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Health Risk Assessment on Drinking Water in Shenzhen, China

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Abstract

Objectives: To conduct health risk assessment on drinking water in 2012 in Shenzhen of China. **Methods:** The water quality monitoring data on product water and pipe water in 2012 were collected and analyzed, and the risk evaluation models recommended by the U.S. environmental protection agency (US EPA) were employed, to perform adults and children's health risk assessments on the three kinds of genetic toxic substances such as hexavalent chromium, cadmium and arsenic and the 12 non-carcinogenic materials such as iron, manganese, lead, fluoride, volatile phenol, cyanide, mercury, ammonia nitrogen, nitrate, copper, zinc and selenium. **Results:** The results about water quality from the 150 factory samples and 207 peripheral water samples showed that the measured indicators in other water samples were accord with the National Health Standards (GB5749-2006) released by Ministry of Health of the People's Republic of China, except manganese level in one factory sample and the same index in one peripheral sample, and nitrate concentration in another water sample were out of limit, respectively. Namely, the total of 3 samples was disqualification. The adults and children's health risks (HI) on the 12 non-carcinogenic materials were 178.04×10^{-8} and 249.96×10^{-8} in the factor water samples, and 363.02×10^{-8} and 509.66×10^{-8} in the pipe samples, respectively. Lead in factory water and fluoride in peripheral water samples were the most serious harm in the all measured non-carcinogenic indicators. The adults and children's cancer risks (R) on the 3 genetic toxic substances were 25.60×10^{-6} and 28.51×10^{-6} in the factor water samples, and 23.47×10^{-6} and 26.08×10^{-6} in the pipe samples, respectively. Hexavalent chromium was the most damage among the three detected carcinogenic indicators. Therefore, the total adults and children's health hazard risks including the 3 carcinogenic and 12 non-carcinogenic substances were 27.38×10^{-6} and 31.00×10^{-6} in the factor water samples, and 27.10×10^{-6} and 31.17×10^{-6} in the pipe samples, respectively. Genetic toxic matters in drinking water are the main hazard and more children's health risk than adults' risk. **Conclusions:** The health risk (R) on the 15 kinds of chemicals in Shenzhen's municipal water supply was in the range of maximum acceptable risk levels (5.0 × 10^{-5}/a) recommended by the International Commission of Radiation Protection (ICRP). The results in this study indicate that the carcinogenic substances are greater risk comparing with the non-carcinogenic substances, and hexavalent chromium is the biggest carcinogenic risk, and lead and fluoride are the most non-carcinogenic risk, and the rather risk of children than adults.

Keywords

Urban Drinking Water, Carcinogenic Materials, Non-Carcinogenic Materials, Health Risk Assessment

1. Introduction

In recent years, serious environmental pollution events appeared occasionally around the world, which injured not only regional ecological environment but also human health [1] [2]. The harms resulted from environment pollution have been attaching more and more attention by governments and researchers [3] [4]. The greatest health risk for individual person per year in Ya'an City of Sichuan Province is caused by Cr (VI). The health risk of carcinogens is much higher than that of non-carcinogens: the greatest risk value due to non-carcinogen pollutants caused by fluoride (F), achieving 1.05 × 10^{-8}/a [5]. The same study in Tianjin results showed that the health risks of carcinogens, non-carcinogens were 3.83 × 10^{-5}, 5.62 × 10^{-9} and 3.83 × 10^{-5} for total health risk respectively. The rank of health risk was carcinogen > non-carcinogen. The rank of carcinogens health risk was urban > new area > rural area, chromium (VI) > cadmium > arsenic > trichlormethane > carbon tetrachloride. The rank of non-carcinogens health risk was rural area > new area > urban, fluoride > cyanide > lead > nitrate. The total health risk level of drinking water in Tianjin was lower than that of ICRP recommended level (5.0 × 10^{-5}), while was between US EPA recommended level (1.0 × 10^{-6} - 1.0 × 10^{-4}) [6]. Health risk assessment (HRA) is an evaluation method to correlate environmental pollution and human health by estimating probabilities of adverse effects. Water environmental health assessment is an important part of environmental health assessment, which is a quantitative method to calculate adverse effects on water pollutants [5] [7]. The typical HRA includes hazard identification, exposure assessment, dose-response analysis and risk assessment [8]. Although there are different uses in various countries, HRA is basically consisted of two parts, namely carcinogenic and non-carcinogenic risk evaluation [9]. Just as the following report, concentrations of the15 kinds of chemicals have been measured and their risk characteristics have been analyzed in this study.

2. Materials and Methods

2.1. Experimental

The chemical dataset of 49 different water monitoring sites 100 different peripheral water sampling sites according to terrain, landform, geology, hydrology, water system, drinking water sources, distributions of waterborne infectious disease and types of water supply project were obtained from the Health Directorate of Shenzhen for this study. Drinking water samples were collected every quarter in 2012, with a total of 150 factory samples and 207 peripheral samples according to correct sampling techniques to analyze their chemical contents. Detection indexes for these samples included iron, manganese, volatile phenol, cyanide, fluoride, lead, mercury, ammonia nitrogen, nitrate, copper, zinc, selenium, arsenic, cadmium and hexavalent chromium.

All filtered and acidified water samples were analyzed for trace metals (Fe, Mn, Pb, Hg, Cu, Zn, Se, As, Cd) (**Table 1**) using inductively coupled plasma mass spectrometer (ICP-MS, 7500 ce, USA). VP (Volatile Phenol, VP) and CN (Cyanide) were analyzed by flow injection analyzer (Futura 3, France). Ion chromatograph (ICS3000, USA) was employed to determine F and NO_3^-. NH_3^-N and Cr^{6+} were detected by ultraviolet and visible spectrophotometer (1750, Japan). In view of data quality assurance, each sample was analyzed in triplicate and after every 10 samples two standard; one blank and another of 2.5 μg/L of respective metal were analyzed on atomic absorption. The reproducibility was found to be at 95% confidence level, the relative standard deviations (RSD) were all less than 15%, conforming to the requirements of the US EPA (RSD is less than 30%). Therefore, the average value of each water sample was used for further interpretation.

2.2. Health Risk Assessment

According to the EPA's Comprehensive risk information database (IRIS) and International Agency for Research on Cancer (IARC), pollutants can be classified as carcinogens (also called no threshold compounds) and non-carcinogens (also called threshold compounds) [8] [10]. In this study, hexavalent chromium, arsenic and cadmium belonged to the no threshold compounds, iron, manganese, volatile phenol, cyanide, fluoride, lead, mercury, ammonia nitrogen, nitrate, copper, zinc and selenium compounds were attributed to the threshold compounds.

2.2.1. Carcinogenic Risk Assessment

Trace amounts of carcinogens produce very great harm to human health, which is generally considered by the gene toxicant quantitative risk assessment. R usually represents the risk of cancer caused by genetic toxic substances (arsenic, hexavalent chromium and cadmium). The calculation method of average personal annual risk of cancer is shown in Formulas (1)-(4):

$$RT = \Sigma Ri \tag{1}$$

Table 1. Detection parameters of chemicals in drinking water.

Chemicals	Detection method	Equipment name and model number	Producers	Lowest detectable limit (mg/L)
Iron (Fe)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.05
Manganese (Mn)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.05
Volatile phenol, (VP)	Drinking water standard testing method GB/T5750-2006	Flow injection analyzer, Futura 3	France	0.002
Cyanide (CN^-)	Drinking water standard testing method GB/T5750-2006	Flow injection analyzer, Futura 3	France	0.002
Fluoride (F^-)	Drinking water standard testing method GB/T5750-2006	Ion chromatograph, ICS3000	USA	0.1
Lead(Pb)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.005
Mercury (Hg)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.0001
Ammonia nitrogen (NH_3^-N)	Drinking water standard testing method GB/T5750-2006	Ultraviolet and visible spectrophotometer 1750	Japan	0.02
Nitrate (NO_3^-)	Drinking water standard testing method GB/T5750-2006	Ion chromatograph, ICS3000	USA	0.02
Copper (Cu)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.005
Zinc (Zn)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.05
Selenium (Se)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.005
Arsenic (As)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.005
Chromium (Cr^{6+})	Drinking water standard testing method GB/T5750-2006	Ultraviolet and visible spectrophotometer 1750	Japan	0.004
Cadmium (Cd)	Drinking water standard testing method GB/T5750-2006	Inductively coupled plasma mass spectrometer, 7500 ce	USA	0.001

$$\mathrm{Ri} = \left[1 - \exp\left(-\mathrm{Di} \cdot \mathrm{qi}\right)\right] / 70 \tag{2}$$

$$\text{Adult:}\quad \mathrm{Di} = 2.0 \times \mathrm{Ci}/64.3 \tag{3}$$

$$\text{Children:}\quad \mathrm{Di} = 1.0 \times \mathrm{Ci}/22.9 \tag{4}$$

RT—total risk of cancer caused by all genetic toxic substances by drinking, annual;

Ri—risk of cancer caused by individual genetic toxicant by drinking, annual;

Di—exposure dose of individual genetic toxicant by drinking, mg/(kg·d);

qi—carcinogenic potency factor of genetic toxic substances by way of drinking, (kg·d)/mg;

70—average lifespan, year;

2.0—average adult daily drinking, L/d;

Ci—concentration of individual measured substance in water, mg/L;

64.3—average weight of adult men in Guangdong province of China, kg;

22.9—average weigh of children aged 7 years in Guangdong province, kg.

2.2.2. Non-Carcinogenic Risk Assessment

Non-genetic toxicant quantitative risk assessment was used to evaluate risks of iron, manganese, volatile phenol, cyanide, fluoride, lead, mercury, ammonia nitrogen, nitrate, copper, zinc and selenium. Health risk index (HI) means average personal annual health risk values due to exposure to individual non-genetic toxicant. The calculation method is shown in Formulas (5) to (6):

$$\mathrm{HIi} = \left(\mathrm{Di}/\mathrm{RfDi}\right) \times 10^{-6}/70 \tag{5}$$

$$\mathrm{HIT} = \Sigma \mathrm{HIi} \tag{6}$$

HIi—average personal health risk of individual non-genetic toxicant by drinking, annual;

HIT—average personal health risk of total non-genetic toxicants by drinking, annual;

Di—exposure dose of individual non-genetic toxicantby drinking, mg/(kg·d), its calculation method is same as Formulas (3) and (4);

70—average lifespan, year;

RfDi—reference dose of individual non-genetic toxicant by drinking, mg/(kg·d);

10^{-6}—a safety factor, dimensionless.

There are no basic data on exposure parameters in China at present, so we generally introduced the qi and RfDi, from USEPA to conduct risk assessment (see Table 2).

Table 2. Exposure parameters of chemicals in drinking water.

Chemicals	Characters	qi [(kg·d)/mg]	RfD [mg/(kg·d)]
Iron (Fe)	Non carcinogens	/	0.3
Manganese (Mn)	Non carcinogens	/	0.14
Volatile phenol, VP	Non carcinogens	/	0.3
Cyanide (CN^-)	Non carcinogens	/	0.037
Fluoride (F^-)	Non carcinogens	/	0.06
Lead (Pb)	Non carcinogens	/	0.0014
Mercury (Hg)	Non carcinogens	/	0.0003
Ammonia nitrogen (NH_3^-N)	Non carcinogens	/	0.97
Nitrate (NO_3^-)	Non carcinogens	/	1.6
Copper (Cu)	Non carcinogens	/	0.04
Zinc (Zn)	Non carcinogens	/	0.3
Selenium (Se)	Non carcinogens	/	0.005
Arsenic (As)	Carcinogens	15	/
Chromium (Cr^{6+})	Carcinogens	41	/
Cadmium (Cd)	Carcinogens	6.1	/

2.2.3. Total Health Risk Assessment

Various chemicals in drinking water, considering their low concentrations, were presumed that their interaction was additive. As a result, total health hazard risk in water can be calculated by Formula (7):

$$\text{Rtotal} = \text{RT} + \text{HIT} \tag{7}$$

R total—total health risk of toxicants by drinking, annual;

RT—total cancer risk of genetic toxicants by drinking, annual;

HIT—total health risk of non-genetic toxicants by drinking, annual.

2.3. Data Analysis

Water quality determinations for various chemicals were performed in the laboratory of Shenzhen CDC, Shenzhen of China. The all data were analyzed descriptive statistically by software program (SPSS 13.0 for windows). There was statistical significance if P value was below to 0.05.

3. Results

3.1. Water Quality Determination Results of Shenzhen City in 2012

All detected indexes for 15 kinds of chemicals in drinking water (150 factory water samples and 207 peripheral samples) in 2012 were in accordance with the standard for drinking water quality of PRC (GB5749-2006) except manganese in one factory and peripheral water sample, and nitrate in another peripheral water sample (see Table 3).

3.2. Health Risk Assessment

3.2.1. Non-Carcinogen Risk Assessment

Total non-carcinogenic risks of the 12 chemicals such as iron, manganese, volatile phenol, cyanide, fluoride, lead, mercury, ammonia nitrogen, nitrate, copper, zinc, selenium, in factory water, were 178.04×10^{-8} for adult and 249.96×10^{-8} for children, respectively. In peripheral water, they were 363.02×10^{-8} for adult and 509.66×10^{-8} for children, respectively. Lead possessed the maximum risk in factory while fluoride in peripheral water. It indicated that health risks on non-carcinogenic chemicals for children were much higher than that on adults (see Table 4).

3.2.2. Carcinogen Risk Assessment

Table 5 showed that total carcinogenic annual risks of the three contaminants (e.g. arsenic, chromium and cadmium) in factory water were 25.60×10^{-6} for adult and 28.51×10^{-6} for children, respectively. In peripheral water, they were 23.47×10^{-6} for adult and 26.08×10^{-6} for children, respectively. Either in factory or in peripheral water, hexavalent chromium was the most dangerous which risk value accounted for close to a half of total carcinogenic risks.

3.2.3. Health risk Assessment for Shenzhen Municipal Water

Table 6 indicated that total annual health risks on Shenzhen municipal water

Table 3. Concentrations of chemical pollutants in Shenzhen drinking water in 2012.

Chemical pollutants	Factory water			Peripheral water			The standard limit (μg/L)
	Number of samples (copies)	Median (μg/L)	Range (μg/L)	Number of samples (copies)	Median (μg/L)	Range (μg/L)	
Iron (Fe)	150	19.44	2.25 - 228.10	207	49.34	0.04 - 240.00	300
Manganese (Mn)	150	13.05	0.25 - 108.00	207	10.96	0.03 - 141.00	100
Volatile phenol, VP	150	1.05	1.00 - 2.00	162	1.06	1.00 - 2.00	2
Cyanide (CN^-)	150	1.50	1.00 - 10.00	184	1.50	0.10 - 2.00	50
Fluoride (F^-)	150	236.17	50.00 - 430.00	204	275.84	50.00 - 870.00	1000
Lead (Pb)	150	2.22	0.10 - 5.00	204	2.00	0.03 - 7.00	10
Mercury (Hg)	150	0.087	0.025 - 1.000	204	0.072	0.025 - 1.000	1
Ammonia nitrogen (NH_3^-N)	2	10.00	10.00 - 10.00	0	0	0 - 0	500
Nitrate (NO_3^-)	150	1564	20 - 3250	204	1777	5 - 13950	10,000
Copper (Cu)	150	3.18	0.50 - 14.00	204	4.04	0.05 - 100.00	1000
Zinc (Zn)	150	15.79	0.40 - 96.00	203	29.95	0.40 - 380.00	1000
Selenium (Se)	150	2.08	0.50 - 5.00	204	1.53	0.09 - 5.00	10
Arsenic (As)	150	2.09	0.50 - 5.00	204	1.62	0.04 - 5.00	10
Chromium (Cr^{6+})	150	3.10	2.00 - 5.00	184	3.30	2.00 - 6.00	50
Cadmium (Cd)	150	1.10	0.01 - 2.00	204	0.72	0.03 - 5.00	5

Note: the standard limit refers to the standard for drinking water quality of PRC (GB5749-2006).

Table 4. Annual risk for non-carcinogenic materials in Shenzhen municipal water (annual).

Chemicals	Factory water(annual)		Peripheral water(annual)	
	adult ($\times 10^{-8}$)	children ($\times 10^{-8}$)	adult ($\times 10^{-8}$)	children ($\times 10^{-8}$)
Iron (Fe)	2.88	4.04	7.31	10.26
Manganese (Mn)	4.14	5.81	3.48	4.88
Volatile phenol, VP	0.15	0.21	0.15	0.21
Cyanide (CN^-)	1.80	2.53	1.80	2.53
Fluoride (F^-)	17.48	24.54	204.40	286.96
Lead (Pb)	70.46	98.92	63.35	88.94
Mercury (Hg)	12.89	18.09	10.66	14.97
Ammonia nitrogen (NH_3^-N)	0.46	0.64	0.00	0.00
Nitrate (NO_3^-)	43.43	60.98	49.35	69.28
Copper (Cu)	3.53	4.96	4.49	6.30
Zinc (Zn)	2.34	3.28	4.44	6.23
Selenium (Se)	18.48	25.95	13.60	19.09
Total	178.04	249.96	363.02	509.66

Table 5. Annual risk for carcinogenic materials in Shenzhen municipal water (annual).

Chemical pollutants	Factory water(annual)		Peripheral water (annual)	
	adult ($\times10^{-6}$)	children ($\times10^{-6}$)	adult ($\times10^{-6}$)	children ($\times10^{-6}$)
Arsenic (As)	8.90	10.65	7.58	9.34
Cadmium (Cd)	2.69	3.63	1.82	2.49
Total	25.60	28.51	23.47	26.08

Table 6. Total annual health risk on Shenzhen municipal water.

Chemical pollutants	Factory water (annual)		Peripheral water (annual)	
	adult ($\times10^{-6}$)	children ($\times10^{-6}$)	adult ($\times10^{-6}$)	children ($\times10^{-6}$)
Carcinogens	25.60	28.51	23.47	26.08
Non carcinogens	1.78	2.49	3.63	5.09
Total	27.38	31.00	27.10	31.17

including the 3 genetic toxicants and 12 non-genetic toxicants were 27.38×10^{-6} for adult and 31.00×10^{-6} for children in factory water, respectively. In peripheral water, they were 27.10×10^{-6} for adult and 31.17×10^{-6} for children, respectively. The major contributor was the carcinogens for the total risk value. Both off-work water and pipe water made higher health risks to children than that to adults.

4. Discussion

Numerous literatures indicate that there have been hundreds kinds of chemical and organic pollutants in drinking water and water sources although concentrations of these contaminants may be low [9] [11]. Some of these possess long biological half-life period, such as lead and cadmium as long as 1460 days and 16 - 31 years respectively, and have biological accumulation and amplification effects on account of the food chain [12] [13]. It is well known that accumulation of toxic metals etc in the body can cause chronic injuries with long-term intake accompanying with drinking water ingestion. Risk assessment is fundamentally an attempt to quantify the possible health consequences of human exposure to particular circumstances [14]. Environmental health risk assessment on contaminants in drinking water can assess directly water comprehensive quality in response to health risk per one year [2]. According to classification of chemicals administrated by the US EPA, contaminants in drinking water may be subdivided into two main groups, namely genetic toxic and non-genetic toxic substances [3] [4]. Hexavalent chromium, arsenic and cadmium discussed herein belonged to the genetic toxic substance which could cause inherited gene defects and carcinogenicity [12] [13]. The twelve kinds of materials mentioned in this study such as iron, manganese, lead, fluoride, volatile phenol, cyanide, mercury, ammonia nitrogen, nitrate, copper, zinc and selenium, were attributed to the non-genetic toxic compounds which may result in adverse health effects under some circumstances because of human exposure. For the genetic toxic pollutants in the produced and peripheral water, its carcinogenic risks derived from this study were 25.60×10^{-6} and 23.47×10^{-6} per one year for adults, and 28.51×10^{-6} and 26.08×10^{-6} per one year for children, respectively. Similarly, non-carcinogenic risks based on the non-genetic chemicals in the factory and pipe water were 1.78×10^{-6} and 3.63×10^{-6} per one year for adults, and 2.49×10^{-6} and 5.09×10^{-6} per one year for children, separately. Therefore, as described above, we concluded that the total human health risks including the three kinds of genetic toxic materials and twelve types of non-genetic toxic substances were 27.38×10^{-6} (factory water) and 27.10×10^{-6} (peripheral water) per one year for adults, and 31.00×10^{-6} (factory water) and 31.17×10^{-6} (peripheral water) per one year for children, respectively. On the basis of the maximum tolerable risk level (5.0×10^{-5} per one year)recommended by the International Commission on Radiation Protection (ICRP) [8] [9], Shenzhen water supply is considered to be safe and protective for public health within the scope of risk value.

These results also revealed that among the water pollutants, hexavalent chromium was the most toxic genetic substance and fluoride and lead among the non-genetic toxicants whose harms to human were the most serious. Furthermore, the mean fluoride concentration increased in the process of water allocation from factory to pipe and the mean lead content changed little, which mechanism is still no known and the implications of this should be further explored. In addition, it showed from this study that the genetic toxic chemicals are greater risk comparing with the non-genetic substances, and the rather risk of children than adults. It should be pointed out that, of course, some uncertainty factors should be taken into account, such as only considering drinking water exposed way, representativeness on exposure parameters and characteristics because of different race and living habits between the eastern and western population, and so on [7] [8] [11]. Therefore, it is basic and key for health risk assessment that sensitive detection techniques on water contaminants and database establishment on Chinese exposure parameters and characteristics.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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