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Health Risk Assessment on Rural Water Quality in Mingshan County, China

NI Fu-quan^{1,2}, LIU Guo-dong¹, DENG Yu², FU Cheng-wei²

¹State Key Lab. of Hydraulics and Mountain River Eng., Sichuan Univ., Chengdu, China
nfq1965@163.com

²College of Information & Engineering, Sichuan Agricultural University, Ya'an, China.

Abstract—Based on ArcGIS and the feature analysis for the water environment and the source identification of water environmental health risks in a typical area in the western edge of Sichuan basin-Mingshan County in Ya'an City of Sichuan Province, China, this study tested the water quality of 41 drinking water sources, applied the health risk evaluation model recommended by USEPA (U.S. Environmental Protection Agency) to calculate and analyze the rural drinking water quality carcinogenic risk(R) and non-carcinogenic risk(hazard index, HI), and drew risk maps including single-factor and integrate factors of carcinogenic and non-carcinogenic substances, the maps were in good agreement with the known spatial distribution of water quality contamination, applied the Tobit regression model to inspect significance and modeling results of HI, pointed out that the first 4 pollutants risk index of water sources were arsenic, fluoride, nitrate and iron, and suggested these 4 kinds of pollutants should be monitored specially. The study revealed the risk level, primary and secondary pollutants, governance priorities, formation mechanism, and provided a scientific basis for risk management for the rural drinking water quality in the study area.

Key words—Water Source; Health Risk Assessment; Water Quality Safety; Mingshan County

How to quantify the severity of drinking water contaminant, and how to use risk degrees to express directly effects on human health hazard, the domestic already had done some research^[1-4]. But most of them focused on evaluation of source water quality in a single water source, and were simple application of USEPA health risk formula. How to carry out rural drinking water quality health risk assessment of county scale, discussing water and soil formation mechanism from evaluation results and revealing the risk mechanism were the main objectives of this study.

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Mingshan County in Ya'an City of Sichuan province located in the southwestern edge of Sichuan basin (29°58'–30°16' north latitude, 103°02'–103°23' east longitude) and covered all 20 towns, with a population of 268000, covering an area of 614.27 square kilometers. It has a humid subtropical monsoon temperate climate, with an annual average temperature of 35.2 degree Celsius, average annual rainfall ranged from 1200 to 1700 millimeters, is well-known as one of the four rainstorm areas in Sichuan province. The poor water quality has seriously affected production and living of them. According to surveying information by the end of 2004, the total population of this area amounted to 268000, but 85000 of them exposed to poor rural drinking water quality. Among them, about 26000 people drink IV class or super IV class untreated surface water, 11000 people drink water of bacteriological indicators exceeding seriously, 9000 people drink the surface water polluted seriously and untreated groundwater, 39000 people exposure to drinking water schistosomiasis epidemic^[5]. It's very urgent and essential to carry on health risk assessment of water quality actively and improve the condition of rural drinking water in this area as soon as possible.

I. MATERIALS AND METHODS

A. Models of Health Risk Assessment

The health risk assessment process recommended by U.S.EPA mainly includes^[6, 7, 8]: Data collecting and evaluating; Exposure assessment; Toxicity assessment; Risk characterization. Health risk management of water environment is a neonatal management philosophy that further developed from water environment management. It is the concretized management which focus on the actual situation of regional water environment and carries out risk management to ensure the health and safety of regional water environment on the basis of regional water environmental risk analysis and assessment. In this study, models and parameters

were used as reference [9].

B. Sampling, Testing, Risk Screening and Identifying

In 2005, according to topography, geomorphology, geology, hydrology, water systems and drinking water sources, distribution of waterborne diseases and water supply project types, 41 water samples were collected. Sampling sites distribution shown in fig. 1, the tested results shown in fig. 2. Must be explained is that the tested concentration values of As, Pb in No.6 sampling sites were both 0.01mg/l and Cr^{6+} was lower than the limit value; tested concentration values of As, Hg, Cd, Cr^{6+} , Pb in other sampling sites were all lower than the limit values.

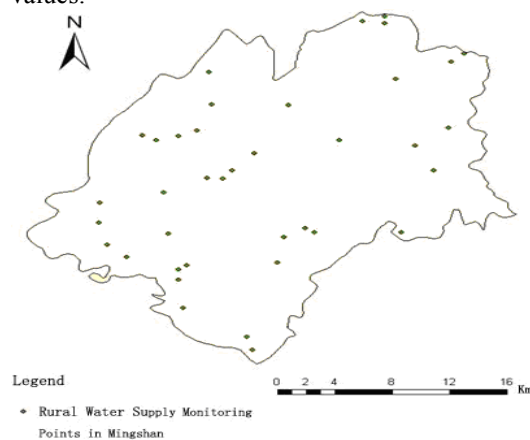
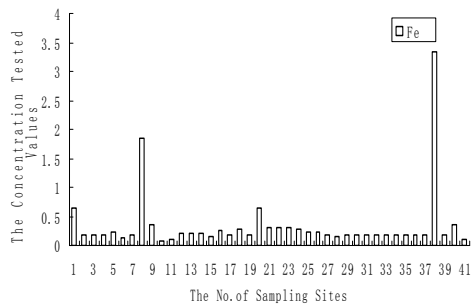
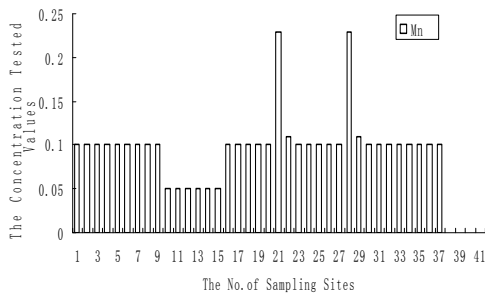


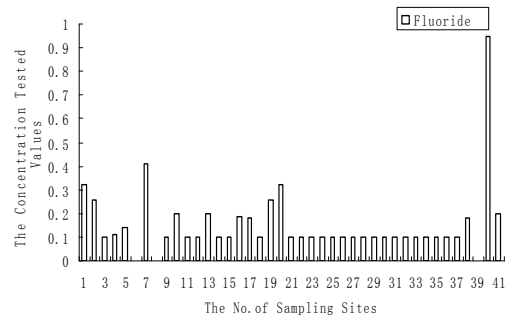
Fig. 1. Sampling sites Distribution



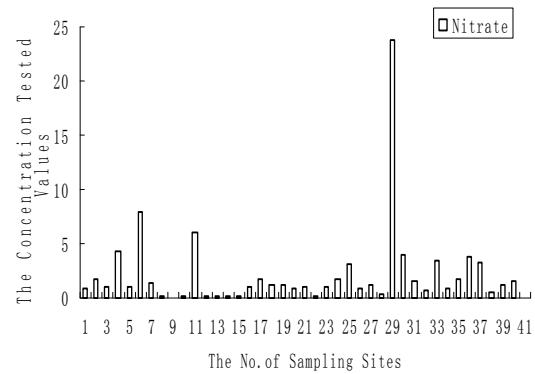
(a)



(b)



(c)



(d)

Fig. 2. Distribution of water quality concentration tested values (mg/l)

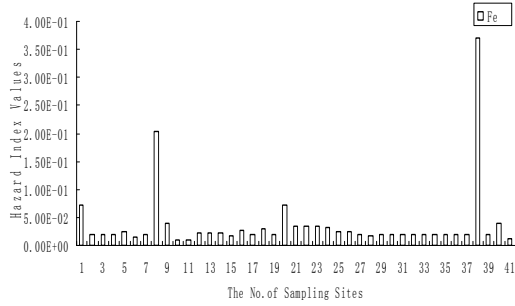
According to whether the water quality indexes are harmful to human body health or not, 9 toxicology index were screened and identified for health risk assessment, including arsenic, lead, mercury, cadmium, chromium, iron, manganese, fluoride and nitrate respectively, among them, the concentrations of arsenic and lead were only detected in No. 6 sampling sites, and the concentrations of mercury, cadmium, chromium were all less than detection limits, the concentrations of manganese in No. 38, 39, 40, 41 sampling sites below the detection limit values, fluoride in No. 6, 8, 39 sampling sites below the detection limits.

II. RESULTS

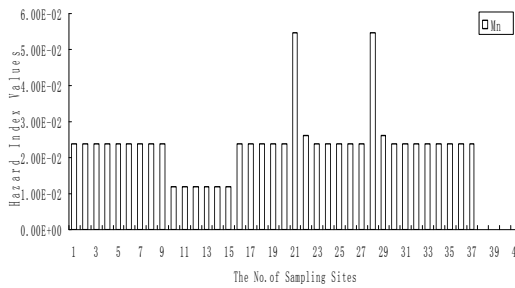
The study calculated the risk of single factor health, integrated factors health risks and the total health risks respectively (presented in fig. 3 (a)-(e)). In order to reveal the spatial distribution of risk levels, the study applied ArcGIS software platform to draw the integrate factors risk maps for carcinogen, non-carcinogen and total risk respectively (presented in fig. 4 (a)-(c)). The maps were in good agreement with the known spatial distribution of water quality contamination.

Must be explained was that the non-carcinogenic risk (Hazard Index, HI) values

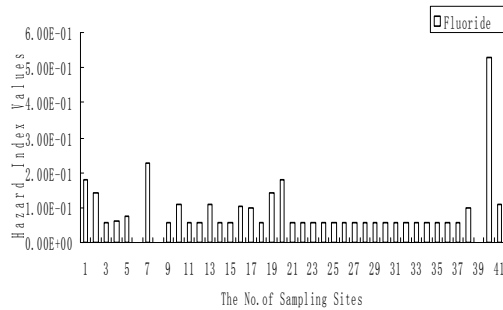
of As and Pb in No.6 sampling sites were 1.11 and 0.0952, the carcinogenic risk (R) of them were $2.14E-04$ and $7.86E-06$; the non-carcinogenic risk and carcinogenic risk values of As, Hg, Cd, Cr^{6+} , Pb in other sampling sites were all negligible.



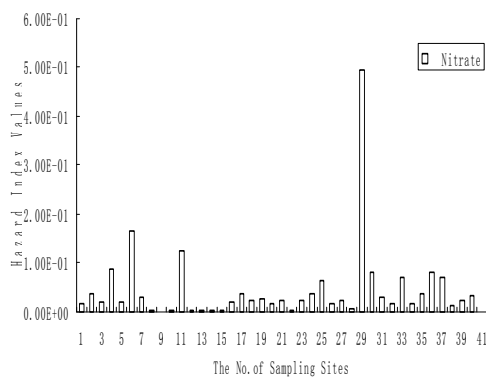
(a)



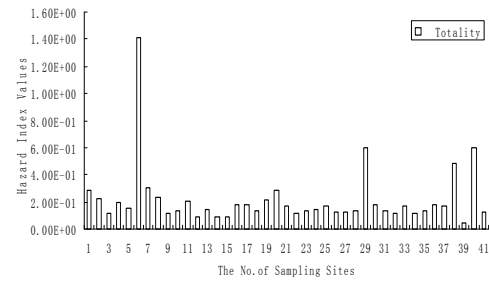
(b)



(c)

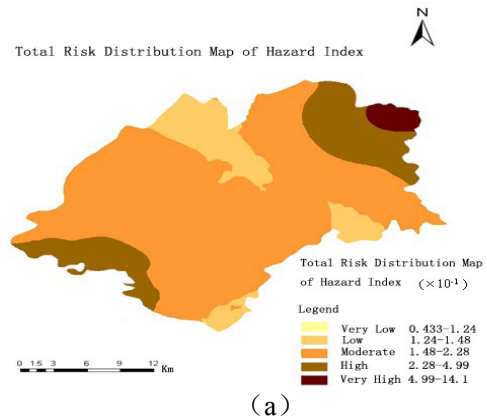


(d)

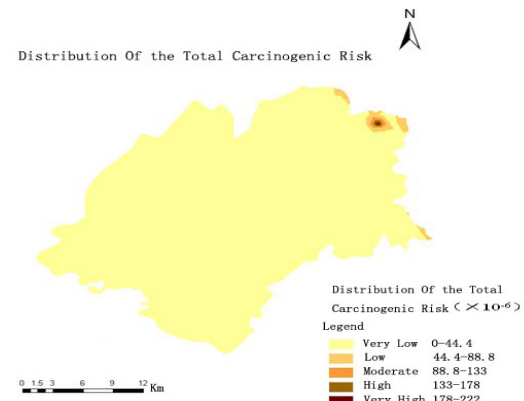


(e)

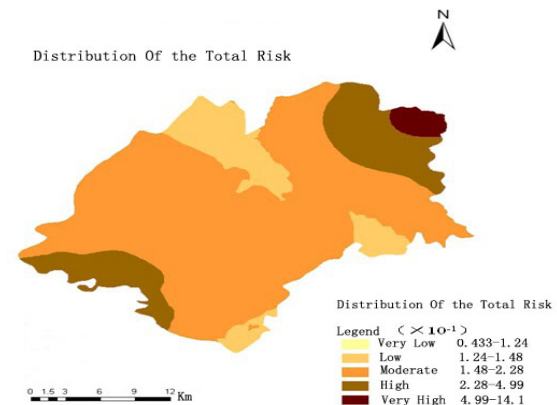
Fig. 3. Distribution of Health Hazard Index



(a)



(b)



(c)

Fig. 4. Total Risk Distribution of Integrate Factors

III. ANALYSIS AND DISCUSSIONS

A. Carcinogenic Risk Assessment

In comparison with the risk assessment criteria (the limit value is 1.00×10^{-6}), the carcinogenic risk values of arsenic and lead exceeded the limit value.

According to classification information of USEPA Integrated Risk Information System (IRIS), arsenic belongs to class A carcinogenic pollutant (USEPA proposed to 1.00×10^{-6} for risk control); lead belongs to class B₂ carcinogenic pollutant (risk-control standards can be raised moderately to 1.00×10^{-5}). Hence, from table 2, and fig.2, only the carcinogenic health risk value of arsenic in No. 6 water source amounted to 0.000214 in all 41 water sources, exceeded up to 214 times. In comparison with arsenic limit 0.05mg/l in *European Union Drinking Water Quality Instruction*, this water source was precisely in the critical state. In comparison with arsenic limit 0.05mg/l in the small central water supply and decentralized water supply of *Drinking Water Health Standards (GB5749-2006)*, *United States Drinking Water Quality Standards*, the I, II, III class standards in *Surface Water Environmental Quality Basic Index Standard Limit Values (GB3838-2002)*, and the class III standard in *Groundwater Quality Standard (GB/T14848-93)*, all water sources didn't exceed the concentration limit values.

The content of lead in No. 6 water source (0.01 mg/l) amounted to critical states of *European Union Drinking Water Quality Instruction*, *Drinking Water Health standards (GB5749-2006)*, the I, II class standard values in *Surface Water Environmental Quality Standard Basic Index Limit Values (GB3838-2002)*; according to the standard of the III Class standard 0.05mg/l in *Groundwater Quality Standard (GB/T14848-93)*, the content of lead in No. 6 water source not exceeded the standard value.

B. Evaluation of Non-carcinogenic Risk (Hazard Index)

Based on the basic statistical analysis for the

risk index of the 41 water sources, the result showed that the mean risk index was 0.219, in the range of 0.0433~1.41, the difference between the maximum and minimum values was 1.367.

Due to the observation precision of the detection equipments, none of the targeted values were below the detection precision could be detected, and this lead to the problem of mutilated data. So, Tobit regression analysis method was applied to analyze the data^[10]. The relationship between non-carcinogenic risk (hazard index) and each examination target was established, the fitting situation of the relationship was examined also (seen in table 1 and fig. 5).

The values of estimates of regression equation coefficients, standard errors, Wald test values, significance level, 95% confidence interval of parameter estimate, the model parameter values (the logarithm likelihood function the values(L), Likelihood function the values (L') after removing the constant term 2π in likelihood equation, the estimate values of the normal distribution parameter σ of samples) are given in table 1 respectively. From table 1, the remarkable level P values of parameter β_1 , β_2 , β_3 , β_6 were all 0.0001, lower than 0.05, amounted the significant level; the remarkable level P values of parameter β_4 , β_5 both were 0.9999, both were over 0.05, didn't amounted the remarkable level. Hence, iron, manganese, fluoride and nitrate were the main risk index. Fig. 5 has given the contrast results between each water source test values and the Tobit regression analysis fitting values. From Fig. 5, the following results can be drawn: the fitting results were very sound, illustrated that the equation established from Tobit regression analysis was well reflected in the change proportional relationship between the risk index and the hazard factors.

Non-carcinogenic risk evaluation criteria: According to the definition of risk index, "1" was risk control standards of the chronic poisons effect for the non-carcinogenicity. The results showed that the total hazard index of 6 kinds of pollutants in 41 water sources except No. 6 greater than 1, the other 40 water sources lower than 1. Thus, may recognize basically that the

Table 1 Tobit Regression Results of Water Sources

	Coefficients	Standard Errors	Wald test values	P Value	95% Confidence Interval	The log-likelihood function L is	The log-likelihood function L' is	Normal distribution parameters σ is
β_0	0.0000	0.0001	0.16	0.6936	-0.0002			
β_1	1.0000	0.0007	2141326.00	0.0001	0.9986			
β_2	1.0021	0.0040	63555.32	0.0001	0.9943	56.7294	94.4059	0.0003
β_3	1.0002	0.0005	3881626.00	0.0001	0.9992			
β_4	1.0791	8266.3420	0.00	0.9999	-16201.0000			
β_5	0.0926	96382.7700	9.22E-13	0.9999	-188910.0000			
β_6	1.0002	0.0005	3612279.00	0.0001	0.9992			

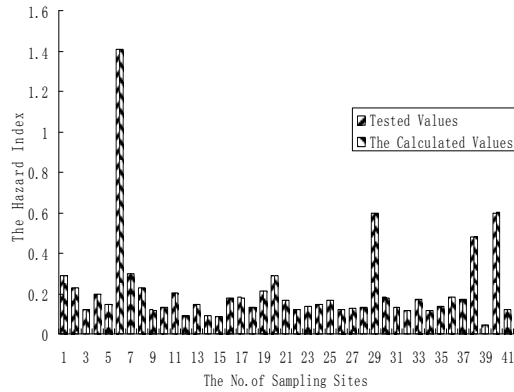


Fig.5 Tobit Regression Fitting of Non-carcinogenic Risk

water supply from most water sources in this area didn't generate the non-carcinogenicity chronic poisoning effects to the water drinking crowds. By sequencing pollutants which hazard index values greater than 0.1, this study illustrated that the main pollutants in water sources were arsenic, fluoride, nitrate and iron respectively. Thus, monitoring these 4 kinds of pollutants was very essential.

C. Water Quality Health Analysis

Arsenic contamination: the hazard index of arsenic in No. 6 water source amounted to 1.11.

Fluoride pollution: The measured concentrations mean value of 38 water sources fluoride was 0.1663, in the range of 0.10~0.95mg/L, the difference between the maximum and minimum values was 0.85 mg/l. All the measured concentration values were lower than all kinds of standards. The fluoride hazard index of No. 1, 2, 10, 13, 16, 17, 19, 20, 38 and 40 water sources were greater than 0.1, the average value of them was 0.165, in the range of 0.10~0.528, the difference between the maximum and minimum values was 0.428. Hazard index in 11 water sources were over 0.1, the mean value was 0.296, in the range of 0.18~0.95, the difference between the maximum and minimum values was 0.77.

In a certain area (e.g., a country), fluoride content in drinking water exceeds the national specified standard (the limit value is 0.5~1.0mg/L) or its high content in foods, it could be defined as endemic fluorides. Endemic fluorides may cause a series of symptoms of central nervous, mussels, gastrointestinal system as well as the changes in bones and teeth. But the main perniciousness were in teeth and bones, besides, it is also an inducement of cardiovascular disease and cancer. Fluorides are mainly derived from the manufacturing of products that contains it, the phosphate fertilizer plant, the steel works, the aluminum smelting works, etc. Therefore, it is suggested that these

enterprises in water source protection areas should be examined emphatically to find out whether there's emission of fluorides during their production process, so that we can achieve targeted prevention and control. Higher fluoride concentration in groundwater mainly correlate with soil materials, soil types and other factors, so regional background value should be examined when solving the problem of excessive fluoride in drinking water of this area.

Nitrate pollution: The nitrate mean value of 41 water sources was 2.1154mg/L, in the range of 0.002-23.73mg/L, the difference between the maximum and minimum values was 23.728 mg/L. According to *United States Drinking Water Quality Standards, Drinking Water Health Standards (GB5749-2006)* (the limit value is 10mg/l), *Drinking Water Health Standards (GB5749-2006)*, and *Groundwater Quality Standard (GB/T14848-93)* (the limit value is 20mg/l), only No. 29 water source didn't reach the standard; according to *EU Drinking Water Quality Directive* (the limit value is 50mg/l), all of them didn't exceed. Nitrate hazard index of No. 6, 11, 29 water source are all greater than 0.1, and were 0.165, 0.125, 0.494 respectively, with an average of 0.261.

Iron and Manganese Pollution: Iron concentration mean value of 41 water sources was 0.342mg/L, in the range of 0.08-3.24 mg/L, the difference between the maximum and minimum values was 3.16mg/L. According to *Drinking Water Health Standard (GB5749-2006)*, *Groundwater Quality Standard (GB/T14848-93)* and *United States Drinking Water Quality Standards* (the limit value is 0.3mg/L), the contents of iron in 9 water sources of No.1, 8, 9, 20, 21, 22, 23, 38, 40 water source exceeded the above standards. According to *Drinking Water Health Standards (GB5749-2006)* (the limit value is 0.5mg/L), the contents of iron in 4 water sources of No.1, 8, 20, 38 water source exceeded the standards. According to *EU Drinking Dater Directive* (the limit value is 0.2mg/L), the contents of iron in 15 water sources exceeded the standards, they were No.1, 5, 8, 9, 16, 18, 20, 21, 22, 23, 24, 25, 26, 38 and 40 water sources, 3 water sources of No.12, 13, 14 water sources were in critical state. The contents of manganese mean value was 0.0995mg/L in 37 water sources, in the range of 0.05 ~ 0.23 mg/L, the difference between the maximum and minimum values was 0.180 mg/L. According to *Drinking Water Health Standards (GB5749-2006)*, 37 water sources don't exceed the standard (the limit value was 0.3mg/L); according to *Groundwater Quality Standard (GB/T14848-93)* and *Drinking Water Health Standards (GB5749-2006)* (the limit value was

0.1mg/L), 3 water sources of No.21, 22, 28 exceeded the standard, 27 water source, i.e., No.1~9, 16~20, 23~27, 30~37 water sources reached critical state; according to *United States Drinking Water Quality Standards* and *EU Drinking Water Directive* (the limit value was 0.05mg/L), except No.10~15 water sources reaches a critical state, the rest all exceeded the standard. Hazard index of iron in No. 8 and 38 water sources all exceeded 0.1, amounted to 0.204 and 0.371 respectively, with an average of 0.287. Drinking water in this area suffered from iron and manganese pollution, which caused the content of iron and manganese in water seriously exceeded the standards, mainly due to the excessive manganese content in the stratum water flowing through, the main features of the spatial distribution about iron and manganese in groundwater are closely related to regional soil material, soil type and human activities^[11].

IV. CONCLUSIONS

Water quality health risk assessment of rural drinking water reflected the quantitative relationship between water quality and human health. By applying this method to evaluate rural drinking water quality and testing the relationship between source water quality and human health provided more in-depth scientific information for the management and conservation of rural water sources. This study took Mingshan County in Ya'an City of Sichuan Province as an example, based on GIS technology, analysis 41 water sources quality, applied the health risk evaluation model recommended by USEPA to calculate the health carcinogenic risk and non-carcinogenic hazard index, drew GIS risk thematic maps including single-factor and integrate factors of carcinogenic and non-carcinogenic substances, and applied the Tobit regression analysis to inspect significant and fitting results of non-carcinogenic hazard index. The results showed that risk index of water sources in the first 4 pollutants were arsenic, fluoride, nitrate and iron respectively. It is recommended specially that these 4 kinds of pollutants should be monitored. The total risk hazard index of 6 kinds of pollutants in No. 6 water source exceeded the limit value (i.e.,1), and the other water sources didn't exceed the limit value. Thus, we could basically determine that most of the water sources wouldn't bring out non-carcinogenic chronic poisoning effects on drinking crowd in this area.

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