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Assessment of Regional Groundwater Quality Based on Health Risk in Xi'an Region, P.R. China

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To reveal the relationship between the dynamic change of groundwater quality and human health, this paper uses the shallow groundwater in Xi'an region as the research object, introduces the health risk assessment into the dynamic study of regional groundwater and finally implements a dynamic assessment of the health risk associated with regional groundwater. The results show that the primary carcinogen in the shallow groundwater of Xi'an region is arsenic, with a carcinogenic risk exceeding the standard rate by 26.3 %. The primary non-carcinogenic chronic toxicity is nitrate, with a 50.66 % non-carcinogenic toxicity risk among the total non-carcinogenic risks. Besides, even for the groundwater satisfying the national standards for drinking water, its arsenic and nitrate pose potential risks for human health. There are generally declining tendencies for both the carcinogenic risk and the non-carcinogenic chronically toxic risk caused by toxic substances in groundwater, with exceptions for certain substances which still exceed maximum acceptable values recommended by US EPA. Therefore, it is extremely necessary for long-term observations and health risk management, especially in those high-risk regions with poorer groundwater quality. In that way, the adverse influences by chemical substances in the groundwater will be reduced for the health of drinking populations.

Keywords: Health risk assessment, Groundwater, Xi'an region.

INTRODUCTION

Groundwater dynamics refers to major indicators showing the change of various factors, which show the volume and quality of groundwater (including water level, flow, quality and temperature, *etc*.) over time and how it response to human activities, climate change, vegetation succession, *etc*. has become a hot academic topic presently[1-3]. The conventional groundwater dynamics monitoring could provide fundamental data for assessment of regional groundwater quality, drinking water quality and pollution. However, the present water quality assessment based on health standards for drinking water could not directly reflect how a specific index exerts an influence on human health. Therefore, in order to reveal the relationship between regional groundwater quality and human health, this paper introduces the health risk assessment into a regional groundwater dynamic assessment and obtains better understandings on the shallow groundwater-associated health risk and its tendency, thus providing scientific basis for the safety of regional drinking water.

Health risk assessment was an emerging research field in the last 80s. It was featured by taking degree of risk as the assessment indicator, quantitatively describing the risk pollution would cause to human health[4]. The present health risk assessments are mostly implemented based on monitored data of heavy metal and organic pollutants in surface water, groundwater and soil[5-7], but the health risk assessments of regional shallow groundwater quality are relatively less.

Xi'an region is located in the southern part of Wei river alluvial plain, adjacent to Wei river and Qinlin mountain at its north and south, respectively, lying southeast high and northwest low with a ladder-like gradually inclining distribution. It belongs to warm temperate and semi-humid continental monsoon climate zone. The types of ground water are primarily bedrock fissure water and pore water in loose sediments. The ground water is recharged by precipitation, seepage of stream and side run-off[8]. According to the 2007 Water Resources Statistical Yearbook of Shaanxi Province, published by Shaanxi Provincial Water Resources Bureau, groundwater composed, respectively 47.7 and 96.0 % of urban and rural residential drinking water in Xi'an region in 2007. Moreover, the produced quantity of shallow groundwater composed 86.7 % of that of the total groundwater. Therefore, the shallow groundwater is an important resource of residential drinking water in Xi'an region. Due to the emission of industrial "three wastes", the utilization of pesticides and chemical fertilizers and the random dumping of solid wastes, toxic substances have been detected to varying degree and become a potential threat to human health[9].

Therefore, this paper views shallow groundwater in Xi'an region as the study object, uses the dynamically monitoring information as the fundamental data, applies the US EPA health risk assessment model[10] and implements a dynamic health risk assessment on regional groundwater, setting an example for dynamic researches on regional shallow groundwater.

EXPERIMENTAL

Data sources: The monitored data of groundwater quality comes from Geological Environment Monitoring Station of Shaanxi Province. There are totally 21 monitoring points (Fig. 1), with a total time series ranging from 1996 to 2005. The monitored objects are mainly 15 indicators, including total dissolved solids (TDS), hardness, chloride, sulfate, ammonium nitrogen, nitrate, nitrite, fluorine, hexavalent chrome, arsenic, phenol, lead, manganese, ferrum, pH, *etc*. Compared to the environmental quality standards for groundwater (GB/T14848-93)[11], several indicators have exceeded the standards at different degrees, such as TDS, hardness, nitrate, fluorine, hexavalent chrome, sulfate, manganese, ferrum, *etc*. The monitored data and how parts of it exceeded the standards in 2005 are shown in Table-1.

Theory and methods for groundwater health risk assessment: Groundwater health risk assessment is the quantitative method to evaluate the relationship between harmful substances in groundwater and human health, including four assessment modes *i.e.*, hazard diagnosis, dose-effect analysis, exposure assessment and risk characterization. On the basis of the dynamic monitoring of regional groundwater quality and the toxic chemical substances listed in the basic information sheet for superfund health risk assessment used in the US EPA[12], the harmful or potentially harmful substances in groundwater could be located and furthermore, the substances used in risk assessment could be ensured. At present, in the domestic dynamic monitoring of groundwater, the monitored objects are mainly confined to inorganic substances and heavy mental, thus the dynamic health risk assessment of groundwater uses actual monitored objects as assessment indicators.

There are two channels through which the substances in groundwater enter human bodies *i.e.*, drinking and bathing. As there are relatively more uncertainties in the health risk assessment associated with bathing, in this paper, we will not take the health responses associated with bathing into consideration. According to the dose-effect assessment results, the substances to evaluate could be divided into the carcinogenic and the non-carcinogenic. The health risk assessment models proposed by the US EPA[10], namely the carcinogenic risk assessment model and the non-carcinogenic risk assessment model[13,14], are utilized as our assessment models.

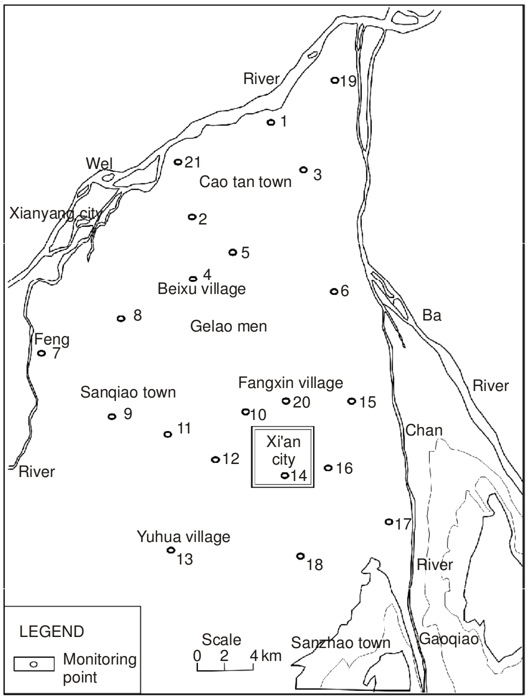


Fig. 1. Monitoring points distribution map of study area

Carcinogenic risk assessment model: Generally, when the human body is exposed to low-dose carcinogen, carcinogenic risk is linearly related to exposed dose. When a high carcinogenic risk is caused by high-dose carcinogen, carcinogenic risk is exponentially related to exposed dose. The above relations could by mathematically expressed as[10,13-15]:

$$\begin{cases} R = E \times SF \\ R = 1 - \exp(-E \times SF) \end{cases} \qquad (1)$$

$$E = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad (2)$$

TABLE-1
STATISTICAL TABLE OF SHALLOW GROUNDWATER QUALITY FOR XI'AN REGION IN 2005

Monitored objects	Monitoring points	Points exceeding standards	Rate of exceeding standards (%)	Measuring range (mg/L)	Average (mg/L)
TDS	21	6	28.6	122-1146	769.76
Hardness	21	10	47.6	40.5-674.4	408.88
Chloride	21	0	0	4.09-113	68.18
Sulfate	21	1	4.8	2.19-264	103.21
Nitrate	21	4	19.0	1.36-169	43.89
Arsenic	21	0	0	<0.0003-0.0096	0.0023
Fluorine	21	1	4.8	0.04-1.87	0.48
Hexavalent chrome	21	1	4.8	0.0075-0.055	0.025
Nitrite	21	4	19.0	0.001-1.37	0.18
Manganese	21	9	42.8	0.07-7.24	1.08
pH	21	0	0	7.06-8.78	7.55
Ferrum	21	6	28.6	0.36-8.25	2.95

where R is the carcinogenic risk caused by drinking groundwater, E is exposed dose, SF is carcinogenic gradient coefficient of carcinogen $(mg/(kg\ d))^{-1}$, C is concentration (mg/L), IR is daily drinking volume, suggested volume for adults is 2 (L/d) and EF is exposure frequency, set as 365d/a. ED is duration of drinking water, which indicates the number of years to ingest carcinogens in one's whole life. BW is average personal weigh, set as 70 kg. AT is average exposure duration(d), the carcinogenic effect is equal to 70a × 365d/a and the non-carcinogenic effect is equal to 30a × 365d/a.

Non-carcinogenic risk assessment model: Generally, the reference dose is used as a measurement standard for the chronically non-carcinogenic hazard. In other words, when the exposure dose of chemical substances outweighs the reference dose, the toxic effect is likely to occur. This hazard is measured by risk coefficient (HI), which refers to the ratio between the exposure dose of chemical substances and the reference dose. Risk coefficient could be mathematically expressed as[10,13-15]:

$$HI = \frac{E}{RfD} \quad (3)$$

where RfD is the reference dose of chemical substances in groundwater (mg/(kg d)).

When a chemical substance has specially both carcinogenic and non-carcinogenic chronic hazard, it is necessary for carcinogenic and non-carcinogenic risk assessments to be synchronically implemented.

Total risk assessment: Using formula (1) and (3), only the carcinogenic risk degree and the non-carcinogenic risk coefficient of a certain target object in groundwater could be calculated. As there are multiple substances in groundwater, the total carcinogenic risk (or non-carcinogenic risk) should be the summation of the multiple carcinogenic risks (or non-carcinogenic risks) and are shown as follows[14]:

$$TR = \sum_{i=1}^{n} R_i \quad (4)$$

$$THI = \sum_{j=1}^{m} HI_j \quad (5)$$

where TR is the total carcinogenic risk in one's whole life through drinking groundwater, THI is the total non-carcinogenic risk indicator in one's whole life through drinking groundwater, n is the total number of carcinogens in groundwater and m is the number of non-carcinogenic chronically toxic substances in groundwater.

Standards for risk assessment: The maximum acceptable value for carcinogenic risk, recommended by International Commission of Radiation Protection (ICRP), is $5.0 \times 10^{-5}\ a^{-1}$ and that recommended by the Swedish Environmental Protection Agency and the Department of Built Environment in Holland is $1.0 \times 10^{-6}\ a^{-1}$. According to the suggestions of the US EPA, the maximum acceptable values for carcinogenic risk of Type-A, Type-B, Type-C carcinogen are, respectively 1.0×10^{-6}, 1.0×10^{-5} and $1.0 \times 10^{-4}\ a^{-1}$ [10,16], with increasing acceptable limits. As "1" is set as the assessment reference for total non-carcinogenic risks, if that risk coefficient outweighs 1, the total non-carcinogenic risk is relatively high in an unacceptable risk range. Otherwise, it will be relatively low in an acceptable risk range.

Assessment index and model parameter: According to the attribute data of health risk assessment, released by the website of the US EPA[12] and the monitoring information on groundwater quality, chemical carcinogens in this region include hexavalent chrome and arsenic and non-carcinogens include ammonium nitrogen, nitrate, nitrite, fluorine, ferrum, manganese, phenol, *etc*. However, as the monitored value of phenol is even lower than the detectable threshold, it will not be considered in this risk assessment.

There are merely two types of parameters which are the carcinogenic gradient coefficient SF of chemical carcinogen and the reference dose RfD of non-carcinogen in the risk characterization, evaluated according to the health risk assessment standards by the US EPA. Specifically speaking, the carcinogenic gradient coefficients of arsenic and hexavalent chrome are 1.5 and $7.3 \times 10^{-3}\ (mg\ kg^{-1}\ d^{-1})^{-1}$, respectively. And the reference doses of hexavalent chrome, arsenic , ammonium nitrogen, nitrate, nitrite, fluorine, ferrum and manganese are 3.0×10^{-3}, 3.0×10^{-4}, 0.97, 1.6, 0.1, 0.06, 0.3 and 0.14 $(mg\ kg^{-1}\ d^{-1})$, respectively[10,16].

RESULTS AND DISCUSSION

Health risk assessment for groundwater: The health risk associated with water quality in 21 monitoring points, exposing to a certain substance between 1996 to 2005, have been calculated in accordance with the above relevant mathematical model and parameters in health risk assessment. The results of health risk assessment for groundwater in 2005 are listed in Table-2. From the risk assessment results of shallow groundwater in 1996-2005, it can be seen that the health risk of arsenic is 2.14×10^{-6}-7.07×10^{-4} and that of hexavalent chrome is 2.09×10^{-7}-6.67×10^{-5}. According to the health risk assessment standards given by the US EPA, the maximum acceptable carcinogenic risk value of arsenic (Type-A carcinogenic substance) is $1.0 \times 10^{-6}\ a^{-1}$ and that of hexavalent chrome (Type-B carcinogenic substance) is $1.0 \times 10^{-5}\ a^{-1}$. So the health risk of hexavalent chrome in groundwater is partially (8.1 % of samples) higher than health risk assessment standards and that of arsenic is wholly (100 % samples) higher than health risk assessment standards, which has reached 707 times of the health risk assessment standard. According to systematical sampling analysis from a geological environment monitoring department, the aquifer is relatively rich in minerals containing arsenic. For example, the average arsenic concentration in water tight silty clay is 8.2 mg/L, which fully illustrates that the background value of arsenic in groundwater is relatively high[17]. Therefore, the maximum acceptable value $5.0 \times 10^{-5}\ a^{-1}$, recommended by International Commission on Radiological Protection (ICRP), is used to evaluate the health risk of arsenic. The results show that the health risk of arsenic in groundwater could at most exceed 14.14 times to the standard recommended by ICRP, with a 26.3 % possibility of samples to exceed. The carcinogenic risk of arsenic is 80.43-99.42 % of the total carcinogenic risk, with that of hexavalent chrome taking another 0.58-19.57 %. All in all, arsenic is the primary carcinogenic substance in the regional shallow groundwater.

TABLE-2
HEALTH RISK ASSESSMENTS FOR SHALLOW GROUNDWATER IN 2005

No.	Arsenic	Hexavalent chrome	Total carcinogenic risk	Arsenic	Hexavalent chrome	Nitrate	Nitrite	Fluoride	Manganese	Ferrum	Ammonium nitrogen	Total non-carcinogenic risk
1	6.43E-05	5.21E-07	6.48E-05	0.333	0.0556	0.0698	1.33×10^{-3}	0.139	0.0524	0.296	3.44×10^{-4}	0.947
2	2.04E-04	5.21E-07	2.04E-04	1.06	0.0556	0.0615	1.00×10^{-3}	0.0222	0.031	0.917	3.44×10^{-4}	2.14
3	6.43E-06	5.21E-07	6.95E-06	0.0333	0.0556	0.0283	3.33×10^{-4}	1.04	0.0333	0.606	3.44×10^{-4}	1.8
4	2.36E-05	1.04E-06	2.46E-05	0.122	0.111	0.396	4.00×10^{-4}	0.256	0.0119	0.0111	3.44×10^{-4}	0.948
5	8.14E-05	5.21E-07	8.20E-05	0.422	0.0556	2.85	3.67×10^{-3}	0.106	0.0167	0.0111	3.44×10^{-4}	3.47
6	5.36E-06	1.04E-06	6.40E-06	0.0278	0.111	1.75	2.67×10^{-3}	0.128	0.0167	0.0111	3.44×10^{-4}	2.05
7	4.71E-05	1.04E-06	4.82E-05	0.244	0.111	2.25	3.33×10^{-3}	0.0667	0.0119	0.0111	3.44×10^{-4}	2.7
8	5.79E-05	1.88E-06	5.97E-05	0.3	0.2	1.97	4.67×10^{-3}	0.528	0.0119	0.0111	3.44×10^{-4}	3.02
9	3.21E-05	7.82E-07	3.29E-05	0.167	0.0833	0.86	4.00×10^{-3}	0.306	0.0119	0.0111	3.44×10^{-4}	1.44
10	1.63E-05	5.21E-07	1.68E-05	0.0844	0.0556	0.041	3.33×10^{-4}	0.122	0.0119	0.0411	3.44×10^{-4}	0.357
11	3.43E-05	5.74E-06	4.00E-05	0.178	0.611	0.796	5.33×10^{-2}	0.189	0.0119	0.0111	3.44×10^{-4}	1.85
12	2.06E-04	5.01E-06	2.11E-04	1.07	0.533	1.15	8.67×10^{-3}	0.4	0.0119	0.0111	3.44×10^{-4}	3.18
13	7.07E-06	5.21E-07	7.59E-06	0.0367	0.0556	0.0721	3.33×10^{-4}	0.3	0.231	0.04	3.44×10^{-4}	0.736
14	4.71E-05	1.15E-06	4.83E-05	0.244	0.122	3.52	2.13×10^{-2}	0.361	0.0119	0.0111	3.44×10^{-4}	4.29
15	2.01E-05	1.04E-06	2.12E-05	0.104	0.111	0.973	3.33×10^{-4}	0.15	–	0.0111	3.44×10^{-4}	1.35
16	2.14E-05	2.40E-06	2.38E-05	0.111	0.256	1.57	1.00×10^{-3}	0.172	1.72	–	1.72×10^{-4}	3.83
17	1.95E-05	5.21E-07	2.00E-05	0.101	0.0556	0.54	8.67×10^{-3}	0.144	0.0119	0.0111	3.44×10^{-4}	0.873
18	1.37E-05	5.21E-07	1.42E-05	0.0711	0.0556	0.0825	3.33×10^{-4}	0.0278	0.0357	0.0111	3.44×10^{-4}	0.284
19	1.37E-05	5.21E-07	1.42E-05	0.0711	0.0556	0.133	3.34×10^{-1}	0.489	0.193	0.0111	3.44×10^{-4}	1.29
20	8.14E-06	1.04E-06	9.19E-06	0.0422	0.111	0.0581	3.33×10^{-4}	0.0278	0.0929	0.0667	3.44×10^{-4}	0.399
21	3.86E-05	5.21E-07	3.91E-05	0.2	0.0556	0.0296	4.57×10^{-1}	0.389	0.381	0.00111	3.44×10^{-4}	1.51

Risk assessment for non-carcinogenic chronically toxic hazards: As for the risk assessment for non-carcinogenic chronically toxic hazards, the risk values of arsenic, hexavalent chrome, ammonium nitrogen, nitrate, nitrite, fluorine, ferrum and manganese are 1.0×10^{-2}-1.28×10^{1}, 1.11×10^{-2}-6.44×10^{0}, 6.87×10^{-5}-3.95×10^{-1}, 1.04×10^{-3}-1.83×10^{1}, 2.67×10^{-4}-2.69×10^{0}, 5.56×10^{-3}-1.28×10^{0}, 4.44×10^{-4}-1.91×10^{0} and 4.76×10^{-3}-1.72×10^{0}, respectively. And those show that ammonium nitrogen does not cause chronically toxic effect to the drinking populations, while arsenic, hexavalent chrome, nitrate, nitrite, fluorine, ferrum and manganese are likely to affect. In a 10-year continuous monitoring, the degrees of contribution of certain substances, including arsenic, hexavalent chrome, ammonium nitrogen, nitrate, nitrite, fluorine, ferrum and manganese, toward the total non-carcinogenic risk are 0.56-94.14, 1.25-89.44, 0.002-20.66, 0.1-95.12, 0.002-74.6, 0.28-76.19, 0.07-79.41 and 0.02-83.92 %, respectively. And their average degrees of contribution are, respectively 11.61, 18.10, 0.23, 50.66, 2.27, 13.09, 2.61 and 1.44 %. Therefore, nitrate is the primary non-carcinogenic chronically toxic substance in the regional groundwater. Based on a comprehensive consideration of the results of carcinogenic and non-carcinogenic chronically toxic risk assessment, water quality in 16 out of 21 dynamically monitoring points in Xi'an region may jeopardize the human health. In other words, 76.2 % of all the monitoring points are in hazard, indicating a severe safety situation of the groundwater in this region.

Comparison between health risk assessment and drinking water quality assessment: As a carcinogenic substance in groundwater, arsenic plays a potential toxic role to jeopardize the drinking population[18]. There have been many researches showing that, for the regions including Taiwan, Japan, Bangladesh, Chile, Argentina, *etc*., the populations exposed to arsenic-polluted water sources are highly risked by skin cancer, lung cancer, liver cancer, *etc.*[19]. Generally, we hold a viewpoint that, when the arsenic concentration in groundwater of studied region is lower than the arsenic limiting value of the national drinking water standards (GB5749-2006)[20], namely when the drinking water standards are applied to evaluate the groundwater quality in the studied region, the groundwater quality in this region will be safe to human health. However, from the results of health risk assessment, arsenic in the shallow groundwater poses carcinogenic risks to drinking populations. Previous researchers have also monitored and evaluated risks of groundwater in a certain region along Huaihe river in China, showing the arsenic concentration to be 0.72-3.34 μg/L and the value of carcinogenic risk[21] to be 1.55×10^{-5}-7.15×10^{-5}. For the drinking water sources of Huangpu river upstream in Shanghai, the arsenic concentration is 0.609-5.085 μg/L, with a value of carcinogenic risk[22] of 0.4×10^{-5}-0.42×10^{-5}. After monitoring and analyzing the groundwater quality of a certain city in Shandong province, the arsenic concentration turned out to be 4.0-10.0 μg/L, with a value of carcinogenic risk[23] of 2.69×10^{-5}-6.72×10^{-5}. The arsenic concentrations in all these regions have met the national drinking water standards (GB749-2006), while the corresponding values of carcinogenic risk are all greater than 10^{-6}. Consequently, even exposed to a low concentration of arsenic, the carcinogenic risk will increase[24,25].

As one of the most common pollutants in the world[26], nitrate is also the primary non-carcinogenic substance in the shallow groundwater in the study region. If there is a high level of nitrate in drinking water, infants will be more susceptible to methemoglobinemia and adults will be more prone to diseases, including gastric cancer[27,28]. According to the assessments on the basis of national drinking water standards (GB5749-2006), the nitrate in groundwater has 19 % possibility to exceed the standards. The health risk assessment results show 33.3 % possibility to exceed the assessment reference for non-carcinogenic risk and indicate that the 33.3 % non-carcinogenic chronically toxic risk associated with nitrate in groundwater is in an unacceptable range. In more straightforward statement, the nitrate in the shallow groundwater is not safe for human health. According to the national drinking water standards (GB5749-2006), groundwater whose nitrate nitrogen higher than 12.6 mg/L falls into the category of drinkable water, while still poses a high risk for human health. In that way, the drinkable water in the conventional sense is not always safe for human health[29].

Comparison between the health risk assessment and drinking water quality assessments on arsenic in shallow groundwater, together with nitrate, the groundwater which satisfies national drinking water standards may pose potential health risk, which alerts relevant authorities to jointly utilize multiple assessments methods for a comprehensive assessment in regional groundwater management. In that way, prompt measures will be taken to reduce the adverse influence associating with groundwater on human health.

Variation trend of health risk associated with shallow groundwater: Fig. 2 is the graph of the ratio between carcinogenic risk and the maximum acceptable value of carcinogenic risk, recommended by ICRP, as the vertical axis and time as the horizontal axis. It shows that, the carcinogen including arsenic and chrome manifest apparently alternating high and low tendency, with peak values reaching around year 1999, 2002 and 2004. Although the reasons for carcinogenic risk peak in 1999 being obviously higher are yet to be investigated, the variation trend of general carcinogenic risk in shallow groundwater is not affected by this fact. Although there is a declining tendency of total health risk associated with carcinogen in the groundwater toward the drinking population, the ratio of carcinogenic risks in some monitoring points are still larger than 1.0, indicating potential carcinogenic risks for the drinking populations of groundwater.

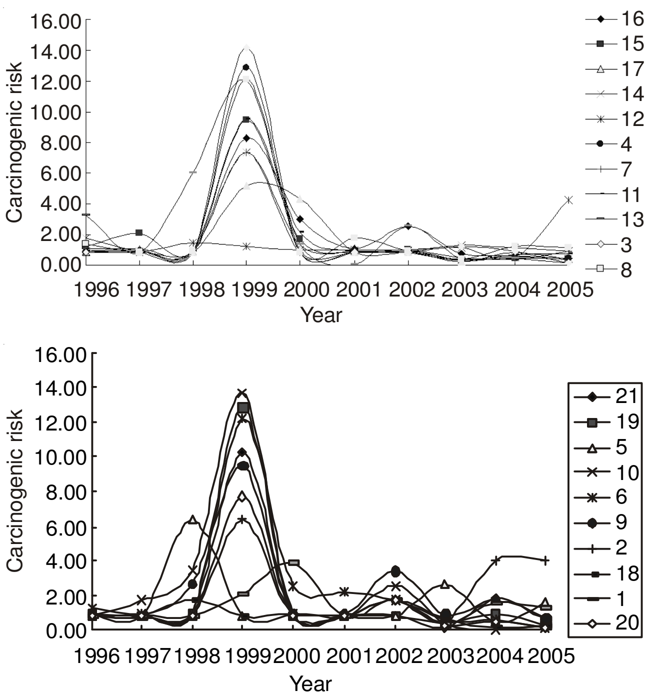
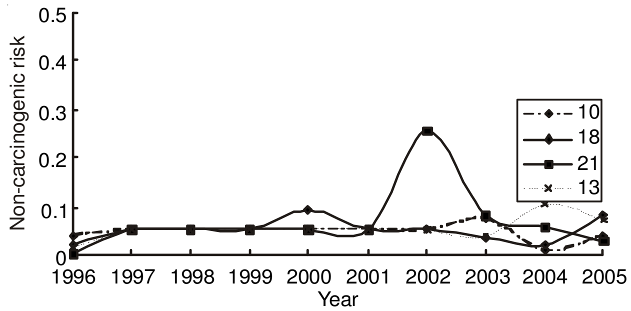
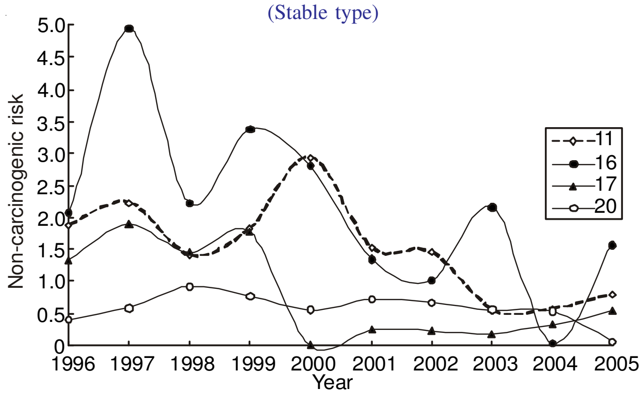


Fig. 2. Carcinogenic risk *vs*. year for groundwater consumers

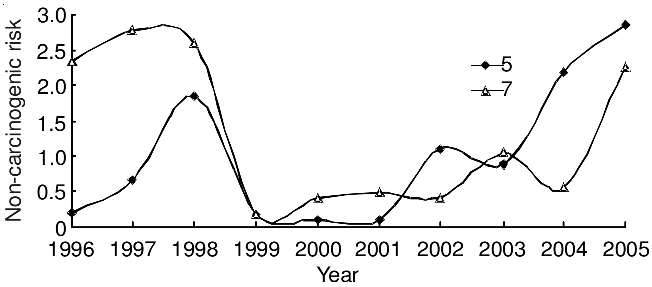
As the non-carcinogenic chronically toxic risk of nitrate accounts for 50.6 % of the total non-carcinogenic chronically toxic risk in this paper, the variation tendency of the total non-carcinogenic risk is approximately evaluated by measuring the dynamic changes in the non-carcinogenic chronically toxic risk of nitrate. Fig. 3 shows the dynamic curves of the non-carcinogenic chronical risk, associated with nitrate in the groundwater, toward the drinking populations. Three variation characteristics could be classified. The first character is stable type, in which the value of non-carcinogenic risk roughly remains constant over time. Besides, these values are far less than 1.0. Good illustrations include monitoring point 18, 21, 10, 13, *etc*., which are mainly located in the suburb and rural areas. The second character is oscillating continuously declining type, which is featured in an increase of non-carcinogenic risk value in the late last 90s and following declining trend in recent years. The examples include monitoring point 15, 11, 17, 20, *etc*., which are mainly located in places, such as Shuyuanmen, Tumen, Xinguomen and Fangxincun, *etc*. These places were previously shantytowns and vegetable cultivation area and at present have became economic and development zones with complete municipal facilities, thus the pollution sources attributing to nitrate pollutions have been reduced. Another reason for declining comes from the fact of natural attenuation of nitrate in groundwater[26-29]. In these ways, the nitrate in shallow groundwater gradually declines. The third character is declining followed by increasing type, which is featured in a decline of non-carcinogenic risk in the last 90s, followed by an apparent increase between 2003 and 2005, with non-carcinogenic risk values higher than the acceptable limit by the drinking populations. The examples include monitoring point 7 and 5 in Gelaomen and Huangjiapo village. An attempting inference is that, due to the aging and damage of municipal sewage pipes, leakages of unprocessed sewage and waste water cause an increase of nitrate concentration in groundwater, followed by an increase of health risk for drinking populations[30]. Overall, the non-carcinogenic risk, associated with groundwater, toward drinking populations shows a declining tendency, while that may still be locally high and further exert a non-carcinogenic toxic effect toward drinking populations.



(Stable type)



(Oscillating continuously declining type)



(Declining followed by increasing type)

Fig. 3. Non-carcinogenic risk *vs.* year for groundwater consumers

From the above discussions, it can be seen that the carcinogenic risk and non-carcinogenic chronically toxic risk generally show oscillating declining trends, while poorer groundwater quality in some areas still pose health risks toward drinking populations. Besides, the health risk assessment which target on monitored data of groundwater for a single time may subject to high uncertainty, thus could not fully reflect the actual situation of health risk associated with regional groundwater. Therefore, long-term observations on groundwater are necessary to increase the accuracy of water quality health risk assessment, thus provide scientific basis for water quality risk management and rational development and utilization. At the same time, several individual scholars have been aware of the significance of the dynamic monitoring of groundwater quality toward its health risk management[31].

Conclusion

The health risk caused by the chemically carcinogenic substance, arsenic, in the shallow groundwater of Xi'an region has exceeded the standard by 26.3 % and that of hexavalent chrome has exceeded by 8.1 %. Also, the non-carcinogenic chronically toxic substance is primarily nitrate, with a 50.66 % non-carcinogenic toxicity risk among the total non-carcinogenic risks. After a comprehensive consideration of the carcinogenic and non-carcinogenic toxicity risk, the groundwater quality in 76.2 % monitoring points may jeopardize the health of water-consuming residents.

After a comparative analysis for health risk assessment and drinking water quality assessment, there may still be risks for the groundwater satisfying the national standards for drinking water. This is a hint for relevant authorities to comprehensively evaluate after synchronically using multiple assessment methods in their groundwater quality management. In order to increase the accuracy in health risk assessment and fully reflect the actual situation of the regional groundwater health risk, it is quite necessary to implement long-term observations and management on groundwater, especially for those groundwater high-risk regions.

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