Uncertainty Health Risk Assessment and Regional Control of Drinking Water: A Case Study of Hanyuan County, Southwest Mountainous Area, China

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Uncertainty Health Risk Assessment and Regional Control of Drinking Water: A Case Study of Hanyuan County, Southwest Mountainous Area, China

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Abstract. To evaluate the health risks of drinking water in Hanyuan County, 96 samples of peripheral drinking water were collected from 30 sites in the area. The samples were then analysed for physicochemical properties including Fe, Mn, NH_3-N, NO_3^-, F-, Pb, Hg, As, Cr^{6+}, Cd, and so on. The health risks of ten trace elements in drinking water were probabilistically assessed using the health risk assessment model and Monte Carlo simulation. On this basis, sequential indicator simulations were used to classify the health risk levels of drinking water in the region, to conduct hierarchical management and control. The results showed that except for NO_3^-, all other indicators met World Health Organisation standards and China's drinking water sanitation standards. Drinking water presents a specific carcinogenic risk to adults, and the cumulative contribution of As and Cr^{6+} exceeds 95%, and has a specific non-carcinogenic risk to children if the cumulative contribution of F^-, NO_3^-, and As exceeds 90%. Grade I, II, and III non-carcinogenic risk areas accounted for 0.89%, 24.72%, and 74.39% of the total area of Hanyuan County, respectively, while grade I, II, and III carcinogenic risk areas accounted for 27.71%, 45.56%, and 26.73% of the total Hanyuan County area, respectively. Finally, according to the health risk characteristics of each control area, corresponding zoning control suggestions were proposed.

Keyword: *Drinking water; Uncertain health risk assessment; Monte Carlo simulation; Sequential indicator simulation*

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INTRODUCTION

Safe drinking water is essential to public health, yet a report jointly issued by the United Nations and the World Health Organisation in 2019 shows that as of 2017, billions of people still lack access to safe drinking water (WHO, 2019). From the water source to the user, drinking water is affected by issues such as water source pollution, outdated water treatment technology, and pipeline network pollution (GUAN et al., 2018). The current focus on drinking water quality is mainly limited to whether it meets, or exceeds, the standard. However, long-term inhalation of, or indirect exposure to, low-dose carcinogens and non-carcinogens in water can also cause significant health risks. (Adimalla, 2020a; Zheng et al., 2017)

Water quality health risk assessments can quantitatively describe the health hazards of various indicators in the water to the human body. Radfard et al. investigated the concentration of pollutants in drinking water in Iran's Sistan and Baluchistan provinces and conducted a health risk assessment of As presence (Radfard et al., 2019). Hadi Rezaei et al. conducted a non-carcinogenic risk assessment of fluoride, nitrate, and nitrite in drinking water in Sanandaj, Iran (Rezaei et al., 2019). Lu et al. conducted carcinogenic and non-carcinogenic risk assessments on 13 trace elements (Co, Mn, Ni, Cu, Zn, Se, Mo, Cr, As, Cd, Sb, Hg, and Pb) in drinking water in Shenzhen, China (Lu et al., 2015). However, due to the number of samples, measurement methods, and differences in individual exposure parameters, the entire process of health risk evaluation is ambiguous, and uncertain analysis methods are sometimes introduced into the assessment. To address the complex drinking water risk analysis problems Lindhe et al. introduced Fault Tree Analysis and a Monte Carlo simulation to effectively evaluate the probability of various water supply system incidents and residents' health risks (Lindhe et al., 2009). Wang et al. used fuzzy interval numbers to evaluate uncertainty with fewer data conditions, which better reflected the influence of exposure parameters such as pollutant concentration, average daily drinking water, and body weight (Wang et al., 2020). Zuzolo et al. used a Monte Carlo simulation and sensitivity analysis to fully assess the influence of pollutant concentration, average daily drinking water, exposure frequency, exposure time, and body weight, as well as obtaining the probabilistic health risk results of As in drinking water in Italy. In addition, they evaluated the parameters that have a more significant impact on health (Zuzolo et al., 2020). Probabilistic evaluation based on a Monte Carlo simulation puts ambiguous parameters in a probability distribution into the risk equation. It then calculates a health risk probability density curve, which reduces the variability caused by changes in pollutant concentration and individual residents' living characteristics in the evaluation process (Saha and Rahman, 2020). Compared to fuzzy interval numbers, the probability density curve can better identify the characteristics of undefined parameters. However, none of the above studies considered the spatial influence of a limited number of sampling sites.

Based on Monte Carlo simulation to describe the influence of exposure parameters, Sequential Indicator Simulation (SIS) was used to assign limited water quality sample data to spatial heterogeneity, through non-parametric stochastic simulation without a hypothetical distribution. It achieved the probabilistic evaluation of drinking water health risks in the Hanyuan area, and the classification of health risk control areas. At the same time, a graded regional health risk management strategy was proposed.

2. Materials and Method

2.1 Study area

Hanyuan County belongs to Ya'an City, Sichuan Province, located on the western edge of the Sichuan Basin (Figure 1). It has good mineralisation conditions and rich mineral resources within the territory; the mining of which may increase the concentration of toxic trace elements in regional water bodies.

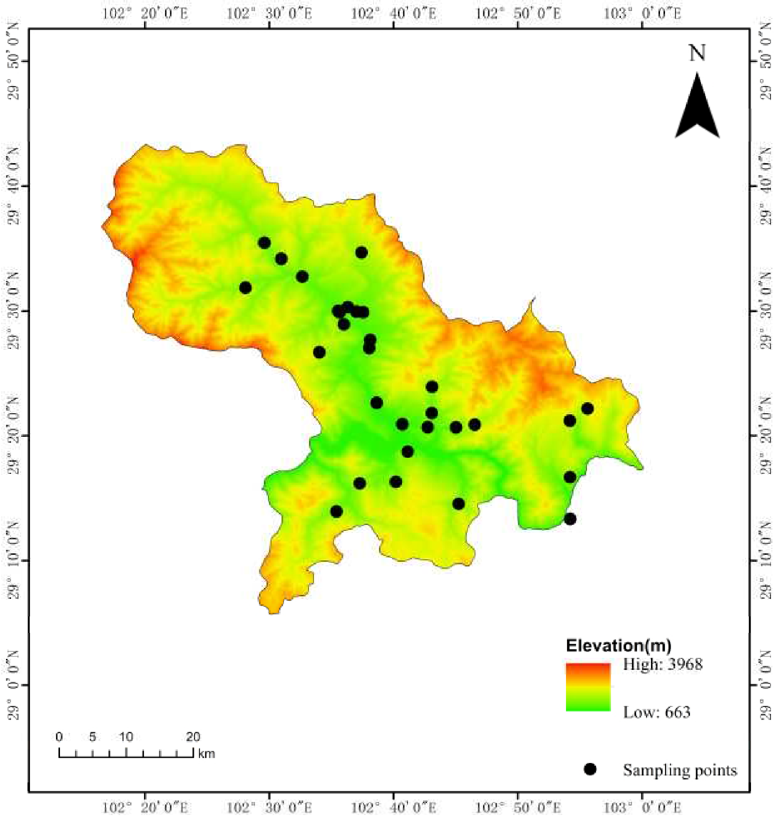

Figure 1. The sampling location of peripheral drinking water and the location of the research area

2.2 Data sources

The study collected 96 peripheral drinking water samples from 30 sites in Hanyuan County from 2012 to 2016, with 27 monitoring indicators. We used Fe, Mn, NH_3-N, NO_3^-, F^-, Pb, Hg, As, Cr^{6+}, and Cd as the evaluation factors for health risk analysis.

2.3 Uncertainty analysis and human health risk assessment procedure

Based on the health risk assessment model recommended by USEPA, the study introduces Monte Carlo simulation and SIS to construct a new uncertainty health risk assessment model. the structure of which is shown in Figure 2.

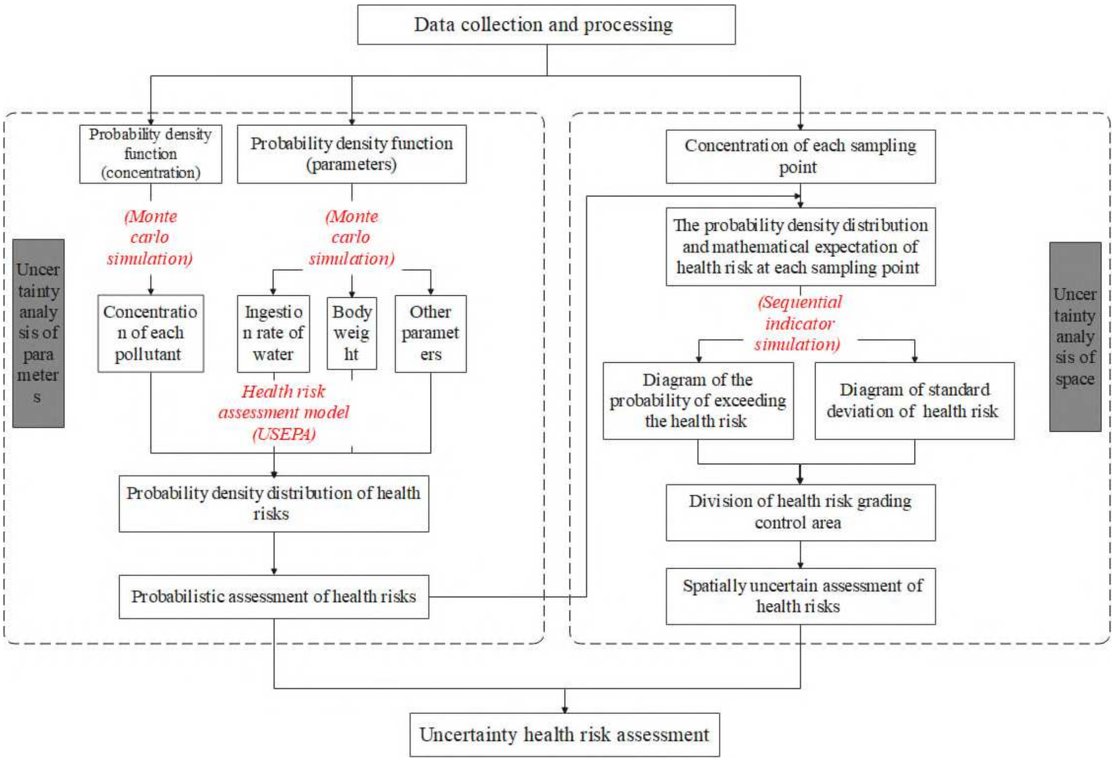

Figure 2. Uncertainty health risk assessment steps

2.3.1. Probabilistic assessment of health risks

Toxic trace elements in drinking water enter the human body mainly through inhalation and skin contact, bringing about carcinogenic and non-carcinogenic risks. Existing research shows that the health risks caused by water ingestion are far more significant than those caused by skin contact (Adimalla, 2020b; Chai et al., 2021; Gao et al., 2020). Therefore, this study only considers the threats to health produced by ingesting water. Combining the health risk assessment model proposed by USEPA and actual data from Hanyuan County, the study revised some health risk exposure parameters (Table 1).

Table 1. Distribution of probabilistic health risk evaluation parameters

Parameters	Symbol	Units	Probabilistic Distribution types	Values
Ingestion rate of water (Adult)	**IR(A)**	L/day	Triangular distribution	1.95（0.5~3.66）[a,c]
Ingestion rate of water (Children)	**IR(C)**	L/day	Triangular	1.25（0.3~3）[a]
Body weight (Adult)	**BW(A)**	kg	Normal	59.5 ± 9.2[a]
Body weight (Children)	**BW(C)**	kg	Triangular	30（10，70）[a]
Exposure frequency	**EF**	day/year	Constant	365[b]
Exposure duration (Adult)	**ED(A)**	year	Constant	30 [b]
Exposure duration (Children)	**ED(C)**	year	Constant	9 [b]
Averaging time (Non-carcinogen. Adult)	**AT(nc,A)**	day	Constant	ED(A)×365
Averaging time (Non-carcinogen. Children)	**AT(nc,C)**	day	Constant	ED(C)×365
Averaging time (Carcinogen)	**AT(c)**	day	Constant	71.2×365 [c]
Gastrointestinal absorption coefficient	**ABS**		Constant	
Carcinogenic slope factor (Ingestion)	**SF**	$(mg/(kg \cdot day))^{-1}$	Constant	See Table 2
Reference dose (Ingestion)	**Rfd**	mg/(kg·day)	Constant	

[a](DENG, 2013); [b](USEPA, 1996); [b](Xiao-di, 2013);

According to the International Cancer Institute research on the carcinogenicity of substances, As, Cr^{6+}, Cd, and their compounds are chemical substances with proven evidence of human carcinogenicity, and thus were selected for the carcinogenic risk assessment. Fe, Mn, NH_3-N, NO_3^-, F^-, Pb, Hg, As, Cr^{6+}, and Cd were selected for the non-carcinogenic risk assessment. The gastrointestinal absorption factors, reference doses of non-carcinogens, and Carcinogen intensity coefficients are shown in Table 3. The study considered the impact of toxic trace elements on adults and children, and the risk assessment model is shown in formulae 1-5 (USEPA, 1996).

$$ADD_{ingestion} = \frac{C \times IR \times EF \times ED \times ABS}{BW \times AT} \quad (1)$$

$$HQ_{ingestion} = \frac{ADD_{ingestion}}{Rfd_{ingetion}} \quad (2)$$

$$CR_{ingestion} = ADD_{ingestion} \times SF \quad (3)$$

$$HI = \sum HQ \quad (4)$$

$$TCR = \sum CR \quad (5)$$

where ADDi is the exposure dose of chemical i; Ci is the concentration of chemical i, mg/L; IR is the daily water intake, L/d; EF is the exposure frequency, d/a; ED is the exposure duration, a; BW is body weight, kg; AT is the average time, day; ABS is the gastrointestinal absorption factor; HQ is the hazard quotient of the drinking water route; Rfd is the reference dose of non-carcinogen for drinking water, mg/(kg·day); CR is the carcinogenic risk of the chemical; SF is the carcinogenic slope factor, $(mg/(kg \cdot day))^{-1}$; HI is the sum of the harm quotients of multiple pollutants in drinking water; TCR is the total risk of carcinogens in drinking water for multiple pollutants, $(mg/(kg \cdot day))^{-1}$; See Table 2 for specific parameter values.

Table 2. Evaluation index toxicity parameters and physicochemical parameters

Trace elements	ABS	$Rfd_{Ingestion}$	$SF_{Ingestion}$
Fe	0.15[a]	0.3[a]	
Mn	0.04[a]	0.046[a]	
NH3-N	0.2[c]	0.97[c]	
NO_3^-	0.5[a]	1.6[a]	
F-	1[b]	0.06[a]	
Pb	1[b]	0.0014[a]	
Hg	0.07[a]	0.0003[a]	
As	0.41[a]	0.0003[a]	15[a]
Cr^{6+}	0.02[a]	0.003[a]	41[a]
Cd	0.05[a]	0.0005[a]	6.1[a]

[a](USEPA, 2010);[b](There is no relevant data at present. use '1' instead);[c](PRPTV, 2021)(Laboratory)

2.3.2. Spatial uncertainty analysis of health risks

The study regards the expected HI and TCR values at the sampling points as variables that change with space, uses SIS to simulate their spatial distribution, and obtains the non-carcinogenic health risk and carcinogenic risk exceedance probability map and standard deviation map. The specific algorithm steps are as follows (Goovaerts, 2001).

(1) 0-1 discrete coding

The expected values of HI and TCR of 30 sampling points are converted into indicator values I (x, z).

$$I(x,z)=\begin{cases}1, & x\leq z\\ 0, & x>z\end{cases} \quad (6)$$

where z is the desired cut-off value of x (HI and TCR). Take HI as 1 (USEPA, 2004). For TCR, take the ICRP recommended value $5\times10^{-5}a^{-1}$ (Valentin, 2002). When I (x; z) is 0, HI or TCR exceeds the standard value. That is, a health risk is identified. When I (x, z) is 1, the situation is reversed.

(2) Obtain several indicator variograms corresponding to the given cutoff values z_k according to Eq. (7):

$$\gamma_I(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}[I(x_i,z_k)-I(x_i+h,z_k)]^2 \quad (7)$$

where h is the distance between locations x_i and x_i+h, and N(h) is the number of data pairs for xi and xi+h.

(3) Grid the study area and perform sequential simulation

Divide the study area into a 70×70 grid and outline a random path through all unknown points. The first unknown point is selected according to a random path, and the probability $\tilde{I}(x, z)$ =Prob{x≤z} that HI and TCR exceed the corresponding threshold is estimated by the Kriging method. Randomly select a random number p uniformly distributed in the interval [0,1], compare p with $\tilde{I}(x, z)$, and determine the HI and TCR indication values at that position. Add the new simulation value to the known data and repeat the simulation process until all points are simulated. If needed, this process can be repeated numerous times.

(4) Probability spatial distribution of health risks

Through Formula (8) and Formula (9), the probability and standard deviation of each simulated HI and TCR point exceeding the standard value, can be calculated (SHI et al., 2007).

$$P_{SIS}\{x>z\}=\frac{n\,(x>z)}{N_{SIS}} \quad (8)$$

$$S^2_{P_{SIS}\{x>z\}}=\frac{P\,(1-P)}{N_{SIS}} \quad (9)$$

where $P_{SIS}\{x>z\}$ is the health risk probability; $S^2_{P_{SIS}\{x>z\}}$ is the standard deviation of the health risk; x is the HI and TCR at the simulated point; z is the threshold of HI and TCR; NSIS is the total number of SIS, the number of simulations in this study is 100; n is the number of times the result at the simulation point exceeds the threshold in all N_{SIS} simulations.

The research used Matlab software to implement SIS, Oracle Crystal Ball 11 to implement Monte Carlo simulation, and ArcGIS 10.2 to draw the sequential indicator health risk simulation results.

3. Results and Discussion

3.1 Monitoring data statistics

Monitoring data showed that all indicators met the standards except for the maximum NO_3^- concentration which exceeded WHO safe levels and China's drinking water sanitation standards. Heavy metals and Fe were not detected during most months, and the concentrations in individual months were also low.

Table 3. Descriptive statistics of water quality indicators included in the health risk assessment

Trace elements (mg/L)	Detection limit	Mean	Min.	Max.	Standard value （WHO）	Standard value （China）
Fe	0.05	0.025	0.025	0.025	0.3	0.3
Mn	0.05	0.025	0.025	0.025	0.4	0.1
NH_3-N	0.02	0.01	0.01	0.01	-	0.5
NO_3^-	0.15	2.76	0.075	28.26	11	20
F-	0.1	0.22	0.03	0.835	1.5	1
Pb	0.0025	0.00125	0.00125	0.00125	0.01	0.01
Hg	0.0001	0.00005	0.00005	0.00005	0.006	0.001
As	0.0001	0.000421	0.00005	0.006	0.01	0.01
Cr^{6+}	0.004	0.002	0.002	0.002	0.05	0.05
Cd	0.0005	0.00025	0.00025	0.00025	0.003	0.005

- (there is no standard value).

3.2 Probabilistic health risk assessment

3.2.1 Non-carcinogenic and carcinogenic risks

When conducting probabilistic health risk evaluation, the maximum result value may be higher than the actual value, therefore the 95% quantile of the probabilistic evaluation result is determined as the maximum estimated value of the health risk evaluation result (Kavcar et al., 2009).

The results of the non-carcinogenic risk assessment show that the maximum estimates of the total hazard index for adults and children are 0.89 and 1.41, respectively, and the probability of exceeding safety level 1 is 2.58% and 14.58%, respectively (Figure 3). The contribution of each index to the total hazard index is F^->NO_3^->As>Pb>Cd>Mn>Cr^{6+}>Fe>Hg>NH_3-N (Figure 5). The non-carcinogenic risk assessment results show that children have a specific non-carcinogenic risk. Among them, F-, NO_3^-, and As represent 45.14%, 25.05%, and 22.33%, respectively.

The results of the carcinogenic risk assessment show that, the probability of the total carcinogenic risk of adults and children exceeding 5×10^{-5} a^{-1} are 93.84% and 4.12%, respectively, and the maximum estimated TCR values are 5.24×10^{-4}, $a^{-1}$$4.82 \times 10^{-5}$ a^{-1} (Figure 4). The contribution of each index to the total carcinogenic risk is As>Cr^{6+}>Cd (Figure 5). According to the carcinogenic risk assessment results, adults have a greater risk of carcinogenesis, among which As and Cr^{6+} contribute significantly at 88.52% and 10.97%, respectively.

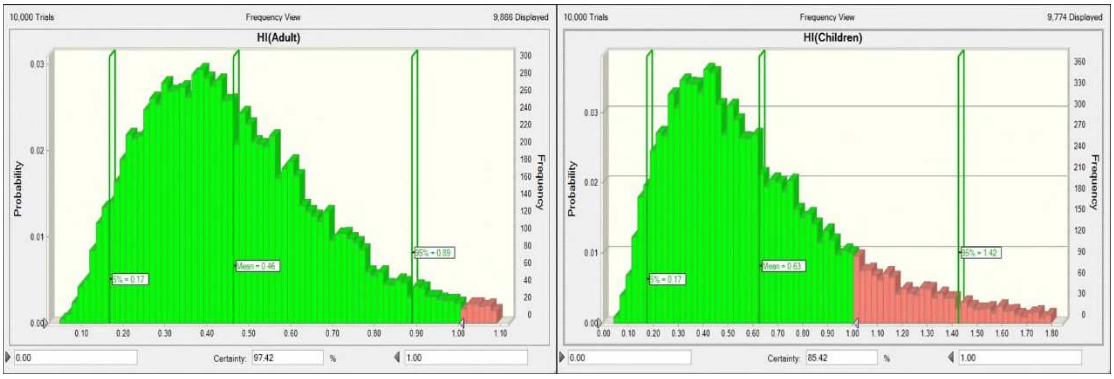

Figure 3. Probabilistic assessment results of non-carcinogenic risk

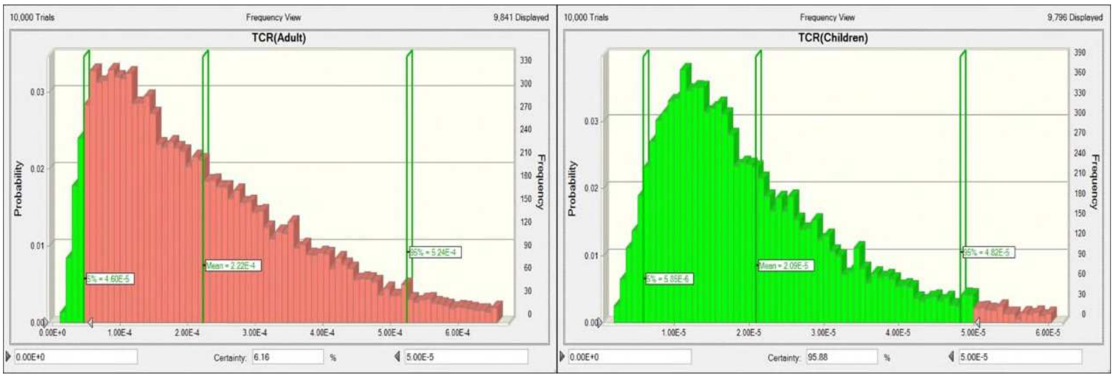

Figure 4. Probabilistic assessment results of carcinogenic risk

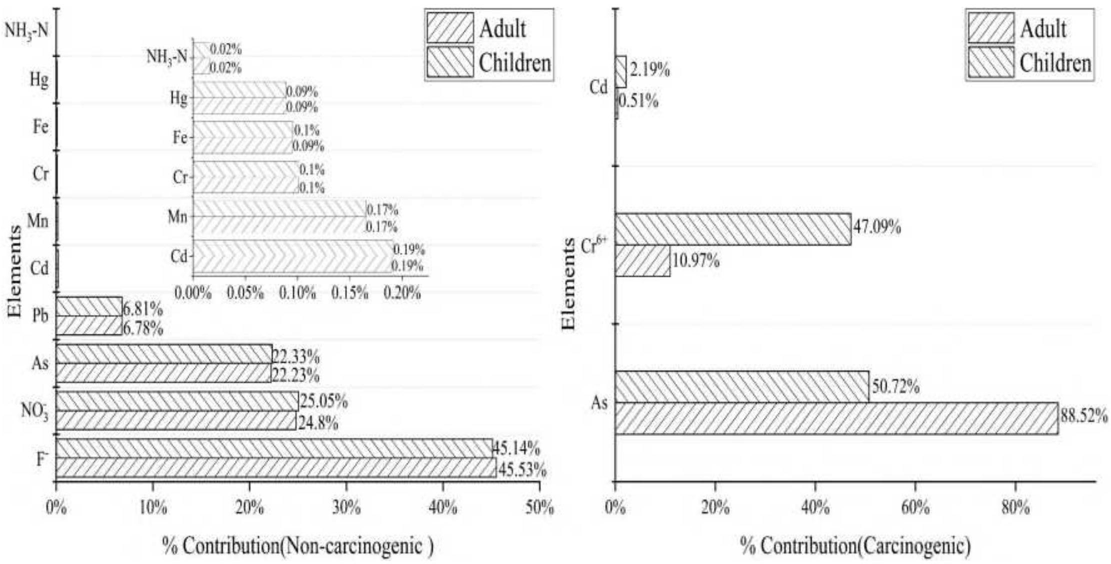

Figure 5. Non-carcinogenic risk and carcinogenic risk contribution rate of each trace element

3.2.2 Sensitivity analysis

Sensitivity analysis results reflect the relationship between each evaluation parameter variable and health risk. The absolute value of the sensitivity reflects the correlation between the evaluation parameter variable and the health risk, and the positive or negative sensitivity indicates whether the evaluation parameter variable is positively or negatively correlated with that health risk.

The results of non-carcinogenic risk sensitivity analysis are shown in Figure 6. IR has the most significant impact on the non-carcinogenic risk of adults and children, with correlation coefficients of 48.8% and 40.6%, respectively. In addition, as far as adults are concerned, changes in F^-, As, and NO_3^- concentration have a more significant impact on non-carcinogenic risk than body weight. This conclusion is contrary to the results of the sensitivity analysis of children. That is, changes in F^-, As, and NO_3^- concentration will increase the likelihood of non-carcinogenic risks in adults.

The carcinogenic risk sensitivity analysis results are shown in Figure 7. The concentration of arsenic has the most significant impact on the carcinogenic risk of adults, and IR has the most significant effect on the carcinogenic risk of children, with correlation coefficients of 74.1% and 40.8%, respectively. Bodyweight is also a significant factor in cancer risk in both adults and children.

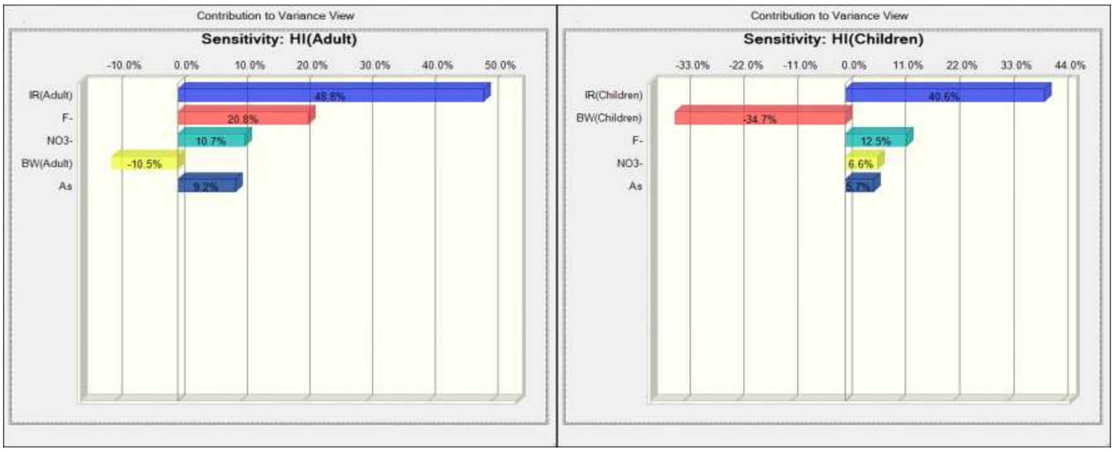

Figure 6. Non-carcinogenic risk sensitivity analysis

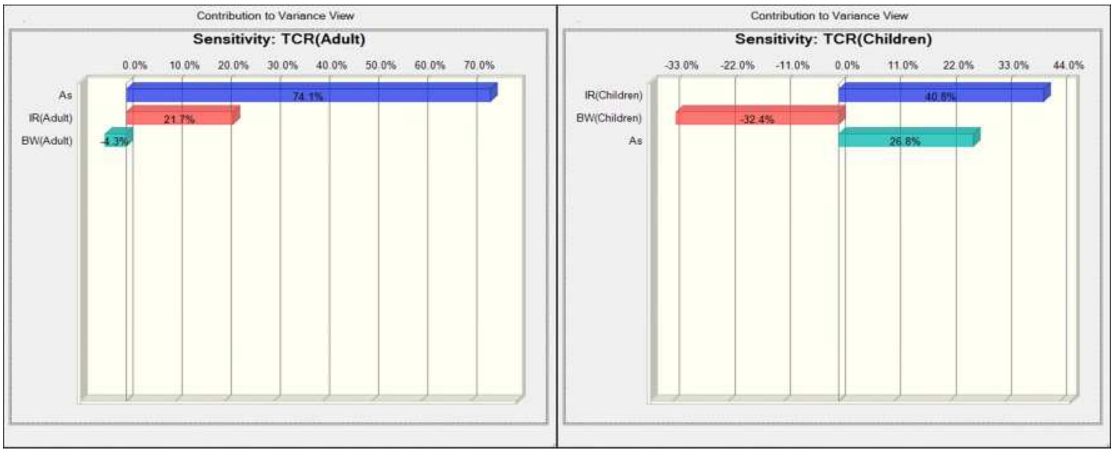

Figure 7. Sensitivity analysis of carcinogenic risk

3.3 Spatial uncertainty health risk analysis

3.3.1 Semivariogram of indicator variables

In the SIS, ‘1’ and ‘5e-5’ were selected as the indicator variable thresholds for HI and TCR, respectively. In this research, we used a particle swarm optimisation algorithm and least-squares method to fit three theoretical variation models (spherical, exponential, and Gaussian) of indicator variables including adult HI, adult TCR, child HI, and child TCR. The theoretical semivariogram with the least error was selected as the experimental semivariogram, and the parameter values are shown in Table 4.

Table 4. Fitting error of semivariogram and model parameters

Simulation index	Model type	RMSE	Model parameters		
			C_0	$C+C_0$	Range (m)
	Spherical	0.0188			
Adult HI,	**Exponential**	0.0187	0.023	0.021	35000
	Gaussian	0.0186			
	Spherical	0.0271			
Adult TCR	**Exponential**	0.0333	0.164	0.098	2867
	Gaussian	0.0331			
	Spherical	0.0188			
Child HI	**Exponential**	0.0187	0.023	0.019	33824
	Gaussian	0.0186			
	Spherical	0.0306			
Child TCR	**Exponential**	0.0339	0.202	0.050	2348
	Gaussian	0.0333			

3.3.1 Probability spatial distribution of health risks

According to the probabilistic health risk assessment results, the drinking water in Hanyuan County contains various health risks to both adults and children. To study the distribution and uncertainty of the health risks, to both adults and children, of drinking water in this area, SIS was used to conduct random modelling. Taking adult non-carcinogenic risks as an example, the random model generated by the SIS method better describes the spatial distribution of health risks in the study area and reflects its spatial uncertainty (Figure 8 and Figure 9).

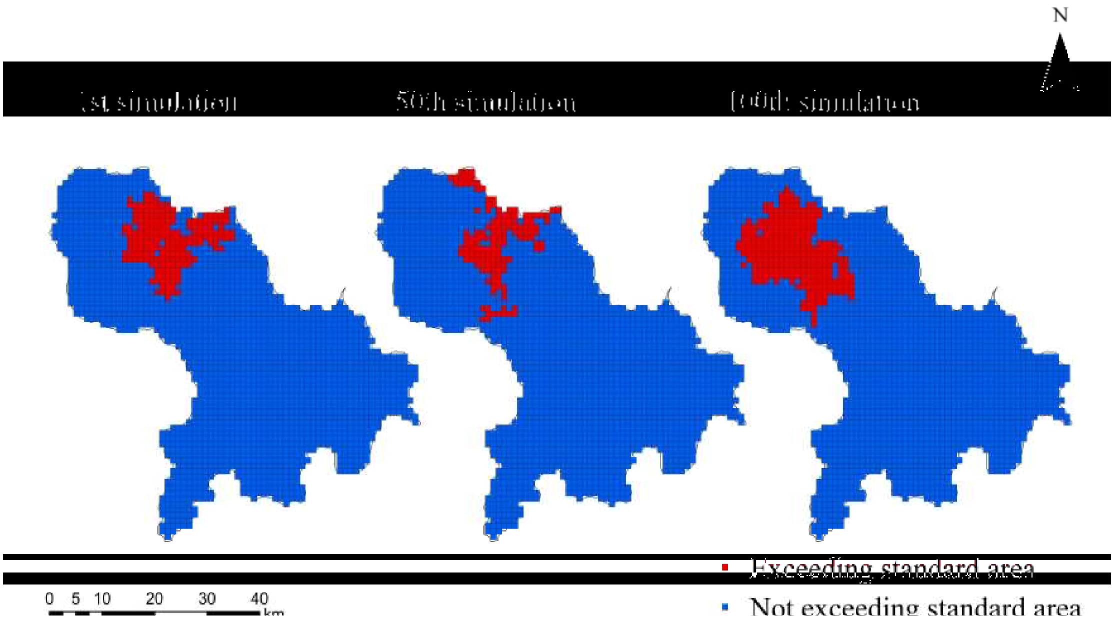

Figure 8. Results of the 1st, 50th, and 100th SIS simulations of non-carcinogenic risk of drinking water to adults in Hanyuan County

After performing 100 SIS on the health risks to adults and children in the study area, we used Formulae (8)-(9) to perform statistical analysis to obtain the diagram of the probability of health risk and the digram of variance of health risk (Figure 9, Figure 10). The regional risk probability value and standard deviation respectively represent the possibility and uncertainty of health risks to humans caused by various pollutants in drinking water. When the risk probability value is high, risks to health are more likely in that area. When the risk probability value is low, the health risk is low, but its standard deviation is large, which leads to increased uncertainty. To provide environmental risk managers with extensive, intuitive, and accurate information, we referred to the classification of groundwater and soil health risk assessments and hierarchical risk control areas by Zeng Guangming and Huang Jinhui (Huang et al., 2016; Zeng et al., 2009). This study uses 5%, 25%, 50%, 75%, and 95% probability of exceeding the standard as the benchmark, and the health risks of the study area are separated.

As shown in Figure 9, the spatial distribution of non-carcinogenic risks exceeding the probability is the same in adults and children. The area with a standard-exceeding probability value greater than 0.75 is mainly located around the S30 point. The areas where the risk of adult carcinogenesis is more significant than 0.75 are mainly located around S5, S8, S12, S13, S19, and S21. The areas where the risk of children's carcinogenesis is more significant than 0.75 are mainly located around S10, S12, S13, S18, S19, and S21.

It can be seen from Figure 9 and Figure 10 that the areas with a health risk probability significant standard deviation within the study area are mainly concentrated in the locations where the health risk exceeds the standard probability of 25% to 75%. This signifies significant uncertainty, indicating that the health risk level of the region is unstable, and could possibly change to high risk.

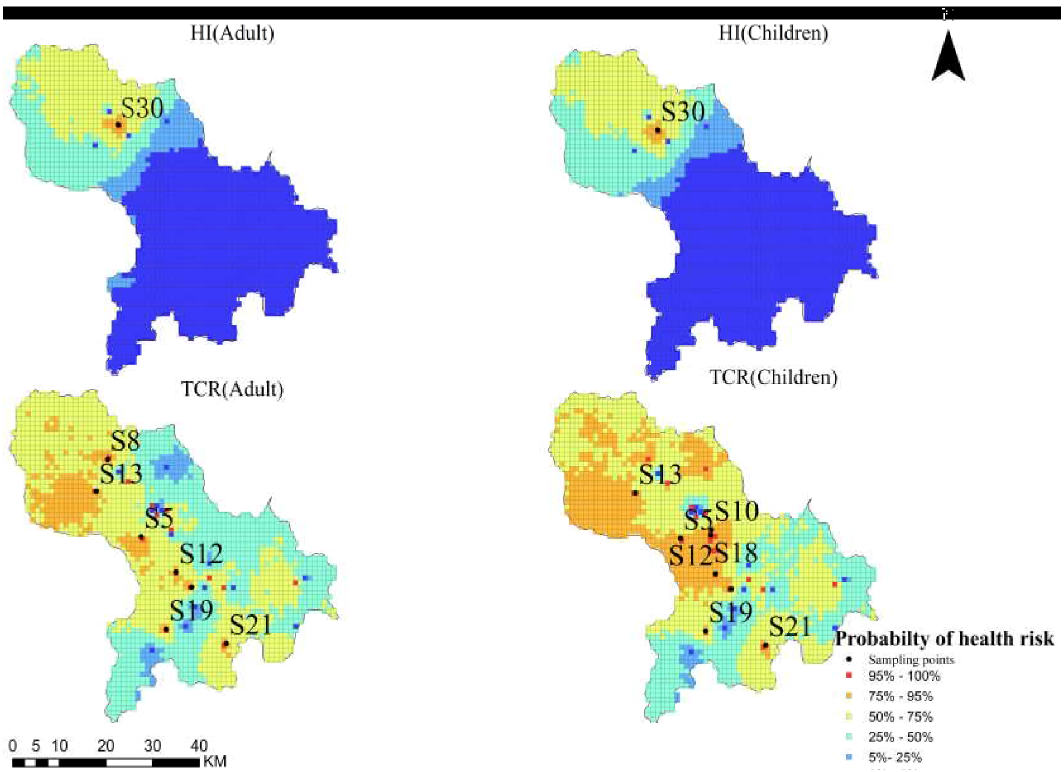

Figure 9. Spatial distribution of health risk probability in Hanyuan County

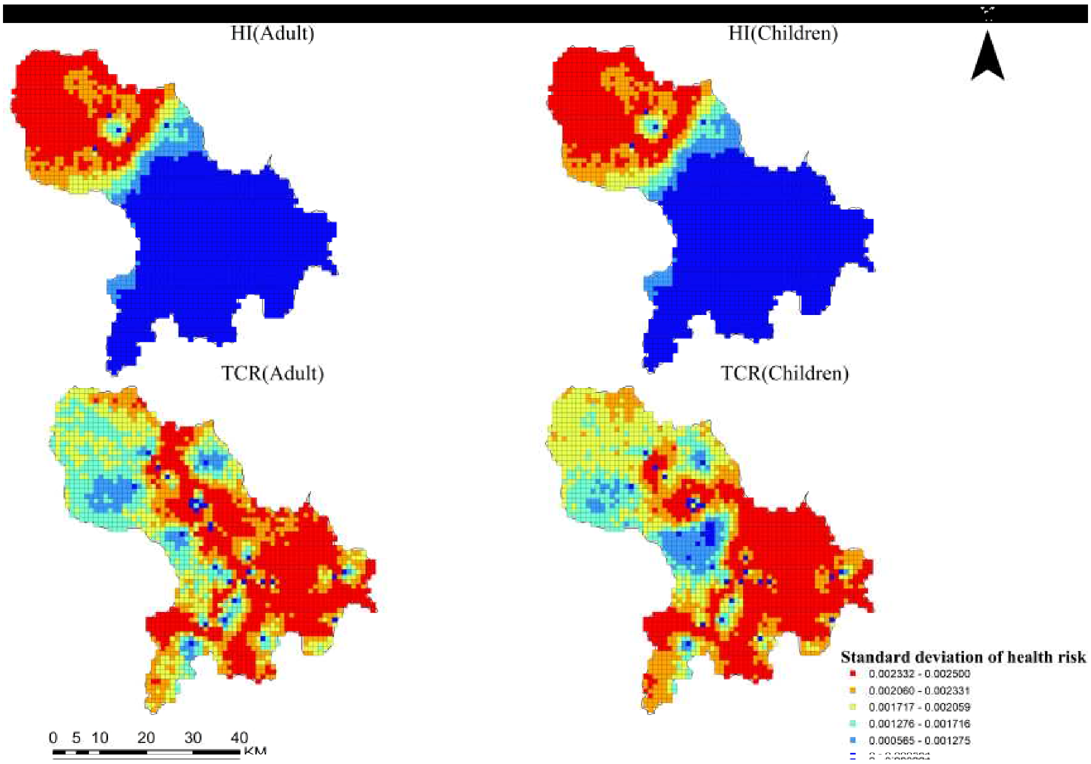

Figure 10. Spatial distribution of health risk standard deviation in Hanyuan County

3.4 Grading of control areas according to health risk levels

Combining Figure 9 and Figure 10, the areas with carcinogenic risk and non-carcinogenic with over-standard probability greater than 75% are classified as Class I areas, and areas with a 25%-75% probability, that is, areas with large standard deviations, are classified as Class II areas. The remaining areas are described as level III areas (Figure 11).

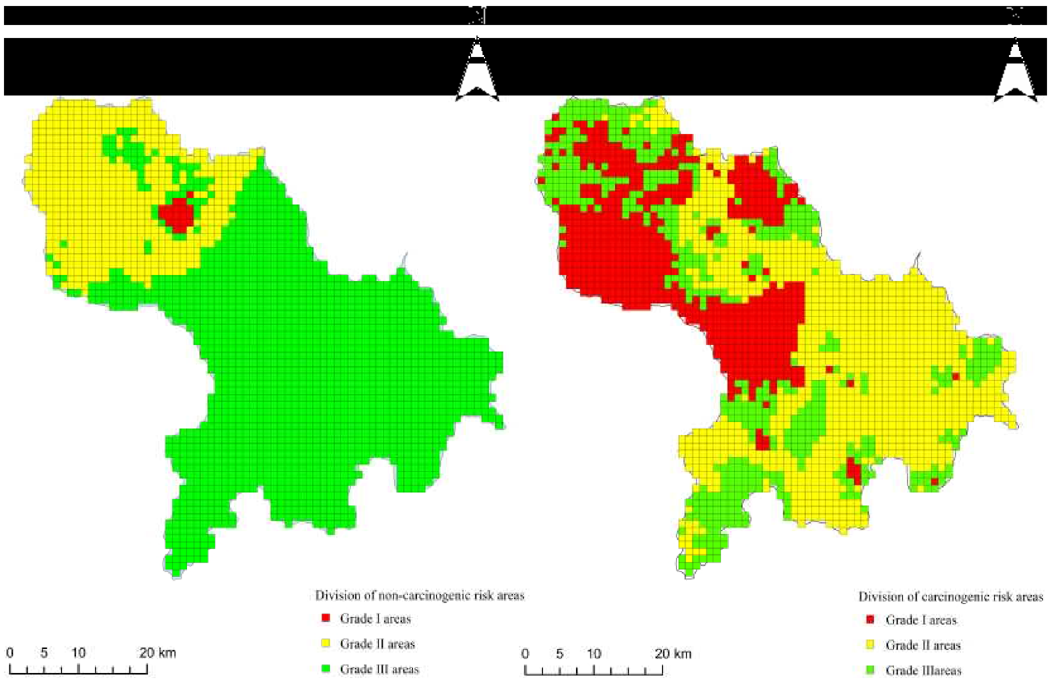

Figure 11. Health Risk Zoning of Drinking Water in Hanyuan County

The Grade I non-carcinogenic and carcinogenic risk covered 19.67km^2 and 612.58km^2, accounting for 0.89% and 27.71% of the total Hanyuan County area, respectively. For drinking water in Grade I areas, due to the high probability of non-carcinogenic and carcinogenic risk exceeding the standard, various pollutants in the drinking water pose a more significant threat to health, thus this area should be regarded as a priority control area for environmental risks. For pollutants containing F^-, NO_3^-, As, and Cr^{6+} contributing to health risks, the water processing plants within those study areas need to undertake corresponding purification processes. In addition, all risk information should be made public, to prompt widespread awareness among local residents and encourage them to monitor their drinking water quality.

Grade II non-carcinogenic and carcinogenic risk areas constituted 546.48km^2 and 1007.19km^2, accounting for 24.72% and 45.56% of the total Hanyuan County area, respectively. For drinking water in Grade II areas, since the non-carcinogenic risk, and probability of carcinogenic risk exceeding the standard are relatively small, the standard deviation is large, and the drinking water health risk could increase from low to high. Therefore, these areas should be considered as environmental risk key control areas. Relevant departments need to strengthen the monitoring and early warning system of water sources and drinking water quality in high-risk areas within the study area and take measures to reduce pollution when necessary to avoid deterioration of drinking water quality.

Grade II non-carcinogenic and carcinogenic risk areas covered 1644.53km^2 and 590.92km^2, accounting for 24.72% and 45.56% of the total area of Hanyuan County, respectively. For drinking water in Grade III areas, since various pollutants in this area constitute low non-carcinogenic and carcinogenic risk to adults and children, the sites should be determined as general environmental risk control areas. It is recommended that relevant departments conduct regular sampling and inspections of the drinking water quality in these areas.

4. Conclusion

The study evaluated the hazards to human health posed by Fe, Mn, NH_3-N, NO_3^-, F^-, Pb, Hg, As, Cr^{6+}, and Cd in the peripheral drinking water of Hanyuan County, analysed the uncertainty of risk, and classified of health risk control areas. The conclusions are as follows:

(1) Except for NO_3^-, all other indicators met World Health Organisation standards and China's water sanitation standards.

(2) The maximum estimated value of the children's total hazard index is 1.41, with a 14.58% probability of exceeding safety level 1, and the contribution of F-, NO_3^-, and As is relatively large. The maximum estimate of the total carcinogenic risk for adults exceeding $5.24 \times 10^{-4} a^{-1}$ is 93.84%, and the contribution of As and Cr^{6+} is relatively significant.

(3) Sensitivity analysis results showed that daily water intake, body weight, F-, NO_3^-, and As concentration significantly affect the health risks of both adults and children.

(4) The non-carcinogenic risks of grade I, grade II, and grade III areas account for roughly 0.89%, 24.72%, and 74.39% of the total area of Hanyuan County. The carcinogenic risks of grade I, grade II, and grade III areas accounted for about 27.71%, 45.56%, and 26.73% of the total area of Hanyuan County.

(5) The drinking water quality meets relevant standards, which does not denote that there is no health risk. Combining Monte Carlo simulation uncertainty analysis and

sequential indicator simulation can effectively determine different risk control areas. In view of the risk characteristics of various regions, suggestions are made to assist relevant departments in formulating more scientific, economic, and flexible drinking water safety management strategies.

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COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the research. Conceptualization: Ying Liu; Methodology:Zhengjiang Lin, Ying Liu, Zhihui Cheng; Formal analysis and investigation: Zhengjiang Lin, Ying Liu, Zhihui Cheng; Writing - original draft preparation: Zhengjiang Lin; Writing - review and editing: Ying Liu, Rui Zhao, Han Zhang; Funding acquisition:Ying Liu; Resources: Ying Liu; Supervision: Ying Liu. The final manuscript read and approved by all authors.

COMPLIANCE WITH ETHICAL STANDARDS

All authors have read this manuscript and would like to have it considered exclusively for publication in Environmental Science and Pollution Research. None of the material related to this manuscript has been published or is under consideration for publication elsewhere, including the internet. The authors have no relevant financial or non-financial interests to disclose. The Research did not involve human participants and/or animals.

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