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Monitoring and Health Risk Assessment of disinfection byproducts in Drinking Water in Chengdu, China, 2023-2025

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Abstract:

Objective To characterize the occurrence levels and distribution of disinfection byproducts in drinking water of Chengdu in China, evaluate health risks to the adult population via oral, dermal, and inhalation exposure routes, and identify key health risk drivers.

Methods From 2023 to 2025, water samples were collected from 118 centralized water supply units across 23 districts to detect trihalomethanes and haloacetic acid disinfection byproducts, analyze differences in detection and concentration levels across water periods, regions, and water supply scales, and applied the US EPA health risk assessment model to assess exposure risks of trichloromethane, bromodichloromethane, dibromochloromethane, tribromomethane, dichloroacetic acid, and trichloroacetic acid through oral and dermal routes.

Results All 4464 samples had disinfection byproduct concentrations met national standards, with 100.0% pass rate.Trichloromethane had the highest detection rate (86.0%) and median concentration (9.00 μ g/L). Concentrations of trichloromethane, bromodichloromethane, dichloroacetic acid, and trichloroacetic acid were higher in the wet season than in the dry season. Trichloromethane and bromodichloromethane concentrations were higher in urban versus rural samples, whereas dibromochloromethane and dichloroacetic acid were higher in rural areas. Detection rates and concentrations in large centralized water supply units exceeded those in small units ($P < 0.05$). The health risk assessment showed that the cumulative non-carcinogenic risk (HI < 1) was within acceptable limits, and the cumulative carcinogenic risk (TCR = 4.15×10^{-5}) fell within the commonly used regulatory benchmark range but warrants continued attention. Trichloromethane contributed the largest share (26.5%).

Conclusion Disinfection byproduct concentrations in Chengdu's drinking water comply with national standards, and the associated non-carcinogenic health risks are low. The cumulative carcinogenic risk is within the commonly accepted benchmark range but is sufficiently elevated to justify continued surveillance and source-control measures, with trichloromethane and trichloroacetic acid as priority compounds.

Key words: Drinking water; disinfection byproducts; Health risk assessment

Word count: 3191 words, excluding references

Introduction

Ensuring the safety of drinking water is crucial for protecting public health and maintaining social stability. Chlorine disinfection, the predominant method for water treatment, effectively eliminates harmful microorganisms and lowers the incidence of waterborne diseases [17]. However, the reaction between chlorine and natural organic matter produces disinfection byproducts (DBPs) with potential carcinogenic, teratogenic, and mutagenic properties, notably trihalomethanes (THMs) and haloacetic acids (HAAs) [2]. Long-term exposure to DBPs has been linked to diseases such as bladder and colorectal cancer [3][5]. Balancing microbial control and chemical risks poses a persistent challenge to global drinking-water safety. Although numerous studies have been conducted on DBPs in drinking water across various regions, most have focused on pollution levels or risk assessments of single exposure pathways. Future research should integrate extensive monitoring data, elucidate multidimensional distribution patterns, employ probabilistic models to assess risk uncertainties, and accurately identify priority pollutants and high-risk zones.

Chengdu, a major megacity and central city in western China, plays a vital role in ensuring drinking water safety, with significant public health implications. This study was conducted between 2023 and 2025, and 4,464 samples were collected, including finished water, tap water, and secondary water supply, during both dry and wet seasons. The samples were analyzed for six disinfection byproducts: trichloromethane (TCM), bromodichloromethane (BDCM), dibromochloromethane (DBCM), tribromomethane (TBM), dichloroacetic acid (DCAA), and trichloroacetic acid (TCAA). The main objectives were to characterize the pollution levels and spatiotemporal distribution patterns of these disinfection byproducts in Chengdu's drinking water, evaluate the health risks posed to adults through oral, dermal, and inhalation exposure routes, quantify associated uncertainties, pinpoint the primary health risk factors, and establish a scientific foundation for the enhanced management of drinking water safety in Chengdu.

1 Methods

1.1 Research Object

Monitoring points were established in 23 districts of Chengdu, considering factors such as the scale of water supply units, population served, and the water supply environment. Five rounds of water quality monitoring were conducted during the wet season in 2023 and the dry and wet seasons from 2024 to 2025, with a total of 4464 samples collected. The monitoring encompassed 20 municipal centralized water supply units, 4 urban self-built facility water supply units, 41 large rural centralized water supply units (with a daily capacity exceeding 1,000 tons or serving over 10,000 people), 40 small rural centralized water supply units, and 13 rural school self-built facility water supply units in the city. At least one finished water sample was collected from each water supply unit during every monitoring round, the number of terminal water monitoring points was determined based on the coverage area of the water supply, ensuring that terminal water covered every street and township. In regions with secondary water supply, secondary water supply samples were collected concurrently. The sample comprised 389 factory water samples, 3274 terminal water samples, and 801 secondary water supply samples. Detailed sample distribution for each year, water period, and district is provided in the supplementary materials.

1.2 Sample collection, testing and Evaluation

Water samples were collected, preserved, and transported according to the guidelines outlined in the "*Standard Test Methods for Drinking Water - Part 2: Collection and Preservation of Water Samples*" (GB/T5750.2-2023). The analysis of six disinfection byproducts, trichloromethane , bromodichloromethane , dibromochloromethane , tribromomethane , dichloroacetic acid , and trichloroacetic acid, was conducted in adherence to the national standard method "*Standard examination methods for drinking Water - Part 10: disinfection byproducts indices*" (GB/T 5750.10-2023). Subsequently, the test outcomes were assessed following the regulations stipulated in the "Standards for Drinking Water Quality (GB 5749-2022).

1.3 Quality Control

Qualified and authorized technicians performed sample collection, preservation, and transportation. For each batch of samples, a set of transportation blanks and on-site parallel samples was established. All laboratories engaged in water sample testing either had either metrological certification or national laboratory accreditation. During the analysis, samples with questionable test results or those near the standard limit were retested to ensure the accuracy of the experimental results.

1.4 Health Risk Assessment

In accordance with the "Technical guide for environmental health risk assessment of chemical exposure" (WS/T 777-2021), the health risks associated with exposure to trichloromethane , bromodichloromethane , dibromochloromethane , tribromomethane , dichloroacetic acid , and trichloroacetic acid via oral , dermal and inhalation routes were assessed using the health risk assessment model recommended by the United States Environmental Protection Agency (US EPA).Showering is the primary route of dermal contact and inhalation exposure to disinfection byproducts in drinking water **Error! Reference source not found.**; therefore, this study focused on exposure risks associated with showering.

1.4.1 Daily exposure levels (Average daily intake, ADD)

$$ADD_{oral} = (C_{water} \times IR \times EF \times ED) / (BW \times AT) \quad (1)$$

$$ADD_{dermal} = (C_{water} \times CF \times SA \times PC \times EF \times ED \times ET) / (BW \times AT) \quad (2)$$

$$ADD_{inhalation} = (C_{air} \times VR \times EF \times ED \times ET) / (BW \times AT) \quad (3)$$

where ADD is the average daily exposure in mg/(kg·d). For oral exposure, C_{water} is the concentration of a specific byproduct in water (mg/L), and IR is the intake rate (L/d). For dermal exposure, CF is the conversion factor (1×10^{-3} L/cm^3), SA is the skin contact area (cm^2), PC is the dermal permeability coefficient (cm/h), and ET is the exposure time (h/d). For inhalation exposure, VR is the inhalation rate (L/min) and C_{air} is the concentration of the byproduct in bathroom air (mg/m^3). C_{air} was calculated using the Little model [7], which accounts for the water concentration, temperature-corrected Henry's law constant, shower duration, water flow rate, bathroom volume, and air exchange rate. EF is the exposure frequency (d/year), ED is the exposure duration (years), BW is body weight (kg), and AT is the average time (days). The corresponding parameter values are presented in Table 1.

Referring to the recommended data for the Sichuan region in the "*Manual of Exposure Parameters for the Chinese Population*" [8], IR was taken as 2.236L/d, BW was 59.3 kg, SA was 16,000 cm^2[6], and ET was 0.1h/d. When assessing the carcinogenic effect, the ED was set to 70 years and AT was the number of days corresponding to 70 years. When assessing non-carcinogenic effects, ED was set to 30 years, and AT was the number of days corresponding to 30 years.

1.4.2 Non-carcinogenic risk assessment

Non-carcinogenic risk was characterized using the hazard quotient (HQ), calculated as follows:

$$HQ_{oral}=ADD_{oral}/RfD \quad (4)$$

$$HQ_{dermal}=ADD_{dermal}/RfD \quad (5)$$

$$HQ_{inhalation}=ADD_{inhalation}/RfD \quad (6)$$

$$HQ=HQ_{oral}+HQ_{dermal}+HQ_{inhalation} \quad (7)$$

$$HI=\sum HQ \quad (8)$$

Where RfD is the reference dose [mg/ (kg·d)]. Reference dose values for each disinfection byproduct are listed in Table 1.

1.4.3 Carcinogenic Risk assessment

The formula for calculating the carcinogenic risk (CR) is as follows:

$$CR_{oral} = ADD_{oral} \times SF_{oral} \quad (9)$$

$$CR_{dermal} = ADD_{dermal} \times SF_{dermal} \quad (10)$$

$$CR_{inhalation} = ADD_{inhalation} \times SF_{inhalation} \quad (11)$$

$$CR = CR_{oral} + CR_{dermal} + CR_{inhalation} \quad (12)$$

$$TCR = \sum CR \quad (13)$$

Where SF represents the slope factor (kg·d) /mg, and its values are listed in Table 1.

1.4.4 Risk Assessment

According to the "Technical Guide for Environmental Health Risk Assessment of Chemical Exposure" (WS/T 777-2021)[12], for non-carcinogenic risks, an HQ ≤ 1 suggests that the exposure level remains below the adverse reaction threshold, indicating a relatively low non-carcinogenic risk. Conversely, HQ > 1 suggests that the exposure level surpasses the threshold, signifying a relatively high non-carcinogenic risk that requires serious consideration. Regarding cancer risk, a CR below 1.0×10^{-6} signifies a relatively low cancer risk, whereas a CR between 1.0×10^{-6} and 1.0×10^{-4} indicates a certain level of carcinogenic risk that should be noted. A CR > 1.0×10^{-4} suggests a relatively high cancer risk that demands special attention.

1.4.5 Probability Risk Assessment

To address the uncertainty of the point estimation, a Monte Carlo simulation was performed for probabilistic risk assessment using R version 4.1.0 with the fitdistrplus package (v1.1-8) for distribution fitting. First, the risk value for each sample was calculated. After obtaining the risk value vector for each DBP, distribution fitting was performed. Four candidate distributions (Uniform, Normal, Lognormal, and Gamma) were fitted to the empirical risk values of each DBP. The optimal distribution was selected based on the lowest Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Only the concentration of each disinfection byproduct was treated as a random variable; all other exposure parameters were treated as fixed values. The final distribution choices are presented in Supplementary Table S2.

Using the optimal distribution model, 10000 random samples were generated for each DBP. The same procedure was applied to the cumulative risks (HI and TCR). Percentile values for the fitted risk distributions are presented in supplementary Table S3 (non-carcinogenic) and Table S4 (carcinogenic).

1.5 Statistical Analysis

Data organization was performed using Excel 2010, and statistical analysis and plotting were performed using R4.1.0. Values below the detection limit were imputed as half the limit of detection (LOD). To account for the repeated measurements from the same water supply units across different seasons and years, linear mixed-effects models (LMMs) were fitted for each of the six disinfection by-products using the lme4 package (v1.1-31). The log-transformed concentration (ln[concentration + 0.001]) was set as the dependent variable. Fixed effects included: water period (dry vs. wet season), sampling type (urban vs. rural), water supply scale (large vs. small),source type (surface water vs. groundwater), disinfection method (sodium hypochlorite, liquid chlorine, high-purity chlorine dioxide, etc.). A random intercept was included for each water supply unit to account for the non-independence of repeated measurements. Model parameters were estimated using restricted maximum likelihood (REML). Statistical significance was set at $\alpha = 0.05$.

2 Results

2.1 Overall monitoring of disinfection byproducts

In total, 4,464 water samples were collected for this study, comprising 2,077 urban and 2,387 rural samples. These samples represent a population of 19.14 million, which constitutes 90.4% (1,941.0/2,147.4) of Chengdu's permanent resident population [13]. The concentrations of the six disinfection byproducts were below the standard limits, resulting in a pass rate of 100.0 %. As shown in Table 2, TCM had the highest detection rate, followed by DBCM. Among the detected compounds, TCM exhibited the highest median concentration.

2.2 Factors influencing DBP concentrations

To evaluate the independent effects of water period, water source type, water supply scale and sampling type (urban/rural) on DBP concentrations while accounting for repeated measurements, linear mixed-effects models were fitted for each DBP. The results are summarized in Table 3 and detailed in Supplementary Table S5.

Water period had a significant influence on all DBPs ($P < 0.05$). Compared with the wet season, the dry season was associated with lower concentrations of TCM (coefficient = -0.69, $P < 0.001$), DCAA (-0.18, $P < 0.001$), and TCAA (-0.33, $P < 0.001$), but with higher concentrations of BDCM (0.36, $P < 0.001$), DBCM (0.13, $P = 0.013$), and TBM (0.31, $P < 0.001$) .

Water source type (surface water vs. groundwater) showed a strong positive association with concentrations of TCM (1.43, $P < 0.001$), BDCM (0.53, $P < 0.001$), DBCM (1.15, $P < 0.001$), and DCAA (0.30, $P < 0.001$). For TCAA, the association was not statistically significant ($P = 0.106$).

Water supply scale (large vs. small) significantly affected all DBPs except TBM. Small-scale units had consistently lower concentrations, with the largest effects observed for TCM (-0.83, $P < 0.001$), DBCM (-0.66, $P < 0.001$), and BDCM (-0.51, $P < 0.001$).

2.3 Health Risk Assessment

Figure 1 illustrates the distribution of health risks associated with oral ingestion and dermal absorption of disinfection byproducts by Chengdu residents from 2023 to 2025. Both non-carcinogenic and carcinogenic risk estimates exhibited right-skewed distributions. The median hazard quotients (HQ) for TCM and DCAA, key contributors to non-carcinogenic risk, were 3.58×10^{-2} and 2.45×10^{-2}, respectively. Other substances showed lower hazard quotients, indicating an overall low risk. Regarding carcinogenic risk, DBCM and TBM had risks below 1.0×10^{-6}, whereas risks for the other four disinfection byproducts fell between 1.0×10^{-6} and 1.0×10^{-4}. Although these values lie within the commonly used regulatory benchmark range, they warrant continued attention. Notably, TCM contributed 26.5% to the cumulative carcinogenic risk (TCR = 4.15×10^{-5}), followed by TCAA (19.9%) and BDCM (12.0%).

Owing to the uncertainty associated with point evaluation, a Monte Carlo simulation was used for probabilistic risk assessment. Probability statistics indicate that the hazard factor (HQ) of four disinfection byproducts is below the safety threshold [Pr ($HQ \leq 1$)]. The median cumulative non-carcinogenic risk (HI) for the six disinfection byproducts was 0.092, with no instances where the HI exceeded 1. The likelihood of the non-carcinogenic risk exceeding the standard was exceptionally low, indicating that the overall risk was manageable.

In terms of carcinogenic risk, the probability of $CR < 1.0\times10^{-4}$ for the six disinfection byproducts exceeded 95%. The median cumulative carcinogenic risk of these six disinfection byproducts was 4.15×10^{-5}, as shown in Figure 2.

2.4 Spatial Distribution of Health Risks

This study assessed the non-carcinogenic and carcinogenic risks associated with disinfection byproducts in drinking water across 23 districts to identify key areas for risk management and generate regional distribution heat maps. The findings indicate that both the non-carcinogenic hazard quotient and the cumulative hazard quotient for various disinfection byproducts in each district (city) and county were < 1. According to US EPA standards, this level of risk is deemed acceptable; however, there is notable spatial heterogeneity in the risk values (Figure 3). Cumulative risk was relatively elevated in Chenghua and Wuhou districts, whereas it was comparatively low in Tianfu, Pujiang, and Dayi. Regarding carcinogenic risk (Figure 4), the cumulative carcinogenic risk was notably high in Chongzhou, Chenghua and Wuhou, whereas it remained relatively low in Tianfu, Pujiang, and other locations. The figure shows that trichloromethane, dichloroacetic acid, and trichloroacetic acid were the primary pollutants contributing to both carcinogenic and non-carcinogenic risks.

3 Discussion

This study systematically assessed the pollution levels, distribution characteristics, and health risks associated with six common disinfection byproducts in the drinking water of Chengdu from 2023 to 2025. The results indicated that the concentrations of disinfection byproducts in all monitored samples complied with the limit requirements outlined in the "Standards for drinking water quality" (GB 5749-2022), achieving a pass rate of 100%. Nevertheless, within the acceptable limit range, significant differences were observed in the detection rates, concentration distributions, and estimated health risks among the different DBPs.

TCM exhibited the highest detection rate (86.0%) among all disinfection byproducts, with the highest median concentration. This finding is consistent with the research outcomes in Beijing [14], Jiangsu [15], and other regions, possibly because of its relatively elevated formation potential and inherent stability in water. A recent systematic review and meta-analysis**Error! Reference source not found.** reported that global THM concentrations in drinking water vary widely, with many regions exceeding the WHO guideline value of 100 μg/L. The total concentration of THMs in Chengdu ranged between 0 and 70μg/L which falls at the lower end of this global range and is substantially lower than values reported for many developing countries, such as India (274–511 μg/L)**Error! Reference source not found.** and Pakistan (21–373 μg/L)**Error! Reference source not found.**.

Water period significantly influenced all six DBPs. Compared with the dry season, the wet season was associated with higher concentrations of TCM, DCAA, and TCAA, but with lower concentrations of BDCM, DBCM, and TBM. This seasonal pattern can be partly explained by increased precipitation during the wet season, which elevates natural organic matter (NOM) content in source water [19], and by higher water temperatures that accelerate halogenation reactions and DBP formation [20]. The opposite trend for brominated DBPs may reflect seasonal variations in bromide concentration in source water, a factor not measured in this study. Surface water sources were associated with substantially higher levels of these DBPs compared with groundwater sources. This finding is consistent with the generally higher natural organic matter (NOM) content in surface waters, which serve as precursors for DBP formation**Error! Reference source not found.**. Groundwater, being less rich in organic matter, tends to yield lower DBP concentrations under similar disinfection conditions. Water supply scale was also a significant predictor. Small-scale water supply units had consistently lower DBP concentrations than large-scale units for all DBPs except TBM. Large-scale centralized systems in Chengdu primarily serve urban and suburban areas and typically use surface water conveyed through longer distribution networks, whereas small-scale units in rural areas more often rely on groundwater with simpler piping systems. Longer hydraulic retention times and more complex pipe networks in large-scale systems allow more time for DBP formation and accumulation [22]-[24].

This study employed the health risk assessment model recommended by the US EPA to comprehensively evaluate both non-carcinogenic and carcinogenic risks associated via oral, dermal, and inhalation exposure routes. Point estimates showed that the non-carcinogenic hazard quotient (HQ) for all individual DBPs was well below 1, and the cumulative hazard index (HI) was 0.092, indicating that non-carcinogenic risks are not a major concern under current exposure conditions. For carcinogenic risk, individual DBPs had CR values mostly in the range of 10^{-6} to 10^{-5}, while the cumulative carcinogenic risk (TCR) was 4.15×10^{-5}, which is comparable to assessment results from most other Chinese cities. In Jiangsu Province, the carcinogenic risk associated with oral exposure to disinfection byproducts ranges from 2.91×10^{-5} to 3.13×10^{-5} [22]. In Shanghai, the TCR derived from factory water research varies between 7.25×10^{-6} and

2.53×10^{-5} [25], in Chongqing, it is 4.31×10^{-5} [26]. A multi-route risk assessment in Hong Kong reported a TCR of 1.15×10^{-4} **Error! Reference source not found.**. This value is below the commonly used regulatory benchmark of 1×10^{-4} but above 10^{-6}, meaning it is not negligible. Analysis of risk contributions revealed that TCM and DCAA were the primary contributors to non-carcinogenic risk. Furthermore, TCM, TCAA, and BDCM collectively accounted for > 50% of the cumulative carcinogenic risk. Notably, TCM, the most prevalent disinfection byproduct, constitutes 26.5% of the cumulative carcinogenic risk and should be prioritized as a key pollutant for risk management [28][29].

To account for uncertainty in point estimation, Monte Carlo simulation was performed. The results of the probability risk assessment indicated that the overall health risk associated with drinking water disinfection byproducts in Chengdu remains within the commonly used regulatory benchmark range, but continued surveillance is advisable. Percentile estimates (P5, P50, P95) derived from the fitted distributions confirmed that even at the 95th percentile, non-carcinogenic risks remained below 1, while the 95th percentile of TCR was 1.45×10^{-4}(in Table S4), slightly above 1×10^{-4}. This “tail risk” warrants continued attention, particularly for TCM and TCAA, which were the main contributors to overall risk uncertainty. Consequently, in accordance with the precautionary principle, prioritizing the control of key Byproducts such as TCM and TCAA remains essential; stakeholders should not be satisfied with merely achieving average standards of "compliance" or "acceptability."

Nevertheless, the spatial heterogeneity identified in our study (higher risks in Chenghua, Wuhou, and Chongzhou) indicates that risk management should be tailored to local conditions. Given the inherent complexity of large-scale centralized water supply systems, characterized by sophisticated treatment processes, numerous disinfection stages, and an extensive network of pipelines that collectively foster the continuous production and accumulation of disinfection byproducts [30][31]—these systems should be prioritized for intervention in high-risk areas. Consequently, a shift from a mere focus on regulatory compliance to a more nuanced approach to risk stratification control is recommended, with a particular emphasis on designating large, centralized water supply systems as pivotal targets. Specific interventions may include optimizing disinfection processes, reducing precursor levels through enhanced coagulation, or implementing point-of-use treatment in sensitive settings.

Several limitations should be acknowledged. First, individual variations exist in the drinking and water usage habits among residents. Some households or demographic groups choose to install water purifiers, purchase bottled water, or consume boiled water. Research has demonstrated that the concentration of disinfection byproducts in drinking water decreases following filtration by water purifiers [32]. Additionally, it is common for Chinese individuals to consume plain and boiled water. Wang et al. found that the median health risk associated with drinking plain boiled water is only one-fifth that associated with drinking tap water [33]. Consequently, this may have resulted in a discrepancy between the evaluation outcomes of this study and actual circumstances. Moreover, interactions between chemical substances within the human body are complex. Relying on simple additive accumulation is overly simplistic. Therefore, further investigation is necessary to assess the health risks associated with the combined effects of multiple disinfection byproducts.Third, although the mixed-effects models accounted for repeated measurements, they did not include all potentially relevant covariates (e.g., bromide concentration, water age, temperature variations within seasons). Therefore, the explanations for urban - rural and seasonal differences should be considered as plausible hypotheses rather than confirmed causal mechanisms. Future research incorporating direct measurements of NOM, bromide, chlorine residual, and hydraulic retention time would help clarify causality.

It is important to recognize that the six DBPs examined in this study represent only a fraction of the complex mixture of disinfection byproducts formed during chlorination. A substantial body of evidence suggests that regulated trihalomethanes and haloacetic acids may not be the primary drivers of the adverse health outcomes associated with chlorinated drinking water; instead, a large proportion of the observed toxicity is attributable to unidentified, non-volatile DBPs [34]. Integrative parameters such as adsorbable organic halogen (AOX) have recently been proposed as more comprehensive metrics for health risk assessments, as they capture the collective burden of halogenated organic compounds, including the unknown fraction [34]. Furthermore, recent research indicates that while trihalomethane concentrations may increase with water age in distribution systems, the overall cytotoxicity of the water can decrease, likely due to the transformation or decomposition of initially formed, more toxic DBPs into less potent species [35]. These considerations highlight the inherent limitations of relying solely on a small set of regulated DBPs to estimate health risks and underscore the need for future studies to incorporate broader DBP profiling and integrative toxicity indicators.

In summary, DBP concentrations in Chengdu’s drinking water comply with national standards, and the associated non-carcinogenic health risks are low. The cumulative carcinogenic risk (TCR $= 4.15\times10^{-5}$) is within the commonly accepted benchmark range but is sufficiently elevated to justify continued surveillance and source-control measures, with TCM, TCAA, and BDCM as priority compounds. Spatial heterogeneity and seasonal patterns suggest that targeted interventions in large-scale urban water supply systems and during wet seasons could be most effective.

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Author contributions statements

Su Lan wrote the main manuscript and prepared figures 1–4. Su Lan and Wei Huang completed the data analysis.All authors reviewed the manuscript.

Competing interests

The authors declare that they have no competing interests.

Data availability statement

The data used in this study were sourced from the "China Disease Prevention and Control Information System" database, a national public health surveillance system operated under the authority of the Chinese Center for Disease Control and Prevention. The dataset contains routine drinking water quality monitoring results collected as part of the legally mandated public health surveillance activities. All data were handled in accordance with the "Personal Information Protection Law of the People's Republic of China" and relevant data security regulations. Owing to legal restrictions governing public health surveillance data and to protect the security of critical public health infrastructure, the raw data cannot be publicly deposited. However, summarized data and analysis codes supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional review and compliance with data usage agreements.

Ethical Review

This study involved the collection and analysis of drinking water samples and did not involve experimental animals or direct interventions with human subjects. All data were obtained from the "China Disease Prevention and Control Information System" database, which collects routine drinking water monitoring data as mandated by national regulations. The data were anonymized prior to the analysis and did not include any personally identifiable information. According to Article 32 of the "Measures for the Ethical Review of Life Science and Medical Research Involving Human Subjects" (National Health Commission of the PRC, 2023), research using anonymized information data that causes no harm to human subjects and does not involve sensitive personal information is exempt from institutional review board approvals. Therefore, formal ethical approval was not required for this study.

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Tables

Table 1 Risk classification and toxicological parameters of disinfection byproducts

DBPs	SF_{oral}[(kg·d)/mg]	SF_{dermal}[(kg·d)/mg]	$SF_{inhalation}$[(kg·d)/mg]	PC(cm/h)	RfD[mg/(kg·d)]
TCM	0.031	0.031	8.05×10^{-5}	6.83×10^{-3}	0.01
DBCM	0.084	0.084	0.095	2.89×10^{-3}	0.02
BDCM	0.062	0.062	0.13	4.02×10^{-3}	0.02
TBM	0.0079	0.0079	0.00385	2.35×10^{-3}	0.02
DCAA	0.048	0.048	N/A	1.21×10^{-3}	0.004
TCAA	0.084	0.084	N/A	1.45×10^{-3}	0.02

Note: The reference values of relevant toxicological parameters are based on relevant data recommended and disclosed by the US EPA Integrated Risk Information System (IRIS) [9] and the International Agency for Research on Cancer (IARC) [10].$SF_{inhalation}$ were obtained from the study by Pardakhti et al**Error! Reference source not found.**. N/A = not available (negligible volatility).

Table 2 Detection of disinfection byproducts in drinking water in Chengdu from 2023 to 2025

DBPs	Standard Limit (μg/L)	Detection Rate (%)	Range (μg/L)	M (P_{25} , P_{75}) (μg/L)
TCM	60	86.0	ND~54.30	9.00 (2.84,18.90)
BDCM	100	51.4	ND~40.00	0.25 (0.01,0.71)
DBCM	60	79.0	ND~29.00	2.00 (0.46,3.98)
TBM	100	10.1	ND~20.00	0.02 (0.02,0.06)

DCAA	50	36.0	ND~50.00	2.50 (1.00,5.50)
TCAA	100	33.3	ND~100.00	2.50 (0.50,6.48)

Table 3 Linear mixed-effects model results for log-transformed disinfection byproducts concentrations

DBPs	Fixed effect	Coefficient	95% *CI*	*P*
TCM	Intercept	-1.369	-2.043, -0.695	<0.001
	Dry season	-0.694	-0.789, -0.598	<0.001
	Urban	-0.217	-0.340, -0.094	<0.001
	Small scale	-0.834	-1.049, -0.618	<0.001
	Surface water	1.428	1.179, 1.676	<0.001
BDCM	Intercept	-3.621	-4.259, -2.983	<0.001
	Dry season	0.357	0.250, 0.464	<0.001
	Urban	-0.115	-0.253, 0.023	0.102
	Small scale	-0.508	-0.750, -0.266	<0.001
	Surface water	0.530	0.252, 0.809	<0.001
DBCM	Intercept	-2.823	-3.465, -2.181	<0.001
	Dry season	0.132	0.028, 0.235	0.013
	Urban	-0.285	-0.418, -0.151	<0.001
	Small scale	-0.664	-0.899, -0.430	<0.001
	Surface water	1.146	0.876, 1.415	<0.001
TBM	Intercept	-3.487	-4.004, -2.970	<0.001
	Dry season	0.311	0.256, 0.367	<0.001
	Urban	-0.098	-0.170, -0.027	0.007
	Small scale	-0.082	-0.207, 0.044	0.202
	Surface water	0.134	-0.010, 0.279	0.068
DCAA	Intercept	1.120	0.756, 1.485	<0.001
	Dry season	-0.176	-0.232, -0.121	<0.001
	Urban	0.042	-0.029, 0.114	0.246
	Small scale	-0.056	-0.182, 0.069	0.378
	Surface water	0.300	0.155, 0.444	<0.001
TCAA	Intercept	1.291	0.873, 1.709	<0.001
	Dry season	-0.327	-0.388, -0.266	<0.001
	Urban	0.037	-0.042, 0.115	0.362
	Small scale	-0.171	-0.309, -0.033	0.015
	Surface water	-0.131	-0.290, 0.028	0.106

Note: The dependent variable is ln(concentration + 0.001) for each DBP. Fixed effects include water period (reference: wet season), sampling type (reference: rural), water supply scale (reference: large), water source type (reference: groundwater), and disinfection method (reference: all other methods combined). The full model results are provided in Supplementary Table S5.

Figures

1. Measured and fitted risk of disinfection byproducts

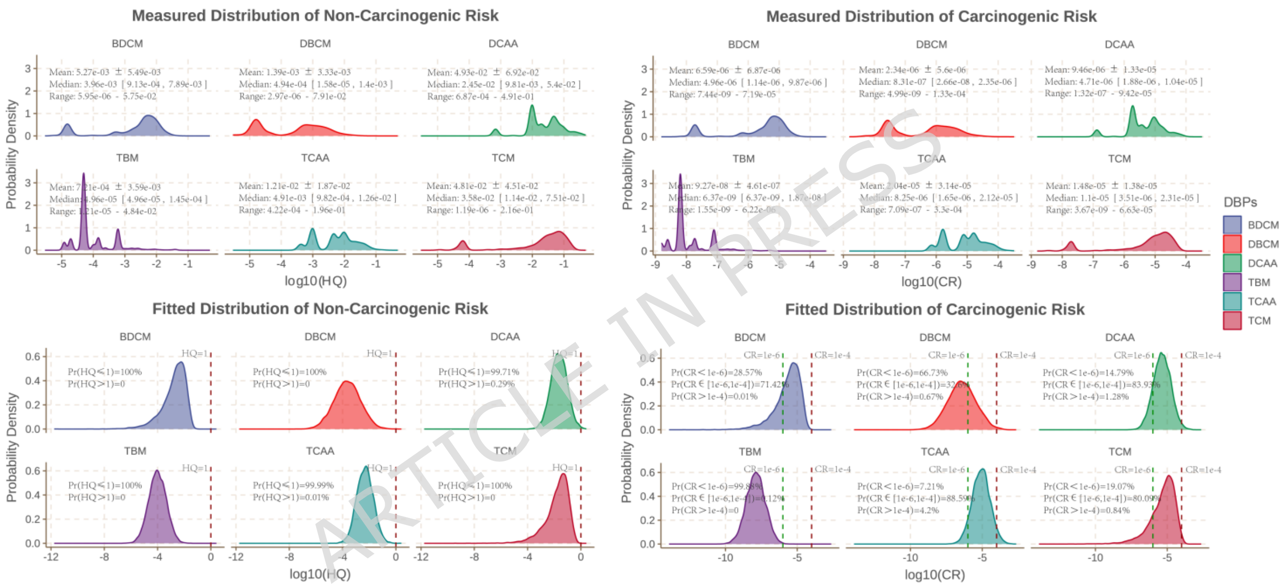


Figure 1. Non-carcinogenic and carcinogenic risks of disinfection byproducts in drinking water in Chengdu during 2023 - 2025

2. Cumulative risks of disinfection byproducts

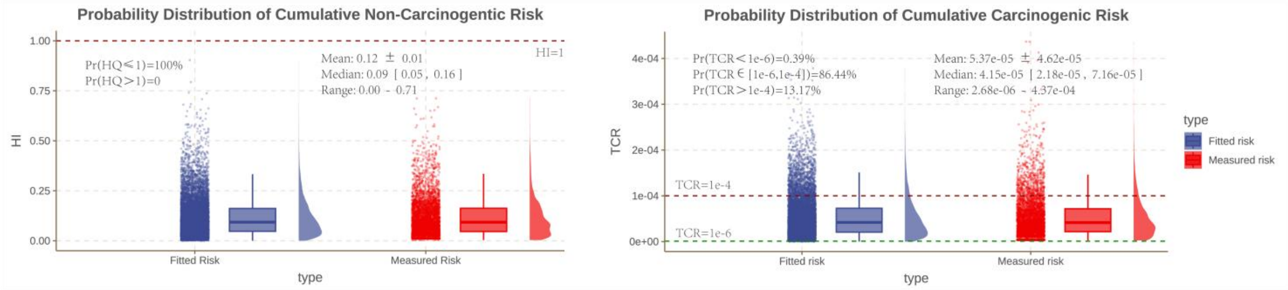
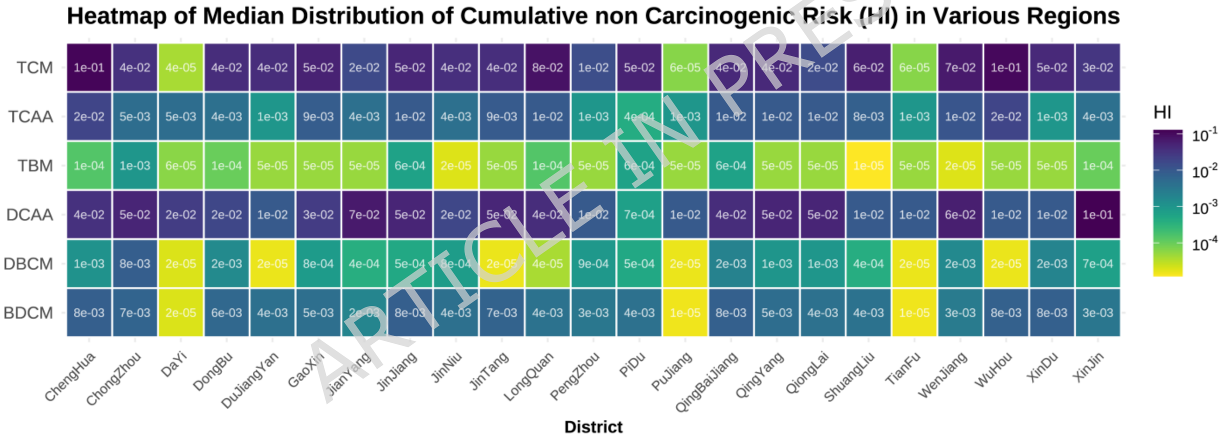


Figure 2. Cumulative non-carcinogenic and carcinogenic risks of disinfection byproducts in drinking water in Chengdu during 2023 - 2025

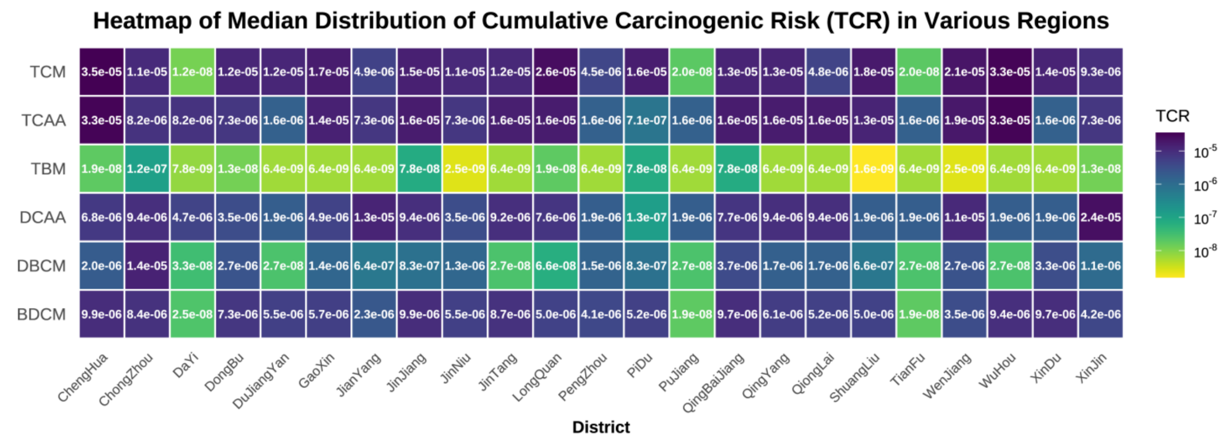
3. Non-carcinogenic risk of disinfection byproducts in various regions



	ChengHua	ChongZhou	DaYi	DongBu	DuJiangYan	GaoXin	JianYang	JinJiang	JinNiu	JinTang	LongQuan	PengZhou	PiDu	PuJiang	QingBaiJiang	QingYang	QiongLai	ShuangLiu	TianFu	WenJiang	WuHou	XinDu	XinJin
TCM	1e-01	4e-02	4e-05	4e-02	4e-02	5e-02	2e-02	5e-02	4e-02	4e-02	8e-02	1e-02	5e-02	6e-05	4e-02	4e-02	2e-02	6e-02	6e-05	7e-02	1e-01	5e-02	3e-02
TCAA	2e-02	5e-03	5e-03	4e-03	1e-03	9e-03	4e-03	1e-02	4e-03	9e-03	1e-02	1e-03	4e-04	1e-03	1e-02	1e-02	1e-02	8e-03	1e-03	1e-02	2e-02	1e-03	4e-03
TBM	1e-04	1e-03	6e-05	1e-04	5e-05	5e-05	5e-05	6e-04	2e-05	5e-05	1e-04	5e-05	6e-04	5e-05	6e-04	5e-05	5e-05	1e-05	5e-05	2e-05	5e-05	5e-05	1e-04
DCAA	4e-02	5e-02	2e-02	2e-02	1e-02	3e-02	7e-02	5e-02	2e-02	5e-02	4e-02	1e-02	7e-04	1e-02	4e-02	5e-02	5e-02	1e-02	1e-02	6e-02	1e-02	1e-02	1e-01
DBCM	1e-03	8e-03	2e-05	2e-03	2e-05	8e-04	4e-04	5e-04	8e-04	2e-05	4e-05	9e-04	5e-04	2e-05	2e-03	1e-03	1e-03	4e-04	2e-05	2e-03	2e-05	2e-03	7e-04
BDCM	8e-03	7e-03	2e-05	6e-03	4e-03	5e-03	2e-03	8e-03	4e-03	7e-03	4e-03	3e-03	4e-03	1e-05	8e-03	5e-03	4e-03	4e-03	1e-05	3e-03	8e-03	8e-03	3e-03

Figure 3. Non-carcinogenic risk of disinfection byproducts in drinking water in various regions of Chengdu during 2023 - 2025

4. Carcinogenic risk of disinfection byproducts in various regions



	ChengHua	ChongZhou	DaYi	DongBu	DuJiangYan	GaoXin	JianYang	JinJiang	JinNiu	JinTang	LongQuan	PengZhou	PiDu	PuJiang	QingBaiJiang	QingYang	QiongLai	ShuangLiu	TianFu	WenJiang	WuHou	XinDu	XinJin
TCM	3.5e-05	1.1e-05	1.2e-08	1.2e-05	1.2e-05	1.7e-05	4.9e-06	1.5e-05	1.1e-05	1.2e-05	2.6e-05	4.5e-06	1.6e-05	2.0e-08	1.3e-05	1.3e-05	4.8e-06	1.8e-05	2.0e-08	2.1e-05	3.3e-05	1.4e-05	9.3e-06
TCAA	3.3e-05	8.2e-06	8.2e-06	7.3e-06	1.6e-06	1.4e-05	7.3e-06	1.6e-05	7.3e-06	1.6e-05	1.6e-05	1.6e-06	7.1e-07	1.6e-06	1.6e-05	1.6e-05	1.6e-05	1.3e-05	1.6e-06	1.9e-05	3.3e-05	1.6e-06	7.3e-06
TBM	1.9e-08	1.2e-07	7.8e-09	1.3e-08	6.4e-09	6.4e-09	6.4e-09	7.8e-08	2.5e-09	6.4e-09	1.9e-08	6.4e-09	7.8e-08	6.4e-09	7.8e-08	6.4e-09	6.4e-09	1.6e-09	6.4e-09	2.5e-09	6.4e-09	6.4e-09	1.3e-08
DCAA	6.8e-06	9.4e-06	4.7e-06	3.5e-06	1.9e-06	4.9e-06	1.3e-05	9.4e-06	3.5e-06	9.2e-06	7.6e-06	1.9e-06	1.3e-07	1.9e-06	7.7e-06	9.4e-06	9.4e-06	1.9e-06	1.9e-06	1.1e-05	1.9e-06	1.9e-06	2.4e-05
DBCM	2.0e-06	1.4e-05	3.3e-08	2.7e-06	2.7e-08	1.4e-06	6.4e-07	8.3e-07	1.3e-06	2.7e-08	6.6e-08	1.5e-06	8.3e-07	2.7e-08	3.7e-06	1.7e-06	1.7e-06	6.6e-07	2.7e-08	2.7e-06	2.7e-08	3.3e-06	1.1e-06
BDCM	9.9e-06	8.4e-06	2.5e-08	7.3e-06	5.5e-06	5.7e-06	2.3e-06	9.9e-06	5.5e-06	8.7e-06	5.0e-06	4.1e-06	5.2e-06	1.9e-08	9.7e-06	6.1e-06	5.2e-06	5.0e-06	1.9e-08	3.5e-06	9.4e-06	9.7e-06	4.2e-06

Figure 4. Carcinogenic risk of disinfection byproducts in drinking water in various regions of Chengdu during 2023 - 2025