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ORIGINAL PAPER

Assessment and Causes of Groundwater Organic Pollution in Typical Plain Areas in Xinjiang, China

Yanyan Zeng[1,2] · Jinlong Zhou[1,2] · Yinzhu Zhou[3] · Ruiliang Jia[1,2]

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Abstract To study the organic pollution situation in groundwater in plain areas in Xinjiang, Shihezi region (SHZ), plain area of Yanqi Basin (YQ) and Ruoqiang-Qiemo area (RQ) were selected as the typical areas. 83 groundwater samples were collected, tested, and analyzed for 39 organic indexes for the first time. Results showed that the local groundwater in SHZ, YQ, and RQ had been slightly affected by organic pollution with the detection rates of 8.7, 33.3, and 33.3 %, respectively. Seven organic pollutants were detected, including chloroform (with the highest detection rate of 21.7 %), 1,2-dichloroethane, 1,2-dichlorobenzene, toluene, benzo(a)pyrene, α-BHC, and γ-BHC. The contents of all the detected organic pollutants were low, which were under the limits of the "*Standards for Drinking Water Quality* (GB5749-2006)". Vertical distribution of detection rates was that in SHZ, shallow confined groundwater (12.5 %) > deep confined groundwater (10.0 %) > unconfined groundwater (0.0 %); in YQ, unconfined groundwater (66.7 %) > deep confined groundwater (29.2 %) > shallow confined groundwater (25.0 %); in RQ, shallow confined groundwater (66.7 %) > unconfined groundwater (33.3 %) > deep confined groundwater (16.7 %). The sources and properties of organic pollutants were the main factors that affected groundwater organic pollution in the study areas. The infiltration recharge of surface water mainly affected groundwater organic pollution in SHZ and YQ. Besides, the vadose zone had a certain restriction on the occurrence and migration of groundwater organic pollution components in RQ. Direct discharge of sewage came from human life and production without treatment, and leakage due to crude anti-seepage facilities had led to groundwater organic pollution. The organic wastewater produced in livestock and poultry breeding, chemical fertilizers, and insecticides in agricultural activities were also the main sources of groundwater organic pollution.

Keywords Groundwater · Organic pollution · Detection rates · Typical areas in Xinjiang

✉ Jinlong Zhou
zjzhoujl@163.com

[1] College of Water Conservancy and Civil Engineering, Xinjiang Agricultural University, Urumqi 830052, China

[2] Xinjiang Hydrology and Water Resources Engineering Research Center, Urumqi 830052, China

[3] School of Water Resources and Environment, China University of Geosciences, Beijing 100083, China

Introduction

Groundwater is the most important part of the water resource system, which plays a crucial role in ensuring supply of domestic water, industrial water, and agricultural water, maintaining ecological balance, and supporting social and economic development, with the irreplaceable function, especially in areas lack of surface water resources (Avtar et al. 2013; Yao et al. 2014). However, the increase of global population, expansions of industrialization and urbanization, and development of agricultural contribute to the intensifying human activities which lead to an increasing demand of groundwater and the risk of groundwater pollution. For example, the discharge of various wastewaters, infiltration of residential sewage, rupture of underground pipelines, and the extensive uses of pesticides and chemical fertilizers in agricultural production all cause severe groundwater pollution (Borden et al. 1995; Wang et al. 2012; Li et al. 2013). Due to high population density, intensifying human activities, increasing water

demand, and vulnerable environment, groundwater pollution has become one of the most serious problems relating to human survival since the twenty-first century in China, especially in the northwest (Wu and Sun 2015). Groundwater quality is deteriorating extremely rapidly (Li et al. 2012). Among the major contaminants (including heavy metals, nitrate, arsenic, fluoride, organic pollutants, etc.) (Li et al. 2014a; Wu et al. 2015), groundwater organic pollutants have diverse species which cannot be detected easily by means of routine methods of water-quality analysis due to small concentrations. Once contaminated, it is still difficult to recover to previous groundwater quality even after treatment (Seth et al. 2014). Groundwater organic pollution is complex and invisible. Therefore, to study groundwater organic pollution situation, monitor and predict its development, to take corresponding measures, and to remediate contaminated groundwater are crucial to environmental protection.

Previous investigations and researches on groundwater pollution in China were mainly focused on inorganic indexes with significant results achieved. However, as for researches on groundwater organic pollution, it is still at its preliminary stage in China. Since the 1990s, China Geological Survey (CGS) started to conduct pilot investigation on groundwater organic pollution in Beijing and Suzhou–Wuxi–Changzhou areas. Preliminary investigation results showed that groundwater organic pollution was present in these areas. Then, long-term investigations were conducted by CGS on groundwater organic pollution in economy-developed regions, such as the North China Plain, the Yangtze River Delta, the Pearl River Delta, and the Huang River-huai River-hai River Plain. The results showed that groundwater pollution range had been expanding with an overall deterioration of groundwater quality in China. Carcinogenic, teratogenic, and mutagenic organic pollutants, and the persistent organic pollutants (POPs) in groundwater were partly detected. However, due to a lack of systematic investigation and evaluation in the twentieth century in China, little general status of groundwater quality and pollution could be comprehensively known (Wen et al. 2012). Therefore, the first round of investigation and evaluation plan on groundwater pollution was initiated by CGS in 2005, aimed at finding out groundwater quality and pollution condition, and providing a basis for policy protection and rational use of water resources in China.

The establishment of the Silk Road Economic Belt is an exciting prospect that may bring enormous economic benefits to Eurasian countries (Li et al. 2015a). Silk Road Economic Belt has long been an important tie to promote idea and technology exchange between China and other Eurasian countries, and also contribution to development and long-term stability in Xinjiang. Xinjiang is the center of the Silk Road economic belt, as an important bridge to connect China and Central Asia, and then to Europe (Abudureyimu and Han 2014). However, with the revival of the Silk Road and increase of population and human activities, it may lead to an increasing environmental pressure (e.g., water resources) in Xinjiang (Libert et al. 2008; Li et al. 2015a). Xinjiang is a typical inland arid area located in the northwest of China with dry climate, scarce rainfall, strong evaporation, and a shortage of water resources. Groundwater is the dominant source of drinking water in Xinjiang (Li et al. 2014b). Hence, groundwater quality has an important impact on the safety of drinking water which relates closely to human health in Xinjiang. This is the first investigation (conducted in 2014) on groundwater organic pollution in typical areas in Xinjiang, which focused preliminarily on study of groundwater organic pollution status in study areas and analysis of the causes. It is of important guiding significance for groundwater protection in Xinjiang.

Study Area

The study areas are located in the typical areas of northern Xinjiang (SHZ) and the typical areas of southern Xinjiang (YQ and RQ) (Fig. 1).

Shihezi Region (SHZ)

SHZ (85°45′E 44°10′N ~ 86°20′E 45°00′N) is located in the middle of northern piedmont of Tianshan Mountain and the southern Gurbantonggut Desert in Xinjiang, which has a continental arid climate with an annual average temperature of 7.5–8.2 °C, annual precipitation of 180–270 mm, and annual evaporation of 1000–1500 mm (Dong et al. 2013).

SHZ (high in the south and low in the north) with an average altitude of 451 m is demarcated by the Urumqi-Yili highway, the south of which is a piedmont plain with single unconfined aquifer while the north of which is a multilayer confined aquifer. In the southern SHZ, the aquifer is mainly constituted of pebbles and gravel (Q_1–Q_4) with buried depth of unconfined groundwater from 15 to 80 m. The aquifer has loose structure, abundant pore, and good permeability. In the northern SHZ, the unconfined aquifer and shallow confined aquifer are distributed within the depth of 100 m. The unconfined groundwater overflows near the plain reservoirs in the north of Shihezi City. In the north of the overflow zone, the aquifer is mainly constituted of sandy loam and silt sand (Q_3–Q_4), as well as thin layers of sandy gravel and coarse–medium-grained sand in some parts. The depth of deep confined aquifer is less than 100 m where the multilayer confined groundwater and

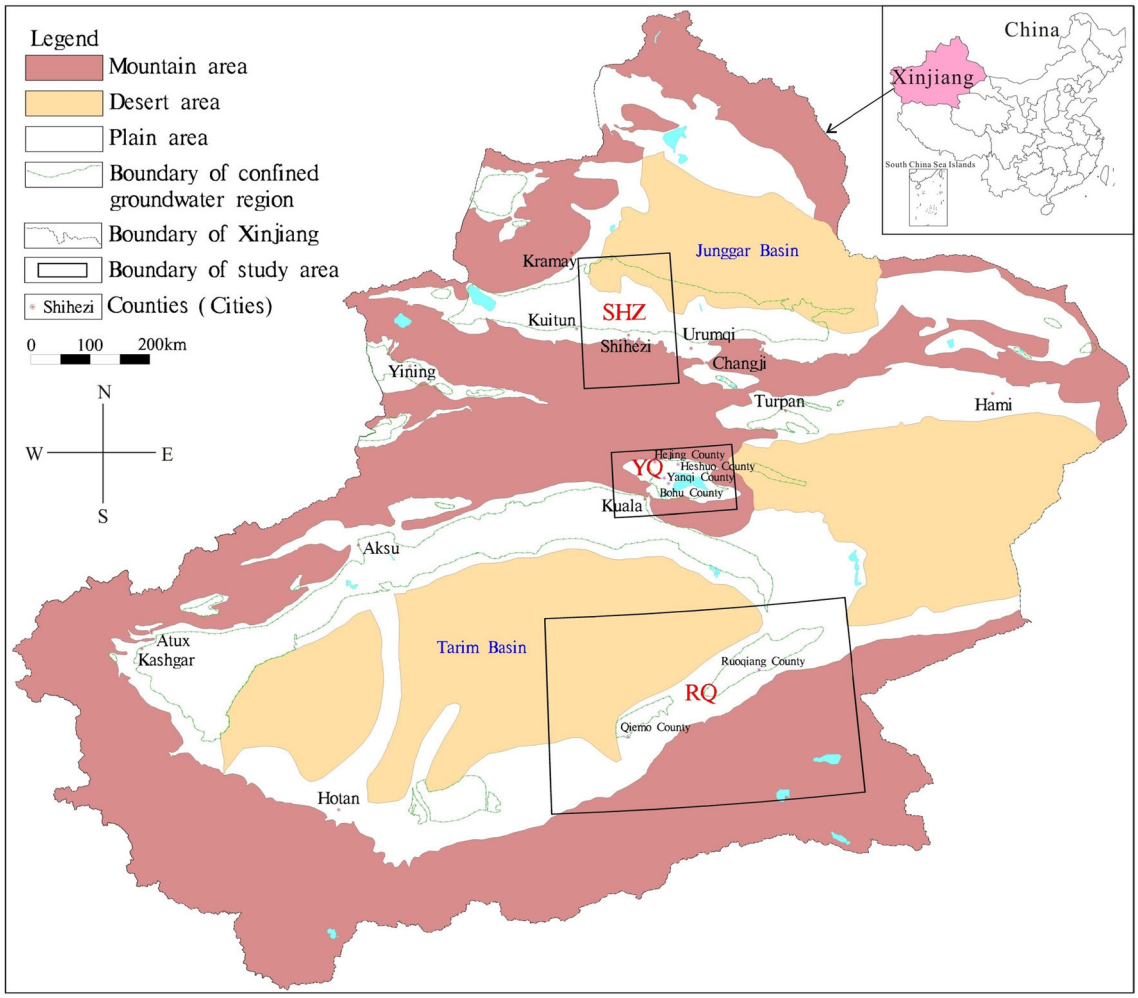

Fig. 1 Location of the typical areas in Xinjiang

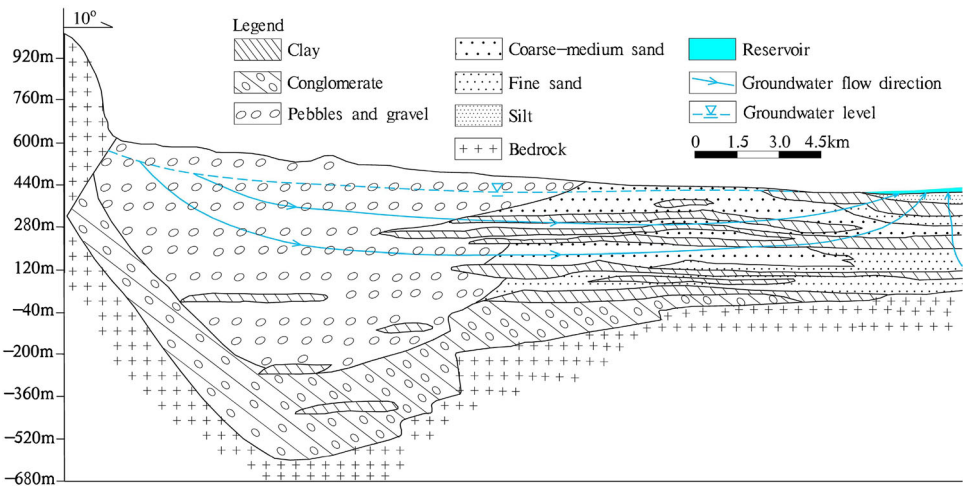

Fig. 2 Regional hydrogeological cross section in SHZ from south to north

artesian water are distributed. The aquifer is mainly constitutive of sandy gravel or sand layer (Q_3–Q_4) (Fig. 2) (Duan et al. 2007; Wu 2007; Li et al. 2015b).

Groundwater is mainly recharged by the leakage of river water and canal system water in SHZ. Besides, the infiltration of field irrigation water, spring melt water, plain

reservoirs water, and precipitation are also the recharge sources. The groundwater runoff condition is related to the lithology. As the aquifer particles size and water permeability decrease from south to north, the runoff conditions deteriorate. The major discharge forms of groundwater are spring water overflow, evaporation, and transpiration, artificial exploitation, and lateral outflow.

Plain area of Yanqi Basin (YQ)

YQ (85°30′E 41°45′N ~ 88°15′E 42°15′N) is located in the middle of southern piedmont of Tianshan Mountain, the northeastern Tarim Basin, and the northern Bayingolin Mongol Autonomous Prefecture in Xinjiang. It is composed of four counties, namely, Hejing County, Heshuo County, Yanqi County, and Bohu County, and eight farms belong to the Second Division of Xinjiang Production and Construction Corps. YQ is a typical oasis of arid climate with large temperature difference between day and night, scarce precipitation, and intensive evaporation.

YQ is a rhombus basin (high in northwest and low in southeast) surrounded by mountains. The surrounding mountains tilt from the basin margin to its center, the Bosten Lake. The basin is surrounded by the pre-Quaternary strata. The Quaternary alluvial and diluvial deposits, lakes, and marsh sediments distribute in the Basin. The Quaternary lithologic structure sees a gradual decrease of particle sizes from northwest to southeast in YQ, which mainly composed of sandy gravel, medium-coarse sand, medium-fine sand, sandy loam, and loam. The land slopes downward from the top of alluvial fan to the alluvial plain with a decreased slope from steep to gentle, and particle sizes change from coarse to fine (Fig. 3), which leads to the formation of single unconfined aquifer, upper unconfined–lower multilayer confined aquifer, and upper unconfined–lower multilayer confined artesian aquifer from the west and northwest piedmont alluvial–proluvial plain to the downstream alluvial plain (Wang 2013; Zhao et al. 2015).

Groundwater is recharged by lateral runoff, infiltration of river water, precipitation, and field irrigation water, and leakage of canal system water in YQ. While it is discharged by evapotranspiration, farmland drainage, discharge into river, merging into Bosten Lake, and artificial exploitation.

Ruoqiang-Qiemo Area (RQ)

RQ (84°00′E 36°00′N and 92°00′E 39°30′N) is located in the southeastern Bayingolin Mongol Autonomous Prefecture and the southern Tarim Basin in Xinjiang. The whole area is divided into the southern alpine area, the central oasis plain, and the northern desert. It is high in south and low in north, with the terrain tilting from southwest to northeast. There are 14 rivers in the territory, including Ruoqiang River, Washixia River, etc. RQ has an arid and a semiarid desert continental climate with four distinctive seasons, cold winter, heat, and dry summer, large temperature difference between day and night, long frostless period, small precipitation, and intensive evaporation.

There are mainly unconfined groundwater and confined groundwater in loose Quaternary sediments distributed in RQ. Aquifer is mainly constitutive of sandy gravel, sandy loam, and loam (Fig. 4). The aquifer in the southern part is a single unconfined aquifer with buried depths ranging from 6 to 38 m. Besides the unconfined groundwater, there is confined groundwater in the northern part with buried depths of confined groundwater ranging from 4 to 18 m (Lu 2007; Zeng et al. 2015).

Groundwater is mainly recharged by piedmont lateral runoff, and the infiltration of precipitation, irrigation water, canal system water, and river water in RQ. Groundwater runoff is intensive with flow direction consistent with surface water runoff (from south to north). Lateral runoff discharge into northern desert, intensive surface evaporation, and plant transpiration, and artificial exploitation are the major forms of groundwater discharge.

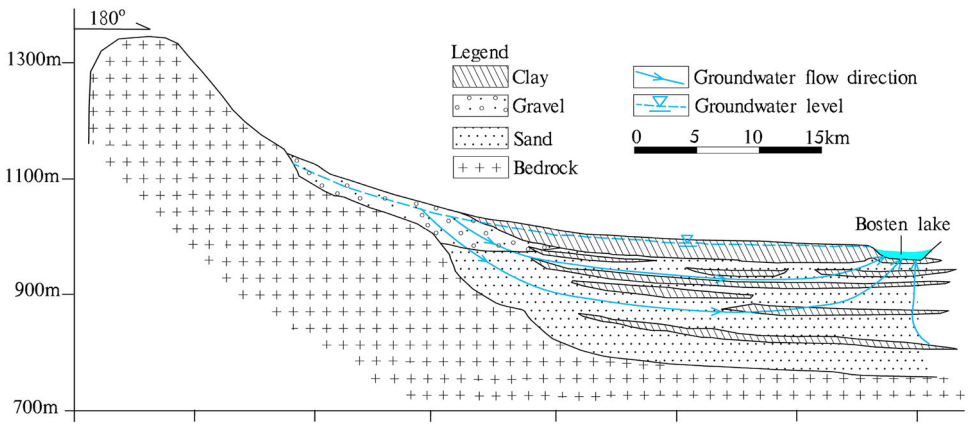

Fig. 3 Regional hydrogeological cross section in YQ from mountains to lake

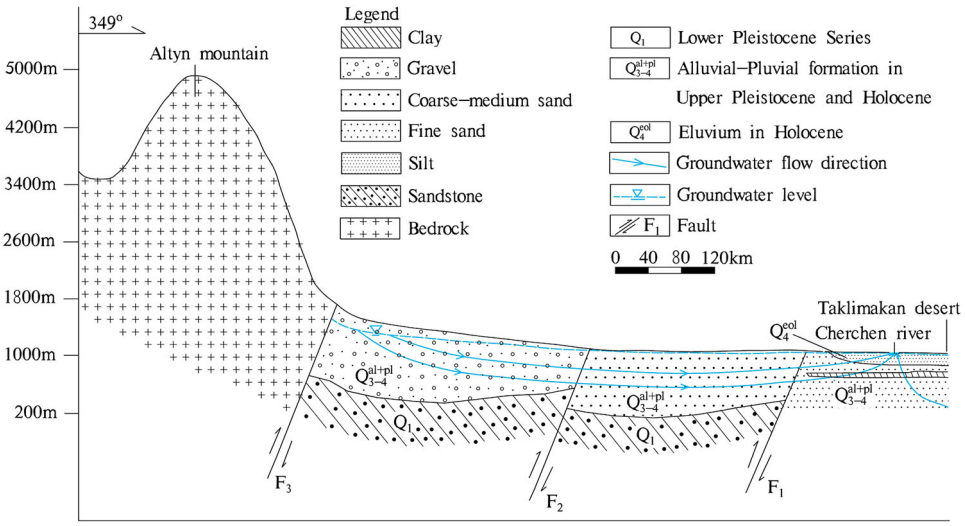

Fig. 4 Regional hydrogeological cross section in RQ from south to north

Materials and Methods

Groundwater Samples

Based on systematic integration of geographic, hydrogeological, and pollution information, groundwater pollution survey in the study areas was conducted with the accuracy of 1:250,000 according to the technical requirements of the *Geological Survey and Evaluation Criteria for Groundwater Pollution* (DD2008-01). The contaminated groundwater sampling points were laid out according to regional control combining with distribution characteristics of pollution sources in key areas. The groundwater and surface water sampling points were mainly distributed in the plain oasis. GPS was used to get the geographic coordinates of the sampling points. Groundwater types (unconfined groundwater, shallow confined groundwater, and deep confined groundwater) were determined according to regional hydrogeological mapping. In SHZ, there were 23 groundwater samples (five unconfined groundwater samples, eight shallow confined groundwater samples, and 10 deep confined groundwater samples) and five surface water samples collected in August 2014 with the control area of 2534 km^2. In YQ, there were 42 groundwater samples (six unconfined groundwater samples, 12 shallow confined groundwater samples, and 24 deep confined groundwater samples) and seven surface water samples collected in July 2014 with the control area of 8100 km^2. In RQ, there were 18 groundwater samples (nine unconfined groundwater samples, three shallow confined groundwater samples, and six deep confined groundwater samples) and five surface water samples collected in July 2014 with the control area of 9800 km^2. Distribution of sampling points is shown in Figs. 5, 6, and 7.

Quality Control and Determination of Water Samples

In this investigation, strict quality control was emphasized, including collection of field samples and laboratory determination. The purpose of quality control of field samples collection is to track erroneous and distorted data, which can help to propose improvement measures when dealing with inacceptable samples collection and error analysis, confirm the data correctness, and provide uncertainties of samples collection and measurement in the analysis of results. Incubator and ice were used for low-temperature preservation. Samples were transported to the laboratory for inspection as soon as possible. Besides, field blank samples, blank samples with the addition of standard samples and parallel samples were used for sampling reliability assessment.

Groundwater samples were determined at the Mineral Water Testing Center of Institution of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences which has been qualified by China Metrology Accreditation, China National Accreditation Service for Conformity Assessment (CNAS), and the Product Quality Supervision, and Inspection Center of the Ministry of Land and Resources. The detection items included 27 volatile organic compounds (vinyl chloride, 1,2-dichloroethylene, dichloromethane, trans-1,2-dichloroethylene, cis-1,2-dichloroethylene, chloroform, 1,1,1-trichloromethane, carbon tetrachloride, benzene, 1,2-dichloroethane, trichloroethylene, 1,2-dichloropropane, bromodichloromethane, toluene, 1,1,2-trichloroethane, tetrachloroethylene, chlorodibromomethane, chlorobenzene, ethylbenzene, meta-xylene-para-xylene, o-xylene, styrene, bromoform, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2-dichlorobenzene, and 1,2,4-trichlorobenzene) and 12 semivolatile organic com-

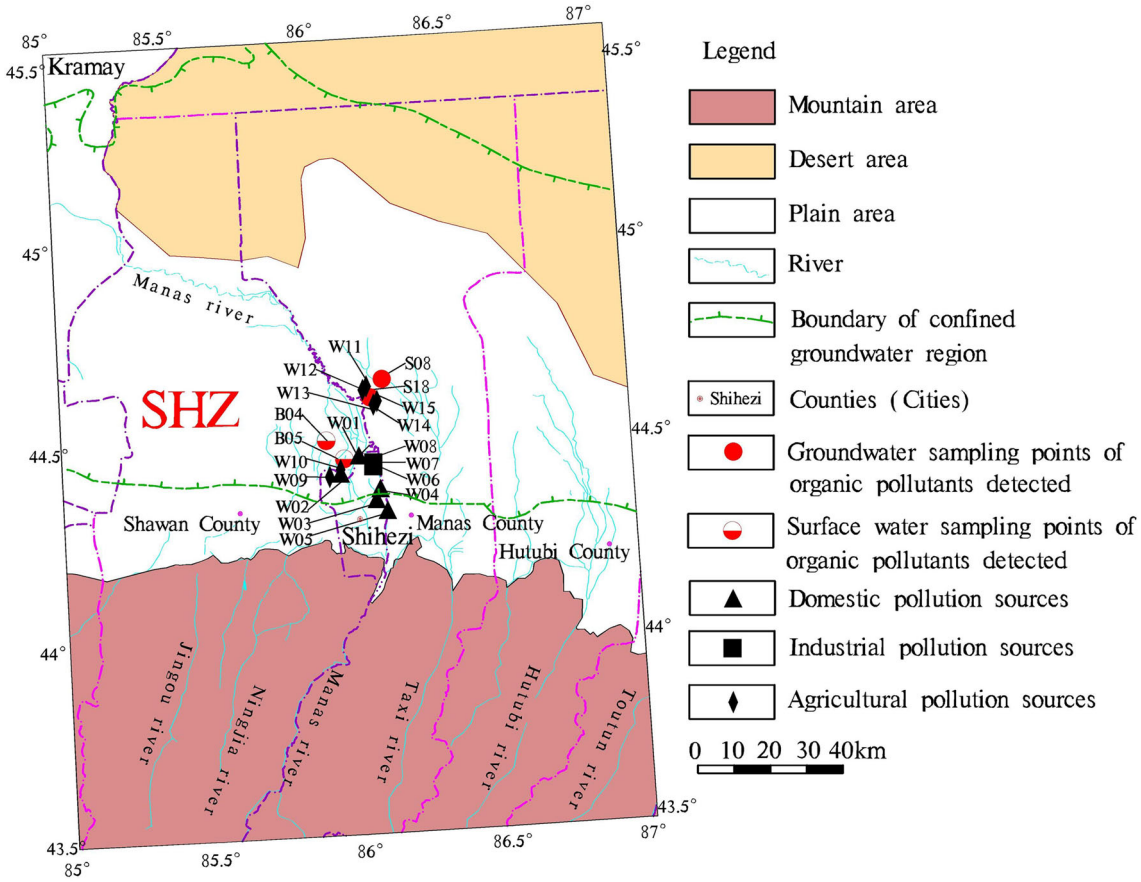

Fig. 5 Distribution of groundwater and surface water sampling points polluted by organic pollutants and the pollution sources in SHZ

pounds (hexachlorobenzene, α-BHC, β-BHC, γ-BHC, δ-BHC, total benzene hexachloride (BHC), total DDT, p,p′-DDE, p,p′-DDD, o,p′-DDT, p,p′-DDT and benzo(a)pyrene). Trace dsq GCMS-QP2010 (Thermo Fisher Scientific) was used to detect these volatile and semivolatile organic compounds. The detection limits of different compounds are listed as follows: 0.50 μg/L for vinyl chloride, m-xylene, p-xylene, bromoform, and dichloromethane; 0.30 μg/L for toluene, benzene, and ethylbenzene; 0.25 μg/L for 1,2-dichloroethane, and styrene; 0.20 μg/L for 1,2-dichlorethylene, chloroform, carbon tetrachloride, trichloroethylene, 1,2,4-trichlorobenzene, tetrachloroethylene, and o-xylene; 0.15 μg/L for trans-1,2-dichloroethylene, cis-1,2-dichloroethylene, 1,1,1-trichloromethane, 1,2-dichloropropane, bromodichloromethane, 1,1,2-trichloroethane, and chlorodibromomethane; 0.10 μg/L for 1,3-dichlorobenzene, 1,4-dichlorobenzene, and 1,2-dichlorobenzene; 0.05 μg/L for chlorobenzene; 0.01 μg/L for α-BHC, β-BHC, γ-BHC, δ-BHC, total DDT, o,p′-DDT, and p,p′-DDT; 0.005 μg/L for hexachlorobenzene; 0.002 μg/L for p,p′-DDE, p,p′-DDD, and benzo(a)pyrene.

Results and Analysis

Assessment of Groundwater Organic Pollution

Statistics of Detected Organic Pollutants

The test results of groundwater organic pollutants were shown in Table 1.

Results of groundwater organic pollutants (Table 1) showed that groundwater is contaminated by organic pollution in the study areas. Five organic pollutants (namely, 1,2-dichloroethane, toluene, benzo(a)pyrene, α-BHC, and γ-BHC) were detected among 23 groundwater samples with a detection rate of 4.3 % in SHZ (Table 1).

In YQ, three organic pollutants (chloroform, 1,2-dichloroethane, and 1,2-dichlorobenzene) were detected among 42 groundwater samples with detection rates of 31.0, 2.4, and 2.4 %, respectively (Table 1).

In RQ, two organic pollutants (chloroform and 1,2-dichlorobenzene) were detected among 18 groundwater samples with detection rates of 27.8 and 11.1 %, respectively (Table 1).

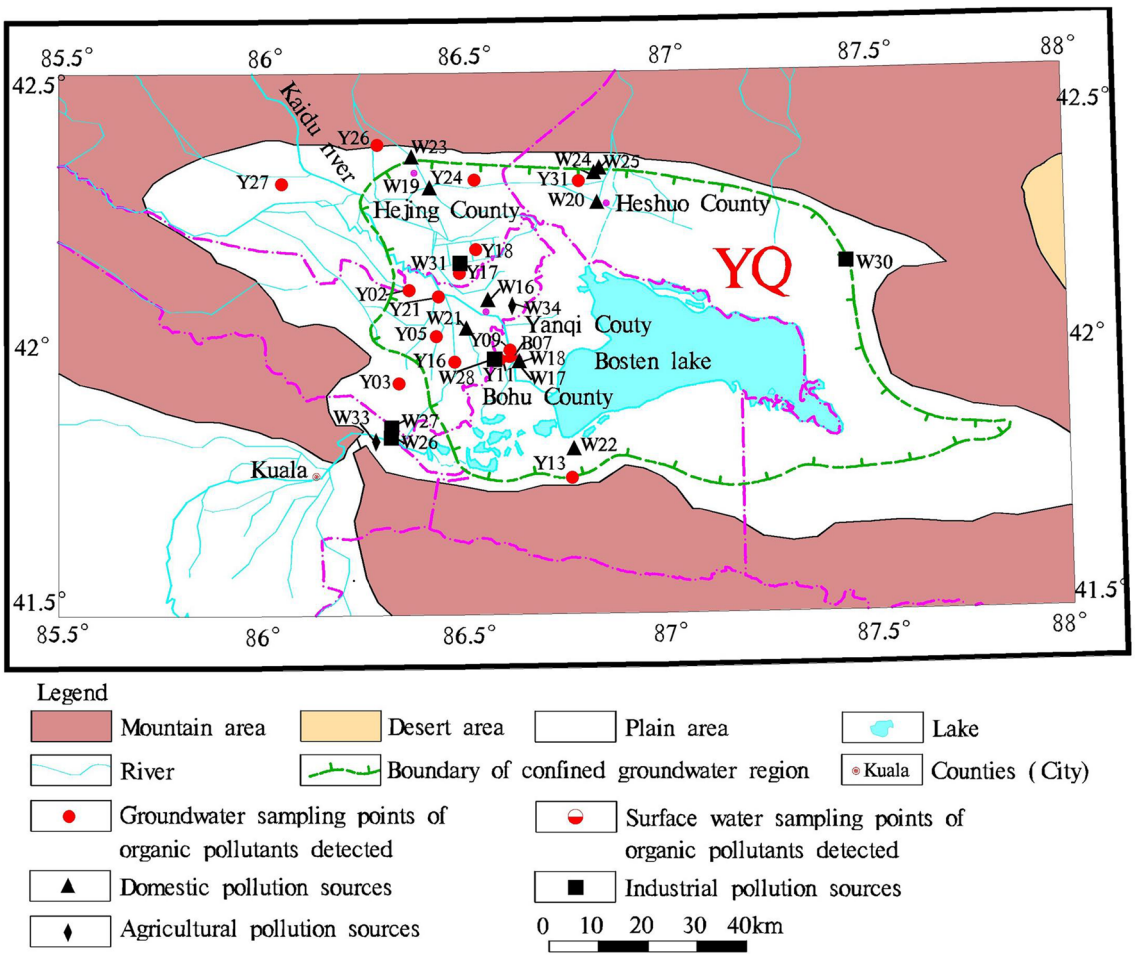

Fig. 6 Distribution of groundwater and surface water sampling points polluted by organic pollutants and the pollution sources in YQ

The rest of the selected organic pollutants were not detected. And the contents of the detected organic pollutants in three typical plain areas were under the limits of the *Standards for Drinking Water Quality* (GB5749-2006). It indicated that groundwater in study areas were slightly contaminated by organic pollutants.

Spatial Distribution of Detection Rates for Organic Pollutants

Horizontal Distribution

The contents of detected organic pollutants in different regions are shown in Table 2.

It is shown that organic pollutants were detected in two of 23 groundwater samples in SHZ with a detection rate of 8.7 % (Table 2; Fig. 5). The detected organic pollutants were 1,2-dichloroethane, toluene, benzo(a)pyrene, α-BHC, and γ-BHC. One of the polluted groundwater sampling points (S08) was located in Laokugou Village, Shihezi Township (in which 1,2- dichloroethane, α-BHC, and γ-BHC were detected). The other sampling point (S18) was located in No.147 Farm (in which toluene and benzo(a)-pyrene were detected).

Organic pollutants were detected in 14 of 42 groundwater samples in YQ with a detection rate of 33.3 % (Table 2; Fig. 6). The detected organic pollutants were chloroform, 1,2-dichloroethane, and 1,2-dichlorobenzene. The sampling points where chloroform was detected were distributed in Yanqi County, Hejing County, and Bohu County, with six, five, and two polluted sampling points and detection rates of 60.0, 41.7, and 33.3 %, respectively. There was only one sampling point (Y31 distributed in Heshuo County) where 1,2-dichloroethane was detected with a detection rate of 7.1 %. The only sampling point (Y17) where 1,2-dichlorobenze was detected with a detection rate of 8.3 % is distributed in Hejing County. Chloroform was also detected there. In YQ, the groundwater sampling points contaminated by organic compounds were generally scattered but partly concentrated.

Organic pollutants (including chloroform and 1,2-dichlorobenzene) were detected in six of 18 groundwater

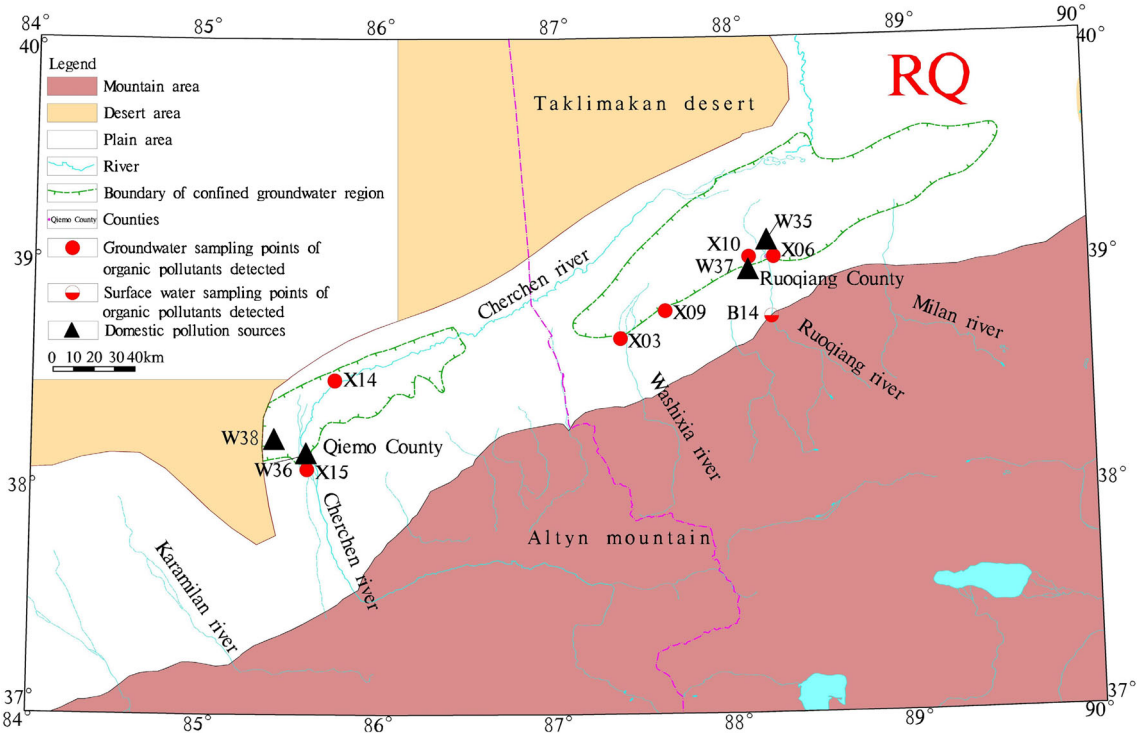

Fig. 7 Distribution of groundwater and surface water sampling points polluted by organic pollutants and the pollution sources in RQ

samples in RQ with a detection rate of 33.3 % (Table 2; Fig. 7). The sampling points where chloroform was detected were mainly distributed in Ruoqiang County where there were four polluted points with a detection rate of 40.0 %. There were two sampling points (X10 and X15) contaminated by 1,2-dichlorobenzene both in Ruoqiang County and Qiemo County with detection rates of 10.0 and 12.5 %, respectively. At the same time, chloroform was also detected at point X10.

Vertical Distribution

Organic pollutants were not detected in the unconfined groundwater in SHZ. However, 1,2-dichloroethane, α-BHC, and γ-BHC were detected in the shallow confined groundwater with a detection rate of 12.5 %. Moreover, in the deep confined groundwater, toluene, and benzo(a)pyrene were detected with a detection rate of 10.0 %.

The organic pollutant with the highest detection rate in groundwater in YQ was chloroform which was detected in unconfined groundwater, shallow confined groundwater, and deep confined groundwater with detection rates of 66.7, 25.0, and 25.0 %, respectively. Besides chloroform, 1,2-dichloroethane and 1,2-dichlorobenzene were detected in the deep confined groundwater with a detection rate of 4.2 %, while the remaining organic pollutants were not detected.

Chloroform was detected in all the three types of aquifers in RQ with the highest detection rates of 33.3 % (unconfined aquifer), 33.3 % (shallow confined aquifer), and 16.7 % (deep confined aquifer), respectively. In shallow confined groundwater and deep confined groundwater, 1,2-dichlorobenzene was detected with detection rates of 33.3 and 16.7 %, respectively, while the remaining organic pollutants were not detected (Table 3).

Origins of Organic Pollution of Groundwater

Impacts of the Sources and Properties of Organic Pollutants

The major groundwater organic pollutants detected in study areas were chloroform, 1,2-dichloroethane, 1,2-dichlorobenzene, toluene, benzo(a)pyrene, α-BHC, and γ-BHC.

Chloroform Since chloroform was detected in groundwater in the plain areas of YQ and RQ with the highest detection rate among all the detected organic pollutants, it was representative in this organic pollutant analysis.

Chloroform is the by-product of chlorination of drinking water and wastewater as well as the by-product of disinfection of private and public well. It is mainly used as the raw material for organic synthesis (e.g., producing Freon),

Table 1 Statistics of groundwater organic pollutants

Region	Detection items	Chloroform	1,2-Dichloroethane	1,2-Dichlorobenzene	Toluene	Benzo(a)pyrene	α-BHC	γ-BHC
Standard value (μg/L)		60	30	1000	700	0.01	–	–
SHZ	Sample size/group	23						
	Minimal value (μg/L)	ND	<0.25	ND	<0.30	<0.002	<0.01	<0.01
	Maximal value (μg/L)		0.98		0.82	0.005	0.007	0.005
	Mean (μg/L)		0.17		0.18	0.001	0.005	0.005
	Standard deviation (μg/L)		0.18		0.14	0.001	0.0004	0.0001
	Coefficient of variation		1.06		0.78	0.79	0.08	0.01
	Point detection rate (%)	0.0	4.3	0.0	4.3	4.3	4.3	4.3
YQ	Sample size/group	42						
	Minimal value (μg/L)	<0.20	<0.25	<0.10	ND	ND	ND	ND
	Maximal value (μg/L)	0.84	0.89	0.10				
	Mean (μg/L)	0.20	0.15	0.05				
	Standard deviation (μg/L)	0.18	0.12	0.008				
	Coefficient of variation	0.90	0.79	0.15				
	Point detection rate (%)	31.0	2.4	2.4	0.0	0.0	0.0	0.0
RQ	Sample size/group	18						
	Minimal value (μg/L)	<0.20	ND	<0.10	ND	ND	ND	ND
	Maximal value (μg/L)	0.37		0.17				
	Mean (μg/L)	0.15		0.06				
	Standard deviation (μg/L)	0.09		0.03				
	Coefficient of variation	0.59		0.51				
	Point detection rate (%)	27.8	0.0	11.1	0.0	0.0	0.0	0.0

Standard values adopt those in the *Standards for Drinking Water Quality* (GB5749-2006); *ND* indicates that the index is not detected, and the same below; – indicates that the index does not have a clearly defined standard limit

the solvent and extractant of antibiotics, spices, oils, and rubber, and as pesticides. Accumulation of chloroform may see an increase with the growth of concentration of organic compounds in water (Golfinopoulos 2000). It is easy for chloroform (with a relative strong leaching mobility in soils and sediments) to migrate to groundwater under suitable hydrogeological conditions, causing groundwater pollution. Chloroform in groundwater is not easily biodegradable and can persistently exist in groundwater system, especially in anaerobic environment. It has a long half-life of more than 1000 years (Li et al. 2011).

1,2-Dichloroethane There was one groundwater sampling point where 1,2-dichloroethane was detected in both SHZ and YQ.

1,2-dichloroethane is mainly used as the synthetic intermediate for tetrachloroethylene, vinyl chloride, and other preparations, serves as the solvent of lipids, rubber, paint, phosphorus, iodine, etc., and also widely used as fumigant. 1,2-dichloroethane in water is mainly derived from the emissions from industrial chemical reagent factories (Liu et al. 2008). 1,2-dichloroethane in surface soil can rapidly volatilize into the atmosphere or infiltrate into groundwater. Due to the slow volatilization rate and high density in deep soil, it is easy for 1,2-dichloroethane to infiltrate downward and contaminate groundwater.

1,2-Dichlorobenzene There was one groundwater sampling point where 1,2-dichlorobenzene was detected in both YQ and RQ.

1,2-dichlorobenzene serves as the additive of nitro spray lacquer and varnish, the solvent of wax and tar, and the degreaser of leather and metal. Industrial wastewater emission is the major source of 1,2-dichlorobenzene contamination in water. Due to the strong volatility, 1,2-dichlorobenzenes in water and soil usually volatilize into the air rapidly (Zhao et al. 2015). Hence, 1,2-dichlorobenzene contaminated water and soil can be treated in a short period. 1,2- dichlorobenzene is biodegradable by some microbes in oxygen-rich water after adaption.

Table 2 Statistics of organic pollutants and their concentrations in each groundwater sampling point (μg/L)

Region	No.	Location	Groundwater types	Chloroform	1,2-Dichloroethane	1,2- Dichlorobenzene	Toluene	Benzo(a)pyrene	α-BHC	γ-BHC
SHZ	S08	Laokugou Village in Shihezi Township	Shallow confined groundwater	ND	0.98	ND	ND	ND	0.007	0.005
	S18	No.147 Farm	Deep confined groundwater	ND	ND	ND	0.82	0.005	ND	ND
YQ	Y03	Yanqi County	Unconfined groundwater	0.30	ND	ND	ND	ND	ND	ND
	Y26	Hejing County	Unconfined groundwater	0.63	ND	ND	ND	ND	ND	ND
	Y27	Hejing County	Unconfined groundwater	0.25	ND	ND	ND	ND	ND	ND
	Y13	Bohu County	Unconfined groundwater	0.24	ND	ND	ND	ND	ND	ND
	Y05	Yanqi County	Shallow confined groundwater	0.30	ND	ND	ND	ND	ND	ND
	Y16	Yanqi County	Shallow confined groundwater	0.42	ND	ND	ND	ND	ND	ND
	Y21	Yanqi County	Shallow confined groundwater	0.47	ND	ND	ND	ND	ND	ND
	Y02	Yanqi County	Deep confined groundwater	0.29	ND	ND	ND	ND	ND	ND
	Y11	Yanqi County	deep confined groundwater	0.27	ND	ND	ND	ND	ND	ND
	Y17	Hejing County	Deep confined groundwater	0.84	ND	0.1	ND	ND	ND	ND
	Y18	Hejing County	Deep confined groundwater	0.54	ND	ND	ND	ND	ND	ND
	Y24	Hejing County	Deep confined groundwater	0.39	ND	ND	ND	ND	ND	ND
	Y09	Bohu County	Deep confined groundwater	0.56	ND	ND	ND	ND	ND	ND
	Y31	Heshuo County	Deep confined groundwater	ND	0.89	ND	ND	ND	ND	ND
RQ	X03	Ruoqiang County	Unconfined groundwater	0.26	ND	ND	ND	ND	ND	ND
	X09	Ruoqiang County	Unconfined groundwater	0.20	ND	ND	ND	ND	ND	ND
	X14	Qiemo County	Unconfined groundwater	0.21	ND	ND	ND	ND	ND	ND
	X06	Ruoqiang County	Shallow confined groundwater	0.32	ND	ND	ND	ND	ND	ND
	X15	Qiemo County	Shallow confined groundwater	ND	ND	0.17	ND	ND	ND	ND
	X10	Ruoqiang County	Deep confined groundwater	0.37	ND	0.11	ND	ND	ND	ND

Table 3 Statistics of detection rates of organic pollutants in groundwater of different aquifers

Region	Aquifers types	Detection items	Chloroform	1,2-Dichloroethane	1,2- Dichlorobenzene	Toluene	Benzo(a)pyrene	α-BHC	γ-BHC
SHZ	Unconfined groundwater	Sample size/group	5						
		Detection rate (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Shallow confined groundwater	Sample size/group	8						
		Detection rate (%)	0.0	12.5	0.0	0.0	0.0	12.5	12.5
	Deep confined groundwater	Sample size/group	10						
		Detection rate (%)	0.0	0.0	0.0	10.0	10.0	0.0	0.0
YQ	Unconfined groundwater	Sample size/group	6						
		Detection rate (%)	66.7	0.0	0.0	0.0	0.0	0.0	0.0
	Shallow confined groundwater	Sample size/group	12						
		Detection rate (%)	25.0	0.0	0.0	0.0	0.0	0.0	0.0
	Deep confined groundwater	Sample size/group	24						
		Detection rate (%)	25.0	4.2	4.2	0.0	0.0	0.0	0.0
RQ	Unconfined groundwater	Sample size/group	9						
		Detection rate (%)	33.3	0.0	0.0	0.0	0.0	0.0	0.0
	Shallow confined groundwater	sample size/group	3						
		Detection rate (%)	33.3	0.0	33.3	0.0	0.0	0.0	0.0
	Deep confined groundwater	Sample size/group	6						
		Detection rate (%)	16.7	0.0	16.7	0.0	0.0	0.0	0.0

Therefore, the trace amounts of 1,2- dichlorobenzene detected in YQ and RQ maybe enter groundwater in a short time.

Toluene Toluene was only detected in groundwater in SHZ. Toluene has the best water solubility among petroleum and various fuel oils, which is the most common organic pollutant in groundwater and has been proven to be carcinogenic (Kazumi et al. 1997). Toluene is mainly used as gasoline additive as well as raw material of solvent and organic chemical products. Air contact is the major way to contact toluene. The industrial wastewater emission from chemical plants is the main source of toluene. Smoking and automobile exhaust can also contribute to toluene contamination.

Benzo(a)pyrene Benzo(a)pyrene was only detected in groundwater in SHZ. Benzo(a)pyrene is a polycyclic aromatic hydrocarbon with high boiling point, low volatility and genetic toxicity (Cui et al. 2008). Benzo(a)pyrene, comes from two sources (natural sources and anthropogenic sources) widely exists in soil, atmosphere, and surface water in the natural environment.. Volcanic eruptions, forest, and grassland burning, and the biosynthesis of aquatic plants and microorganisms make up the natural background value of benzo(a)pyrene. Therefore, benzo(a)pyrene is a kind of natural organic compound. There are many anthropogenic sources of benzo(a)pyrene as well, including incomplete combustion of various fossil fuels (e.g., coal, oil, or natural gas), wood, paper, and other hydrocarbons or their pyrolysis under reduction condition. In general, concentrations of benzo(a)pyrene in industrial wastewaters from tire manufacturing, plastic production, iron and steel manufacturing, and aluminum and energy industries are high, which are the major sources of surface water benzo(a)pyrene (Li et al. 2006). Water containing benzo(a)pyrene may transfer into soil through irrigation and leakage, which becomes the main source of soil benzo(a)pyrene. Benzo(a)pyrene has a strong hydrophobicity, and can be strongly adsorbed on the organic carbon of soil particles. Therefore, it is difficult to have benzo(a)pyrene migrated from the surface soil to groundwater, which means that soil and sediment are the main environmental fate.

α-BHC and γ-BHC α-BHC and γ-BHC were only detected in groundwater in SHZ. α-BHC and γ-BHC are the two isomers of benzene hexachloride (BHC, hexachlorocyclohexane) which are mainly derived from pesticides used in agricultural production (Wei et al. 2015). The use of pesticides containing BHC has been prohibited by the Chinese government since 1987. However, the BHC residue with a high concentration is still detected in many mediums (Lee et al. 2007; Xu et al. 2007). BHC can kill insects through contact, fumigation, and stomach toxicity. The γ isomer of BHC has the highest insecticidal potency followed by α isomer of BHC. However, due to the strong stability and low degradability, overuse of BHC can directly cause pollution of crops. Meanwhile, the pesticides can accumulate in water and soil or migrate downwards causing groundwater pollution.

Impact of Surface Water Recharge

Surface water is the main recharge of groundwater in the study areas and has certain impacts on groundwater quality. According to the *Environmental Quality Standard of Surface Water* (GB3838-2002), trace organic pollutants were detected in surface water in study areas, including vinyl chloride, chloroform, and benzo(a)pyrene (Table 4).

SHZ

Groundwater in SHZ is mainly recharged by surface water. 1,2-dichloroethane, toluene, benzo(a)pyrene, α-BHC, and γ-BHC were detected in groundwater while vinyl chloride, chloroform, and benzo(a)pyrene were detected in surface water in SHZ. Vinyl chloride and chloroform detected in surface water were not detected in groundwater. Benzo(a)pyrene was detected in surface water sampling points B04 and B05. It showed that the groundwater sampling point S18 with benzo(a)pyrene detected located in the downstream of B04 and B05 with a distance less than 30 km, which suggest that the benzo(a)pyrene pollution at S18 may be caused by the infiltration recharge of surface water at B04 and B05 (Fig. 5).

YQ

Chloroform, 1,2-dichloroethane, and 1,2-dichlorobenzene were detected in groundwater while chloroform was detected in surface water at B07 (in Bohu County) in YQ. Y09 (in the upperstream of B07) and Y11 (less than 30 km downstream from B07) were the two groundwater sampling points with chloroform detected near the surface water sampling point B07 (Fig. 6). It suggested that the chloroform contamination at Y11 may be caused by the infiltration recharge of surface water at B07 while Y09 do not contribute to the recharge of surface water at B07.

RQ

Chloroform and 1,2-dichlorobenzene were detected in groundwater in RQ while chloroform was the only organic pollutant detected in surface water at B14 in Ruoqiang County. It showed that chloroform was detected at X03,

Table 4 Contents of trace organic pollutants in surface water (μg/L)

Region Standard value	No.	Vinyl chloride 5	Chloroform 60	Benzo(a)pyrene 0.01
SHZ	B01	ND	ND	ND
	B02	ND	ND	ND
	B03	ND	ND	ND
	B04	0.62	0.82	0.02
	B05	ND	ND	0.006
YQ	B06	ND	ND	ND
	B07	ND	0.30	ND
	B08	ND	ND	ND
	B09	ND	ND	ND
	B10	ND	ND	ND
	B11	ND	ND	ND
	B12	ND	ND	ND
RQ	B13	ND	ND	ND
	B14	ND	0.26	ND
	B15	ND	ND	ND
	B16	ND	ND	ND
	B17	ND	ND	ND

The standard value refers to the standard value of class III water in t*he Environmental Quality Standard of Surface Water* (GB3838-2002)

X06, X09, and X10 (all of which were located more than 30 km downstream from B14) in Ruoqiang County (Fig. 7). Therefore, the recharge of surface water at B14 had little influence on groundwater chloroform detected in this area.

Impact of Pollutant Sources

Domestic, industrial, and agricultural pollution were the main pollution sources in SHZ (Fig. 5) and YQ (Fig. 6), while domestic pollution was the main pollution sources in RQ (Fig. 7).

Domestic Pollution Sources

The domestic pollution sources in study areas included sewage treatment plant and landfill which were the main sources of chloroform, 1,2-dichloroethane, and toluene (Huang et al. 2013; Zhang et al. 2009). Due to the direct discharge of untreated sewage or leakage caused by rough impervious facilities, some organic pollutants may migrate downstream and flow through unconfined groundwater into confined groundwater, causing organic pollution in the confined groundwater (Grøndahl-Rosado et al. 2014). Most of the sampling points with organic pollutants detected in SHZ and RQ were located less than 10 km downstream from the domestic pollution sources. Hence, the detected groundwater organic pollutants were closely related to the domestic pollution sources. Most of the sampling points with organic pollutants detected in YQ were in the upstream of domestic pollution sources. Therefore, the hazardous substances from the landfills and sewage treatment plants may not affect the groundwater quality. Although the remaining detected sampling points in YQ were located $\geq$10 km downstream from pollution sources,, the impact of domestic pollution sources on groundwater quality of these sampling points was also limited.

Industrial Pollution Sources

The industrial pollution sources in SHZ included chemical plants, aluminum industry and energy companies. While the industrial pollution sources in YQ were mainly paper mills, mining, steel mills, chemical plants, etc. 1,2-dichloroethane, 1,2-dichlorobenzene, and toluene mainly came from industrial wastewater discharged from the chemical plants. Benzo(a)pyrene mainly came from industrial wastewater of aluminum industry, steel mills, and energy companies (Li et al. 2006). With the discharge of industrial wastewater, organic pollutants migrated downstream. Some of the sampling points with organic pollutants detected in SHZ and YQ were in the downstream of the industrial pollution sources. It indicated that the organic pollutants detected in groundwater were related to the industrial pollution sources.

Agricultural Pollution Sources

The agricultural pollution mainly came from livestock farms in SHZ and YQ. The wastewater produced during

livestock and poultry breeding was generally organic wastewater with high concentration. Once enter groundwater, the organic pollutants may cause persistent groundwater organic pollution.

Impact of Land Use Types

There were three major land use types in the study areas, namely, cultivated land, pasture land, and construction land. The detection rates of groundwater organic pollutants in cultivated land and pasture land were higher than that in construction land. It mainly result from overuse of chemical fertilizer, pesticides, and insecticides (main sources of chloroform and 1,2-dichlorobenzene) in the pasture land and cultivated land. It is difficult for sewage to permeate into groundwater due to a sound drainage and treatment system in urban areas. Therefore, it had little impact on groundwater organic pollution.

Organic pollutants mainly enter groundwater through soil (an important medium). The vadose zone is an important medium for the connection of surface soil and aquifer. The volatile organic pollutants have high vapor pressure and water solubility, and low n-octanol/water partition coefficient, viscosity, and interfacial tension (Liu et al. 2008). Once enter the soil, it may cause pollution in the vadose zone and further pollution in aquifers under certain conditions. The pollution caused by volatile organic pollutants is mainly affected by rainfall, agricultural irrigation, and the use of pesticides and chemical fertilizers. Rainfall can carry organic pollutants in atmosphere, ground surface and soil into aquifer through scouring atmosphere, accelerating surface runoff and infiltration. Due to the elevation of groundwater level affected by rainfall and irrigation, the pollutants partially adsorbed on the organic matters migrate downwards into groundwater by desorption, which lead to groundwater pollution. In the cultivated land, overuse of organic chlorine pesticides in agricultural production leads to the accumulation of pollutants (including chemical fertilizers, pesticides, and soil salts), of which infiltrate into groundwater, and then contaminate groundwater through irrigation or rainfall.

Impact of Vadose Zone

The vadose zone controls the various physical and chemical processes of the infiltration water in vadose zone, such as degradation, adsorption, precipitation, complexation, neutralization, and biodegradation. Larger medium particles in vadose zone contribute to a better permeability and more pollutants entering the aquifer, which lead to higher detection rates of organic pollutants. On the contrary, the detection rates of organic pollutants would be lower (Zhou et al. 2010, 2012).

SHZ

The vadose zone in SHZ is mainly consisted of sandy gravel (including three sampling points, no organic pollutants were detected of which with a detection rate of 0.0 %) and sandy loam (including 20 sampling points, organic pollutants were detected in two of which with a detection rate of 10.0 %). The detection rate of sandy gravel was lower than that of sandy loam (inconsistent with the general rule). It is mainly because that the sandy gravel is distributed in the Gobi area with low intensity of human activities (agriculture and industry) and rare pollution sources.

YQ

The vadose zone in YQ is mainly consisted of sandy gravel (including 15 sampling points, organic pollutants were detected in three of which with a detection rate of 20.0 %), sandy loam (including 10 sampling points, organic pollutants were detected in four of which with a detection rate of 40.0 %) and loam (including 17 sampling points, organic pollutants were detected in seven of which with a detection rate of 41.2 %). The detection rate (sandy gravel $<$ sandy loam $<$ loam) was inconsistent with the general rule. It is mainly because that the sandy gravel is distributed in the Gobi area with low intensity of human activities and rare pollution sources.

RQ

The vadose zone in RQ is mainly consisted of sandy gravel (including five sampling points, organic pollutants were detected in three of which with a detection rate of 60.0 %) and silt sand (including 13 sampling points, organic pollutants were detected in three of which with a detection rate of 23.1 %). The detection rate of silt sand is lower than that of sandy gravel, which is consistent with the general rule. Therefore, the vadose zone is one of the main influence factors of the groundwater organic pollution in RQ.

Discussion

Due to the shallow buried depth, unconfined groundwater can be easily affected by external environment. Therefore, unconfined groundwater organic pollution is more serious than confined groundwater generally (Guo 2012; Wen et al. 2012). According to the survey results, organic pollution in unconfined groundwater was more serious than that in confined groundwater in YQ and RQ, while organic pollution in confined groundwater was more serious than that in unconfined groundwater in SHZ. The main reason is that

there are less human activities in the single unconfined aquifer distributed in the gravel belt in southern piedmont gobi in SHZ, which have less effect on groundwater organic pollution. Mixed exploitation of groundwater in SHZ can facilitate the transfer of inferior groundwater from unconfined aquifers into confined aquifers through side-wall infiltration, which may cause the transfer of groundwater organic pollution into deeper aquifers. This may lead to an increase of organic pollutants in confined groundwater and more serious groundwater organic pollution. Meanwhile, groundwater level dropped dramatically due to groundwater overexploitation in some areas in SHZ, resulting in groundwater depression cones. Decrease of groundwater level may change the original groundwater dynamic conditions, which may easily cause continual transfer of contaminated groundwater in shallow confined aquifers into deep confined aquifers, and further organic pollution in confined aquifers (Luo 2008).

Twenty-seven volatile organic compounds and 12 semivolatile organic compounds were determined in this study. Only four volatile organic compounds and three semivolatile organic compounds were detected in groundwater, while the remaining organic pollutants were not detected. Volatile organic compounds mainly came from coal, oil, and gas as industrial fuel or chemical feedstocks and other related chemical industry (Squillace et al. 1999; Lu and Jiang, 2009). 12 semivolatile organic compounds include one polycyclic aromatic hydrocarbon (Benzo (a) pyrene) and 11 organochlorine pesticides. Anthropogenic Benzo (a) pyrene mainly came from incomplete combustion or pyrolysis under reduction condition of various fossil fuels, wood, paper, and other hydrocarbons and discharge of industrial wastewater from tire manufacturing, plastic production, iron and steel manufacturing, aluminum and energy industries (Li et al. 2006). Organochlorine pesticides were mainly derived from a wide range of application of chemical fertilizer, pesticides and insecticides in agricultural production, and "three wastes" emission from local industrial and mining enterprises and landfill leachate (Yu et al. 2007). It showed that the contamination was more serious in industrial areas than that in agricultural areas, and that the transportation mode and speed of organochlorine pesticides in industrial areas were of great difference with that in agricultural areas, although the organochlorine pesticides pollution areas in industrial areas were smaller compared with that in agricultural areas (Elfvendahl et al. 2004; Concha-Grana et al. 2006). In general, organic pollutants were mainly derived from industrial with less agricultural and living sources. The sampling points in this study were mainly distributed in fine soil zone in agricultural areas and living areas. Therefore, most of the organic pollutants were not detected. Part of the detected groundwater organic pollutants was related to the local point source pollution and its characteristics.

Conclusions

(1) Groundwater in typical areas in Xinjiang suffered from a relatively slight organic pollution. The detected organic pollutants were chloroform (with the highest detection rate of 21.7 %), 1,2-dichloroethane, 1,2-dichlorobenzene, toluene, benzo(a)pyrene, α-BHC, and γ-BHC. Further, the concentrations of detected organic pollutants were relatively low, under the limits of the *Standards for Drinking Water Quality* (GB5749-2006). The rest of the organic pollutants were not detected.

(2) Spatial distribution of the concentrations of groundwater organic pollutants in typical areas in Xinjiang varied greatly. In SHZ, the detection rates of groundwater organic pollutants were shallow confined groundwater (12.5 %) > deep confined groundwater (10.0 %) > unconfined groundwater (0.0 %). In YQ, the detection rates of groundwater organic pollutants were unconfined groundwater (66.7 %) > deep confined groundwater (29.2 %) > shallow confined groundwater (25.0 %). In RQ, the detection rates of groundwater organic pollutants were shallow confined groundwater (66.7 %) > unconfined groundwater (33.3 %) > deep confined groundwater (16.7 %). Organic pollutants detected in confined groundwater were mainly related to vertical infiltration of organic pollutants. Meanwhile, mixed exploitation of groundwater in this area can facilitate the transfer of inferior groundwater from unconfined aquifers into confined aquifers through side-wall infiltration.

(3) Accelerated urbanization and industrial and agricultural development were the main factors affecting groundwater organic pollution in the study areas. Although some anti-seepage facilities had been applied in prevention of wastewater infiltration from the domestic, industrial, and agricultural pollutions, infiltration may occur because of the rough facilities. It led to a migration of some organic pollutants from upstream to downstream and from unconfined aquifers into confined aquifers, causing groundwater organic pollution. The use of chemical fertilizers and pesticides in cultivated land and pasture land was also an important source of groundwater organic pollution.

(4) The sources and characteristics of organic pollutants had significant impacts on groundwater organic pollution. Recharge of surface water had a

significant impact on groundwater organic pollution in SHZ and YQ, but little impact on that in RQ, since the groundwater organic pollutants detection points were located more than 30 km downstream from surface water pollution detection point. Vadose zone had a certain restriction on the occurrence and migration of groundwater organic pollutants in RQ.

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