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Occurrence and risk assessment of heavy metals in urban water systems of Beijing, China

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ABSTRACT

Heavy metals pollution in urban water systems is a common difficulty for global metropolises, in particular, in the developing Asian countries like China. Although heavy metals pollution in urban soils of Beijing has already been reported frequently, the study about heavy metals pollution in urban water systems is still rare. To evaluate the accumulation of heavy metals in urban water systems and assess the risk of heavy metals for the health of citizens, we conducted this study and examined the concentrations of some heavy metals including Cr, Cd, Cu, Pb, and Zn in surface water, groundwater, influents, and effluents of sewage treatment plants (STPs), and effluents of hospitals in Beijing. Concentrations of all the determined heavy metals were lower than the standard limits of China. The highest concentration was detected in the effluents of hospital with as high as 5–33 times in the surface water of the Wenyu River and ground water, and the concentration in the influents of STPs took the second highest place. From the perspective of spatial distribution, heavy metals pollution in the midstream and downstream of surface water (Wenyu River) was more serious than that in the upstream. In addition, the concentrations of heavy metals were not correlated with different depths in groundwater. The result of health risk assessment showed that carcinogenic and non-carcinogenic risks for drinking water were within the acceptable range. Our data demonstrated that women were more sensitive to the toxicity of heavy metals, especially, for Cr.

Keywords: Ecological risk; Groundwater; Heavy metals; Hospital; Sewage treatment plant; Surface water

1. Introduction

With rapid developments of industry and urbanization, heavy metal contamination is increasingly serious and causes a series of severe consequences to natural and social environments in the world as well as in China in recent years [1–4]. Especially, heavy metals have their own characteristics of high toxicity, long persistence, slow abiotic degradation, and pronounced bio-accumulation, making heavy metals-induced environmental pollution attracts the attention of relative ecologists [5,6]. In human society, heavy metals bring the effect of "teratogenicity, mutagenesis and

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death" to people, having a persistent and potential threat to human health and environmental security such as drinking water security, by the enrichment and transmission through food chains [7–9]. Many studies reported that heavy metals were detected in various water bodies in China as well as other countries, which caused varying degrees of risk to humans and their living environments [7–9]. Particularly, the problem of heavy metals pollution in various water bodies of big cities is more prominent than suburbs and villages because of massive population and increased human activities.

Cities consume and release massive heavy metals to surrounding environments due to excessive aggregation of heavy industrial production and social economic activity. These released heavy metals to the water environment have already been detected frequently, causing a serious threat to the public health [10–12]. The results of many relative studies have shown that most heavy metals in the water environment originate mainly from various sources [3,10]. The important sources of heavy metals in the urban water environment include mainly industrial and agricultural waste waters, domestic sewage, sewage treatment plants (STPs), and hospital wastewater [13–15]. Usually, most urban sewage was aggregated in the STPs before it is discharged [16,17]. According to the current technical level, however, the ability to remove heavy metals from urban polluted water bodies is limited, making these heavy metals cannot be completely removed and can cause a threat to the water quality of the receiving rivers [18,19].

As an international metropolis and the capital of China, Beijing is the second most densely populated city with a large population of 21.73 million and a population density of 1,324 people/km^2. Beijing is located in the Haihe River Basin, with an apparent shortage of water resources. Mean annual precipitation is about 600 mm, and water resource per capita is less than 300 m^3, which is only 1/30 of the world average level [20]. During the past 10 y, more than 600,000 people moved to Beijing city and about 60 million tons of sewage discharged into the urban water systems [20]. However, the speed of STPs' construction cannot reach to the speed of urban expansion and heavy metals discharge, making all the existing STPs in the central city of Beijing are extremely overloaded and massive accumulation of unprocessed sewage water causes a threat to the quality of the water environment in Beijing. Although the published data show that most urban water systems in Beijing have already polluted with different levels by various heavy metals [21,22], most of them is concerned on a single type of water body such as rivers, reservoirs, groundwater, or other types. In addition, there is no reliable scientific study reflecting and evaluating the quality and pollution level of water environments in Beijing.

Based on the research status mentioned above, our study examined the behavior of 5 heavy metals (Cr, Cd, Cu, Pb, and Zn) in some typical urban water systems of Beijing, involving surface water, groundwater, influents, and effluents from STPs and effluents of hospital. The purpose was to investigate the accumulation of heavy metals in different types of water bodies in Beijing and evaluate the pollution level and their potential risk to human society. This study could help us to understand the pollution level of heavy metals in typical water bodies of densely populated modern metropolis like Beijing.

2. Materials and methods

2.1. Description of studied area

Beijing is located in the northeast of China, with the Bohai Sea in its east direction. Before the move and dispersal of all the heavy industries and factories in the city center to surrounding provinces and areas, Beijing did not only be a center of politics, culture, and economy, but also was it a center for heavy industry. In addition, a large area of mountains distributed the north of Beijing prevents from the atmospheric circulation and pollutant transfer, resulting in massive deposition of heavy metals and environmental heavy metals pollution. The total area of Beijing is about 16,810 km^2 and total population size is about 21.73 million, with a mean population density of 1,324 individuals per km^2.

2.2. Sample collection and analysis

Because the ability to remove heavy metals from all the water systems is limited and the heavy metals in the polluted water systems cannot be completely removed using the current processing technology, resulting in a potential threat to the water quality of the receiving rivers and groundwater [18,19]. Thus, unprocessed heavy metals might be transferred from STPs, hospitals, groundwater, or rivers to the drinking water for human populations in cities, which are the main polluted water bodies in Beijing. Sixteen sites were selected to collect water samples during the dry period of 2017 and all the sampling points were pinned in Fig. 1. Samples for surface waters were taken from Wenyu River and its main tributary inlet, sampling location were mainly located in the important bridges across the river. Seven sampling locations labeled from WHY1 to WHY7, according to the flow direction and location, were named by Shahe floodgate, Mafang bridge, Xisishang village, Wenyu bridge, Yigezhuang bridge, Wenyu river Bridge, and Beiguan floodgate. Samples for groundwater was taken from Shunyi District, including five wells named as from G1 to G5. The maximum sampling depth in the locations of G1, G2, G4, and G5 reached to the depth of 29 m, G3 is a multi-level monitoring well with the depth of 6.79, 11.64, and 22.53 m. Samples from STPs included water bodies of influents and effluents, respectively, located in the Haidian District (HW), Chaoyang District (CW), and Miyun District (MW). The population size in the relative service industry was 0.3–0.4 million and the processing quantity of the STPs could be reached to 0.03–0.04 m^3/d. The sewage treatment processes of HW, CW, and MW were respectively anaerobic/anoxic/oxic (A^2/O) activated sludge + MBR process, cyclic activated sludge technology (CAST), and anoxic/oxic (A/O) activated sludge + MBR process. Both an influent and an effluent were taken from a hospital located in HW, the sewage treatment processes chlorination. Detailed information on the STPs and hospital was shown in Table 1.

For the STPs and hospital, the influent and effluent samples were collected every 2 h, totally for 24 h, which

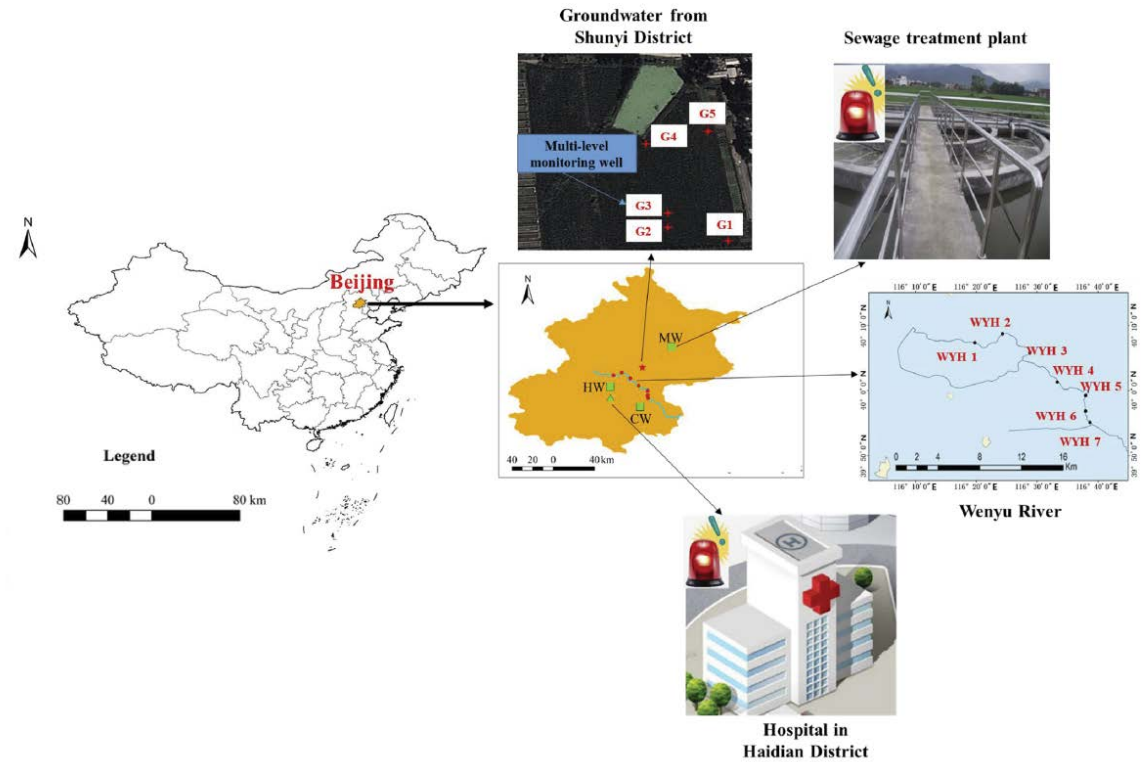

Fig. 1. Sampling sites of multiple water bodies in Beijing.

according to the discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002). All samples were filtered through 0.45 μm membrane filter paper, then collected into polyethylene bottles with screw caps. Nitric acid was added to bottle when the pH was lower than 2. Then samples were stored in refrigerator at 4°C in the laboratory for further processes. The concentration of heavy metals were determined by inductively coupled plasma-mass spectrometry (ICP-MS).

2.3. Quality control

All chemicals were guarantee reagent and Milli-Q water was used for solution preparation. The polypropylene bottles and glass containers were cleaned, soaked in 5% HNO_3 for more than 24 h, then rinsed repeatedly with Milli-Q water and dried. Sample bottles were rinsed three times with water filtered through 0.45 μm membrane filter paper. All samples were analyzed by triplicate to improve the accuracy of the measurement. The standard deviation of the duplicate samples was less than 10% in the batch treatments.

2.4. Statistical analysis

All the statistical analyses were carried out using SPSS 23.0 (IBM SPSS Corporation, Chicago, IL, USA). The statistical significance of the differences was evaluated by one way-ANOVA, which was considered significant at $p < 0.05$. The hierarchical cluster analysis (HCA) was accomplished on account of the heavy metals dataset of 24 studied samples. Two-dimensional HCA heat map was composed by a heat map with two dendrograms connected by colored mosaics, and the color map was on behalf of the intension of each metal for each sampling location [23,24], which was carried out using MATLAB software. In the heat map, the deep-slight color gradient presented the concentrations of individual heavy metals from highest to lowest intensity.

2.5. Evaluation methods

Drinking water is one of the major sources of human exposure to heavy metals. Using the health risk assessment model recommended by the US EPA to assess the health risks caused by heavy metals in surface water bodies of Wenyu River and groundwater surrounding Beijing [25,26], the formulas were as follows:

$$R_k^c = \frac{\left[1 - \exp\left(-D_k q_k\right)\right]}{\mathrm{LT}} \tag{1}$$

$$R_j^n = \left(\frac{D_k}{RfD_j}\right) \times 10^{-6} / \mathrm{LT} \tag{2}$$

$$D_k = \frac{\mathrm{IR} \times C_k}{\mathrm{BW}} \tag{3}$$

where R_k^c is the level of carcinogenic risk to humans each year through drinking caused by the genotoxic substance k, a^{-1}; R_j^n is the level of non-carcinogenic risk to humans each year through drinking caused by non-gene toxic substance j, a^{-1};

Table 1
Detail information of hospital and sewage treatment plants

	Location	Service population	Daily treating quantity	Sewage treatment process	Other information
Hospital	Haidian district (HDH)	The outpatient volume (2,000,000/y), total hospitalization patients (40,000 people/y)	–	Chlorination	1,000 beds. professional departments (more than 50)
Sewage treatment plant (STPs)	Haidian district (HD)	300,000–400,000 people	30,000–40,000 m^3/d	Anaerobic/anoxic/oxic (A^2/O) activated sludge + MBR process	
	Chaoyang district (CY)			Cyclic activated sludge technology (CAST)	
	Miyun district (MY)			Anoxic/oxic (A/O) activated sludge + MBR process	

D_k is the daily weight exposure of heavy metal i to drinking water per weight; q_k is the carcinogenic coefficients of genotoxic substance through drinking water, mg/(kg d); RfD_j is the reference dose of non-gene toxic substance j is absorbed by the body every day, mg/(kg d); LT is the average life expectancy for a person, *a*; BW is the average body weight for a person, kg; IR is the water ingestion rate, L/d; C_k is the heavy metal concentration in surface water, mg/L. According to the classification system compiled by IARC and WHO, Cr, and Cd belong to carcinogens, Pb, Cu, and Zn belong to non-carcinogens, the reference dose is shown in Table 2.

Table 3 showed the relative values of exposure to contaminants in drinking water, the data were recommended by the Exposure Factors Handbook of Chinese Population [27] and Sankararamakrishnan et al. [28].

3. Results and discussion

3.1. Occurrence of heavy metals in the surface water of Wenyu River

The average concentrations of determined heavy metals in surface water of Wenyu River are shown in Fig. 2. All elements decreased in the order of Zn > Cr > Pb > Cu > Cd, being lower than the first grade of the surface water quality standards (GB3838-2002). The variation coefficient range was 25.17–49.97, indicating that the concentration of heavy metals along the Wenyu River varies greatly, especially for Cd and Pb. According to the investigation, there were a total of 230 sewage outfalls in the main tributaries of the Wenyu River, and the total amount of discharged sewage per day was 128.2×10^4 m^3 [29,30]. The significant variation of heavy mental concentrations along Wenyu River was caused by the poor distribution of the sewage outfalls [15]. From the perspective of spatial distribution (Fig. 3), the degree of heavy metals pollution in the midstream and downstream was more significant than that in the upstream, except for Zn. Due to the replenishment in midstream and downstream of Wenyu River was mainly from Qinghe River and Bahe River, which mainly received domestic sewage, industrial wastewater, livestock wastewater, and farmland retreating from Changping District, Shunyi District, and

Table 2
Reference value of every metal mg/(kg·d)

Cr	41
Cd	6.1
Pb	0.0014
Cu	0.04
Zn	0.3

Table 3
Human exposure parameter values

	IR/L/d	LT/a	BW/kg
Man	3.08	78.3	65.1
Woman	3.495	82.2	57.0

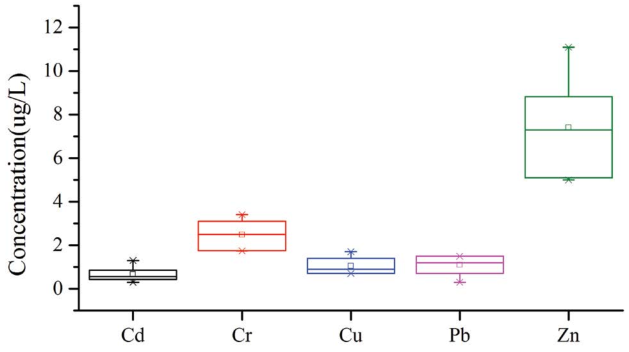

Fig. 2. Average concentration of heavy metals in surface water of Wenyu River.

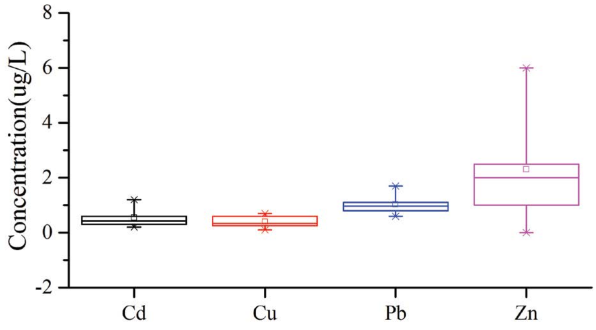

Fig. 4. Average concentration of heavy metals in groundwater of Beijing.

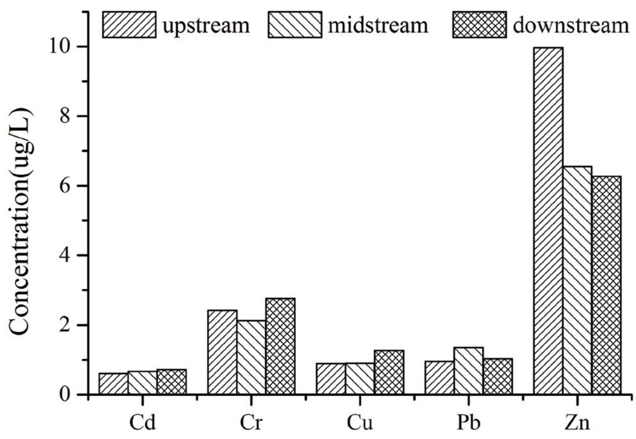

Fig. 3. Spatial distribution of heavy metals in surface water of Wenyu River.

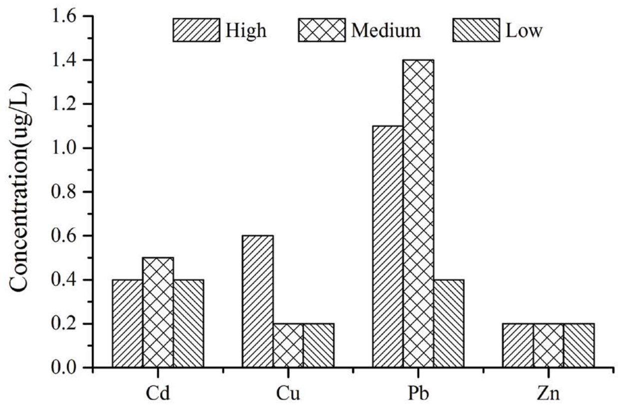

Fig.5. Concentration of heavy metals in different depths of groundwater of Beijing.

Tongzhou District, and the ratio of pollution to the water is 0.94 and 0.87, respectively [31–33]. In addition, because of the block of downstream Sluices and Dams, water bodies was lack of fluidity and self-purification ability to pollutants, resulting the water quality of the downstream was worse than upstream water quality [34].

3.2. Occurrence of heavy metals in groundwater

Heavy metals in groundwater were detected in different degrees except for Cr, and the result of this study was consistent with the findings of previous studies [35]. The concentrations of heavy metals were decreased in the order of Zn > Pb > Cd > Cu, being lower than the first grade of the groundwater water quality standards (GB/T 14848–2017) (Fig. 4), indicating that the groundwater was not contaminated by heavy metals. However, there was a pronounced variation in concentration among different sampling sites, the variation coefficient range was 34.68–99.15, representing that human activity modes significantly influenced the concentration of heavy metals in groundwater, especially for Zn and Cd. In the perspective of vertical direction, there was no any prominent regularity among different depths (Fig. 5). It was shown that the concentration of heavy metals in groundwater was apparently affected by water-contained lithology and hydrogeological conditions [19,36]. In addition, with the development of industrialization and urbanization, soil was contaminated at severe degrees by various heavy metals, then directly affected the concentration of heavy metals in groundwater through leaching process [35,37].

3.3. Occurrence of heavy metals in the STPs

The concentration of heavy metals in the influent of STPs is shown in Fig. 6. The average concentrations of heavy metals were decreased in the order of Zn > Cr > Pb > Cu > Cd, which was consistent with the results observed in other cities [38–40]. For concentration of heavy metals, there was a significant difference in four STPs ($p < 0.05$), which might be related to different sources of wastewater that was treated by STPs. In this study, the concentration of Zn in the influent of STPs was much higher than that of other elements, which was caused by the large use of galvanized pipes in China's cities [41,42]. In addition, it was related to the production of Zn in China. It was reported that annual production of Zn in China ranked the first compared to other metals such as Cu, Pb, Cd, and Cr, during the past 20 y [43,44]. The water lowering from STPs was not only the main source of water supplement for urban drainage channels, but also included the largest source of

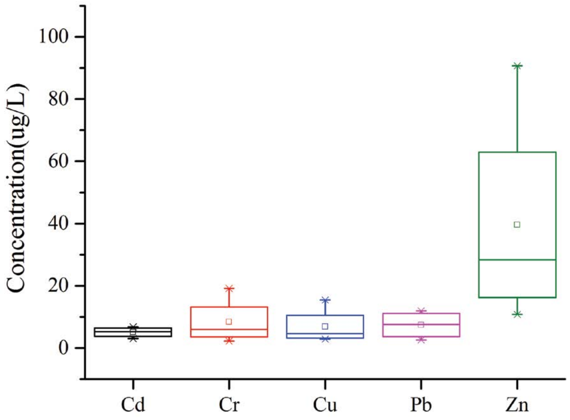

Fig. 6. Concentration of heavy metals in influent of sewage treatment plants.

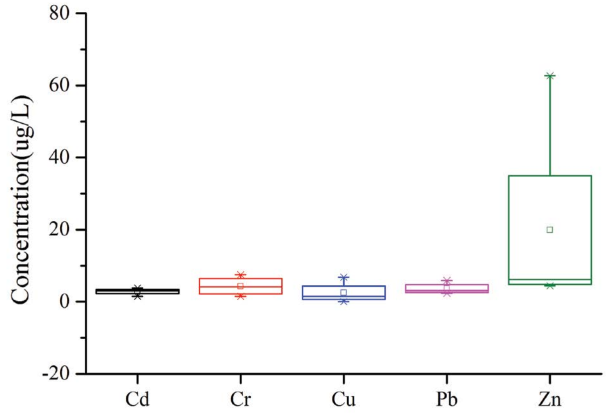

Fig. 7. Concentration of heavy metals in effluent of sewage treatment plant.

pollution sources [45]. The concentration of heavy metals in the effluent of STPs was shown in Fig. 7. The average concentrations of heavy metals were decreased in the order of Zn > Cr > Pb > Cd > Cu. The concentration was decreased significantly after the treatment through the STPs. The concentrations did not exceed the discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002) in China. There was a significant difference in the concentration of heavy metals in the effluent of STPs in this study ($p < 0.05$), due to the water quality of influent and the treatment process and facilities used in the STPs was different [38,39].

For the concentration of heavy metals in effluent compared with influent of STPs, all elements were removed at a various degrees (Table 4). However, the removal efficiencies of some heavy metals were not always satisfactory, the removal rate were decreased in the order of Zn > Cu > Cd > Cr > Pb. The elimination of heavy metals in STPs was a complex process that could be affected by many factors. ÜSTÜN indicated that heavy metals removal efficiencies were directly proportional to metal influent concentrations [46]. However, other conditions such as hydraulic retention time, solid retention time, activated sludge, pH value, temperature, and pollution load may also affect the removal efficiency [47,48]. Therefore, removal rates can vary significantly in different STPs. Compared with CAST (STPs in Chaoyang District) and A/O (STPs in Miyun District), A^2/O+MBR (STPs in Haidian District) technology was more effective for the removal of heavy metals, especially for Cr, Pb, and Zn. As a currently rare sewage treatment process, CAST technology showed the highest removal efficiencies for Cu. In contrast, the removal rate of Pb was the lowest. Many studies showed that when the concentration of Pb in influent of STPs was below than 0.05 mg/L, then their removal rate would be greatly reduced [26,49]. In this study, the concentration of Pb in influent was considerably lower than 0.05 mg/L, and the removal rate of Pb was only 21.58%.

To evaluate the removal efficiencies of the STPs in Beijing, we compared the results [24,38–40,50], and the result is shown in Fig. 8. As shown in Fig. 8, the removal rate of Cu was higher than the medians reviewed, and Zn and Cd were equal to the medians level. However, the removal rates of Cd, Cr, and Pb were lower than the medians reviewed. In general, the average removal rates of Cd, Cr, Cu, Pb, and Zn were within the range of relevant references.

Table 4
Removal rate of heavy metals in sewage treatment plant(%)

	Cd	Cr	Cu	Pb	Zn
Haidian district	50.00	39.86	78.95	33.72	85.23
Chaoyang district	33.33	25.79	100.00	21.34	59.26
Miyun district	37.04	35.71	50.00	9.69	66.67
Average	40.12	33.79	76.32	21.58	70.39

3.4. Occurrence of heavy metals in hospital

The concentrations of heavy metals in the influent and effluent of hospital are shown in Table 5. The average concentrations of heavy metals in influent and effluent were decreased in the order of Zn > Cr > Cu > Pb > Cd, Zn > Cu > Cr > Pb > Cd, respectively. The concentrations of heavy meals in effluent were considerably lower than the discharge standard of water pollutants for medical organization (GB18466-2005). The elimination rate was decreased in the order of Pb > Cr > Cu > Cd > Zn, compared with the STPs, the elimination rates of Cu and Zn were both low. Hospital wastewater is an extremely complex system, which is mainly due to the mixing of wastewater from different departments. Chlorination was the only sewage treatment process, which probably limited the removal efficiency for Cu and Zn in medical wastewater. In addition, hospital wastewater contains a lot of pharmaceutical products and chemical residues [51,52], these contaminants will generate interaction with heavy metals and create synergistic effect [51,53], and affects the removal of heavy metals.

3.5. Concentration of heavy metals in urban water

The concentration of heavy metals in urban water is shown in Fig. 9. The average concentration of heavy metals

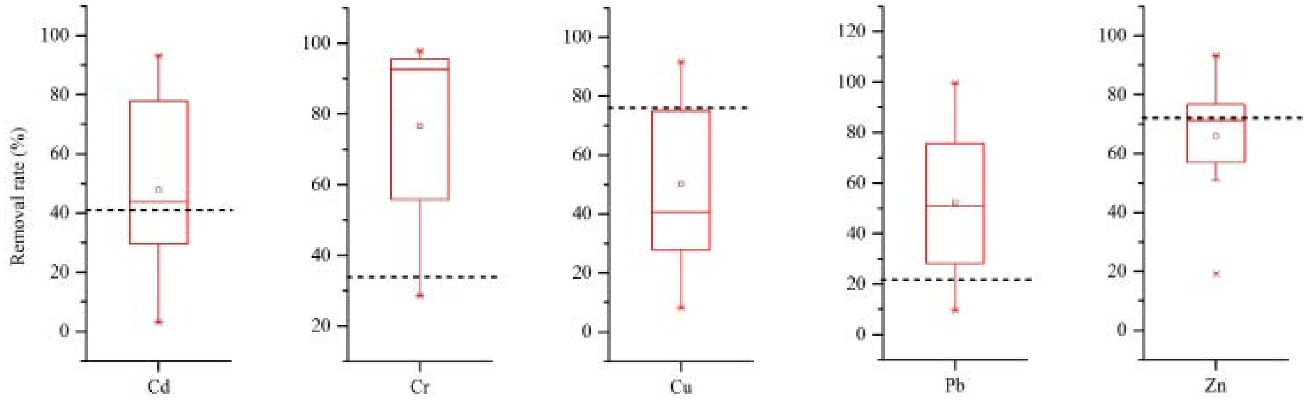

Fig. 8. Removal rate of heavy metals in Beijing and the reviewed Sewage Treatment Plants. The box plots indicated the removal rate of heavy metals in the reviewed Sewage Treatment Plants; the dash lines indicated average values of Sewage Treatment Plants in this study.

Table 5
Concentration of heavy metals in the influent and effluent of hospital

	Cd	Cr	Cu	Pb	Zn
Influent	6.75	19.18	15.40	12.00	90.70
Effluent	3.00	6.80	7.48	3.51	62.70
Elimination rate	55.56	61.02	55.84	70.75	30.87

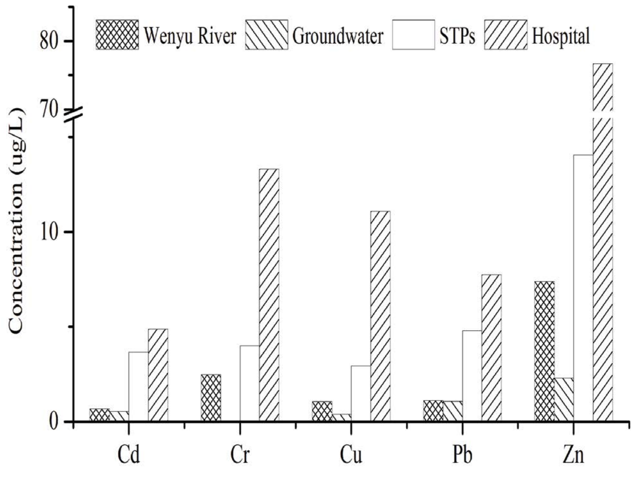

Fig. 9. Concentration of heavy metals in multiple water bodies of Beijing.

ranged from ND-76.70 ug/L in multiple water samples. The highest concentration was in hospital, followed by STPs, groundwater was the lowest. The concentration of heavy metals in hospital were 5–33 times higher than that in the surface water of the Wenyu River and groundwater, which probably due to the process of dental treatment, printing, and testing produced wastewater containing large amounts of heavy metals. The migration of heavy metals was hindered because of the natural soil infiltration layer, which could remove most heavy metals from rainfall, irrigation, and other human activities and result in low concentration of grandwater.

3.6. Risk assessment and source analysis

3.6.1. Health risk assessment on heavy metals in surface water of Wenyu River

Table 6 summarizes the calculated carcinogenic risk (R_k^c) value to man and woman each year through drinking. The average R_k^c value of Cr was higher than that of Cd, and higher risk to woman. For man, the health risk caused by Cd and Cr in drinking water was much lower than the maximum allowance levels (10^{-6}–10^{-4}) recommended by USEPA (USEPA 2013). For woman, the integral level of health risk caused by Cd and Cr was on the high side, Cr was closed to the acceptable level and its maximum value has exceeded 1×10^{-4}, which indicated that Cr was the main carcinogens for woman.

Table 7 summarizes the calculated non-carcinogenic risk (R_k^n) value to man and woman each year through drinking, the average R_k^n value was decreased in the order of Pb > Cu > Zn, and higher risk to woman. The non-carcinogenic risk levels were ranged from 10^{-11} to 10^{-10}, considerably lower than the maximum allowance levels (10^{-6}–10^{-4}) recommended by USEPA [28], the risk level was negligible.

The average annual health risk level of carcinogens to man and woman was much higher than that of non-carcinogens, with a difference of 5–6 orders of magnitude. The health risk caused by carcinogens Cr was the greatest and should be given sufficient attention. Overall, the health risks of heavy metals in Wenyu River were relatively low for the surrounding residents, especially Zn and Cu. However, aquatic organisms are generally more sensitive to Cu and Zn in water than humans, such as fishes and crustaceans [43,54]. It has been shown that Cu and Zn in waters posed the greatest risks to freshwater organisms in typical water bodies of China, in comparison to Cr, Cd, Pb, and As [43,54]. Therefore, the research on health risks of Cu and Zn should be further strengthened.

Table 6
Average annual carcinogenic risk level of carcinogens through drinking water (a^{-1})

		Cd ($\times10^{-6}$)	Cr ($\times10^{-5}$)
Man	Range	1.12–4.79	4.29–8.43
	Average	2.49	6.13
Woman	Range	1.36–5.91	5.30–10.39
	Average	3.07	7.56

Table 7
Annual non-carcinogenic risk level of non-carcinogens through drinking water (a^{-1})

		Pb ($\times10^{-10}$)	Zn ($\times10^{-11}$)	Cu ($\times10^{-11}$)
Man	Range	1.29–6.47	1.01–2.24	1.06–2.57
	Average	4.75	1.49	1.59
Woman	Range	1.59–7.99	1.24–2.76	1.31–3.17
	Average	5.86	1.84	1.97

3.6.2. Health risk assessment on heavy metals in groundwater

The result of carcinogenic risk (R_k^c) of Cd in groundwater of Beijing was shown in Table 8. The average R_k^c value of Cd was much lower than the maximum allowance levels (10^{-6}–10^{-4}) recommended by USEPA (USEPA 2013). However, the carcinogenic risk to woman was slightly higher than that of man.

The result of non-carcinogenic risk (R_k^n) of Pb, Zn, and Cu in groundwater is shown in Table 9. The average R_k^n value was decreased in the order of Pb > Cu > Zn, and the risk level ranged from 10^{-12} to 10^{-10}, considerably lower than the maximum allowance levels (10^{-6}–10^{-4}) recommended by USEPA (USEPA 2013), the risk level was negligible.

Consistent with the results of health risk assessment of surface water, the health risk level of carcinogens to man and woman was much higher than that of non-carcinogens, with a difference of 5–6 orders of magnitude.

3.6.3. Source of heavy metals

The dendrogram associated with clustering of the variables for urban water is shown in Fig. 10. As shown, Cd and Pb clustered together in group 1; Cu and Zn clustered in group 2; and Cr was divided into group 3. Heavy metals clustered in the same group may have a similar source. Many studies have indicated that Cd and Pb were significantly affected by frequently artificial interference such as the disposal of household refuse, vehicle exhaust emissions, application of phosphate fertilizers and pesticide, and so on [4,55]. Cu and Zn were often used in pesticides, chemical fertilizers, and feed additives, and entered into the water environment with the discharge of agricultural runoff and livestock wastewater. Difference from Cd, Pb, Cu, and Zn, Cr was less affected by human activities, and mainly came from natural sources. In addition, the sampling sites in urban water were mainly clustered into three main groups. Overall, group 1 mainly comprised

Table 8
Average annual carcinogenic risk level of Cd through drinking water ($\times10^{-6}$ a^{-1})

	Man	Woman
Range	0.74–4.42	0.91–5.46
Average	2.02	2.49

Table 9
Annual non-carcinogenic risk level of non-carcinogens through drinking water (a^{-1})

		Pb ($\times10^{-10}$)	Zn ($\times10^{-11}$)	Cu ($\times10^{-11}$)
Man	Range	3.45–7.34	0.17–1.21	0.15–1.06
	Average	4.63	0.49	0.59
Woman	Range	4.26–9.06	0.21–1.49	0.19–1.31
	Average	5.72	0.61	0.74

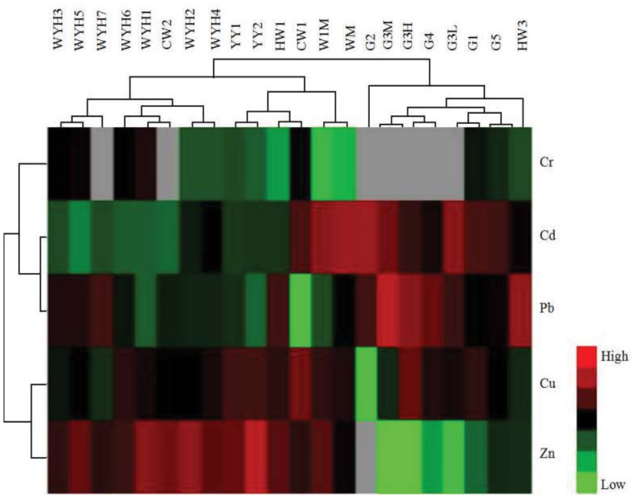

Fig. 10. Results of two-dimensional HCA heat map for five heavy metals in multiple water bodies of Beijing.

the groundwater samples; group 2 comprised the water samples from the Wenyu River; and group 3 comprised the water samples from hospital and STPs. This result indicated that there were differences in the concentration of heavy metals in urban water.

4. Conclusion

Investigations in surface water, groundwater, influents, and effluents from STPs and hospital revealed that:

- The concentration of heavy metals in surface water, groundwater, influents, and effluents from STPs and hospital in Beijing was lower than the corresponding standard limits in China, and the risk level was within the acceptable range.
- All elements decreased in the order of Zn > Cr > Pb > Cu > Cd in surface water of Wenyu River. The

carcinogenic risk (R_k^c) revealed that the health risk caused by carcinogens Cr was the greatest in Wenyu River.
- Heavy metals in groundwater showed that the groundwater was not contaminated by heavy metals. The carcinogenic risk (R_k^c) revealed that the carcinogenic risk for woman was slightly higher than that of man.
- All heavy metals were removed to various degrees, which the removal rate as Zn > Cu > Cd > Cr > Pb through the STPs.
- Compared with the STPs, the removal rate of Cu and Zn was relatively low in hospital wastewater.

This study is only a research for the accumulation of heavy metals in different types of water bodies including surface water, groundwater, influents, and effluents from STPs and hospital in Beijing. In addition, sediment is not only a major carrier of contaminants, but also the potential source of contaminants in aquatic systems [56,57]. Therefore, future studies are necessary to investigate the distribution, accumulation of heavy metals in sediments of Wenyu River.

Ethical consideration

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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