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Arsenic Contamination Levels in Drinking Water and Health Risk Assessment in a Certain Area of Shaanxi Province

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Abstract: ***Objective:*** *To analyze the quality status and major risk indicators of drinking water in a certain area of Shaanxi Province, China, from 2023 to 2025, to explore factors associated with arsenic exceedance, and to assess the health risks of arsenic exposure through drinking water.* ***Methods:*** *A total of 137 drinking water samples collected from 2023 to 2025 were included. Water quality was evaluated according to the Standards for Drinking Water Quality (GB 5749–2022). Chi-square test and logistic regression were used to analyze factors associated with arsenic exceedance. Based on the health risk assessment model recommended by the US Environmental Protection Agency (US EPA), non-carcinogenic and carcinogenic risks of arsenic exposure through drinking water were estimated for different population groups.* ***Results:*** *The overall compliance rate of drinking water quality was 77.37% during 2023–2025. The main indicators exceeding the standard were arsenic, total bacterial count, and manganese. Among them, arsenic was the predominant risk indicator, with 29 samples exceeding the standard and an exceedance rate of 21.17%. Significant differences were observed in arsenic exceedance rates among different years (P<0.05), but no significant linear trend was found. Multivariable logistic regression showed that, compared with urban centralized water supply, rural centralized water supply and decentralized water supply were associated with higher risks of arsenic exceedance, with the risk being more pronounced in decentralized water supply. Year was also associated with arsenic exceedance, whereas no significant association was found for hydrological period. Health risk assessment indicated that under the general exposure scenario, the hazard quotient (HQ) was >1 for children aged 0-5 years; under the high-exposure scenario, HQ was >1 for all population groups. In addition, the carcinogenic risk exceeded 10-4 in all groups.* ***Conclusions:*** *The quality of drinking water in this area still requires improvement. Arsenic was identified as the primary risk indicator. Rural centralized water supply and decentralized water supply were the key risk settings, and children, especially those aged 0-5 years, should be regarded as the priority population for protection. Strengthened monitoring, source tracing, and health risk management for arsenic contamination are warranted.*

Keywords: Drinking water, Arsenic, Water quality monitoring, Influencing factors, Health risk assessment.

1. Introduction

Safe drinking water is fundamental to public health. However, changes in water sources and fluctuations in supply system operation can lead to physicochemical or microbiological anomalies, posing persistent risks. Unsafe water can cause diarrhea, cholera, typhoid, and other diseases [1-2]. Continuous monitoring and systematic analysis of water quality data help identify major risk indicators and improve management. Shaanxi Province has complex topography and distinct surface water–groundwater recharge conditions, which vary regionally and may influence the mobilization and enrichment of arsenic and other constituents. Although routine monitoring has been conducted in recent years, systematic integration and comprehensive analysis — particularly regarding the trends, influencing factors, and health risks of key contaminants—remain limited. This study therefore analyzed monitoring data from 2023 to 2025 to identify major risk indicators, explore factors associated with arsenic exceedance, and conduct a health risk assessment to inform local drinking water safety management and protection of vulnerable populations.

2. Materials and Methods

2.1 Data Sources

Water quality monitoring data for drinking water in a specific region from 2023 to 2025 were collected. Sampling and testing were conducted by local disease prevention and control institutions following national standards. A total of 137 water samples were included: 54 in 2023, 56 in 2024, and 27 in 2025. A total of 35 parameters—including microbiological, physicochemical, and disinfection by-product indicators—were tested according to the Standard Examination Methods for Drinking Water (GB/T 5750–2023) [3].

2.2 Evaluation Criteria

Water quality compliance was assessed against the Standards for Drinking Water Quality (GB 5749–2022) [4]. A sample was deemed unqualified if any parameter exceeded the respective limit.

2.3 Statistical Analysis

Statistical analyses were performed using SPSS 26.0. Categorical data were expressed as frequencies and rates, with group comparisons using the chi-square test. Univariate and multivariable logistic regression analyses were conducted with arsenic exceedance (yes/no) as the dependent variable and year, hydrological period, and water supply type as independent variables, calculating odds ratios (OR) and 95% confidence intervals (CI). A P-value < 0.05 was considered statistically significant.

2.4 Health Risk Assessment

Health risks from arsenic exposure through drinking water were assessed using the USEPA risk assessment model, with toxicological parameters from the IRIS database [5-7].

2.4.1 Average daily dose (ADD) For long-term exposure, ADD was calculated as: (1)

$$ADD = \frac{C \times IR}{BW} \quad (1)$$

where ADD = average daily dose (mg·kg^{-1}·d^{-1}); C = arsenic concentration in drinking water (mg/L); IR = daily water intake (L/d); BW = body weight (kg).

2.4.2 Non-carcinogenic risk Non-carcinogenic risk was expressed as the hazard quotient (HQ)

$$HQ = \frac{ADD}{RfD} \quad (2)$$

where RfD = reference dose (0.0003 mg·kg^{-1}·d^{-1}for arsenic). HQ < 1 indicates no significant non-carcinogenic risk; HQ ≥ 1 suggests potential risk.

2.4.3 Carcinogenic risk Carcinogenic risk (CR) was calculated as:

$$CR = ADD \times SF \quad (3)$$

where SF = slope factor (1.5 (mg·kg^{-1}·d^{-1})$^{-1}$ for arsenic). CR < 10^{-6} is negligible; 10^{-6}–10^{-4} is acceptable; > 10^{-4} warrants attention.

2.4.4 Exposure parameters

Exposure parameters were adopted from Chinese exposure factor handbooks [8-9]: adult male: IR = 1.816 L/d, BW = 66.2 kg; adult female: IR = 1.718 L/d, BW = 57.3 kg; children (0–5 years): IR = 0.795 L/d, BW = 14.3 kg; children (6–17 years): IR = 1.496 L/d, BW = 43.6 kg. Values below the detection limit were replaced with half the detection limit. The average arsenic concentration over the three years was used for the general exposure scenario, and the maximum detected concentration was used for the high-exposure scenario.

3. Results

3.1 Sample Characteristics and Overall Compliance

A total of 137 samples were analyzed: 54 (2023), 56 (2024), and 27 (2025); 82 were from the dry season and 55 from the wet season. Supply types included urban centralized, rural centralized, and decentralized systems; sample types included finished water, tap water, and self-supplied well water. The overall compliance rate was 77.37% (106/137). Annual compliance rates were 87.04%, 67.86%, and 77.78% for 2023, 2024, and 2025, respectively, with no significant difference (χ^2 = 5.90, P = 0.052). Compliance rates for dry and wet seasons were 82.93% and 69.09%, respectively (χ^2 = 3.64, P = 0.056). Significant differences were observed across water supply types (χ^2 = 18.28, P < 0.001) and sampling types (χ^2 = 15.50, P < 0.001) (Table 1).

Table 1: Overall compliance rates of drinking water samples by different characteristics, 2023–2025

Variable	Category	No. of samples	No. compliant	Compliance rate (%)	χ^2	P-value
Year	2023	54	47	87.04		
	2024	56	38	67.86		
	2025	27	21	77.78	5.90	0.052
Hydrological period	Dry season	82	68	82.93		
	Wet season	55	38	69.09	3.64	0.056
Water supply type	Urban centralized	35	34	97.14		
	Rural centralized	68	54	79.41		
	Decentralized	34	18	52.94	18.28	<0.001
Sample type	Finished water	25	19	76.00		
	Tap water	78	69	88.46		
	Self-supplied well	34	18	79.41	15.50	<0.001

3.2 Identification of Major Risk Indicators

Among the 35 parameters, only arsenic, total bacterial count, and manganese exceeded the standards. A total of 40 exceedance events were recorded: arsenic (29 events, 21.2% exceedance rate, 72.5% of total exceedances), total bacterial count (8 events, 5.8%, 20.0%), and manganese (3 events, 2.2%, 7.5%) (Table 2). Arsenic was the predominant risk indicator and was selected for further analysis.

Table 2: Distribution of major non-compliant indicators, 2023–2025

Indicator	No. of exceedances	Exceedance rate (%)	Proportion (%)
Arsenic	29	21.2	72.5
Total bacterial count	9	5.8	20.0
Manganese	3	2.2	7.5
Total*	41*	—	100

*Some samples had multiple exceedances.

3.3 Annual Distribution of Arsenic, Manganese, and Total Bacterial Count

Annual distributions showed that arsenic concentrations were generally low, with more high-value samples in 2023 and 2024; manganese showed fluctuations, with higher values in 2024; total bacterial count was more variable in 2024. Arsenic exceeded the standard in all three years, manganese in 2023 and 2024, and total bacterial count in all years (Figure 1).

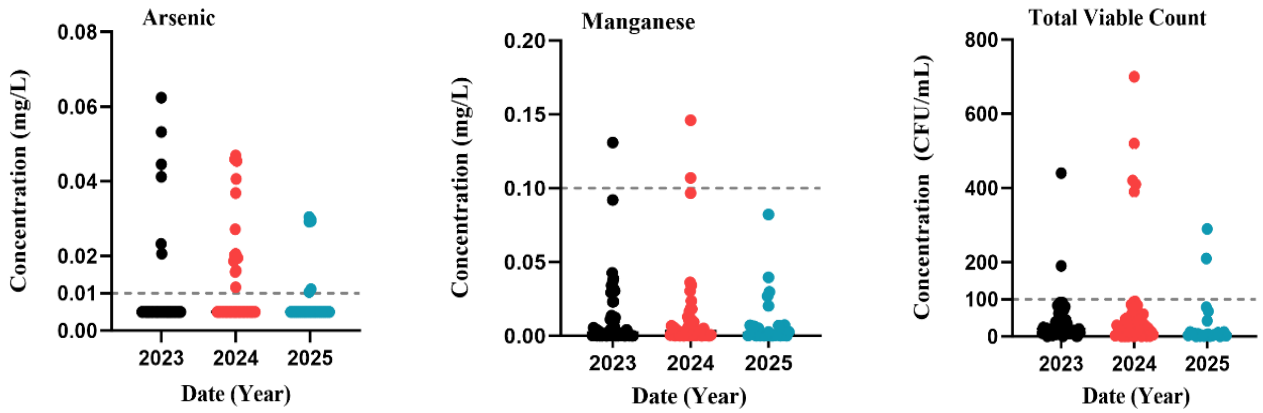


Figure 1: Boxplots showing annual distributions of arsenic, manganese, and total bacterial count, 2023–2025

Table 3: Arsenic exceedance rates by year, 2023–2025

Year	No. samples	Exceedances	Limit (mg/L)	Concentration (mg/L)					Exceedance rate (%)
				Range	P_{25}	M	P_{75}	P_{95}	
2023	54	6	0.0100	0.0050-0.0624	0.0050	0.0050	0.0050	0.0445	11.11
2024	56	17		0.0050-0.0469	0.0050	0.0050	0.0186	0.0459	30.36
2025	27	6		0.0050-0.0304	0.0050	0.0050	0.0050	0.0297	22.22
Total	137	29		0.0050-0.0624	0.0050	0.0050	0.0111	0.0445	21.17

Note: Values below the reporting limit (< 0.01 mg/L) were set to 0.0050 mg/L for analysis. Kruskal–Wallis H test: H = 4.982, P = 0.083; Pearson χ^2 for rates: χ^2 = 6.125, P = 0.047; linear trend: χ^2 = 2.568, P = 0.109.

Table 4: Univariate logistic regression analysis of factors associated with arsenic exceedance

Variable		*β*	*SE*	*Wald* χ^2	*P*	*OR*	95%*CI*
Year		—	—	5.741	0.057	—	—
	2024	1.249	0.522	5.737	0.017	3.487	1.255-9.691
	2025	0.827	0.634	1.701	0.192	2.286	0.660-7.917
Hydrological period		—	—	2.022	0.155	—	—
	Wet	0.600	0.422	2.022	0.155	1.821	0.797-4.162
Water supply type		—	—	10.916	0.004	—	—
	Rural centralized	2.176	1.058	4.232	0.040	8.815	1.108-70.110
	Decentralized	3.170	1.073	8.730	0.003	23.800	2.907-194.860

3.4 Annual Variation of Arsenic

Arsenic concentration ranges were 0.0050–0.0624 mg/L (2023), 0.0050–0.0469 mg/L (2024), and 0.0050–0.0304 mg/L (2025). The 25th percentile and median were 0.0050 mg/L for all years; 75th percentiles were 0.0050, 0.0186, and 0.0050 mg/L, respectively; 95th percentiles were 0.0445, 0.0459, and 0.0297 mg/L. The Kruskal–Wallis test showed no significant difference in concentration distributions across years (H = 4.982, P = 0.083). Exceedance rates were 11.11%, 30.36%, and 22.22% for 2023, 2024, and 2025, respectively (overall 21.17%). The chi-square test showed significant differences in exceedance rates (χ^2 = 6.125, P = 0.047), but the linear trend was not significant (χ^2 = 2.568, P = 0.109) (Table 3).

3.5 Univariate logistic regression for arsenic exceedance Logistic

Univariate analysis showed that water supply type was significantly associated with arsenic exceedance (P = 0.004). Compared to urban centralized supply, rural centralized supply (OR = 8.815, 95% CI: 1.108–70.110) and decentralized supply (OR = 23.800, 95% CI: 2.907–194.860) had higher risks. Year as a whole was borderline (P = 0.057), but 2024 showed significantly higher risk than 2023 (OR = 3.487, 95% CI: 1.255–9.691, P = 0.017); 2025 was not significant (P = 0.192). Hydrological period was not significantly associated (P = 0.155) (Table 4).

3.6 Multivariable Logistic Regression and Sensitivity Analysis

Multivariable logistic regression showed that both water supply type and year remained significantly associated with arsenic exceedance, while hydrological period did not. In the main analysis, water supply type was significant overall (P = 0.010), with OR of 8.847 (95% CI: 1.085–72.145) for rural centralized and 23.599 (95% CI: 2.751–202.428) for decentralized supply. Year was also significant (P = 0.045), with OR of 3.739 (95% CI: 1.236–11.310) for 2024 and 4.943 (95% CI: 1.029–23.757) for 2025. Since 2025 included only dry-season samples, a sensitivity analysis excluding 2025 was performed. Results remained consistent: water supply type was significant (P = 0.014), with decentralized supply showing OR = 17.586 (95% CI: 2.071–149.342); rural centralized was no longer significant (P = 0.094); hydrological period remained non-significant; year remained significant (OR = 3.718, 95% CI: 1.231–11.230, P = 0.020) (Table 5).

Table 5: Multivariable logistic regression and sensitivity analysis for arsenic exceedance

Variable		Main analysis OR (95% CI)	*P*	Sensitivity analysis OR (95% CI)	*P*
Water supply type		—	0.010	—	0.014
	Rural centralized	8.847(1.085-72.145)	0.042	6.330(0.728-55.037)	0.094
	Decentralized	23.599(2.751-202.428)	0.004	17.586(2.071-149.342)	0.009
Hydrological period	wet	1.798(0.605-5.346)	0.291	1.786(0.603-5.294)	0.295
Year		—	0.045	—	0.020
	2024	3.739(1.236-11.310)	0.020	3.718(1.231-11.230)	0.020
	2025	4.943(1.029-23.757)	0.046	—	—

Note: Sensitivity analysis excluded 2025 samples. Reference groups: urban centralized supply, dry season, 2023.

3.7 Health Risk Assessment

3.7.1 General population health risks

Using the three-year average arsenic concentration (0.0067 mg/L) for the general exposure scenario and the maximum concentration (0.0624 mg/L) for the high-exposure scenario, health risks were estimated. Under general exposure, HQ values for adult males, adult females, and children (6–17 years) were 0.61, 0.67, and 0.77, respectively, all below 1; for children (0–5 years), HQ = 1.24, indicating non-carcinogenic risk. Under high exposure, HQ values for all groups exceeded 1 (5.71, 6.24, 11.59, and 7.15, respectively). Carcinogenic risks under general exposure ranged from 2.76×10^{-4} to 5.59×10^{-4}, and under high exposure from 2.57×10^{-3} to 5.21×10^{-3}, all exceeding 10^{-4}, with the highest risk in children (0–5 years) (Table 6).

3.7.2 Temporal trends in health risks

Under the general exposure scenario, both HQ and CR showed an initial increase followed by a decrease, peaking in 2024 and declining in 2025. Under high exposure, both HQ and CR showed a decreasing trend over time. Across all scenarios, children (0–5 years) had the highest risk, followed by children (6–17 years), adult females, and adult males. Under the general scenario, only children had HQ > 1 in 2023 and 2025, while all groups exceeded 1 in 2024; under high exposure, all groups exceeded 1 in all years. CR values for all groups exceeded 10^{-4} in both scenarios (Figure 2).

Table 6: Health risk assessment results for different population groups

Population	General exposure			High exposure		
	ADD ($mg\cdot kg^{-1}\cdot d^{-1}$)	HQ	CR	ADD ($mg\cdot kg^{-1}\cdot d^{-1}$)	HQ	CR
Adult male	1.84×10^{-4}	0.61	2.76×10^{-4}	1.71×10^{-3}	5.71	2.57×10^{-3}
Adult female	2.01×10^{-4}	0.67	3.02×10^{-4}	1.87×10^{-3}	6.24	2.81×10^{-3}
Children (0–5 years)	3.73×10^{-4}	1.24	5.59×10^{-4}	3.48×10^{-3}	11.59	5.21×10^{-3}
Children (6–17 years)	2.31×10^{-4}	0.77	3.46×10^{-4}	2.14×10^{-3}	7.15	3.22×10^{-3}

Note: ADD: average daily dose; HQ: hazard quotient; CR: carcinogenic risk.

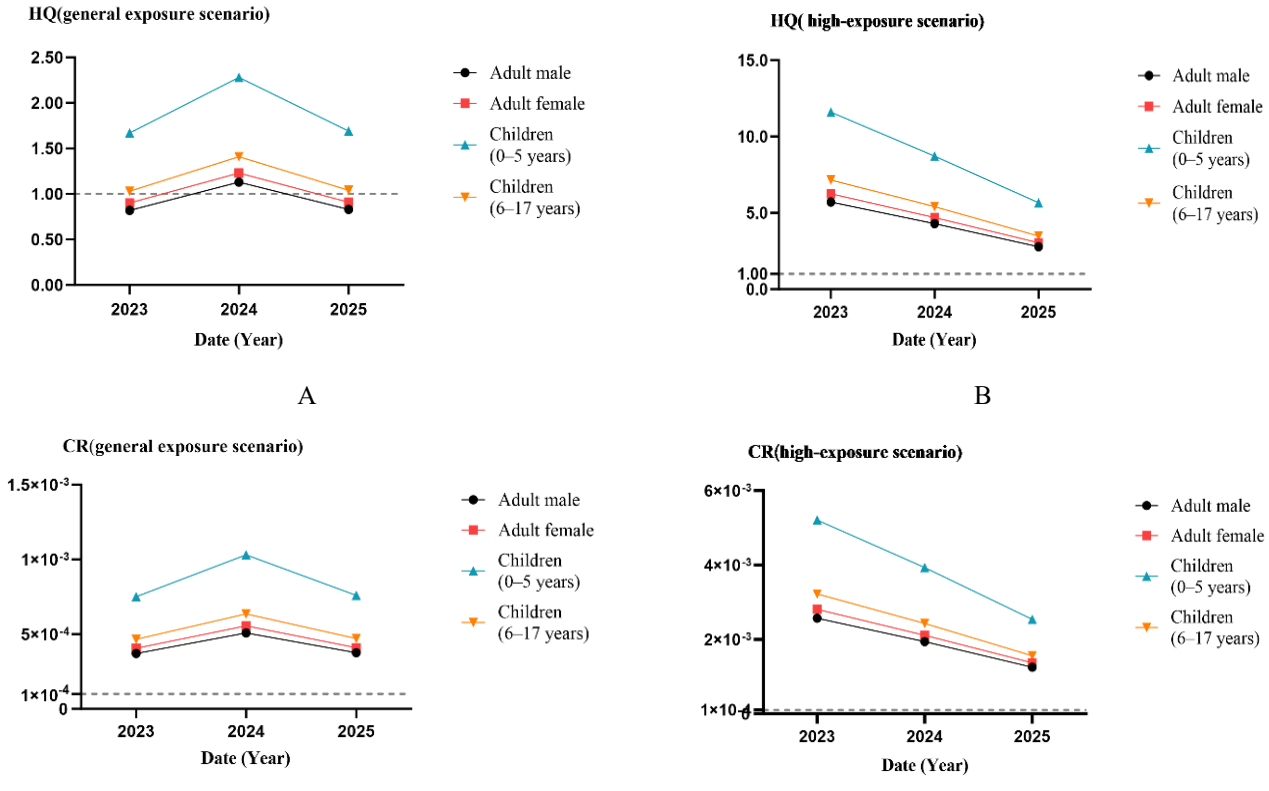


Figure 2: Temporal trends in HQ and CR for different populations under general and high-exposure scenarios, 2023–2025

Note: A, HQ under the general exposure scenario; B, HQ under the high-exposure scenario; C, CR under the general exposure scenario; D, CR under the high-exposure scenario.

4. Discussion

This study provides a comprehensive analysis of drinking water quality, major risk indicators, factors influencing arsenic exceedance, and associated health risks in a region of Shaanxi Province from 2023 to 2025. The overall compliance rate of 77.37% indicates that drinking water quality is generally acceptable but still poses safety concerns. Arsenic, total bacterial count, and manganese were the main non-compliant parameters, with arsenic being the predominant risk indicator (21.17% exceedance rate). This finding is consistent with national-level probabilistic exposure assessments suggesting that arsenic remains a potential health concern in China [10-11].

Annual fluctuations in compliance were observed, with 2024 showing relatively lower compliance, though the differences were not statistically significant. Hydrological period did not show a significant association, but water supply type and sample type did, indicating that water safety is more closely linked to system type, operation, maintenance, and source conditions than to seasonal variation alone. This aligns with studies from other rural regions in China, where decentralized and rural supplies are often the weakest links.

Arsenic is a key toxicological parameter in drinking water; chronic ingestion can affect the skin, nervous system, cardiovascular system, liver, kidneys, and endocrine system, and is associated with multiple chronic diseases and increased cancer risk [12]. Regional differences in arsenic contamination are well documented and are linked to geological background, groundwater conditions, hydrogeochemical environment, and anthropogenic activities [13]. Shaanxi Province's complex terrain and varied recharge conditions may influence arsenic release and transport [14]. Hu et al. [14] also reported potential health risks from metals and metalloids in rural drinking water in a Shaanxi city. Thus, arsenic exceedance in this study is likely related to local hydrogeological factors and inadequate treatment in some supply systems.

Although no significant difference was found in arsenic concentration distributions across years, exceedance rates varied significantly, with no linear trend. This suggests episodic rather than monotonic changes. The 25th percentile and median were consistently 0.0050 mg/L, indicating that most samples had low concentrations; however, elevated 75th and 95th percentiles in some years suggest that a few high-value samples contributed substantially to exceedance rates. This implies that the contamination risk is not widespread but concentrated in specific high-risk sites. For public health management, focusing solely on mean or median values may underestimate risks from tail-end high values; exceedance sites, repeated exceedances, and near-limit values are more informative for risk prioritization [10]. Long-term low-dose and localized high exposures both warrant attention [16].

Logistic regression analyses consistently showed that water supply type and year were associated with arsenic exceedance. Rural centralized and especially decentralized supplies had significantly higher risks compared to urban centralized systems. This disparity may reflect differences in source protection, treatment capacity, operational maintenance, and monitoring frequency. Urban systems typically have comprehensive management protocols, while rural systems often have simplified treatment and infrequent monitoring, and decentralized supplies rely on private wells or small facilities lacking arsenic removal [17]. These findings highlight the inequity in water safety across supply models.

Year remained associated with arsenic exceedance in multivariable analysis, and the sensitivity analysis supported the robustness of this finding. However, year is not a direct causal factor; its effect likely reflects periodic fluctuations rather than a long-term trend, so interpretation should be cautious. Hydrological period was not significantly associated with arsenic exceedance, but given the limited 2025 data (only dry season) and uneven distribution, further balanced monitoring is needed to clarify seasonal effects.

Health risk assessment showed that under general exposure, only children (0–5 years) had HQ > 1, while under high exposure, all groups exceeded 1, indicating potential non-carcinogenic risks from long-term high-arsenic water consumption. Carcinogenic risks for all groups exceeded 10^{-4}, suggesting potential carcinogenic hazards. Children showed higher risks than adults, likely due to higher water intake per body weight and greater susceptibility during development [18-19]. Previous studies have also shown that even low-level arsenic exposure over long periods can accumulate health risks [20-21]. Therefore, compliance with water quality standards should not replace health risk assessment. Targeted interventions—such as source substitution, arsenic removal, and health education—are needed, particularly for high-risk sites and vulnerable groups.

This study has several limitations. The sample size is relatively small, and the 2025 data include only dry-season samples, which may affect interannual comparisons. The health risk assessment used a deterministic model with exposure parameters from national handbooks, which may not fully reflect local consumption patterns; actual risks could be overestimated or underestimated. Future studies should incorporate larger sample sizes, locally calibrated exposure parameters, and probabilistic risk assessment methods to improve accuracy and generalizability.

The overall compliance rate of drinking water in this region from 2023 to 2025 is suboptimal, with arsenic being the primary risk indicator. Rural centralized and decentralized water supplies are key risk scenarios, and children—especially those aged 0–5 years—are the priority protection group. We recommend establishing a risk-oriented drinking water safety management system focusing on arsenic, with enhanced monitoring, source tracing, engineering treatment, and health risk communication. Public education on drinking water safety should also be strengthened to reduce anthropogenic contamination and protect public health [23].

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