



Article

Assessment of Heavy Metal Contamination in Drinking Water Sources

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Citation: Shawais Z. A. Assessment of Heavy Metal Contamination in Drinking Water Sources. Central Asian Journal of Theoretical and Applied Science 2026, 7(4), 355-366.

Received: 10th Jul 2026

Revised: 11th Aug 2026

Accepted: 20th Sep 2026

Published: 30th Oct 2026



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Abstract: Drinking water quality monitoring is important where aging distribution infrastructure and reliance on bottled water may affect consumer exposure. This study assessed physicochemical parameters, three metals, and modeled non-carcinogenic hazards in 7 drinking-water sources in Kirkuk, Iraq, comprising 7 municipal tap-water sources (W1-W7). Cadmium, nickel, and zinc were measured using a Shimadzu AA-7000 flame atomic absorption spectrometer. The reported physicochemical measurements were within the comparison ranges presented in the manuscript. Zinc ranged from 0.0009 to 0.1324 mg/L, and all the other samples were under the 3 mg/L comparison value. Cadmium exceeded 0.003 mg/L in 4 of seven (57.1 %). Nickel ranged from 0.00 to 0.0388 mg/L, two samples exceeded the Iraqi comparison value of 0.02 mg/L While none exceeded the WHO value of 0.07 mg/L. Under the study's stated screening assumptions, hazard indices exceeded one at two sources for adults and three sources for children. The highest calculated child hazard index was approximately 4.26 at Al-Iskan (W3). These results identify potential exposure concerns in the sampled sources. The modeled risks remain conditional on the selected toxicity benchmarks. The measurements do not establish the origins of contamination or demonstrate clinical health effects.

Keywords: Tap water, Cadmium, Nickle Zinc, exposure assessment, Kirkuk.

1. Introduction

Water is essential to human life, socioeconomic development, environmental stability. It support drinking-water supplies, aquatic biodiversity, industry and agriculture.

Rapid population growth, industrialization and unregulated urban and agricultural activities have increased pressure on groundwater and surface-water resources, contributing to declining water quality [1]. Water bodies receive residues from many human activities [2].

Heavy metal pollution is a serious environmental concern because of the toxicity, persistence and potential biological accumulation of these contaminants in aquatic organisms and ultimately the human food chain [3].

Lead, cadmium, chromium, iron, manganese, copper, and zinc can originate from natural processes, including rock weathering and mineral dissolution, and human

activities, including industrial discharges, agricultural runoff, untreated sewage, and hospital or municipal waste disposal [4].

Heavy metals can pose long-term environmental and public-health concerns because, unlike many organic contaminants, they do not biodegrade. Depending on their chemical forms, they may accumulate in sediments, soils, and living tissues [5].

In aquatic ecosystems, metals may be transferred from water to phytoplankton and fish through the food web. This transfer does not imply equal concentrations in water and organisms [5].

Exposure to metals through drinking water may have adverse health effects. Prolonged lead exposure is associated with impaired neurological development, anemia, and renal dysfunction. Cadmium exposure is associated with kidney dysfunction, bone damage and carcinogenic effects. Chromium toxicity depends strongly on its oxidation state. excessive exposure to iron or manganese may also have adverse effects [6], [7].

National standards and international guidance provide reference values for assessing drinking-water quality. The Iraqi Drinking Water Standard (IQS 417/2009) [8] and the WHO Guidelines for Drinking-water Quality, fourth edition incorporating the first and second addenda [9], provide the comparison framework used in Tables 1 and 2. Health-based guideline values should be distinguished from acceptability criteria and operational recommendations.

previous studies in Kirkuk have examined drinking water and heavy metal contamination;

The current research offers a localized evaluation of nickel, cadmium, and zinc in seven municipal tap-water samples, along with preliminary non-carcinogenic risk assessments (CDI, HQ and HI) for both adults and children.

Table 1. Physicochemical comparison values for drinking water from Iraqi standard IQS 417/2009 and WHO 2022 guidance.

Parameter	IQS 417/2009	WHO (2022)	Units
Physical parameters			
Temperature	-----	-----	C
pH	6.5 – 8.5	6.5 -8.5	----
Turbidity	5	5	NTU
Electrical conductivity (EC)	100-1500	1000-1500	µS/cm
Total dissolved solids (TDS)	1000	1000	mg/L
Chemical Parameters			
Total Hardness as CaCo ₃	500	500	mg/L
Calcium Ca ⁺²	150	200	mg/L
Magnesium Mg ⁺²	100	150	mg/L
Sodium Na ⁺	200	200	mg/L
Chloride Cl ⁻	350	250	mg/L
Sulfate SO ₄ ⁻²	400	250-500	mg/L
Nitrate NO ₃ ⁻	50	50	mg/L

Nitrite NO ₂ ⁻	3	3	mg/L
Fluoride F	1.5	1.5	mg/L
Free Residual Chlorine	0.3	0.2-0.5	mg/L

Table 2. Drinking-water comparison values for selected heavy metals.

Heavy Metal	IQS417/2009	WHO (2022)	Unit
Cadmium Cd	0.003	0.003	mg/L
Nickel Ni	0.02	0.07	mg/L
Zinc Zn	3	3	mg/L

Several values presented in the Iraqi standard and WHO guidance are numerically similar. However, studies in Kirkuk, Samarra, and other Iraqi cities have reported concentrations of some metals above relevant comparison values, indicating differences between regulatory expectations and observed water quality [1], [10].

AL-Jumaily [11] Investigated the hydrochemistry and heavy metal concentrations of the Al-Haweja canal in Kirkuk, Iraq, at nine sites along its 29-km length. Measurement included pH, electrical conductivity, total dissolved solids, major ions, and trace elements. Total dissolved solids ranged from 184 to 215 mg/L, and pH ranged from 7.35-8.51. The reported hydrochemical type was Mg-Na-Ca-HCO₃-Cl-SO₄. The Wilcox diagram indicated suitability for agricultural use. Cadmium and manganese concentrations exceeded EPA comparison values used in that study. The authors discussed untreated wastewater, urban waste and agricultural runoff as possible pollution sources, while Gibbs analysis indicated a contribution from natural weathering.

Al-Jumaily [12] assessed a heavy metal contamination in Kirkuk's drinking-water distribution system using 26 tap-water samples collected in July 2015. Seven trace elements (arsenic, chromium, copper, manganese, lead, nickel, and zinc) were measured by inductively coupled plasma mass spectrometry. The assessment used the heavy metal evaluation index (HEI), degree of contamination (Cd), and metal index (MI). Metal concentrations were reported below the WHO and Iraqi comparison values. Mean HEI, Cd and MI values were 0.465, -6.530, and 0.863, respectively. Special differences included higher arsenic and chromium in Rahimawa and higher copper, manganese and nickel in AL-Khadra. The findings indicated low contamination according to the indices used.

Ibrahim et al. [1] investigated water quality in Samarra. Three surface-water samples from the Tigris River and six groundwater samples from the Quaternary aquifer were collected in winter 2017. The Study assessed 20 metals and several physicochemical parameters. Many metal concentrations exceeded results indicated that most heavy metals exceeded international and Iraqi comparison values used by the authors. Elevated uranium and cobalt concentrations were also reported. High biochemical oxygen demand, chemical oxygen demand, electrical conductivity, total dissolved solids, and turbidity indicated that the sampled waters were unsuitable for drinking without treatment. The authors discussed agricultural, industrial and military-related activities as possible contributors.

Hussein et al., [10] assessed wastewater quality from three hospitals in Kirkuk between September 2016 and February 2017. Untreated wastewater exceeded Iraqi environmental comparison values for electrical conductivity, total dissolved solids, and total suspended solids. Biochemical oxygen demand, chemical oxygen demand, phosphate and nitrate were also elevated, whereas pH and sulfate were within the values used for

comparison. Cardium and chromium exceeded the relevant limits while Iron did not. The authors reported limited improvements in total suspended solids and biochemical oxygen demand after treatment and discussed deficiencies in the available treatment systems.

Al-Tamimi et al., [13] assessed Assistant arsenic, cadmium, copper, iron, manganese, nickel, zinc, chromium, and lead at the Kirkuk unified water treatment plant, ground storage tanks and residential taps in Zone 3. Samples were collected during wet and dry seasons in 2016- 2017.

All assessed metals except zinc were reported within WHO comparison values. Zinc concentration were elevated across the distribution network. The study estimated ingestion and dermal hazard quotients, hazard indices and cancer risks for adults and children. Zinc hazard indices exceeded one under the study's assumptions, indicating a potential non-carcinogenic concern.

Al-Salihy et al., [14] evaluated the hydrochemistry and performance of the Kirkuk unified water project during dry and wet seasons 2019–2020. Eleven samples were analyzed for major and minor ions, pH, electric conductivity, total dissolved solids and turbidity. Most results were within the WHO and Iraqi comparison values used in the study, although raw-water turbidity was elevated. Some ions and Total dissolve with solids where higher during wet season, whereas calcium was higher during the dry season. The water quality index classified untreated water as unsuitable and treated water as good. Treatment was effective in reducing turbidity. The authors recommended continued monitoring of the Lower Zab River and assessment of potentially toxic metals associated with nearby oil activities.

Ali et al., [4] investigated water quality and mercury, cadmium, lead, copper, cobalt and chromium concentrations at the Darbandikhan Dam and the Sirwan and Tanjaro river inlets in the Kurdistan Region of Iraq. Sampling took place from August 2021 to January 2022, and metals were measured using inductively coupled plasma optical emission spectrometry. Water temperature ranged from 13 to 30.9°C, dissolved oxygen from 4.82 to 9.5 mg/L, and pH from 6.11 to 7.97. Total hardness exceeded the comparison value of 100 mg/L used by the authors; this should not be described as a WHO health-based limit. Sulfate Ranged from 51 to 145 mg/L and electrical conductivity from 191 to 595 $\mu\text{S}/\text{cm}$. Nitrate reached 14.7 mg/L at the Tanjaro site; the meaning of the cited 10 mg/L threshold depends on whether concentrations were expressed as nitrate or nitrate nitrogen. Metal concentrations varied by location and month, with some metals undetected at particular sites. The authors discussed wastewater inputs and reduced river flow as possible contributors to the observed patterns.

Khazal and Azeez [15] investigated groundwater contamination in Kirkuk Governorate, Iraq. Samples from 52 wells were collected in September 2023. Lead and cadmium were measured by atomic absorption spectrometry, and boron was determined using the carmine method. Results were compared with WHO drinking-water guidance and FAO irrigation criteria. Spatial distribution were analyzed using ArcGIS 10.4.1. The study used the heavy metal pollution index, metal index, synthetic pollution index and degree of contamination.

All sampled wells met the boron comparison values and the FAO lead criterion for irrigation, but lead exceeded the WHO drinking-water guideline in every well. The study reported cadmium exceedances in 41.42% of wells, mainly in the western area.

The synthetic pollution index and degree of contamination classified the wells as heavily contaminated. The authors discussed atmospheric pollution, industrial waste and agricultural inputs as possible contributors. Lead was the principal contaminant, followed by cadmium.

Mohammed and Ahmed [5] conducted a cross-sectional study between September 2024 to February 2025 to assess physicochemical properties and metal concentrations in

water and fish from four sites in Kirkuk Governorate, near the Lower Zab and Tigris rivers. Water measurements included turbidity, pH, nitrates, phosphates, total alkalinity, potassium, copper, zinc, lead and iron. Fish size, mass and metal concentrations were also assessed, with metals measured by atomic absorption spectrometry. Turbidity ranged from 57.18 to 72.59 NTU and pH from 7.80 to 7.97. Nitrate, phosphate and copper concentrations were lower than those reported in earlier studies, whereas lead concentrations were higher. Metal concentrations differed among fish species. The authors reported associations between physicochemical properties and metal concentrations and discussed seasonal conditions and food-web transfer as possible influences.

Noori et al. [15] assessed drinking-water quality in Kirkuk using geographic information systems and multiple linear regression. Fifteen tap-water sites were assessed for 2020 and 2022 using 14 physicochemical parameters and comparison with WHO and Iraqi guidance. Water was slightly to moderately alkaline, and some parameters exceeded the comparison values. Total dissolved solids and electrical conductivity improved, but turbidity remained variable. Regression analysis indicated association between turbidity, total dissolved solids, electrical conductivity and total hardness. The authors emphasized continued treatment and monitoring.

These studies indicate that water contamination in Iraq can reflect geological conditions, land use, industrial and agricultural discharge, and treatment or distribution problems. Monitoring metals in untreated and treated water is important for assessing exposure and informing environmental management.

The Novelty of this study lies in the combined assessment of cadmium, nickel and zinc in 7 municipal tap-water samples from Kirkuk Iraq, using laboratory measurements, comparison with Iraqi and WHO drinking water standards, and non-carcinogenic health-risk assessment for adults and children. The findings provide a focused local comparison of drinking water source and identify potential exposure concerns to support future water quality monitoring.

Study Area

Kirkuk is a city in northern Iraq, located at approximately 35°28' N and 44°23' E. Population growth and expanding industrial and economic activities have increased demand for infrastructure, including drinking-water treatment and distribution.

The lower Zab River is a major raw-water source for Kirkuk. Water is treated at the Kirkuk unified water project and distributed through the municipal network and storage facilities to residential neighborhoods [12], [14].

River water is treated centrally at the Kirkuk unified water project before distribution to neighborhoods and ground storage tanks. [13], [14].

Although treatment can reduce turbidity and other water-quality indicators, water quality may change during distribution. Aging metal pipes and galvanized steel components may corrode and release metals into the water. [12]–[14], [17].

These mechanisms are possible explanations rather than causes demonstrated by the present dataset.

Previous studies have reported differing results for Kirkuk's water quality. Some found metal concentrations below comparison values, whereas others reported elevated zinc or contamination by cadmium and lead in particular wells and water sources [13], [15].

Cadmium, lead, and nickel can be toxic at sufficient exposure levels. Their persistence and potential accumulation may contribute to renal or neurological effects, depending on the metal and exposure conditions. [10], [12], [18].

Children may be more vulnerable to some metal exposures than adults. In the present model, their higher estimated intake per unit body weight produces higher calculated exposure doses [6], [13], [18]. This study assessed cadmium, nickel and zinc in seven municipal tap-water samples in Kirkuk. Chronic daily intake (CDI), hazard quotient (HQ) and hazard index (HI) were calculated for adults and children using the stated exposure assumptions and literature-based toxicity benchmarks. Measured concentrations were compared with WHO guidance and the Iraqi Drinking Water Standard IQS 417/2009 [8], [9].

2. Materials and Methods

Sampling

A cross-sectional assessment was conducted using seven municipal tap-water samples from in Kirkuk Governorate. Samples W1-W7 represented municipal tap water from 7 locations. Source identifiers are presented in Tables 3 and 4.

Analytical methods

Physicochemical parameters were measured using the methods in the manuscript.

pH was measured with a pH meter, electrical conductivity and total dissolved solids were measured with the corresponding meters. Total hardened, expressed as mg/L CaCO₃, and calcium and magnesium concentrations were determined by complexometric titration with EDTA, Turbidity was measured using a turbidity meter.

Metals were analyzed at the U-Science Scientific Laboratory using a Shimadzu AA-7000 flame atomic absorption spectrometer equipped with an ASC-7000 autosampler and deuterium background correction (BGC-D2). Element-specific operating condition were used.

Health risk assessment

Potential non-carcinogenic concerns from oral exposure were assessed using CDI, HQ, and HI calculations adapted from the cited literature [6], [13], [18].

The implemented adult assumption were a body weight of 70 kg and water intake of 2.0 L/day. The child assumptions were a body weight of 15 kg and water intake of 1.0 L/day.

The calculations comprised three stages:

Chronic Daily Intake (CDI):

Chronic daily intake from drinking water was calculated using the following exposure equation.

$$CDI = \frac{C_w * IR * EF * ED}{BW * AT} \quad \text{Eq. 1}$$

Where:

C_w is the measured metal concentration in water, expressed in mg/L.

IR is the water ingestion rate: 2.0 L/day for adults and 1.0 L/day for children [18], [19].

EF is the exposure frequency assumed to be 365 days/ year.

ED is the exposure duration, assumed to be 30 years for adults and 6 years for children [13].

BW is body weight, assumed to be 70 kg for adults and 15 kg for children in the implemented calculation.

AT is the averaging time for non-carcinogenic effects calculated as $ED * 365$ days: 10,950 days for adults and 2,190 days for children (Al-Tamimi et al., 2019).

Because $EF * ED$ equals AT under these assumptions, the time-dependent factor is one. Therefore, CDI simplifies to $C_w * IR/BW$. The adults and child multipliers are 0.028571 and 0.066667 L/kg/day, respectively.

$$CDI_{adult} = C_w * \frac{2}{70}$$

$$CDI_{child} = C_w * \frac{1}{15}$$

Hazard quotient (HQ)

The hazard quotient for each metal was calculated by dividing CDI by the selected oral toxicity benchmark (Equation 2) [6], [13], [18]:

Equation 2, $HQ = CDI / \text{selected oral toxicity benchmark}$

$$HQ = \frac{CDI}{RfD} \quad \text{Eq. 2}$$

The calculations used the following oral toxicity benchmark values, expressed in mg/kg/day.

The oral reference toxicity benchmarks (RfD, mg/kg/day) were retrieved from USEPA repository data and verified through recent toxicological literature [6], [18]:

Cadmium: 0.0005 mg/kg/day.

Nickel: 0.0200 mg/kg/day.

Zinc: 0.3000 mg/kg/day.

An HQ above one indicates a potential non-carcinogenic concern under the selected assumptions. An HQ at or below one indicates that the modeled intake does not exceed the selected benchmark; it does not establish absence of all health risks [13].

Hazard Index (HI):

The hazard index was calculated by the sum of the three metal-specific hazard quotients (Equation 3) [13], [18].

$$HI = \sum_{i=1}^n HQ_i = HQ_{Cd} + HQ_{Ni} + HQ_{Zn} \quad \text{Eq. 3}$$

An HI above one identifies a potential component, screening concern under the model assumption. An HI at or below 1 does not establish that the drinking water is safe with respect to all contaminants or exposure pathways.

3. Results and Discussion

Physical and Chemical parameters

The physical and bulk chemical parameters of the 7 water samples are detailed in (Table -3) alongside benchmark from WHO and Iraqi standard IQS.417/2009.

Table 3. physicochemical measurements in the seven municipal tap water samples in Kirkuk.

Sample	Source	CL mg/l	Mg mg/l	Ca mg/l	T.H mg/l	T.D.S mg/l	TURB NTU	Cond. (EC) µS/cm	PH 6.5 – 8.5
W1	Al-Qadisiya	20	4.56	16	59	119	2,68	239	7,53
W2	Mussalla	15	4.56	16	59	118	2,71	236	7,72
W3	Al-Iskan	10	6.96	12	59	119	2,84	237	7,84
W4	Almas	10	2.16	20	59	119	4,83	238	7,91
W5	Arafa	20	2.88	24	72	144	0,81	285	7,92
W6	Al-Mansoor	10	2.16	20	59	118	3,66	235	8,05
W7	Tiseen	10	4.56	16	59	118	2,16	235	8,12
IQS 417/2009		350	100	150	500	1000	5	100- 1500	6.5 – 8.5
WHO (2022)		250	150	200	500	1000	5	1000- 1500	6.5 – 8.5

Municipal tap-water pH ranged from 7.53 to 8.12, with a mean of 7.87. All measured pH values were within the comparison range of 6.5–8.5 presented in Table 3.

The slightly alkaline pH is consistent with the influence of carbonate-rich geology in the Lower Zab catchment and northern Iraq.

Mean municipal tap-water total dissolved solids and electrical conductivity were 122.1 mg/L and 243.6 µS/cm, respectively. The largest values occurred at Arafa (W5), where electrical conductivity was 285 µS/cm and total dissolved solids were 144 mg/L.

Tap-water turbidity averaged 2.81 NTU and ranged from 0.81 NTU at Arafa (W5) to 4.83 NTU at Almas (W4). All measurements were below the comparison value of 5 NTU.

Heavy Metal Levels in Drinking Water

Cadmium, nickel and zinc were measured in all 7 samples using a Shimadzu AA-7000 flame atomic absorption spectrometer. Although the reported physicochemical values were within the comparison ranges, metal concentrations varied among sources and some exceeded drinking-water guideline values. Table 4 summarizes the measured concentrations alongside the official thresholds specified by the Iraqi drinking water code (IQS: 417/2009) [8] and the word health organizations [9].

Table 4. Metals concentrations in municipal tap-water samples in Kirkuk and drinking-water comparison values.

Sample ID	Sampling Source	Location /	Cadmium Cd	Nickel Ni	Zinc Zn
			mg/L	mg/L	mg/L
W1	Al-Qadisiya		0.0179	0.0226	0.1324
W2	Mussalla		0.0124	0.0016	0.0009
W3	Al-Iskan		0.0319	0.0014	0.0029
W4	Almas		0.0007	0.0388	0.0045
W5	Arafa		0.0031	0.0006	0.0337
W6	Al-Mansoor		0.0000	0.0011	0.0109
W7	Tiseen		0.0002	0.0000	0.0109
IQS 417/2009			0.003	0.02	3
WHO (2022)			0.003	0.07	3

Zinc concentrations ranged from 0.0009 mg/L at Mussalla (W2) to 0.1324 mg/L at Al-Qadisiya (W1), with a mean of 0.0280 mg/L across the 7 samples. All values were below the 3 mg/L comparison value used in the manuscript. Al-Tamimi et al. [13] reported substantially higher zinc concentrations.

In Tiseen (W7), nickel was below detection, but reached 0.0388 mg/L in W4. W1 (0.0226 mg/L) and W4 (0.0388 mg/L) exceeded the Iraqi comparison value of 0.0200 mg/L, while all other samples were below the WHO value of 0.0700 mg/L. In municipal networks, corrosion of galvanized pipes and nickel-chrome fittings is associated with increased nickel.

Cadmium exceeded 0.003 mg/L in four samples (57.1%): Al-Iskan (W3: 0.0319 mg/L), Al-Qadisiya (W1: 0.0179 mg/L), Mussalla (W2: 0.0124 mg/L), and Arafa (W5: 0.0031 mg/L). Possible contributors include corrosion of galvanized components and contamination of source water where Cadmium is an impurity in zinc coatings, is the main cause of cadmium in municipal tap supply. the cumulative burden may also be increased by leaching from agricultural and industrial runoff upstream.

Health risk assessment

Comparison with drinking-water guideline values provides an initial assessment of the measured concentrations. Modeled intake and non-carcinogenic screening indices were also calculated for adults and children under the stated exposure assumptions.

CDI was calculated for each metal and used with the selected toxicity benchmarks to obtain HQ and HI values. Tables 5 and 6 present the calculated intakes and screening indices, respectively.

Table 5. Calculated chronic daily intake (CDI, mg/kg/day) of metals for adults and children in the sampled sources.

Station	Group	CDI Cd	CDI Ni	CDI Zn
W1	Adults	0.000511	0.000646	0.003783
	Children	0.001193	0.001507	0.008827
W2	Adults	0.000354	0.000046	0.000026
	Children	0.000827	0.000107	0.000060
W3	Adults	0.000911	0.000040	0.000083
	Children	0.002127	0.000093	0.000193
W4	Adults	0.000020	0.001109	0.000129
	Children	0.000047	0.002587	0.000300
W5	Adults	0.000089	0.000017	0.000963
	Children	0.000207	0.000040	0.002247
W6	Adults	0.000000	0.000031	0.000311
	Children	0.000000	0.000073	0.000727
W7	Adults	0.000006	0.000000	0.000311
	Children	0.000013	0.000000	0.000727

Table 6. Calculated hazard quotients (HQ) and hazard indices (HI) for adults and children across the stated screening assumptions

Station	Group	HQ Cd	HQ Ni	HQ Zn	HI	Safety status
W1	Adults	1.023	0.032	0.013	1.068	Potential concern (HI >1)
	Children	2.387	0.075	0.029	2.491	Potential concern (HI >1)
W2	Adults	0.709	0.002	0.000	0.711	Acceptable (HI <1)
	Children	1.653	0.005	0.000	1.659	Potential concern (HI >1)
W3	Adults	1.823	0.002	0.0003	1.825	Potential concern (HI >1)
	Children	4.253	0.005	0.0006	4.259	Potential concern (HI >1)
W4	Adults	0.040	0.055	0.0004	0.096	Acceptable (HI <1)
	Children	0.093	0.129	0.001	0.224	Acceptable (HI <1)
W5	Adults	0.177	0.001	0.003	0.181	Acceptable (HI <1)
	Children	0.413	0.002	0.007	0.423	Acceptable (HI <1)
W6	Adults	0.000	0.002	0.001	0.003	Acceptable (HI <1)
	Children	0.000	0.004	0.002	0.006	Acceptable (HI <1)
W7	Adults	0.011	0.000	0.001	0.012	Acceptable (HI <1)
	Children	0.027	0.000	0.002	0.029	Acceptable (HI <1)

Using the manuscript's stated screening benchmarks, adult HI exceeded one at two sources: Al-Qadisiya (W1, HI $\approx$ 1.068), Al-Iskan (W3, HI $\approx$ 1.825).

Child HI exceeded one at three of the seven sources (42.9%) : W1, W2, and W3

The largest child HI values were approximately

(HI $\approx$ 2.491) at (W1) Al-Qadisiya , Mussalla (W2, HI $\approx$ 1.659) and Al-Iskan (W3, HI $\approx$ 4.259). These are screening results based on the selected assumptions and benchmarks.

The derived HI values were mainly determined by the cadmium HQ values, the nickel and zinc HQ values were consistently under one at all selected locations for both exposure groups.

Adult Cd HQ exceeded one at Al-Iskan (W3: 1.823) and Al-Qadisiya (W1: 1.023). Child Cd HQ exceeded one at three sources: Al-Iskan (W3: 4.253), Al-Qadisiya (W1: 2.387) and Mussalla (W2: 1.653).

nickel and zinc HQ values were below one for both groups under the manuscript's selected benchmarks.

Calculated child exposure doses and hazard indices were approximately 2.33 times the adult values because the assumed water ingestion rates per unit body weight were 0.0667 and 0.0286 L/kg/day, respectively. Absorption and physiological susceptibility were not separately included in these calculations

4. Conclusion

The measured physicochemical parameters in seven municipal tap-water samples were within the comparison ranges presented in the manuscript. These measurements do not establish microbiological safety or demonstrate treatment-plant performance.

Zinc concentrations ranged from 0.0009 to 0.1324 mg/L and were below the comparison value used in the manuscript.

Nickel concentrations ranged between 0.000 mg/L to 0.0388 mg/L, two samples passed the Iraqi benchmark of 0.02 mg/L but none exceeded the WHO threshold of 0.07 mg/L.

Cadmium exceeded 0.003 mg/L in 4 of seven samples (57.1%) With the highest concentration at Al-Iskan (W3; 0.0319 mg/L).

Under the study's stated screening assumptions, HI exceeded one at two sources for adults and three for children. The largest calculated HI was approximately 1.825 for adults and 4.259 for children, both at Al-Iskan W3. These findings indicate potential exposure concerns, while interpretation remains conditional on the selected toxicity benchmarks.

Evaluated metal concentration occurred in several consumer tap-water samples. Distribution system corrosion and contamination during the source water collection are possible explanations, but the current measurements do not identify that causes. The finding warrant attention to the quality of the sampled drinking-water sources.

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