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Heavy Metals Pollution of Storm Sewer Sediments in Xicheng District, Beijing, China

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Total organic carbon (TOC) and heavy metal content, like Cr, Cu, Zn, Cd, Pb and Ni, in the sediment samples taken from 6 different locations in Xicheng District, Beijing, were analyzed. The chemical forms of the metals in the sediment samples were determined after five-steps sequential extraction. The results reveal that the sediments in the storm sewer contain high concentration of total organic carbon and heavy metals. The values of total organic carbon range from 23.39-58.17 mg/g, with mean value of 50.64 mg/g. The mean concentrations of Cr, Cu, Zn, Cd, Pb and Ni are 78.84, 137.92, 590.08, 0.474, 44.67 and 43.61 mg/kg, respectively. The contamination level and ecological risk were assessed using geo-accumulation index (I_{geo}) and potential ecological risk indexes (RI), respectively. A negative conclusion can be drawn that the sediments in the storm sewers located in Xicheng district, Beijing, China contain high content of some heavy metals, which can lead to high potential ecological risk to receiving water bodies with the help of rainwater runoff.

Key Words: Storm sewer sediments, Heavy metal, Sequential extraction, Geo-accumulation, Risk assessment, Beijing.

INTRODUCTION

It is well known that streambed sediments may lead to the accumulation of heavy metal- and organic-based pollutants in the urban areas, where rainwater runoff is associated with vehicle trafficking, pavements, roofs and event industry[1,2]. The pollutants were transported with the surface runoff and deposited, even stored as sediments in urban drainage systems. Therefore, the pollutants transported and stored in urban drainage systems have the potential to provide considerable loadings of heavy metals and other pollutants to the receiving waters, particularly under changing environmental conditions[3] . In sediment, heavy metals can be present in a number of chemical forms, which will exhibit different physical and chemical behaviours, mobility, biological availability and potential toxicity[4,5] . It has been found that the chemical forms of a metal, rather than its total concentration, is the key factor to understand its effect on the biological[6], as well as its biogeochemical transformation ultimate fate[7]. The determination of toxic pollutions in sediments is fundamental to solve many environmental problems[8] and can be of great importance for local people's health[9].

In present paper, the current chemical forms and their corresponding concentrations of heavy metal in storm sewer sediment sampled from some typical urban areas in Beijing were investigated and the contamination level caused by different heavy metals was also assessed using geoaccumulation index (I_{geo}) and potential ecological risk indexes (RI), respectively.

EXPERIMENTAL

Study areas: Xicheng District is located in the west of Beijing, China. In this area, the hybrid, combined and separated drainage systems were co-existed, due to the construction during different historical periods. The selected experimental area is about 1,500 m wide and 3,000 m long, with separated sewers densely located, which extends to the Fuwai avenue in the south, the Xizhimenwai street in the north, the Xinjiekounan avenue in the east and the Xisanhuanbei road in the west. And also part of the Beijing Financial Street was also included as sampling area. Different functional sites like old and new residential subdivisions, schools and commercial districts were included in the sampling areas.

Description of the sampling sites: Obvious sediments were found in about 80 % storm sewers in XiCheng district. Six typical locations (named C1 to C6, respectively) with obvious storm sewer sediments were selected in this study as the representative ones and the details are shown in Table-1.

Sampling and sample preparation: Sediment samples were collected with a pre-cleaned stainless steel shovel during April and May, 2008, just before the rainy season in Beijing. Approximately 1 kg of each sample was taken from selected sites and put into a polyethylene bag and stored at 4 ºC during

TABLE-1
LOCATION AND DESCRIPTION OF THE SAMPLING SITES

Location	Site	Corresponding catchments	Sewer pipes diameter (mm)	The sediment depth (mm)	Date of sampling (mm/dd/yy)
C1	West of Beijing Tax Bureau	Old residential and impermeable road	1000	210	05/17/2008
C2	The Zhanlan road No. 1 Primary school gate	School area and impermeable road	300	130	04/04/2008
C3	Nearby the Beike bookstore	Commercial district	400	100	04/09/2008
C4	Xizhimenbeili No. 9 department	New residential area	300	30	04/22/2008
C5	Yinlan international Building	Business district	500	200	04/16/2008
C6	The Huaxia Bank opposite	Business district	500	50	04/16/2008

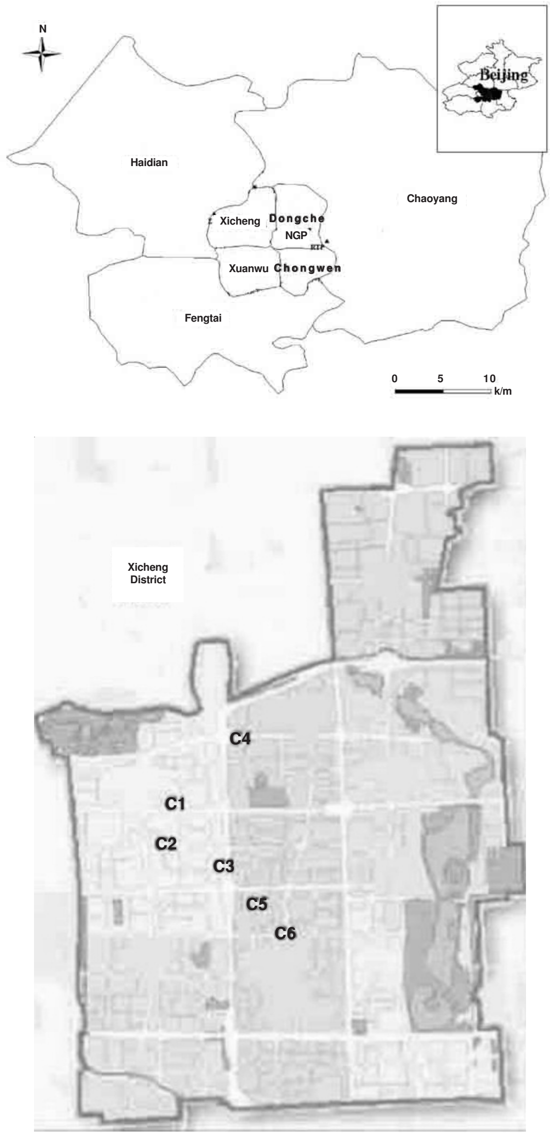

Fig. 1. Location of the sampling sites

its transport to the laboratory. Sediments were dried in an oven at 50 ºC for 48 h and only the fine fraction (diameter < 2 mm) of the representative sample from the dried soils was chosen to be analyzed. Half of the samples were ground in an agate mortar and were sieved with nylon sieve into four major grain sizes (841-420, 420-250, 250-147 and > 147 μm). At last, sediment samples were stored in acid washed polyethylene bottles with plastic screw caps until the sample extraction.

Sample analysis

Total organic carbon analysis: The total organic carbon (TOC) of the sediment samples was measured by titration method, using $FeSO_4$ as titrant after the samples were digested with $K_2Cr_2O_7$-H_2SO_4 solution[10,11].

Sequential extraction of heavy metals and heavy metal analysis: 1 g (± 0.005 g) well prepared samples were moved into Teflon tubes and a five-step sequential extraction was carried out to determine the concentration of different chemical forms of Cd, Cr, Cu, Ni, Pb and Zn (HJ/T 166-2004, China) in the storm sewer sediments.

The concentrations of different chemical forms of Cr, Cu, Zn, Pb, Ni and Cd in digested solutions were determined by ICP-AES (IRIS INTREPID).

Assessment methods of heavy metal contamination in sewer sediments

Geoaccumulation index (I_{geo}): Geoaccumulation indexes (I_{geo}), was originally defined by Muller[12] to determine metals contamination in sediments, by comparing current concentrations with preindustrial levels and can be calculated by the following equation:

$$I_{geo} = \log_2\left(\frac{C_n}{(1.5B_n)}\right) \quad (1)$$

where, C_n is the measured concentration of the examined metal (n) in the sediment, B_n is the geochemical background concentration of the metal (n) and factor 1.5 is the background matrix correction factor due to lithogenic effects. Muller[13] has distinguished seven classes of geoaccumulation index (Table-2). The highest class (class 6) reflects 64-fold enrichment over the background values[14].

TABLE-2
MULLER'S CLASSIFICATION FOR THE GEO-ACCUMULATION INDEX[13]

I_{geo} value	I_{geo} class	Quality of sediment
≤ 0	0	Unpolluted
0-1	1	From unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	From moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	From strong to extremely polluted
>5	6	Extremely polluted

Potential ecological risk index (RI): Potential ecological risk index (RI) was introduced to assess the degree of heavy metal pollution in soil, which was originally introduced by Hankanson[15], according to the toxicity of heavy metals and response of the environment:

$$RI = \Sigma E_i \quad (2)$$

$$E_i = T_i f_i \quad (3)$$

$$f_i = \frac{C_i}{B_i} \quad (4)$$

where potential ecological risk index is calculated as the sum of all six risk factors for heavy metals in soils, E_i is the monomial potential ecological risk factor, T_i is the metal toxic factor developed by Hakanson[15], the order of the level of heavy metal toxicity[16] is Cd > Pb = Ni = Cu > Cr > Zn.

The toxic factor for Pb, Ni and Cu is 5, for Cd is 30, for Cr is 2 and for Zn is 1, f_i is the metal pollution factor, C_i is the concentration of metals in soil and B_i is a reference value for metals. In this study, the adjustment of factors standards was made according to Zhu *et al.*[17]. Four categories of metal pollution were low contamination (RI = 50), moderated contamination (50 < RI = 100), considerable contamination (100 < RI = 200) and high contamination (RI > 200).

Potential ecological risk index represents the sensitivity of various biological communities to toxic substances and illustrates the potential ecological risk caused by heavy metals.

RESULTS AND DISCUSSION

Total organic carbon in sewer sediment: Total organic carbon concentrations in different sewer sites with different particle diameter were listed in Table-3. The values of total organic carbon range from 23.39-58.17 mg/g, with mean value of 50.64 mg/g. The highest concentrations of total organic carbon were found at sites C1 and C3 (59.63 and 58.17 g/kg, respectively). The total organic carbon concentrations in the sediments increase with the decrease of particle diameter in location C1 and C2. High total organic carbon contents are likely attributed to oil leak, tire dusts or asphalt particles.

TABLE-3
TOTAL ORGANIC CARBON IN DIFFERENT SEDIMENTS WITH DIFFERENT GRAIN DIAMETER (mg/g)*

Grain diameter (mm)	C1	C2	C3	C4	C5	C6
0.42-0.841	110.53	70.98	48.16	53.23	32.95	17.74
0.25-0.42	58.30	65.91	60.84	63.37	25.35	30.42
0.147-0.25	65.91	45.63	53.23	35.49	35.49	25.35
< 0.147	48.16	27.88	65.91	17.74	22.81	12.67
Mean	59.63	43.59	58.17	38.78	29.62	23.39
Average	42.20					

*The results are reported in mg/g of dry weight.

Geochemical partitioning of metals

Result of sequential extraction: Heavy metal concentrations in different grain diameter sediment in this study were shown in Table-4.

The sediments showed a significant heterogeneity for the concentrations of Cr, Cu, Zn, Cd, Pb and Ni. It was suggested that the concentrations of Cr, Cu, Zn, Cd, Pb and Ni show a significant spatial control which was likely attributed to their corresponding catchments.

Chromium: Chromium partitioning is dominated by the residual (F5) fraction (average 83.5 % of the total Cr) and the organic (F4) fraction (average 8.50 %), indicating that these two fractions are of major importance as the Cr carriers in the sediments. However, these two fractions showed significant site-to-site variability. The remaining chemical fractions of Cr are negligible (< 8 %) in the sediments. Distribution of Cr in storm sewer sediments is mainly determined by its geochemistry properties. Chromium is one of lithophile elements and easily became a stable oxide-containing acid anion, which would make it difficult to erode[12]. However, the concentration of exchangeable Cr (grain diameter < 0.147 mm) is very high in location C6.

Copper and zinc: Copper and zinc existed mainly in carbonate, reducible, organic and residual fractions, while the exchangeable fraction is insignificant. Copper and zinc coexist with iron oxide generally and their inert iron-manganese oxide fraction exhibited high content. Carbonate and exchangeable Cu contributed to 13.3 and 1.1 % of the total content, respectively. Zn is dominated by the carbonate (F2) fraction (even up to 25.1 % of the total content) because it coexists easily with $CaCO_3$ as a combination. For their high carbonate fraction content, pollution load of Cu and Zn would be easily released with pH lowered (*e.g.* acid rain) and transformation to exchangeable state, which is more unstable.

Lead: As shown in Table-3, the state distribution of Pb is dominated by the residual fraction (F5) (average 56.4 % of the total content) and the reducible one (F3) (about 26.0 % of the total content), while lower organic fraction was presented as 5 % of the total content. Carbonate fraction of Pb were higher than other fractions in C1, C4 and C5 locations, while exchangeable fraction were very low even nearly to undetected. Such variability of the Pb partitioning may be a function of different levels of anthropogenic contamination.

Nickel: Different nickel concentrations were obtained in different study locations. In C4 and C6, it was identified as potentially the most bio-available element contents for their highest contents percentage bound to exchangeable sites. For its great balance power, Ni is easily enriched in clay minerals. Adamo *et al.*[18] verified that Ni was mainly associated with inorganic 'residual' forms of a sulphide and oxide nature in the soil with scanning electron microscopy and energy dispersive X-ray analysis (SEM/EDX). However, the concentrations of exchangeable and carbonate Ni was higher in location C1, which is possibly due to the fact that existion of a pollution source nearby.

Cadmium: Distinct difference was exhibited in fraction distribution of cadmium than other heavy metals in this study. The concentrations of four fractions (exchangeable, carbonate, reducible and organic fraction) were distributed nearly evenly, while the residual one is insignificant. Cadmium partitioning is dominated by the carbonate (F2) (average 34.0 % of total Cd) and the exchangeable (F1) fraction (even up to 22.4 %), indicating that these two factions are of major importance as the Cd carriers in the sediments. It was also verified that the concentration of exchangeable Cd exceeded Beijing background in locations C1, C2 and C3. As a result, frequent and careful monitoring of Cd in sewer sediments in location C1, C2 and C3 is particularly necessary to evaluate its potential hazards to the receiving waters.

Environmental significance of metal partitioning: It has been suggested that the mobility and bioavailability of trace metals in soils and sediments decreases approximately in the order of the extraction sequence (F1-F5) because the strength of extraction reagents used increases from fraction F1 to fraction F5[19-21]. Considering the exchangeable and carbonate fractions, the comparative mobility and bioavailability of the heavy metals in storm sewer sediments in this study in Beijing tends to decrease in the following order: Zn > Cu > Ni > Pb > Cr > Cd. The results of metal partitioning in storm sewer sediments reveals that the environmental change to weak acidic conditions may potentially remobilize less than 2.0 % for Cr, 14.4 % for Cu, 25.1 %-56.4 % for Zn and Cd, corresponding to the percentages of F1 and F2. Higher extractable content for Zn and Cd may be expected under reducing and acidic environmental conditions. Hence, acid rain (pH < 5.6) may appreciably dissolve Zn and Cd. Therefore, it could be suggested that frequent and careful monitoring of Zn and Cd are also necessary.

TABLE-4
FIVE CONFIGURATION HEAVY METAL IN DIFFERENT GRAIN DIAMETER SEDIMENT (mg/kg)*

	Grain diameter (mm)	Cr					Cu					Zn				
		1*	2	3	4	5	1	2	3	4	5	1	2	3	4	5
C1	0.42-0.841	0.0490	0.279	3.85	4.11	49.2	1.40	4.59	33.4	5.56	13.3	2.52	53.4	77.4	26.4	56.8
	0.25-0.42	0.0180	0.278	3.54	4.06	46.0	0.863	3.61	22.4	3.76	11.6	1.99	51.9	80.0	57.4	54.5
	0.147-0.25	0.0420	0.274	2.32	3.85	54.7	0.339	3.65	11.9	3.13	10.1	1.61	32.4	37.4	21.5	39.4
	< 0.147	0.0290	0.256	2.54	4.08	70.3	0.407	3.21	14.9	3.05	7.43	1.53	33.0	38.9	16.0	43.5
C2	0.42-0.841	0.0660	0.181	4.53	6.36	37.8	0.751	7.20	35.9	14.2	18.8	1.84	47.9	105	107	64.4
	0.25-0.42	0.0120	0.300	5.87	5.40	41.0	0.956	13.7	51.8	15.6	8.17	1.83	76.5	129	52.4	71.2
	0.147-0.25	0.0110	0.280	5.66	6.88	75.3	1.01	10.3	42.5	10.4	10.0	1.89	53.6	125	40.5	155
	< 0.147	0.0310	0.178	3.20	6.12	88.2	0.366	9.74	26.0	17.3	34.1	1.60	41.2	73.6	80.3	109
C3	0.42-0.841	0.0650	0.121	7.69	4.45	59.7	1.33	3.91	56.0	8.53	22.8	0.624	46.2	163	95.2	85.4
	0.25-0.42	0.0860	0.115	7.04	5.09	89.5	1.20	2.85	48.1	6.63	14.0	0.508	34.7	150	65.9	67.9
	0.147-0.25	0.0700	0.109	5.42	4.98	34.7	0.858	4.04	43.1	5.34	12.4	0.688	40.9	119	35.0	56.0
	< 0.147	0.107	0.111	6.64	4.69	61.7	0.930	4.01	50.0	9.30	16.3	0.552	48.9	154	51.8	102
C4	0.42-0.841	0.0930	0.279	2.71	1.66	113	0.788	5.07	13.4	13.0	28.8	5.24	151	139	115	112
	0.25-0.42	0.0700	0.298	2.35	2.59	21.0	0.667	12.5	20.3	19.4	13.0	3.72	130	111	58.7	113
	0.147-0.25	0.0470	0.258	1.71	2.34	27.2	0.362	14.4	18.6	8.67	6.96	3.11	148	109	40.4	237
	< 0.147	0.108	0.373	3.44	46.8	68.9	0.968	21.7	39.7	173	29.1	4.58	277	264	808	100
C5	0.42-0.841	0.0900	0.150	2.35	3.63	85.6	0.250	1.83	12.4	2.46	13.1	0.930	19.7	33.0	17.4	132
	0.25-0.42	0.0900	0.160	2.33	3.05	50.7	0.250	1.78	13.0	1.53	10.2	0.750	20.4	29.2	11.6	56.3
	0.147-0.25	0.0800	0.170	2.62	4.85	45.6	0.300	1.96	14.0	2.62	8.82	0.760	23.0	35.3	13.7	97.8
	< 0.147	0.0800	0.140	3.00	6.45	57.9	0.330	2.17	17.2	3.07	9.78	0.950	28.0	47.0	18.4	122
C6	0.42-0.841	0.100	0.290	2.02	2.18	44.1	1.39	70.2	91.6	76.3	36.7	7.55	335	308	198	150
	0.25-0.42	0.0700	0.290	2.07	2.19	37.3	1.67	73.4	112	57.4	64.8	9.10	349	335	154	490
	0.147-0.25	0.0600	0.270	1.96	2.79	39.1	1.57	82.6	101	82.8	21.7	8.67	347	330	190	103
	< 0.147	42.5	0.330	3.62	3.07	46.6	2.33	155	205	226	122	9.59	614	618	473	407
		Cd					Pb					Ni				
C1	0.42-0.841	0.130	0.160	0.0800	0.0900	nd	0.0900	11.2	10.8	0.820	15.8	2.52	3.21	18.7	2.01	3.34
	0.25-0.42	0.100	0.130	0.0700	0.0400	nd	nd	5.95	10.4	1.13	13.1	1.99	16.7	19.4	1.66	2.85
	0.147-0.25	0.0800	0.0800	0.0200	0.0200	nd	0.0300	7.44	6.36	0.940	17.0	1.61	11.2	13.2	1.14	3.01
	< 0.147	0.0800	0.0700	0.0300	0.0300	nd	0.0200	2.78	6.51	0.760	9.94	1.53	5.95	28.7	1.38	3.38
C2	0.42-0.841	0.150	0.160	0.170	0.210	nd	nd	0.950	10.9	3.08	29.2	1.84	0.0800	0.390	2.32	5.07
	0.25-0.42	0.150	0.180	0.140	0.0700	nd	0.0600	1.72	16.0	2.18	10.8	1.83	0.100	0.760	3.01	3.81
	0.147-0.25	0.140	0.140	0.150	0.140	nd	0.120	1.02	15.8	4.09	16.8	1.89	0.100	0.590	3.21	5.41
	< 0.147	0.0700	0.130	0.0900	0.0700	nd	nd	1.08	8.22	9.83	26.1	1.60	0.0700	0.400	2.05	5.91
C3	0.42-0.841	0.140	0.180	0.220	0.140	nd	nd	0.510	18.7	2.27	47.7	0.624	0.110	0.770	2.40	1.70
	0.25-0.42	0.120	0.130	0.190	0.130	nd	nd	0.420	23.3	3.74	37.4	0.508	0.120	0.620	2.42	2.10
	0.147-0.25	0.100	0.110	0.150	0.0900	nd	nd	0.490	21.5	2.57	27.0	0.688	0.110	0.570	1.88	1.99
	< 0.147	0.110	0.170	0.210	0.140	nd	nd	0.790	27.3	5.48	50.6	0.552	0.0900	0.830	2.38	1.91
C4	0.42-0.841	0.120	0.180	0.0600	0.140	nd	nd	1.43	4.25	1.59	23.5	5.24	0.0600	0.460	0.970	1.24
	0.25-0.42	0.0900	0.110	0.0500	0.0400	0.0400	nd	6.80	6.96	1.99	16.6	3.72	0.0600	0.350	0.710	1.33
	0.147-0.25	0.0700	0.100	0.0200	0.0100	nd	0.0400	2.47	4.91	1.75	24.7	3.11	0.0600	0.370	0.660	1.75
	< 0.147	0.160	0.180	0.0900	0.200	nd	nd	3.78	9.66	35.0	23.0	4.58	0.0700	0.610	2.29	3.50
C5	0.42-0.841	0.0630	0.171	0.158	0.162	0.0200	nd	0.900	5.49	0.920	5.47	0.930	0.150	0.450	1.41	3.58
	0.25-0.42	0.0580	0.176	0.136	0.140	nd	nd	0.760	5.38	1.08	7.91	0.750	0.120	0.430	1.29	2.89
	0.147-0.25	0.0770	0.194	0.144	0.138	0.0100	nd	0.880	6.50	0.700	7.53	0.760	0.130	0.490	1.42	4.28
	< 0.147	0.0870	0.226	0.162	0.158	0.0300	0.550	1.05	9.42	0.910	7.00	0.950	0.130	0.570	1.78	4.59
C6	0.42-0.841	0.0200	0.0700	0.0200	0.0400	nd	nd	0.510	3.64	2.12	20.0	7.55	0.0200	0.200	0.480	1.19
	0.25-0.42	0.0400	0.0700	0.0400	0.0200	0.0800	nd	0.560	5.19	2.44	31.9	9.10	0.0400	0.190	0.600	1.22
	0.147-0.25	0.0300	0.0600	0.0200	0.0500	nd	nd	0.720	4.15	2.35	15.2	8.67	0.0200	0.220	0.570	1.76
	< 0.147	0.0400	0.150	0.100	0.110	nd	nd	0.650	7.13	2.20	46.3	9.59	0.0200	0.430	0.820	1.56

*1: Exchangeable fraction, 2: Carbonate fraction, 3: Reducible fraction, 4: Organic and sulfide fraction, 5: Residual fraction. nd: not detected. [a]The results are reported in mg g^{-1} of dry weight.

Pollution evaluation of heavy metals in sewer sediments in Beijing: As shown in Table-4, the mean concentrations of Cr, Cu, Zn, Cd, Pb and Ni are 78.84, 137.92, 590.08, 0.474, 44.67 and 43.61 mg/kg, respectively. The highest concentrations of Cu and Zn were verified in the range of 29.33-375.57 and 148.90-1288.76 mg/kg, respectively. The concentration of Pb ranged widely from 15.43-66.13 mg/kg, with 44.67 mg/kg as the mean value.

The comparison of heavy metal concentrations in this study with Beijing background (Table-4) shows that the concentrations of most heavy metals studied in Beijing storm sewer sediments are relatively higher.

To evaluate the pollution of heavy metals in sewer sediments, such indices as geoaccumulation index (I_{geo}), contamination factor (CF), Potential ecological risk indexes (RI) and pollution load index (PLI) could be used.

Geoaccumulation index (I_{geo}): The I_{geo} values for the metals of environmental interest in sewer sediment in Beijing were shown in Table-5 as 0.23-0.88 for Cr, 0.06-3.74 for Cu, 0.78-3.90 for Zn, 0.23-1.70 for Cd, -1.25-0.84 for Pb and -1.63-0.64 for Ni. It was indicated that uncontaminated to heavily pollution of investigated metals in the study area, although some deviation is observed depending on each metal and sampling location. Among most toxic metals, Cu and Zn are distinct accumulated in the sewer sediments in Beijing, as indicated by their respective average I_{geo} values of 1.46 and 2.09. In contrast, the I_{geo} value of Pb (-1.26~0.442) and Ni (-1.63~-0.3) are lower than zero, indicating that the area is not polluted by these metals. On the basis of the mean values of I_{geo}, sediments are enriched for metals in the following order: Zn > Cu > Cd > Cr > Pb > Ni and the pollution order for stations is C6 > C2 > C3 > C4 > C1 > C5.

For different traffic and infrastructure conditions, different pollution levels were presented in different sampling sewer sites from different corresponding catchments.

In C1 and C4, the corresponding catchments are mainly residential area, the sediment is not polluted by Pb with low I_{geo} (-0.44), However, light pollution was shown from other five metals with I_{geo} between 0 and 1. The I_{geo} of Cu and Zn were 1.76 and 3.00, respectively in location C4 and corresponding heavy pollution could be concluded. However, in location C2 and C3, the sediment is moderately contaminated by Cu, Zn and Cd according to their I_{geo}, which could be attributed to their sediment sources from roof and municipal roads with higher traffic and more population density. The corresponding runoff catchments of C5 and C6 were mainly business districts with alloy highly used in architecture and the metals would be eroded by the acid rain (pH < 5.6) and enter the storm sewer easily. As a result, I_{geo} of 1.06 for Zn and 1.70 for Cd were obtained, from which meant that the sewer sediments are moderately polluted by Zn and Cd in location C5 and C6. As a result, contrasted with heavy metal background in Beijing, it could be estimated that several heavy metal pollution potential from the I_{geo} in sewer sediment from different runoff catchment's sources in this study is as follows: Zn > Cu > Cd > Cr > Pb > Ni.

Potential ecological risk indexes (RI): As listed in Table-6, Cd posed a medium potential risk to the local, while for other metals the potential ecological risk was low. The ecological risk index, according for the contamination caused by Cr, Cu, Zn, Cd, Pb and Ni indicated that storm sewer sediments were suffering form considerable contamination. Among six locations, the RIs were potentially posed high risk in C2 to C6, moderate contamination in C1.

TABLE-5
DESCRIPTIVE STATISTICS AND GEOACCUMULATION INDEX (I_{geo}) OF HEAVY METALS IN SEWER SEDIMENT

Sample	TOC (mg/kg)	Cr		Cu		Zn		Cd		Pb		Ni	
		Conc. (mg/kg)	I_{geo}	Conc. (mg/kg)	I_{geo}	Conc. (mg/kg)	I_{geo}	Conc. (mg/kg)	I_{geo}	Conc. (mg/kg)	I_{geo}	Conc. (mg/kg)	I_{geo}
C1	59.63	66.63	0.58	31.70	0.18	148.90	0.79	0.23	0.37	27.16	-0.44	62.61	0.64
C2	43.59	82.35	0.88	83.56	1.57	330.82	1.94	0.48	1.43	40.38	0.13	54.08	0.43
C3	58.17	69.87	0.64	74.72	1.41	313.96	1.86	0.56	1.65	66.13	0.84	38.76	-0.05
C4	38.78	52.39	0.23	94.72	1.76	688.31	3.00	0.31	0.80	40.62	0.14	12.99	-1.63
C5	29.62	68.79	0.62	29.33	0.06	179.68	1.06	0.58	1.70	15.43	-1.26	31.19	-0.37
C6	23.39	54.19	0.28	375.57	3.74	1288.76	3.90	0.21	0.23	33.62	-0.13	18.43	-1.13
Max	58.17	82.35		375.57		1288.76		0.58		66.13		62.61	
Min	23.39	52.39		29.33		148.90		0.21		15.43		12.99	
Mean	50.64	78.84	0.54	137.92	1.45	590.08	2.09	0.474	1.03	44.67	-0.12	43.61	-0.35
Beijing background*		29.8		18.7		57.5		0.119		24.6		26.8	

*Background values form Chen *et al*. (2004).

TABLE-6
HEAVY METAL POTENTIAL ECOLOGICAL RISK INDEXES IN SEDIMENTS

Location	E_i						RI	Pollution degree
	Cr	Cu	Zn	Cd	Pb	Ni		
C1	4.47	8.48	2.59	57.98	5.52	11.68	90.72	Moderate
C2	5.52	22.34	5.75	121.01	8.21	10.09	172.92	Considerable
C3	4.69	19.98	5.46	141.18	13.44	7.23	191.98	Considerable
C4	3.52	25.32	11.97	78.15	8.26	2.42	129.64	Considerable
C5	4.62	7.84	3.12	146.21	3.14	5.82	170.75	Considerable
C6	3.64	100.42	22.41	52.94	6.83	3.44	189.68	Considerable

On the basis of potential ecological risk indexes, the pollution order for stations is C3 > C6 > C2 > C5 > C4 > C1. Therefore, a general conclusion can be drawn that the storm sewer sediments in Xicheng district, Beijing have been contaminated by certain metals.

Conclusion

Sediments were found in about 80 % storm sewers in XiCheng district, Beijing, China. With the different catchments considered, six typical storm sewer sediment locations were included in this study to investigate pollution of such heavy metals as Zn, Cu, Ni, Pb, Cr and Cd. The results are as follows: The mean values of total organic carbon range from 23.39-58.17 mg/g, with means value of 50.64 mg/g. The highest concentrations of total organic carbon were found at C1 and C3 (59.63 and 58.17mg/g, respectively).

A five-step sequential extraction of storm sewer sediments showed that Cr occur predominantly in the residual bound fraction, Pb mainly in the reducible and residual fraction, Cd in carbonate fraction and Ni in residual fraction. Considering the exchangeable and carbonate fractions, the comparative mobility and bioavailability of the metals in storm sewer sediments in Beijing tends to decrease in the following order: Zn > Cu > Ni > Pb > Cr > Cd.

The mean concentrations of Cr, Cu, Zn, Cd, Pb and Ni are 78.84, 137.92, 590.08, 0.474, 44.67 and 43.61 mg/kg, respectively. The highest concentrations of Cu and Zn were verified in the range of 29.33-375.57 and 148.90-1288.76 mg/kg, respectively.

Geoaccumulation index (I_{geo}), contamination factor (CF), pollution load index (PLI) and potential ecological risk indexes (RI) were used to evaluate heavy metal pollution level in storm sewer sediments in XiCheng District, Beijing and significant spatial variation of heavy metals (Cr, Cu, Zn, Cd, Pb and Ni) in six study locations from C1 to C6 was verified. Heavy metal pollution states from uncontaminated to extremely contaminated on sewer sediments were practically presented from different Igeo of metals in this study. As a result, contrasted with heavy metal background in Beijing, it could be estimated that several heavy metal pollution potential from the Igeo in sewer sediment from different runoff catchment sources in this study is as follows:

Zn > Cu > Cd > Cr > Pb > Ni

Pollution load indices (PLIs) derived from contamination factors showed that all sediments in the study area exceed Beijing background values and may be considered as heavily contaminated to extremely contaminated. On the basis of RIs, the pollution order for stations is

C3 > C6 > C2 > C5 > C4 > C1

Therefore, a general conclusion can be drawn that the storm sewer sediments in Xicheng District, Beijing have been contaminated by certain metals.

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