (Table 1), remaining below the WHO guideline limit of 0.01 mg/L. However, elevated Pb concentrations were observed in groundwater at site 31, possibly due to agricultural activities, industrial discharges, or domestic wastewater in Sulaymaniyah City.

[81] reported a Pb concentration of 0.012 mg/L in groundwater from Shahabad, Iran, which agrees with this study. The minimum lead concentration (0.0008 mg/L) was observed in tap water from site 2. Pb concentrations in tap water reported by [82] (0.012 ± 0.07 mg/L) in Mashhad City, Iran, were comparable to this study. Similarly, [83] found an average Pb concentration of 0.002 mg/L in tap water at Kermanshah City, Iran, which aligns with these findings. In Karachi, Pakistan, [84] reported Pb levels of 0.006 ± 0.004 mg/L, agreeing with this study. However, [85] found an average concentration of lead of 0.003 mg/L in drinking water from Zahedan City, Iran.

Zinc (Zn):

Zinc is a vital element for human health; however, excessive concentrations can lead to symptoms such as diarrhoea, depression, hair loss, and impaired wound healing. Conversely, Zn deficiency can lead to stunted growth and reduced immunity [86]. In this study, the concentrations of zinc varied between 0.0014 and 0.0746 mg/L, with a mean value of 0.0110 mg/L (Table 1), well within the WHO and national standards (<3 mg/L for drinking water) [59, 87]. All drinking water samples in the study area met the WHO-recommended limits of <5.0 mg/L and <3.0 mg/L for Zn [88].

[89] reported that the zinc (Zn) concentration in tap water from Nowshera District, Pakistan, ranged between 0.01 and 0.5 mg/L, which was higher than the levels in this study. [[83] reported an average zinc (Zn) concentration of 0.046 ± 0.073 mg/L in the tap water of Kermanshah City, Iran, while [76] reported Zn levels between 0.023 and 0.209 mg/L (mean 0.065 mg/L). Similarly, [85] documented an average zinc (Zn) concentration of 0.04 mg/Lin tap water from Zahedan City, Iran, which is higher than the levels observed in this study.

Iron (Fe):

Iron, a highly abundant element in the Earth's crust, is crucial for supporting biochemical processes in plants and animals [90]. In this study, Fe concentrations in all supply and groundwater samples were below 0.05 mg/L, with an average concentration of 0.050 mg/L. These levels were lower than those reported by [55], where Fe concentration varied between 0.00116 and 1.397 mg/L, with an average value of 0.0183 mg/L. Similarly, [85] recorded a mean iron (Fe) concentration of 0.06 mg/L. In tap water from Zahedan City, Iran.

In Sulaymaniyah City, Fe concentrations in drinking water samples had iron concentrations well below the recommended limit of 0.3 mg/L established by the USEPA, WHO, and PCD, and EU guidelines [91, 92, 93]. This indicates that Iron concentrations in the study area fall within the safety standards for drinking water.

Table 1. pH, electrical conductivity (EC), turbidity, and concentrations of heavy metals (mg/L) in the water samples obtained from the study area.

Sample sites	pH	EC (μs.cm^{-1})	Turbidity (NTU)	Cd (mg.L^{-1})	Pb (mg.L^{-1})	Zn (mg.L^{-1})	Fe (mg.L^{-1})
1	7.37	388	<0.01	0.0016	0.0016	0.0014	0.05

2	7.30	378	<0.01	0.0011	0.0008	0.008	0.05
3	7.36	335	<0.01	0.0001	0.0033	0.0146	0.05
4	7.54	396	<0.01	0.002	0.0036	0.008	0.05
5	7.38	354	<0.01	0.0007	0.0037	0.0107	0.05
6	7.36	324	<0.01	0.0004	0.0035	0.008	0.05
7	7.30	385	<0.01	0.0003	0.0037	0.008	0.05
8	7.37	299	<0.01	0.0003	0.003	0.008	0.05
9	7.32	384	<0.01	0.0012	0.0019	0.0121	0.05
10	7.43	300	0.76	0.0019	0.0034	0.008	0.05
11	7.31	404	<0.01	0.0018	0.0025	0.0155	0.05
12	7.33	391	<0.01	0.0026	0.0048	0.008	0.05
13	7.43	304	<0.01	0.003	0.0024	0.008	0.05
14	7.38	383	<0.01	0.0024	0.0046	0.008	0.05
15	7.28	397	<0.01	0.0025	0.0056	0.008	0.05
16	7.43	318	<0.01	0.0027	0.0072	0.008	0.05
17	7.40	404	<0.01	0.0027	0.0062	0.008	0.05
18	7.43	401	<0.01	0.0027	0.0065	0.0135	0.05
19	7.89	368	<0.01	0.0033	0.0059	0.008	0.05
20	7.85	398	<0.01	0.0029	0.0049	0.008	0.05
21	7.79	418	<0.01	0.003	0.0077	0.008	0.05
22	7.69	411	<0.01	0.003	0.0066	0.008	0.05
23	7.48	462	<0.01	0.025	0.0061	0.008	0.05
24 G	7.22	858	<0.01	0.0023	0.0057	0.0209	0.05
25 G	7.15	746	0.69	0.0032	0.0083	0.008	0.05
26 G	7.10	1220	<0.01	0.0029	0.0061	0.008	0.05
27 G	7.16	645	<0.01	0.0031	0.0076	0.008	0.05
28 G	7.10	1120	<0.01	0.0034	0.0085	0.0746	0.05
29 G	7.07	885	<0.01	0.0032	0.007	0.008	0.05
30 G	7.19	771	<0.01	0.0035	0.0091	0.008	0.05
31 G	7.26	421	0.2	0.0029	0.0103	0.008	0.05
32 G	7.21	950	<0.01	0.0027	0.0085	0.008	0.05
33 G	7.18	672	<0.01	0.0032	0.0074	0.008	0.05
34 G	7.09	1097	0.7	0.004	0.0084	0.008	0.05
35 G	7.18	639	<0.01	0.0037	0.0077	0.008	0.05
36 G	7.44	1010	<0.01	0.0043	0.0072	0.0283	0.05
37 G	7.51	824	<0.01	0.0043	0.0094	0.008	0.05
38 G	8.76	908	1.55	0.0038	0.0079	0.008	0.05
39 G	7.21	741	<0.01	0.003	0.0097	0.008	0.05
40 G	7.23	737	<0.01	0.0041	0.0091	0.008	0.05
USEPA				0.005	0.015	5	0.30
PCD				0.003	0.010	5	
Drinking water quality WHO	6.5-8.5	750 and 1500	<1 No more than 5	0.003	0.010	3	0.30
USEPA drinking groundwater				-	0.015	0.8	1
Drinking water quality IS:10500				0.003		5	0.3

Table 2 presents the minimum and maximum (THQ) values for Cd, Pb, Fe, and Zn in the study area, considering both adult and child populations. The minimum, and maximum (TH Q) index calculated for Cd, Pb, Zn, and Fe were Cd 0.0058-0.2473, Pb 0.0131-0.1692, Zn 0.003-0.0143 and Fe 0.0041for adults and were Cd 0.0669-0.3440, Pb 0.0183-0.2354, Zn 0.004-0.0199 and Fe 0.0057 for children. (Dashtizadehet al 2019) reported that the THQ of heavy metals for adults and children in drinking tap water in Zahedan City, Iran, were (Cd 0.0571 and 0.133), (Pb 0.0245 and 0.0571), (Zn 0.00343 and 0.00523) and (Fe 0.00224 and 0.00523), respectively. Lu et al. (2013) assessed the health risks related to heavy metals in the drinking water of Swat, northern Pakistan. Their findings indicated that the (HRI) values for the studied heavy metals were less than

1, suggesting no health hazard to the local population. Similarly, [77] reported that the (THQ) values were also found to be below 1. Nevertheless, the population is likely to face a minimal long-term risk regarding cadmium (Cd) and lead (Pb) contamination and associated toxicity. However, THQ was highest in the Cd for adults (0.2473) and children (0.3440) followed by Pb for adults (0.1692) and children (0.2354), Zn, and Fe. The THQ indices for heavy metals in the study area were observed in the following descending order: Cd > Pb > Fe > Zn. The total THQ calculation indicated that the primary contributors to the non-carcinogenic health risk from drinking water ingestion in the exposed population were cadmium (Cd) followed by lead (Pb). In a similar study, [94] evaluated the health risks associated with metal exposure through groundwater in the Singhbhum Copper Belt, India, while According to [95], the Health Risk Indices (HRIs) for heavy metals were ranked in the following order: Cd was the highest, followed by Pb. The THQ indices, and subsequently the total THQ (TTHQ) index, for all the heavy, the values for both children and adults were below one, suggesting no significant risk of adverse health effects for the local population. As a result, the non-carcinogenic risk associated with heavy metal exposure through drinking water in Sulaymaniyah City is deemed minimal for both adults and children. Based on the data, no significant health risks are expected in this population group due to drinking water consumption. In general, the TTHQ value for children exceeded that of adults, indicating that children may be more vulnerable to toxic contaminants, making them at greater risk for adverse health effects. Notably, Cd at site No. 37 and Pb at site No. 31 were found to be high and are considered as the most hazardous heavy metals in the study area, It is crucial to focus on protecting children in this region. Additionally, thorough environmental monitoring should be conducted regularly.

Table 2: Non-carcinogenic risk (THQ) and total THQ (TTHQ) of heavy metal concentrations in both groundwater and tap water.

Sample sites	THQ (Adults)				TTHQ (Adults)	THQ (Children)				TTHQ (Childern)
	Cd	Pb	Zn	Fe		Cd	Pb	Zn	Fe	
1	0.0920	0.0263	0.0003	0.0041	0.1227	0.1280	0.0366	0.0004	0.0057	0.1707
2	0.0633	0.0131	0.0015	0.0041	0.0820	0.0880	0.0183	0.0021	0.0057	0.1141
3	0.0058	0.0542	0.0028	0.0041	0.0669	0.0080	0.0754	0.0039	0.0057	0.0930
4	0.1150	0.0591	0.0015	0.0041	0.1798	0.1600	0.0823	0.0021	0.0057	0.2501
5	0.0403	0.0608	0.0021	0.0041	0.1072	0.0560	0.0846	0.0029	0.0057	0.1491
6	0.0230	0.0575	0.0015	0.0041	0.0861	0.0320	0.0800	0.0021	0.0057	0.1198
7	0.0173	0.0608	0.0015	0.0041	0.0837	0.0240	0.0846	0.0021	0.0057	0.1164
8	0.0173	0.0493	0.0015	0.0041	0.0722	0.0240	0.0686	0.0021	0.0057	0.1004
9	0.0690	0.0312	0.0023	0.0041	0.1066	0.0960	0.0434	0.0032	0.0057	0.1484
10	0.1093	0.0559	0.0015	0.0041	0.1707	0.1520	0.0777	0.0021	0.0057	0.2376
11	0.1035	0.0411	0.0030	0.0041	0.1516	0.1440	0.0571	0.0041	0.0057	0.2110
12	0.1495	0.0789	0.0015	0.0041	0.2340	0.2080	0.1097	0.0021	0.0057	0.3256
13	0.1725	0.0394	0.0015	0.0041	0.2176	0.2400	0.0549	0.0021	0.0057	0.3027
14	0.1380	0.0756	0.0015	0.0041	0.2192	0.1920	0.1051	0.0021	0.0057	0.3050
15	0.1438	0.0920	0.0015	0.0041	0.2414	0.2000	0.1280	0.0021	0.0057	0.3358
16	0.1553	0.1183	0.0015	0.0041	0.2792	0.2160	0.1646	0.0021	0.0057	0.3884
17	0.1553	0.1019	0.0015	0.0041	0.2627	0.2160	0.1417	0.0021	0.0057	0.3656
18	0.1553	0.1068	0.0026	0.0041	0.2687	0.2160	0.1486	0.0036	0.0057	0.3739
19	0.1898	0.0969	0.0015	0.0041	0.2923	0.2640	0.1349	0.0021	0.0057	0.4067
20	0.1668	0.0805	0.0015	0.0041	0.2529	0.2320	0.1120	0.0021	0.0057	0.3518
21	0.1725	0.1265	0.0015	0.0041	0.3046	0.2400	0.1760	0.0021	0.0057	0.4238
22	0.1725	0.1084	0.0015	0.0041	0.2866	0.2400	0.1509	0.0021	0.0057	0.3987
23	0.1438	0.1002	0.0015	0.0041	0.2496	0.2000	0.1394	0.0021	0.0057	0.3473
24 G	0.1323	0.0936	0.0040	0.0041	0.2340	0.1840	0.1303	0.0056	0.0057	0.3256
25 G	0.1840	0.1364	0.0015	0.0041	0.3260	0.2560	0.1897	0.0021	0.0057	0.4536
26 G	0.1668	0.1002	0.0015	0.0041	0.2726	0.2320	0.1394	0.0021	0.0057	0.3793
27 G	0.1783	0.1249	0.0015	0.0041	0.3087	0.2480	0.1737	0.0021	0.0057	0.4296
28 G	0.1955	0.1396	0.0143	0.0041	0.3535	0.2720	0.1943	0.0199	0.0057	0.4919
29 G	0.1840	0.1150	0.0015	0.0041	0.3046	0.2560	0.1600	0.0021	0.0057	0.4238
30 G	0.2013	0.1495	0.0015	0.0041	0.3564	0.2800	0.2080	0.0021	0.0057	0.4958
31 G	0.1668	0.1692	0.0015	0.0041	0.3416	0.2320	0.2354	0.0021	0.0057	0.4753
32 G	0.1553	0.1396	0.0015	0.0041	0.3005	0.2160	0.1943	0.0021	0.0057	0.4181
33 G	0.1840	0.1216	0.0015	0.0041	0.3112	0.2560	0.1691	0.0021	0.0057	0.4330
34 G	0.2300	0.1380	0.0015	0.0041	0.3736	0.3200	0.1920	0.0021	0.0057	0.5198

35 G	0.2128	0.1265	0.0015	0.0041	0.3449	0.2960	0.1760	0.0021	0.0057	0.4798
36 G	0.2473	0.1183	0.0054	0.0041	0.3751	0.3440	0.1646	0.0075	0.0057	0.5218
37 G	0.2473	0.1544	0.0015	0.0041	0.4073	0.3440	0.2149	0.0021	0.0057	0.5667
38 G	0.2185	0.1298	0.0015	0.0041	0.3539	0.3040	0.1806	0.0021	0.0057	0.4924
39 G	0.1725	0.1594	0.0015	0.0041	0.3375	0.2400	0.2217	0.0021	0.0057	0.4696
40 G	0.2358	0.1495	0.0015	0.0041	0.3909	0.3280	0.2080	0.0021	0.0057	0.5438

The carcinogenic risk (ELCR) indices for heavy metals (Cd and Pb) in adults through drinking water in the sampled communities ranged from 2.18E-06 for Cd (low cancer risk) and 3.91E-07 for Pb (very low cancer risk) to 9.39E-05 for Cd (low cancer risk) and 5.04E-06 for Pb (medium cancer risk) at sites 3, 2, 36, and 37, respectively. The overall average ELCR for adults was 5.58E-05 for Cd (medium cancer risk) and 2.90E-06 for Pb (low cancer risk) [72] (as shown in Table 3).

Similarly, for children, the ELCR for Cd and Pb ranged from 3.04E-06 for Cd (low cancer risk) and 5.44E-07 for Pb (very low cancer risk) to 1.30E-04 for Cd (medium cancer risk) and 7.01E-06 for Pb (low cancer risk) at sites 3, 2, 36, and 37, respectively, with an overall average of 7.77E-05 for Cd (low cancer risk) and 4.03E-06 for Pb [72].

In a similar investigation, [55] observed that the average carcinogenic risk of cadmium (Cd) from consuming well water was 7.52E-07 (extremely low cancer risk) for adults and 1.04E-06 (low cancer risk) for children. Likewise, [96] found that the carcinogenic risk of Cd ranged from 1.45E-06 to 4.21E-06 (low cancer risk) for adults and 1.6E-06 to 4.41E-06 (low cancer risk) for children. Additionally, [97] reported ELCR values for Pb ranging from 1.67E-05 to 3.42E-05 for adults and from 2.77E-05 to 7.19E-05 for children, falling within the acceptable limits for cancer risk associated with carcinogens in water.

These findings indicate higher cancer risks for children compared to adults, which is consistent with results reported by [98], who also noted that the calculated ELCR was greater for children compared to adults. This suggests that children are more vulnerable to carcinogenic risks from heavy metals in drinking water.

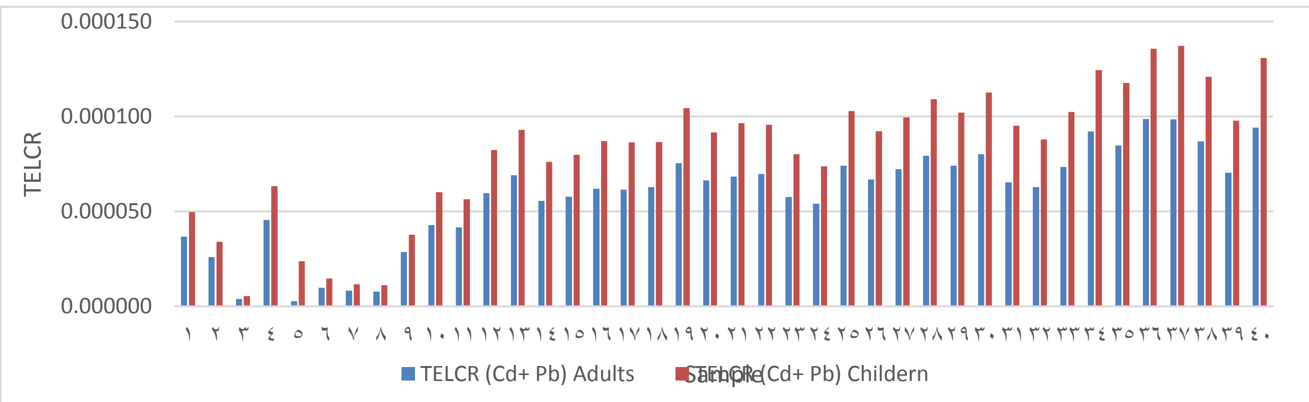
Table 3: Carcinogenic risk (ELCR) of heavy metals (Cd and Pb) in groundwater and tap water for (Adults) and (Children).

	(ELCR) (Adults)		(ELCR) (Children)	
	Cd	Pb	Cd	Pb
1	0.00003496	0.000000782	0.00004864	0.000001088
2	0.000024035	0.000000391	0.00003344	0.000000544
3	0.000002185	0.000001613	0.00000304	0.000002244
4	0.0000437	0.000001760	0.0000608	0.000002448
5	0.000015295	0.000001808	0.00002128	0.000002516
6	0.00000874	0.000001711	0.00001216	0.00000238
7	0.000006555	0.000001808	0.00000912	0.000002516
8	0.000006555	0.000001466	0.00000912	0.00000204
9	0.00002622	0.000000929	0.00003648	0.000001292
10	0.000041515	0.000001662	0.00005776	0.000002312
11	0.00003933	0.000001222	0.00005472	0.0000017
12	0.00005681	0.000002346	0.00007904	0.000003264
13	0.00006555	0.000001173	0.0000912	0.000001632
14	0.00005244	0.000002248	0.00007296	0.000003128
15	0.000054625	0.000002737	0.000076	0.000003808
16	0.000058995	0.000003519	0.00008208	0.000004896
17	0.000058995	0.000003030	0.00008208	0.000004216
18	0.000058995	0.000003177	0.00008208	0.00000442
19	0.000072105	0.000002884	0.00010032	0.000004012
20	0.000063365	0.000002395	0.00008816	0.000003332
21	0.00006555	0.000003763	0.0000912	0.000005236
22	0.00006555	0.000003226	0.0000912	0.000004488
23	0.000054625	0.000002981	0.000076	0.000004148
24 G	0.000050255	0.000002786	0.00006992	0.000003876
25 G	0.00006992	0.000004057	0.00009728	0.000005644
26 G	0.000063365	0.000002981	0.00008816	0.000004148
27 G	0.000067735	0.000003715	0.00009424	0.000005168
28 G	0.00007429	0.000004154	0.00010336	0.00000578
29 G	0.00006992	0.000003421	0.00009728	0.00000476
30 G	0.000076475	0.000004448	0.0001064	0.000006188
31 G	0.000063365	0.000005034	0.00008816	0.000007004
32 G	0.000058995	0.000004154	0.00008208	0.00000578

33 G	0.00006992	0.000003617	0.00009728	0.000005032
34 G	0.0000874	0.000004106	0.0001216	0.000005712
35 G	0.000080845	0.000003763	0.00011248	0.000005236
36 G	0.000093955	0.000003519	0.00013072	0.000004896
37 G	0.000093955	0.000004594	0.00013072	0.000006392
38 G	0.00008303	0.000003861	0.00011552	0.000005372
39 G	0.00006555	0.000004741	0.0000912	0.000006596
40 G	0.000089585	0.000004448	0.00012464	0.000006188

Based on the results, the ELCR indices for heavy metals in this study were ranked as follows: Cd > Pb. obtained for both age groups exposed to selected heavy metals. As discussed earlier, an ELCR value exceeding $1 \times 10{-}4$ is considered significantly high and poses potential health hazards. According to the findings, the ELCR levels for the exposed population were below $1 \times 10{-}4$.

The estimated total ELCR (TELCR) for ingestion (Figure 1) shows that the ELCR values ranged from $3.79 \times 10{-}6$ to $9.85 \times 10{-}5$ for adults and from $5.28 \times 10{-}6$ to $1.37 \times 10{-}4$ for children. The average ELCR values were $5.88 \times 10{-}5$ for adults and $8.18 \times 10{-}5$ for children. These findings indicate that the likelihood of experiencing a carcinogenic risk from drinking water in Sulaymaniyah City is 8.18 in 100,000 for children and 5.88 in 100,000 for adults, indicating a higher TELCR for children due to lifetime exposure to carcinogenic elements (Cd and Pb) through drinking water. According to the acceptable risk range, all water samples analyzed are deemed to present negligible cancer risks to consumers [53; 70; 58]



CONCLUSION

The findings showed that cadmium (Cd) and lead (Pb) concentrations were higher in groundwater compared to tap water, while the levels of cadmium (Cd), lead (Pb), zinc (Zn), and iron (Fe) remained within the WHO guidelines for the study area. The heavy metal concentrations in drinking water were ranged in the following order: Fe > Zn > Pb > Cd. The findings of this study provide valuable information for communicating and managing risks associated with groundwater consumption, particularly for local populations relying on well water. A human health risk assessment using an exposure risk model showed that Cd, Pb, Zn, and Fe are the most significant pollutants contributing to carcinogenic concerns. However, based on the calculated Target Hazard Quotients (THQs) for both adults and children, the drinking water does not present any significant health risks. The THQ values for heavy metals were ranked as follows: Cd > Pb > Fe > Zn. Additionally, the (TTHQ) for all analyzed metals in both age groups was below one, indicating no cause for concern, indicating no significant health risk. Notably, children had higher TTHQ values than adults due to their greater susceptibility.

The Excess Lifetime Cancer Risks (ELCRs) for Cd and Pb in most resources for both adults and children were within acceptable levels, ranging from very low to medium cancer risk. Therefore, the study concluded that the drinking water in Sulaimani City is not associated with significant chronic health risks.

To safeguard public health and ensure the safety of drinking water, it is essential to implement regular monitoring and enforce stringent water quality standards, it is crucial to regularly monitor water quality and adhere to established drinking water guidelines. This study emphasizes the importance of raising awareness about The potential hazards associated with heavy metal contamination in groundwater can pose serious health threats, emphasizing the need for ongoing monitoring and remediation efforts to mitigate exposure, and calls for continuous monitoring and further investigations. Future research should focus on assessing seasonal variability in toxic metal concentrations and their long-term effects in the study area..

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تقييم المخاطر الصحية المحتملة من الكادميوم والرصاص والزنك والحديد في مياه الشرب ومصادر المياه الجوفية في مدينة السليمانية، إقليم كردستان العراق

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الخلاصة

يعد الوصول إلى مصدر مياه الشرب النظيفة أمرا حيويا للبشرية، ويجب الحفاظ على مصادر المياه النظيفة بشكل جيد وتحتاج سلطات الحكومية المحلية إلى التأكد من توصيل المياه النظيفة إلى أفراد المجتمع دون أي تلوث. تهدف هذه الدراسة إلى تقييم المخاطر المتعلقة بصحة الإنسان المرتبطة بمستويات العناصر ***(Cd, Pb, Zn and Fe)*** في عينات مياه الشرب في كل من مياه الحنفية ومصادر مياه الشرب الأخرى في المدينة. وأخذنا في الاعتبار المؤشرات الفيز وكيميائية اللازمة لتقييم المخاطر ووجدنا أن معظم مصدر مياه الشرب تقع ضمن معيار منظمة الصحة العالمية، ومع ذلك، أظهرت بعض العينات مخاطر التراكم البيولوجي للعناصر الثقيلة بسبب التركيزات العالية مثل الرصاص في موقع العينة 31 ***G .*** تم تقييم التعرض للمخاطر المسببة للسرطان داخل منطقة الدراسة والعينات التي تم جمعها ، وكانت قيمة ***TTHQ***للأطفال من التعرض أعلى من قيم البالغين ، مما يشير إلى وجود خطر أعلى على الأطفال. قد يؤدي الافتقار إلى الرصد البيئي المناسب لهذه المخاطر إلى نتائج لا رجعة فيها، خاصة في فئات المجتمع الحساسة في المستقبل.

الكلمات المفتاحية: المعادن الثقيلة والموارد المائية وتقييم المخاطر الصحية والصحة البيئية.