Research Article

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Determination of heavy metals and health risk assessment in drinking water in Bukayriyah City, Saudi Arabia

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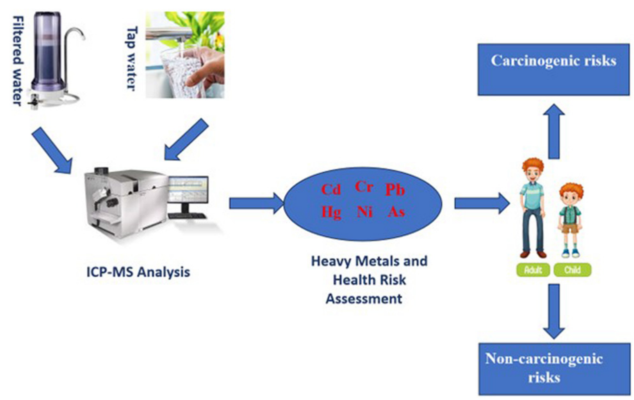
Abstract: Heavy metal levels, including arsenic, lead, cadmium, mercury, chromium, and nickel, were analyzed in 124 samples of tap and filtered water obtained from Bukayriyah city, Saudi Arabia, using inductively coupled plasma mass spectrometry. Additionally, measurements of total dissolved solids, conductivity, and pH were also performed. The study also evaluated the potential non-cancer and cancer risks (CRs) associated with the ingestion of these heavy metals for both children and adults. The results indicated that the average concentrations of heavy metals in both tap and filtered water were found to be below the recommended limits set by the World Health Organization and the Gulf Standard Organization. To assess the non-carcinogenic risks, the chronic daily intake (CDI), hazard quotient (HQ), and hazard index were calculated for analyzed metals present in both tap and filtered water. In both the children and adult populations, the CDI indices for heavy metals in tap and filtered water followed the order of Cr > Hg > Ni > Pb > As > Cd. However, it is worth noting that the CDI values for tap water were higher than those for filtered water for both children and adults. The descending order of HQ values is as follows: Hg > Cr > As > Cd > Pb > Ni. This indicates that the HQ values for all metals are below the acceptable limit of 1. These findings confirm that the exposure to the examined metals from both tap and filtered water in Bukayriyah City is within safe limits and poses no non-carcinogenic risks. To assess the carcinogenic risks, the incremental lifetime cancer risk (ILCR) and total carcinogenic risk (TCR) were calculated. The order of ILCR values for both children and adults in tap and filtered water is as follows: Ni > Cr > Cd > As > Pb. All ILCR values were below the acceptable limit of 10^{-6} to 10^{-4}. However, TCR values exceeded this threshold range only for children exposed to tap water, with a value of 1.43×10^{-4}. Thus, children exposed to tap water have a potential risk of developing carcinogenic diseases.



Graphical abstract

Keywords: drinking-water, health risk assessment, heavy metals, ICP-MS, Bukayriyah, Saudi Arabia

1 Introduction

Safe drinking water is essential for human existence; however, over 1 billion people worldwide lack access to it [1]. The emergence of heavy metal production has raised significant concerns due to its harmful impact on the environment, especially affecting the quality of drinking water and human well-being. This industrial process results in a considerable daily discharge of metals into the air [2]. Over 50 trace elements fall under the classification of heavy metals, with a subset of 17 being the most prevalent and toxic elements. While these metals exist naturally in small quantities in our diets and can be beneficial for health, increased levels of heavy metals in the environment can

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pose a danger. When heavy metals surpass acceptable levels, they can enter the food chain, leading to toxic and detrimental effects on the human body [3–5]. The accumulation of heavy metals such as mercury, lead, cadmium, arsenic, nickel, chromium, and zinc in the body from water contamination can lead to severe health complications and diseases. These toxic heavy metals cannot be metabolized by the body and instead accumulate in adipose tissue, muscles, bones, and joints. Over time, they can affect various organs and systems, including the brain, lungs, liver, kidneys, and other vital organs [6–9]. Additionally, heavy metals are known carcinogens, increasing the risk of cancer. The long-lasting health issues caused by the inability to eliminate these metals promptly can have a significant impact on mental and central nervous function [10,11].

A health risk assessment is an essential tool for quantifying the potential dangers associated with exposure to contaminated water. By conducting comprehensive assessments, appropriate measures can be implemented to prevent the risks posed by various contaminants. Among the widely employed health risk assessment models, the United States Environmental Protection Agency (USEPA) model stands as the most commonly recommended approach in this field [12].

The model incorporates both carcinogenic and non-carcinogenic analyses, taking into account crucial parameters such as chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI), and cancer risk (CR). These parameters enable a complete evaluation of the potential health risks associated with exposure to contaminants [13]. Water quality health risk assessment quantifies the risks associated with exposure to polluted water. By providing a quantitative description of hazards, it enables informed decisions regarding water source protection and management [14,15].

Saudi Arabia heavily relies on groundwater to fulfill its drinking water and irrigation needs. Over the past 30 years, groundwater extraction in the country has significantly increased. In fact, groundwater sources account for 80% of Saudi Arabia's water demands [16]. The annual depletion of water significantly outweighs the groundwater recharge. The imbalance between groundwater recharge and depletion raises significant concerns due to its potential detrimental effects on water quality. The decline in groundwater levels not only reduces the quantity of available water but also compromises its overall quality. Addressing this issue is of absolute importance to ensure sustainable water resources and uphold optimal water quality standards [17], particularly in desert areas where groundwater often exhibits high salinity levels [18]. Studies have been conducted to estimate the concentrations of metals in various types of water in multiple cities across Saudi Arabia, including Riyadh [19–21], Jeddah [22–24], Dammam [25], Jizan [26], Al-Asha [27], and Yanbu [28].

The aim of this study is to estimate the concentrations of certain heavy and trace elements in Bukayriyah City, located in the Qassim region, using the ICP-MS technique. This is the first study to investigate the levels of these potentially toxic elements in Bukayriyah city. Additionally, the study aims to assess the risks associated with these elements for both children and adults.

2 Materials and methods

2.1 Study area

The study area is the city of Al-Bukayriyah, situated in the Qassim region of Saudi Arabia, north of Riyadh, as shown in the map in Figure 1. It is located at the latitude and longitude coordinates of 26.171766 and 43.563328, respectively. Spanning an area of over 5,000 km^2, Al-Bukayriyah is home to a population of 63,551 individuals, according to the latest population census conducted in 2022. In the blistering summers of the Al-Qassim region, where Bukayriyah city is located, the temperatures soar to a scorching 45°C, while the winters bring a chilling chill, with lows dipping to 5°C. Amidst this dramatic temperature swing, the parched and arid region receives a modest 100–150 mm of annual rainfall. In this desert region, groundwater extracted from deep wells serves as the primary water source.

2.2 Collection and preparation of the samples

A total of 62 samples of tap water and 62 samples of filtered water, derived from the same tap water source using house water filters, were collected from household kitchens in Bukayriyah city in October 2023. The samples were collected in 200 mL polypropylene scintillation containers from various locations within the area. Prior to sampling, the tap and filter waters were allowed to run until any sediment on the tap was cleared. The containers were also rinsed three times with the respective water to be sampled, ensuring proper cleanliness. After the samples were collected, each sample was divided into two parts. The first part of each sample was promptly transported to the laboratory for the measurement of pH, conductivity, and total dissolved solid (TDS) salts on the same day. The second part of each sample, comprising 100 mL, was acidified using 3 mL of concentrated nitric acid (HNO_3, 69%) to prevent the precipitation and crystallization of metals. The samples were then stored at 4°C until laboratory analysis.

Figure 1: Map of Bukayriyah city, Al-Qassim region, Saudi Arabia.

Table 1: Operational parameters utilized in the ICP-MS analysis of heavy metals

ICP-MS parameters	Value
Operation power	1,550
Plasma gas flow rate	30 mL/min
Nebulizer mode	MicroMist
Carrier gas flow rate	5 L/min
Makeup gas flow rate	0.15 L/min
Plasma gas flow rate	15 L/min
Nebulizer pump	0.1 rps
Points/peak	3
Repetitions	3
Integration time/mass	0.3 s

2.3 Materials

By dilution of a 10 mg/L stock solution of an inductively coupled plasma (ICP) multi-element standard solution, a daily calibration procedure was carried out. The aforementioned standard solution, obtained from Agilent Technologies (Palo Alto, CA, USA), contained elements including As, Pb, Hg, Cd, Cr, and Ni. In order to calibrate the ICP-MS instrument, standard solutions ranging in concentrations from 0.1 to 150 μg/L were utilized. Throughout the analysis, argon gas was employed as the plasma, nebulization, and auxiliary gas. This gas had a purity level of 99.9999% and was supplied by the air-liquid company in Saudi Arabia.

2.4 Analytical methods

With a conductivity level of 0.055 μS/cm, ultra-purified water was acquired via a Barnstead water purification system ASTM Type II manufactured by Thermo Electron LED GmbH, Germany. The physiochemical parameters were assessed utilizing an Orion Star A215 pH/conductivity meter manufactured by Thermo Scientific, USA. The parameters measured were electrical conductivity, TDS, and pH. Arsenic, lead, mercury, cadmium, chromium, and nickel were analyzed by an Agilent ICP-MS 7800 instrument manufactured by Agilent, USA. Table 1 details the precise operational conditions of the ICP-MS.

2.5 Analytical quality assurance

Three replicates of the assessment of heavy metal concentrations in acidified samples were performed in order to ensure accuracy through the utilization of calibration curves derived from standard solutions analyzed by ICP-MS. Multiple parameters, such as accuracy (recovery level) and limit of detection (LOD), were utilized to validate the method implemented in the research. The LOD was computed by multiplying the formula 3 by σ/S, where S denotes the slope of the calibration line and σ represents the residual standard deviation of the linear regression (as shown in Table 6). In order to assess the precision of the method, recovery experiments were conducted wherein samples of drinking water were supplemented with increasing amounts of each analyte at three concentrations of spiking (10, 25, and 50 μg/L). As shown in Table 2, the mean recovery percentages for the elements ranged from 89.5 to 107%.

Table 2: Average recovery of elements from drinking water samples and percent relative standard deviation (RSD%)

Element/concentration (μg/L)	As	Pb	Hg	Cd	Cr	Ni
Spike level	10	10	10	10	10	10
Mean result	9.99	9.02	9.09	10.5	9.45	10.7
Mean recovery (%)	99.9	90.2	90.9	105	94.5	107
RSD%	2.7	1.5	3.6	1.8	1.2	2.5
Spike level	25	25	25	25	25	25
Mean result	25.2	23.6	24.4	25.6	22.7	25.8
Mean recovery (%)	101	94.4	97.5	103	91.0	103
RSD%	2.6	1.3	2.8	1.4	1.4	1.6
Spike level	50	50	50	50	50	50
Mean result	50.0	49.6	49.3	50.2	44.8	50.2
Mean recovery (%)	100	101	98.7	100	89.5	100
RSD%	0.47	0.52	4.8	0.54	0.79	0.47

2.6 Human health risk assessment

Health risk assessment is a method used to estimate the potential risks of exposure to a pollutant and its harmful effects on human health. It involves analyzing both carcinogenic and non-carcinogenic factors to provide a comprehensive evaluation [29].

2.6.1 Exposure assessment

In order to evaluate the risks associated with both non-cancer and cancer effects in children and adults, the CDI of heavy metals was employed. The CDI, calculated using equation (1), represents the average daily dose of exposure to a contaminant over a person's lifetime, also known as the lifetime average daily dose (LADD). This approach allows for a comprehensive assessment of the potential health risks posed by the presence of THMs in drinking water [30–32].

Table 3: Parameters used to assess health risk assessment of As, Pb, Hg, Cd, Cr, and Ni ingestion through drinking water

Parameters	Non-carcinogenic and carcinogenic risk assessment		Unit
	Children	Adults	
IR	1	2	L/day
ED	6	30	year
EF	365	365	day/year
AT(ED X EF)	2,190	25,550	day
BW	15	70	kg

$$\text{CDI} = \frac{C \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}, \tag{1}$$

where CDI is the chronic daily intake (mg/kg/day), C is the concentration of the contaminant in the water sample (mg/L), IR is the ingestion rate per unit time, ED is the exposure duration, EF is the exposure frequency, BW is the body, and AT is the average exposure time. The parameters used for the assessment of health risks associated with the ingestion of As, Pb, Hg, and Cd through drinking water are given in Table 3 [29,33,34].

2.6.2 Non-CRs

Non-CRs associated with the non-carcinogenic effects of THMs in drinking water were evaluated using the non-cancer HQ, as shown in equation (2).

$$\text{HQ} = \frac{\text{CDI}}{\text{RFD}}, \tag{2}$$

where HQ is the non-cancer hazard quotient; CDI is the chronic daily intake (mg metal/kg/day); and RFD is the reference dose, in mg/kg/day. The reference dose represents the tolerable daily intake of the metal via ingestion, and is listed in Table 4 [30,35].

In the case of multiple heavy metals, the combined non-carcinogenic effect on the population is determined by summing up the HQs of each individual heavy metal. This cumulative value is referred to as the HI, as defined in the USEPA document [36]. The HI can be calculated using the following equation:

$$\text{HI} = \text{HQ}_{\text{As}} + \text{HQ}_{\text{Pb}} + \text{HQ}_{\text{Hg}} + \text{HQ}_{\text{Cd}} + \text{HQ}_{\text{Cr}} + \text{HQ}_{\text{Ni}}, \tag{3}$$

where HQ_{As}, HQ_{Pb}, HQ_{Hg}, HQ_{Cd}, HQ_{Cr}, and HQ_{Ni} represent the HQ of As, Pb, Hg, Cd, Cr, and Ni, respectively.

If the calculated value of HQ or HI is less than 1, it indicates that there are no significant non-CRs. However, if the value is equal to or greater than 1, it suggests the presence of significant non-CRs. Furthermore, the level of risk tends to increase with higher values of HQ or HI [37].

Table 4: RFD and CSF of the heavy metals

CSF/RFD factor	Metals					
	As	Pb	Hg	Cd	Cr	Ni
RFD (mg/kg/day)	3×10^{-4}	3.6×10^{-4}	3×10^{-4}	5×10^{-4}	3×10^{-3}	2×10^{-2}
CSF (mg/kg/day)$^{-1}$	1.5	85×10^{-4}	—	6.3	0.41	0.84

2.6.3 CRs

The CR is determined by the exposure to a pollutant at a lifetime average dose of 1 mg/kg body weight per day. This risk is quantified as the incremental lifetime cancer risk (ILCR), which represents the probability of developing cancer over a 6 or 30-year lifetime due to a 24-h exposure to a potential carcinogen [38]. The calculation of CR involves multiplying the CDI in mg/kg/day by the cancer slope factor (CSF) measured in (mg/kg/day)$^{-1}$, as described in equation (4).

$$\text{ILCR} = \text{CDI} \times \text{CSF}. \tag{4}$$

The total cancer risk (TCR) resulting from exposure to multiple contaminants through the consumption of a specific type of water was estimated by summing up the incremental risks of each metal (∑ILCR). The USEPA defines the minimum or acceptable CR for regulatory purposes to be within the range of 1×10^{-6} to 1×10^{-4} [31,39]. The RFD and CSF of the heavy metals [38,40] are presented in Table 4.

3 Results and discussion

3.1 TDS, conductivity, pH, and metal concentrations in the analyzed water

Table 5 presents information about the levels of TDS, conductivity, and pH in tap and filtered water. The average TDS level in tap water is 5.80×10^2mg/L, exceeding the GSO recommended range but falling within the WHO recommended range. In contrast, the average TDS level in filtered water is 10.8×10^2 mg/L, which falls within the recommended ranges of both WHO and GSO. Regarding conductivity, tap water has an average value of 1.06×10^2 µS/cm, ranging from 9.62×10^2 to 28.6×10^2 µS/cm. In contrast,

Table 5: TDS, conductivity, and pH of tap and filtered water

	TDS (mg/L)		Conductivity (µS/cm)		pH	
WHO	1×10^2 – 1×10^3		—		6.5–8.5	
GSO	1×10^2 – 5×10^2		—		6.5–8.5	
	Mean	Ranges	Mean	Ranges	Mean	Ranges
Tap water	5.80×10^2	4.88×10^2 – 14.0×10^2	1.06×10^2	9.62×10^2 – 28.6×10^2	7.91	6.35–8.51
Filtered water	10.8×10^2	10.5 – 7.87×10^2	2.08×10^2	20.6 – 16.1×10^2	6.97	6.05–8.10

filtered water has an average conductivity of 2.08×10^2 µS/cm, ranging from 20.6 to 16.1×10^2 µS/cm. The average pH of tap water is 7.91, while the average pH of filtered water is 6.97. Both of these values fall within the recommended range of 6.5–8.5 set by both the WHO and the GSO.

In order to present a clear understanding of the large number of results obtained (124 samples × 6 elements = 744 analyses), Figure 2 and Table 6 display the minimum and maximum values, as well as the mean and median values, for all the metals that were analyzed.

When comparing tap and filtered water samples, the concentration of As in both types remains below the WHO and GSO standards of 10 µg/L. In tap water, the mean concentration of arsenic is 0.06 µg/L, with a range of 0.01–0.22 µg/L. Concentrations below the LOD were found in approximately 11.3% of the samples, with the LOD for As set at 1.0×10^{-3} µg/L.

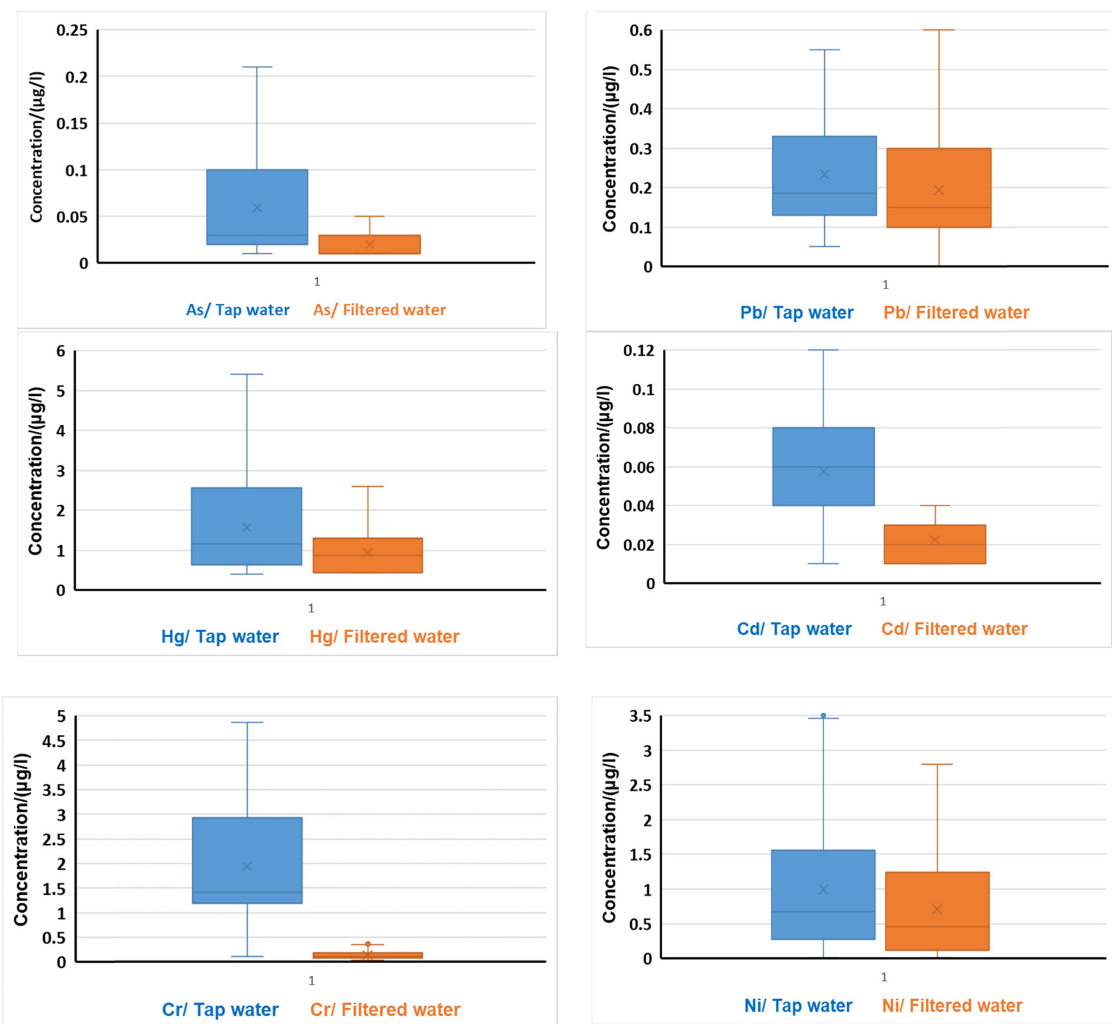

Figure 2: A Box plot of heavy metals in tap and filtered water in Bukayriyah city.

Table 6: Concentration values (μg/L; mean ± relative standard deviation) of the heavy metals analyzed in tap water and filtered water

	Tap water		Filtered water		LOD	WHO	GSO
	Mean ± RSD	Range	Mean ± RSD	Range			
As	0.06 ± 20	0.01–0.22	0.02 ± 16	0.01–0.05	1.0×10^{-3}	10	10
Pb	0.24 ± 1.8	0.08–0.54	0.21 ± 1.6	0.11–0.60	0.5×10^{-3}	10	10
Hg	1.56 ± 19	0.77–5.5	0.94 ± 19	0.43–2.6	28×10^{-2}	6	6
Cd	0.06 ± 7.8	0.01–0.12	0.02 ± 6.0	0.01–0.04	1.3×10^{-3}	3	3
Cr	2.02 ± 0.55	0.10–4.9	0.14 ± 2.0	0.05–0.45	0.7×10^{-3}	50	50
Ni	1.01 ± 5.0	0.01–3.5	0.71 ± 16	0.03–2.46	1.0×10^{-3}	70	70

In contrast, in filtered water, the mean concentration of As is 0.02 μg/L, with a range of 0.01–0.05 μg/L. Around 59.7% of the samples had concentrations below the LOD. Thus, both tap and filtered water meet the safety standards for arsenic levels in drinking water. The mean concentrations of Pb in tap and filtered water are 0.24 and 0.21 μg/L, respectively, with ranges of 0.08–0.54 μg/L and 0.11–0.60 μg/L. The LOD for Pb is 0.05×10^{-3} μg/L. It is worth noting that both tap and filtered water comply with the WHO and GSO standards, which set the maximum allowable concentration of Pb in drinking water at 10 μg/L. The average concentrations of Hg in tap and filtered water were found to be 1.56 and 0.94 μg/L, respectively, with ranges spanning from 0.77 to 5.5 μg/L and 0.43 to 2.6 μg/L. Approximately 56.45% of the tap water samples and 53.22% of the filtered water samples exhibited Hg concentrations below the LOD. The LOD for Hg is determined to be 28×10^{-2} μg/L. Importantly, both tap and filtered water meet the WHO and GSO standards, which allow a maximum concentration of 6 μg/L for Hg in drinking water. The mean concentrations of cadmium in tap and filtered water samples from Bukayriyah City are 0.06 and 0.02 μg/L, respectively, indicating low levels of cadmium in both sources. The range of cadmium concentrations in tap water is 0.01–0.12 μg/L, while in filtered water, it is 0.01–0.04 μg/L. A significant percentage of tap water samples (14.5%) and filtered water samples (62.90%) had concentrations below the LOD. The LOD for cadmium is 1.3×10^{-3} μg/L in both cases. Importantly, these mean concentrations and ranges of cadmium in both tap and filtered water are well below the WHO and GSO standards of 3 μg/L for cadmium in drinking water. Cr concentrations were measured in both tap and filtered water samples from Al-Bukayriyah City. In tap water, the mean concentration of Cr was found to be 2.02 μg/L, with a range of 0.10–4.9 μg/L. None of the samples had concentrations below the LOD, which is 0.7×10^{-3} μg/L. Similarly, in filtered water, the mean concentration of Cr was 0.14 μg/L, with a range of 0.05–0.45 μg/L. Both tap and filtered water samples exhibited Cr concentrations that were below the drinking water standards set by both WHO and the GSO, which are 50 μg/L. This indicates that the levels of Cr in both types of water are within the acceptable limits as defined by these regulatory bodies. The mean concentration of Ni in tap water was determined to be 1.01 μg/L, with a range of 0.01–3.46 μg/L. For filtered water, the mean concentration of Ni was 0.71 μg/L, with a range of 0.03–2.5 μg/L. It is worth noting that both tap and filtered water samples had concentrations within the acceptable limits set by the WHO and the GSO, which define the maximum allowable concentration of nickel in drinking water as 70 μg/L.

The mean concentrations of As, Pb, Cd, Hg, Cr, and Ni in filtered water are generally lower than those in tap water. Moreover, all mean concentrations for each element in both tap and filtered water are below the standards set by the WHO and the GSO. This indicates that the concentrations of these elements in the water samples meet the permissible limits for drinking water.

3.2 Health risk assessment

Table 7 presents the results of the CDI through the ingestion pathway for both children and adults in tap and filtered water samples. The results showed that CDI values were much lower than the reference dose as recommended by USEPA. In both the children and adult populations, the CDI indices for heavy metals in tap and filtered water followed the order of Cr > Hg > Ni > Pb > As > Cd. However, it is worth noting that the CDI values for tap water were higher than those for filtered water for both children and adults. These findings demonstrate that utilizing filtered water significantly decreases the CDI values for all metals, underscoring the advantages of water filtration systems in reducing metal exposure. Additionally, it is noteworthy that the CDI values for children were higher than those for adults in both types of water.

Table 7: CDI and HQ for children and adults by heavy metals and water-type for drinking water in Bukayriyah City

Metal	CDI – children		CDI – adults		HQ – children		HQ – adults	
	Tap water	Filtered water	Tap water	Filtered water	Tap water	Filtered water	Tap water	Filtered water
As	4.0×10^{-6}	1.3×10^{-6}	7.4×10^{-7}	2.5×10^{-7}	1.33×10^{-2}	0.44×10^{-2}	0.25×10^{-2}	0.82×10^{-3}
Pb	1.6×10^{-5}	1.4×10^{-5}	2.9×10^{-6}	2.6×10^{-6}	0.44×10^{-2}	0.39×10^{-2}	0.08×10^{-2}	0.71×10^{-3}
Hg	1.1×10^{-4}	6.3×10^{-5}	1.9×10^{-5}	1.2×10^{-5}	34.7×10^{-2}	20.9×10^{-2}	6.37×10^{-2}	38.4×10^{-3}
Cd	4.0×10^{-6}	1.3×10^{-6}	7.4×10^{-7}	2.5×10^{-7}	0.80×10^{-2}	0.27×10^{-2}	0.15×10^{-2}	0.49×10^{-3}
Cr	1.4×10^{-4}	9.3×10^{-6}	2.5×10^{-5}	1.7×10^{-6}	4.49×10^{-2}	0.31×10^{-2}	0.82×10^{-2}	0.57×10^{-3}
Ni	6.7×10^{-5}	4.7×10^{-5}	1.2×10^{-5}	8.7×10^{-6}	0.34×10^{-2}	0.24×10^{-2}	0.06×10^{-2}	0.44×10^{-3}
HI = ∑HQ					42.1×10^{-2}	22.5×10^{-2}	7.73×10^{-2}	41.4×10^{-3}

3.3 Non-carcinogenic risk

The estimation of non-carcinogenic risk for both adults and children, considering the ingestion pathway, was conducted using HQ and HI calculations. This assessment was performed for both tap and filtered water samples. Upon analyzing Table 7, it is clear that the HQ values for children and adults follow a consistent pattern in both tap and filtered water samples. The descending order of HQ values is as follows: Hg > Cr > As > Cd > Pb > Ni. This indicates that Hg poses the highest non-carcinogenic risk, while Ni poses the lowest risk among the metals evaluated in both water sources. The highest HQ value is 34.7×10^{-2} for children exposed to Hg in tap water, while the lowest HQ value is 0.44×10^{-3} for adults exposed to Ni in filtered water. This indicates that the HQ values for all metals are below the acceptable limit of 1. These findings confirm that the exposure to the examined metals from both tap and filtered water in the city of Bukayriyah is within safe limits and poses no health risks.

The HI values for heavy metals in tap and filtered water were 42.1×10^{-2} and 22.5×10^{-2}, respectively, for children. For adults, the HI values were 7.73×10^{-2} for tap water and 41.4×10^{-3} for filtered water. These results indicate that the presence of heavy metals in both tap and filtered water is within acceptable limits (HI < 1) for both children and adults, ensuring minimal health risks associated with metal exposure.

3.4 Carcinogenic risk

The ILCR and TCR values for children and adults exposed to tap and filtered water in Bukayriyah City are presented in Table 8. Hg was not included in this study due to the lack of available CSF data [38], so the analysis focused on As, Pb, Cd, Cr, and Ni, which have CSF values. The order of ILCR values for both children and adults in tap and filtered water is as follows: Ni > Cr > Cd > As > Pb. The range of ILCR values varies from 5.66×10^{-5} for children exposed to Ni in tap water to 2.18×10^{-8} for adults exposed to Pb in filtered water. All ILCR values were below the acceptable limit of 10^{-6} to 10^{-4}. However, TCR values exceeded this threshold range only for children exposed to tap water, with a value of 1.43×10^{-4}. Thus, children exposed to tap water have a potential risk of developing carcinogenic diseases. Therefore, it is advisable to exercise caution and limit the regular consumption of tap water by children.

Table 8: ILCR and TCR for children and adults of tap and filtered water in Bukayriyah city

Metal	ILCR – children		ILCR – adults	
	Tap water	Filtered water	Tap water	Filtered water
As	6.00×10^{-6}	2.00×10^{-6}	1.10×10^{-6}	3.67×10^{-7}
Pb	1.36×10^{-7}	1.19×10^{-7}	2.49×10^{-8}	2.18×10^{-8}
Cd	2.52×10^{-5}	8.40×10^{-6}	4.63×10^{-6}	1.54×10^{-6}
Cr	5.52×10^{-5}	3.83×10^{-6}	1.01×10^{-5}	7.02×10^{-7}
Ni	5.66×10^{-5}	3.98×10^{-5}	1.03×10^{-5}	7.30×10^{-6}
TCR=∑ILCR	1.43×10^{-4}	5.41×10^{-5}	2.63×10^{-5}	9.94×10^{-6}

4 Conclusion

The application of ICP-MS enabled the assessment of As, Pb, Hg, Cd, Cr, and Ni levels in tap and filtered water samples obtained from Bukayriyah City. The results indicated that the concentrations of these elements were within acceptable ranges and, in certain instances, even below the detection limit. This affirms the suitability of these water sources for drinking purposes, as they comply with the specifications set forth by the WHO and the GSO. Moreover, the measurements of TDS, conductivity, and pH also met the required standards. Furthermore, the results suggest that the overall exposure to heavy metals from both tap and filtered water in Bukayriyah City is within safe limits in terms of non-carcinogenic risks. However, there is a potential risk of carcinogenic effects for children exposed to tap water. Therefore, it is advisable to exercise caution and limit the regular consumption of tap water by children.

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