Health Risk Assessment of Heavy Metals in Drinking Water in Jingzhou City

Aoteng He
Yangtze University
School of Urban Construction
Jingzhou, China

Xiangyang Huang
Yangtze University
School of Urban Construction
Jingzhou, China

Abstract: Objective: To evaluate the potential harm of heavy metals to human health in drinking water in Jingzhou City. Methods In 2021-2022, heavy metals in drinking water in Jingzhou City were detected, and the health risks caused by drinking water routes were preliminarily evaluated. Results The qualification rates of arsenic (As), cadmium (Cd), hexavalent chromium (Cr6+), lead (Pb) and mercury (Hg) in drinking water in Jingzhou City were 100.0%. The carcinogenic risks of As, Cd, Cr6+ and Pb were 3.6×10^{-5}/a, 1.5×10^{-5}/a, 4.8×10^{-5}/a, and 8×10^{-8}/a, respectively, and the cumulative carcinogenic risk was 9.8×10^{-5}/a, and the carcinogenic risk order of different populations was > in children > adult malesadult females; The non-carcinogenic risk values of As, Cd, Cr6+, Pb and Hg were 8.0×10^{-2}/a, 4.8×10^{-4}/a, 1.9×10^{-2}/a, 6.8×10^{-3}/a, 8.0×10^{-2}/a, and the hazard index was 1.1×10^{-1}/a, respectively, and the non-carcinogenic risk order of different populations was > in children > adult malesAdult females. Conclusion The concentrations of As, Cd, Cr6+ and Pb in drinking water in Jingzhou City conform to GB 5749-2022 "Sanitary Standards for Drinking Water", and the cumulative carcinogenic risk is acceptable. The non-carcinogenic health risks of As, Cd, Cr6+, Pb, and Hg are within acceptable limits for the U.S. Environmental Protection Agency.

Keywords: Drinking water; Heavy metal; Carcinogenic risk; Non-carcinogenic risk

1. INTRODUCTION

Drinking water is a fundamental necessity for human health and survival. However, with the rapid advancement of industrialization and urbanization, heavy metal contamination in drinking water has increasingly drawn widespread attention. As a common class of environmental pollutants, the presence of heavy metals in drinking water has become one of the major challenges for public health and environmental protection worldwide. [1] The hazards posed by heavy metals in drinking water cannot be overlooked. The accumulation of heavy metals within the human body occurs gradually, yet their potential health impacts are long-term and severe. Prolonged exposure to drinking water with high heavy metal concentrations can trigger multiple serious health issues, including neurological damage, liver and kidney dysfunction, cancer, and reproductive system abnormalities.

Children, pregnant women, and the elderly are the groups most vulnerable to heavy metal contamination. During critical developmental stages in children, heavy metals can impair neurological and cognitive development, potentially leading to reduced IQ, diminished learning abilities, and even behavioral issues.[2] Exposure to heavy metals in drinking water during pregnancy may cause fetal developmental abnormalities, increasing the risk of miscarriage and birth defects. The elderly, due to slowed physiological metabolism, are more susceptible to the cumulative effects of heavy metals, raising their risk of disease.[3]

The presence of heavy metals in drinking water primarily stems from contamination of water sources through multiple channels, including industrial wastewater, agricultural pollution, mining activities, and urban drainage. Additionally, contamination arises from excessive heavy metal content in water treatment chemicals, disinfectants, water purification structures, water tanks, and piping materials.

Assessing the health risks of heavy metals requires comprehensive consideration of multiple factors, including exposure levels, human exposure pathways, and toxic effects. Given the distinct toxic characteristics of different heavy metals and varying sensitivities among populations, establishing a scientifically sound assessment model that quantifies these factors is crucial for effective health risk evaluation. This study employs the risk assessment model recommended by the United States Environmental Protection Agency (US EPA) to quantitatively describe the magnitude of health risks posed by As, Cd, Cr^{6+}, Pb, and Hg contamination in Jingzhou's drinking water via the drinking water pathway. It provides scientifically sound risk management recommendations for relevant decision-making authorities to ensure the safety of public drinking water and safeguard human health.

2. SAMPLING AND TEST METHODS

2.1 Water Sample Source

The samples were sourced from drinking water monitoring data collected by the Jingzhou Water Quality Testing Center from January to December 2021 and 2022, specifically including tap water during both low-flow and high-flow periods.

2.2 Method

2.2.1 Sample Collecting, Testing and Evaluation Methods

Water samples were collected, preserved, and tested in accordance with 《GB/T 5750—2006 Standard Test Methods for Drinking Water》 [9]. Test parameters included As, Cd, Cr^{6+}, Pb, and Hg. Test results were evaluated against 《GB/T 5749—2022 Drinking Water Quality Standard》.

2.2.2 Health Risk Assessment Methodology

Using the USEPA's four-step health risk assessment model, evaluate the carcinogenic and non-carcinogenic risks to children, adult males, and adult females from the oral ingestion pathway of drinking water, and compare changes in health risks from water samples across different time periods.

2.2.2.1 Hazard Identification

Obtained from the database of the International Agency for Research on Cancer (IARC).[4]

2.2.2.2 Dose-response relationship

The Agency for Toxic Substances and Disease Registry (ATSDR) and the Agency for Toxic Substances and Disease Registry (ATSDR), and the U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS) provided the dose-response parameters for the oral exposure pathways of the five heavy metals studied, namely the oral slope factor (SF) or oral reference dose (RfD). as shown in Table 1.

Table 1. Five Parameters of Dose-Response Relationships for Heavy Metals

Heavy metals	SF[(kg·d)/mg]	RfD[mg/(kg·d)]
As	1.5000	0.0003
Cd	6.1000	0.0050
Cr^{6+}	0.5000	0.0050
Pb	0.0085	0.0014
Hg	-	0.0003

Note: SF—Slope factor for oral exposure; RfD—Reference dose for oral exposure

2.2.2.3 Exposure Assessment

The exposure calculation formula (1) for the drinking pathway is:

$$ADD = \left[(C_i \times IR \times EF \times ED) / (BW \times AT) \right] \qquad (1)$$

Where: ADD — Daily oral exposure dose [mg/(kg·d)];Ci — Concentration of chemical carcinogen i (mg/L);IR — Daily adult water intake, L/d; EF — Exposure frequency, d/a; ED — Exposure duration, a; BW — Adult body weight; AT — Average exposure time, AT = Expected lifespan × 365, unit; d.— Exposure frequency, d/a; ED— Exposure duration, a; BW— Adult body weight; AT— Average exposure time, AT=Life expectancy × 365, in days.

2.2.3 Risk Assessment Model

2.2.3.1 Carcinogenic Risk Assessment Model

The carcinogenic risk is typically described using the cancer risk value (CR), calculated using the following formula (2):

$$CR = ADD \times SF \qquad (2)$$

In the formula:

 CR—carcinogenic risk, /a;

SF—slope factor for oral intake, (kg·d)/mg.

Cumulative cancer risk (CCR), formula (3):

$$CCR = \sum_{i=1}^{n} CR_i \qquad (3)$$

In the formula (3): CCR—cumulative cancer risk; CR_i—carcinogenic risk for exposure pathway i[6].

2.2.3.2 Health Risk Assessment Model for Non-Carcinogenic Pollutants

Non-carcinogenic health risks are typically expressed using the hazard quotient (HQ):

$$HQ = ADD / RfD \qquad (4)$$

In the formula (4):HQ—Hazard quotient for non-carcinogens, /a; RfD—Reference daily intake for oral exposure.

Hazard index (HI), formula (5):

$$HI = \sum_{i=1}^{n} HQ_i \qquad (5)$$

HI—Hazard Index; HQ_i—Hazard Quotient for exposure pathway i.

2.3 Evaluation Criteria

According to USEPA standards, the acceptable risk level for carcinogenicity is set at 1.0×10^{-6}/a to 1.0×10^{-4}/a. A carcinogenic risk $<1.0 \times 10^{-6}$/a indicates negligible risk; A risk between 1.0×10^{-6}/a and 1.0×10^{-4}/a indicates a certain carcinogenic risk that is still acceptable; A risk $>1.0 \times 10^{-4}$/a indicates a relatively high carcinogenic risk. For non-carcinogenic risks, the standard value is 1. A value >1 indicates harm to human health, while <1 indicates relatively minor harm[5].

2.3.1 Parameter Selection

Exposure parameters were determined based on the Exposure Parameters for the Chinese Population. See Table 2.

Table 2. Parameter Values for Health Risk Assessment Model

Parameters	Unit	Child	Adult male	Adult women	General population
IR	L/d	0.85	1.8	1.4	1.7
EF	d/a	365	365	365	365
ED	a	70	70	70	70
BW	kg	15.0	69.2	58.2	65
AT	d	76.63×365	74.6×365	78.81×365	76.68×365

Note: IR—Daily water intake for adults; EF—Annual exposure frequency; ED—Exposure duration; BW—Adult body weight; AT—Average exposure time.

3. RESULT

3.1 Testing Results for Heavy Metals in Drinking Water in Jingzhou City

In 2021 and 2022, a total of 24 water samples were tested. The median values for the five heavy metals—arsenic (As), cadmium (Cd), hexavalent chromium (Cr^{6+}), lead (Pb), and mercury (Hg)—were 0.001, 0.0001, 0.004, 0.0004, and 0.0001, respectively. None of the maximum values exceeded the standard limits, achieving a 100.0% compliance rate. Table 3 shows the heavy metal detection results.

Table 3. Drinking Water Heavy Metal Testing Results for Jingzhou City, 2021–2022

Pollutants	Number of samples	median (mg/L)	min (mg/L)	max (mg/L)	Pass rate (%)
As	24	0.001	<0.001	0.0013	100
Cd	24	0.0001	<0.0001	0.0002	100
Cr^{6+}	24	0.004	<0.004	0.006	100
Pb	24	0.0004	<0.0001	0.0054	100
Hg	24	0.0001	<0.0001	0.0001	100

3.2 Health Risks from Heavy Metals in Drinking Water Sources for the Population

The carcinogenic risks from drinking water exposure to heavy metals arsenic (As), cadmium (Cd), hexavalent chromium (Cr^{6+}), and lead (Pb) are 3.6×10^{-5}/a, 1.5×10^{-5}/a, 4.8×10^{-5}/a, and 8×10^{-8}/a, respectively. with a cumulative carcinogenic risk of 9.8×10^{-5}/a. The carcinogenic risks for each heavy metal fall within acceptable ranges, and the cumulative carcinogenic risk is also within acceptable limits. The hazard quotients for heavy metals As, Cd, Cr^{6+}, Pb, and Hg via drinking water are 8.0×10^{-2}/a, 4.8×10^{-4}/a, 1.9×10^{-2}/a, 6.8×10^{-3}/a, and 8.0×10^{-2}/a, respectively. The hazard index is 1.1×10^{-1}/a, which is <1 and within the acceptable range. See Table 4.

Table 4. Health Risk Assessment Results for Heavy Metals in Drinking Water in Jingzhou City, 2021–2022 (1/a)

Heavy Metals	Carcinogenic Risk	Non-Carcinogenic Risk
As	3.6×10^{-5}/a	8.0×10^{-2}/a
Cd	1.5×10^{-5}/a	4.8×10^{-4}/a
Cr^{6+}	4.8×10^{-5}/a	1.9×10^{-2}/a
Pb	8×10^{-8}/a	6.8×10^{-3}/a
Hg	-	8.0×10^{-2}/a
Total	9.8×10^{-5}/a	1.1×10^{-1}/a

3.3 Health Risks from Heavy Metals in Drinking Water for Children, Adult Males, and Adult Females

The cumulative carcinogenic risk from heavy metals in drinking water for children, adult males, and adult females is 2.1×10^{-4}/a, 1.0×10^{-4}/a, and 8.8×10^{-5}/a, respectively. The risk follows the order: children > adult males > adult females. The cumulative carcinogenic risks for children and adult males exceed acceptable levels, indicating higher carcinogenic risks, while the cumulative risk for adult females remains within acceptable limits. The heavy metal hazard indices via drinking water for children, adult males, and adult females are 2.5×10^{-1}/a, 1.2×10^{-1}/a, and 1.0×10^{-1}/a, respectively, with children > adult males > adult females. All hazard indices are <1, falling within the acceptable range. See Table 5. and 6.

Table 5. Results of Carcinogenic Risk from Drinking Water Sources Among Different Populations in Jingzhou City, 2021–2022 (1/a)

Object	Cancer risk				
	As	Cd	Cr6+	Pb	Total
Child	7.8×10^{-5}	3.2×10^{-5}	1.0×10^{-4}	1.8×10^{-7}	2.1×10^{-4}
Adult male	3.7×10^{-5}	1.5×10^{-5}	4.9×10^{-5}	8.0×10^{-8}	1.0×10^{-4}
Adult female	3.2×10^{-5}	1.3×10^{-5}	4.3×10^{-5}	7.0×10^{-8}	8.8×10^{-5}

Table 6. Non-Carcinogenic Risk Results for Different Populations' Water Consumption Routes in Jingzhou City, 2021-2022(1/a)

Object	Non-carcinogenic risk				
	As	Cd	Cr^{6+}	Pb	Total
Child	1.7×10^{-1}	1.0×10^{-3}	4.1×10^{-2}	1.5×10^{-2}	2.5×10^{-1}
Adult male	8.1×10^{-2}	4.9×10^{-4}	2.0×10^{-2}	7.0×10^{-3}	1.2×10^{-1}
Adult female	7.1×10^{-2}	4.3×10^{-4}	1.7×10^{-2}	6.1×10^{-3}	1.0×10^{-1}

4. DISCUSSION

The results of this study indicate that the concentrations of heavy metals As, Cd, Cr, Pb, and Hg in Jingzhou's drinking water all comply with the requirements of 《GB 5749-2022 Sanitary Standards for Drinking Water》. The carcinogenic risks of As, Cd, Cr^{6+}, and Pb in Jingzhou's drinking water were 3.6×10^{-5}/a, 1.5×10^{-5}/a, 4.8×10^{-5}/a, and 8×10^{-8}/a, respectively. The carcinogenic risk from Pb via drinking water was negligible. The carcinogenic risks for As, Cd, and Cr^{6+} follow the order Cr^{6+} > As > Cd, with values ranging from 1.0×10^{-6}/a to 1.0×10^{-4}/a. While health risks exist, they are considered acceptable. Regulatory authorities are advised to enhance source water monitoring and protection, improve water treatment processes, and implement comprehensive prevention and control measures[11].

The hazard values for heavy metals As, Cd, Cr^{6+}, Pb, and Hg are 8.0×10^{-2}/a, 4.8×10^{-4}/a, 1.9×10^{-2}/a, 6.8×10^{-3}/a, and 8.0×10^{-2}/a, respectively. The hazard index is 1.1×10^{-1}/a. Since the hazard index is <1, it meets safety requirements.

Children face significantly greater health risks from heavy metals ingested through drinking water than adults. This is because children's bodies are still developing, with organs and systems not yet fully mature. Their absorption and metabolic capabilities are relatively weak, making them more susceptible to absorbing higher levels of heavy metals during intake. Children's nervous systems are also not fully developed, meaning heavy metal exposure may have more severe effects on their nervous systems, including impacts on intellectual development and behavioral issues.

Water treatment departments are advised to enhance water quality monitoring of water sources and supply systems. Conduct regular testing of heavy metal concentrations in water to ensure safe and compliant supply, with more frequent monitoring required in areas where children are particularly vulnerable. Collaborate with local communities to implement

health education and awareness campaigns, especially targeting parents and educators on the critical importance of protecting children from heavy metal exposure risks and how to safeguard their health. By adopting these measures, water treatment authorities can better ensure water supply safety, reduce health risks from heavy metal ingestion through drinking water, and enhance public awareness of drinking water quality issues.

This study considered only drinking water as the exposure route, neglecting other pathways such as skin contact and inhalation. Consequently, it underestimates the actual exposure risk to heavy metals. Therefore, further research is needed to conduct a comprehensive health risk assessment of Jingzhou's drinking water, integrating evaluations of health risks from disinfection byproducts and other factors.

5. REFERENCE

As shown in Table 2, the quadratic function is used as the fitting CONCLUSION

[1] Dong Shujiang, Yin Yan, Sui Yuan, Chen Ping, Xu Peilin. Health Risk Assessment of Heavy Metals in Drinking Water in Jurong City in 2021 [J]. Occupational Health, 2023, 39(06): 808-811.

[2] He Xin, Zhang Yujiao, Lai Chengyue. Preliminary Assessment of Heavy Metal Health Risks in Chengdu's Drinking Water Sources [J]. Water Resources Development and Management, 2023, 9(06): 7-12.

[3] Li Wenqi, Li Ziqin, Jia Wenting. Proper Selection of Standards for Heavy Metal Detection Methods in Drinking Water [J]. China Inspection and Testing, 2023, 31(01): 75-79+89.

[4] Jia Ru, Sun Qian, Lei Peiyu, Zheng Jingli, Zhang Tongjun, Hui Xiaofen. Health Risk Assessment of Heavy Metal Elements in Rural Drinking Water in Shaanxi Province [J]. Clinical Medicine Research and Practice, 2022, 7(36): 31-33+38.

[5] Wang Haihe, Sun Yuanyuan, Zhang Shuai, Xu Xiaorong, Shang Chengmei, Li Chunxiang. Heavy Metal Pollution Characteristics and Health Risk Assessment of Centralized Drinking Water Sources in Guiyang City [J]. Acta Ecologica Sinica, 2022, 31(10): 2039-2047.

[6] Zhou Yongtao, Zou Hongmei. Analysis of the Importance of Heavy Metal Detection in Drinking Water[J]. Quality Safety and Inspection, 2022, 32(03): 157-158.

[7] Luo Yun. Health Risk Assessment of Heavy Metal Contaminants in Drinking Water in Mianyang City, 2015–2019 [J]. Occupational Health, 2022, 38(07): 927–931.

[8] Lei Peiyu, Zheng Jingli, Jia Ru, Meng Zhaowei. Health Risk Assessment of Typical Metalloids and Heavy Metals in Rural Drinking Water in Shaanxi Province, 2020 [J]. Health Research, 2022, 51(01): 45-50.

[9] Ministry of Health of the People's Republic of China. "Test Methods for Drinking Water Standards: Metal Indicators." GB/T 5750.6-2006. 2006-12-29.

[10] National Health Commission of the People's Republic of China. "Sanitary Standards for Drinking Water." GB 5749-2022. 2022-03-15.

[11] US EPA.Risk Assessment Guidance for Superfund（RAGS），Volume I：Human Health Evaluation Manual（Part F，Supplemental Guidance for Dermal Risk Assessment）（EPA/540/R -70/002）［R］.Washington DC：US EPA，2009.

[12] US EPA.Concepts，methods，and data sources for cumulative heath risk assessment of multiple chemicals，exposoures and effects：A resource document（EPA/600/R-06/013F）［R］.Washington DC：USEPA，2007.