Research Article

Fractional Characteristics of Heavy Metals Pb, Zn, Cu, and Cd in Sewer Sediment from Areas in Central Beijing, China

Haiyan Li, Mingxiu Wang, Wenwen Zhang, Ziyang Zhang, and Xiaoran Zhang

*Beijing Engineering Research Center of Sustainable Urban Sewage System Construction and Risk Control,
Beijing University of Civil Engineering and Architecture, Beijing 100044, China*

Correspondence should be addressed to Xiaoran Zhang; zhangxiaoran@bucea.edu.cn

Received 15 July 2016; Revised 16 August 2016; Accepted 31 August 2016

Academic Editor: José Morillo Aguado

Copyright © 2016 Haiyan Li et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

To identify the distribution of heavy metals in sewer sediments and assess their potential harmfulness to the environment and human health, the occurrence of Pb, Zn, Cu, and Cd in the sewer sediment of six functional areas and two streets in an inner-city suburb of Beijing, China, was investigated by using a sequential extraction procedure. Results show that the concentrations of Cu, Zn, Cd, and Pb vary between 50 and 175, between 80 and 180, between 0.75 and 2.5, and between 20 and 110 mg/kg, respectively, and Fe-Mn oxide fraction is significant for all metals in sampling areas. Pollution assessment shows that 1–2% of Cu at Chegongzhuang Street and 1–3% of Zn at Fuwai Street in the exchangeable fractions are of low risk. 10–25% of Cd at six functional areas indicates medium risk. 40–60% of Pb at Fuwai Street existing in the exchangeable fractions is of high to very high risk. The sum of these metals associated with exchangeable, carbonate bound, and Fe-Mn oxide fractions is quite high; however, these three fractions represent the proportion of heavy metals that can be remobilized by changes in environmental conditions.

1. Introduction

Over the last three decades, urbanization and industrialization have taken place at an unprecedented pace in China. Urban environmental pollution has become a very important topic for environmental researchers [1]. Beijing, the capital of China, is the political, economic, and cultural central of the nation and is also one of the oldest and most densely populated cities in the world. The rapid development has exerted considerable pressure on the urban environment. The quality of sewer sediment is one of the important potential pollution indicators for urban environment [2].

For the various pollutants, heavy metals are a serious threat to the sediment quality due to their persistence after entering the sewers. In general, the distribution of heavy metals in sewer sediment is affected by the mixed effect model, for which human activity modes, climate variables, and soil properties were identified as fixed effects, while sampled sites were deemed as random effects [3]. Among these, the impacts of human activity modes on metal distribution are biased and mainly include waste disposal and other industrial and urban activities [3]. In different functional

areas and streets, various metals may relate to many mobile or stationary sources, such as vehicular traffic, industrial plants, power generation facilities, residential oil burning, waste incineration, city construction and demolition activities, and the resuspension of surrounding contaminated soils [4]. During rainfall, metals from these sources are washed from roofs, roads, and other surfaces into the rain water system and then into the separate sewers system. Part of heavy metals transferred into sewage is thus stored within the sewer sediment during dry weather [5]. Upon overflows, sewer sediment may contribute up to 50% of the total load of metal contaminants discharged into the receiving waters [6].

In sewer system, the fate and behavior of heavy metals are governed by several reactions, including precipitation, adsorption, complexation, and methylation [7, 8]. Accumulation of heavy metals in this system can reduce the content of microbial biomass, limiting the functional diversity [8]. However, it is difficult to assess the metal pollution levels by determining the total metal concentration only. Chen et al. [8] and Achiba et al. [9] have reported that the distribution of heavy metals in soils was affected by several factors, including physicochemical properties of soils, redox

FIGURE 1: Sampling sites in Xicheng District of Beijing, China. Note: black spots represent functional areas including old residential area (I), comprehensive area (II), new residential area (III), pedestrian only commercial area (IV), educational area (V), and business area (VI). Heavy traffic area at Chegongzhuang Street (C1 to C4) and Fuwai Street (F1 to F5).

potential, and ligand, and the same applies to the distribution of heavy metals in sediment. In general, the toxicity and mobility of heavy metals in the sediment depend on both the total concentration and their specific chemical forms including exchangeable fraction, carbonate bound fraction, Fe-Mn oxide bound fraction, organically bound fraction, and residual fraction [10]. Thus not only the total concentration but also the chemical fractionation should be taken into account in pollution studies.

Although many studies have investigated the distribution of heavy metals in sediment, they mainly focus on the river sediment [11–13] and road dust [14, 15]; limited information is available for sewer system, especially for developing countries, for example, China. In addition, in the previous literatures on sewer system, the heavy metals have generally been assessed in terms of total loads [16, 17]. However, the knowledge of metal distribution characteristics stored in sewers is of prime importance for the management of wet weather flow pollution by heavy metals. Thus, the spatial distribution of heavy metals in sewer sediment of areas in Xicheng District, Beijing, was investigated. The objectives of this study are (i) to determine the total concentration of four metals including Pb, Cd, Zn, and Cu in the sewer sediment; (ii) to determine the chemical fractionations of these metals; (iii) to carry out a preliminary assessment of their environmental risks.

2. Material and Methods

2.1. Sampling. Seventy-two sewer sediment samples were collected from two streets and six surrounding functional

areas in Xicheng District of Beijing in August 2010. The six areas (I to VI in Figure 1) included the old residential area (I); comprehensive area including residential area and a college (II); the new residential area (III), one of the biggest residential areas in Xicheng District; a pedestrian only commercial area (IV); educational area (V): Beijing University of Civil Engineering and Architecture; and business area with lots of commuters (IV). Additionally, spots at Fuwai Street (F1 to F5) and Chegongzhuang Street (C1 to C4) were selected representing heavy traffic areas (Figure 1).

2.2. Analytical Methods. Immediately after collection, samples were dried at room temperature ($25 \pm 2^\circ\text{C}$) and ground with a pestle and mortar. Then the sediments were sieved through a 2 mm sieve to reduce coarse particles. For microwave digestion, 0.5 g of the sediment samples was digested with a mixture of HF-HClO₄ described in a previous study [10]. The concentrations of Cu, Zn, Cd, and Pb in the digests were then determined by the flame atomic absorption spectrophotometry.

Sequential extraction procedures were used to determine the metal fractionation in the sediments [10]. The method consists of the following steps.

- (1) Exchangeable fraction is extracted with magnesium chloride.
- (2) Carbonate bound fraction is extracted with sodium acetate.
- (3) Fe-Mn oxide bound fraction is extracted with hydroxylamine hydrochloride/acetic acid.

- (4) Organically bound fraction is extracted with nitric acid/hydrogen peroxide/ammonium acetate.
- (5) Residual fraction is extracted with hydrochloric/perchloric acids.

Each extraction was followed by centrifugation at 10,400 rpm for 30 min. The supernatants were filtered using 0.45 μm filters and kept in sterilized flasks in a cold room (-4°C) until analysis. All metal concentrations were determined by flame atomic absorption spectrometry. The laboratory standards for the metals were tested with standard reference material. Average values of five replicates of standards were taken for each sample. Quantification of metals was based on the calibration curves of standard solutions.

2.3. Statistical Analysis. SPSS 16.0 software was used for the statistical analysis of this study. The statistical differences among the mean data were analyzed by the one-way analysis of variance, followed by Tukey's post hoc test at 5% level.

2.4. Pollution Assessment. The potential ecological risk index (R_I) is used to assess the ecological risks of heavy metals in sediment [10]. The R_I value is computed using the following equation:

$$\begin{aligned} C_f^i &= \frac{C_n^i}{C_o^i}, \\ E_r^i &= T_r^i \times C_f^i, \\ R_I &= \sum E_r^i, \end{aligned} \quad (1)$$

where C_f^i is the single metal pollution index; C_n^i is the total content of metal i in the samples; C_o^i is the reference value for the metal i ; E_r^i is the single metal potential ecological risk index; T_r^i is metal's toxic response factor, 1 for Zn, 5 for Cu, 5 for Pb, and 30 for Cd; R_I is the potential ecological risk caused by the overall contamination.

3. Results and Discussion

3.1. Total Concentrations of Heavy Metals in Different Sampling Sites. The total metal concentrations in sediment samples collected from different functional areas are summarized in Figure 2(a). The concentrations of Cu, Zn, Cd, and Pb vary between 50 and 175, 80 and 180, 0.75 and 2.5, and 20 and 110 mg/kg, respectively. Except Pb in the new residential area (III), the concentrations of metals studied exceed the background values of sediment in Beijing (the background values of Cu, Zn, Cd, and Pb are 11.27, 76.8, 0.12, and 21.71 mg/kg, resp.) [18], with the levels of Cu, Cd, and Pb being more than 4 times the background values, indicating that the pollution may come from human factors. The highest Cu and Zn concentrations are found in old residential area (I) with the values of 175 and 180 mg/kg, respectively, and followed by commercial (IV) and business areas (VI). Higher accumulation of organic matter in the sediment of the old residential area, heavy traffic, and more

frequent construction and decoration in the commercial and business areas may have contributed to the high levels.

In general, the Cu, Zn, and Pb concentrations in the sediment are significantly higher than Cd on Fuwai Street ($P < 0.05$, Figure 2(b)). The highest Cu concentration is 110 mg/kg at sites F1 and F4, and Cu pollution can be found in house dust relating to the time when there is pollution in exterior dust and soils reported previously in Ottawa [19]. In addition, high concentrations of the four metals are observed in F2, F3, and F4, which may be attributed to the high traffic volumes as these three sites are located near the intersection. The vehicular-related deposition of particles may primarily come from vehicle exhaust particles, lubricating oil residues, tire wear particles, brake lining wear particles, and particles from atmospheric deposition, plant matter, and materials produced by the erosion of the adjacent soil [20].

At Chegongzhuang Street, except Zn from C4, the concentrations of metals in four sites are similar ($P > 0.05$, Figure 2(c)). Compared to the metal concentrations from studies in other Chinese cities, a relatively lower level of heavy metals in the sediment is shown in this study [21, 22]. However, compared to an earlier study in Beijing [23], slight increase in Cu and Pb concentrations is observed in our result, which may be due to the rise of gasoline use. Although leaded gasoline is banned in Beijing from 1997, the sediment may have acted as a reservoir for Pb pollution over the years. In addition, it is clear that Cd is present at higher concentrations relative to the background sediment values of Beijing (0.12 mg/kg, $P < 0.05$), as both sides of the Chegongzhuang Street are residential areas, suggesting that Cd pollution may be due to human factors.

3.2. Metal Speciation in Different Sampling Sites

3.2.1. Metal Speciation in Functional Areas. The Fe-Mn oxide bound fraction is significant for all metals. With the exception of commercial area (IV) and Zn in educational area (V), Fe-Mn oxide bound fraction of Cu (30%–65%) and Zn (30%–45%) are the largest proportions at various functional areas (Figure 3). Cd and Pb are dominated by carbonate bound fraction (25%–40%) and residual fraction (43%–80%), respectively (Figure 3).

The four metals demonstrate significant variations in speciation among sites ($P < 0.05$, Figure 3). Cu in old and new residential areas (I and III), comprehensive area (II), and educational area (V) are dominated by the Fe-Mn oxide bound fraction, with a range of 50%–65%, which may be because of the absorbing capacity and high surface area of Fe-Mn oxide bound fraction plus the ability of Cu to replace Fe^{2+} in the Fe-Mn oxide fraction [24]. In commercial area (IV), however, the organically bound fraction is significant for all metals and is the main part of Cu and Zn (>30%), and similar results are obtained by Li et al. from street dusts [14]. The carbonate bound, Fe-Mn oxide bound, and organically bound Cu fractions are similar in their contributions in business area (VI), with values of 24%, 32%, and 28%, respectively.

Fe-Mn oxide bound fraction plays an important role in nonresidual fraction of Zn, especially at old residential area (I), comprehensive area (II), and new residential area

FIGURE 2: Metal concentrations of (a) six functional areas: (I) old residential area, (II) comprehensive area, (III) new residential area, (IV) pedestrian only commercial area, (V) educational area, and (VI) business area; (b) Fuwai Street; (c) Chegongzhuang Street.

(III). The large part for Fe-Mn oxide bound fraction may be attributed to the adsorption, flocculation, and coprecipitation of metal Zn with the colloids of Fe and Mn oxy-hydroxide [25]. In commercial (IV) and business areas (VI), fraction distribution of Zn shows a similar pattern to Cu.

Compared to other metals, Cd shows more evenly fractional distribution, with Fe-Mn oxide bound fraction $\approx$ carbonate bound fraction $\approx$ organically bound fraction $\approx$ exchangeable fraction $>$ residual fraction. Similar results are obtained in previous studies on street dusts [14]. It is worth noting that a significant difference is observed that some Cd exists in very labile forms at all sites. Exchangeable fraction

and carbonate bound fractions reach up to 40%–70% of the total Cd.

Most of Pb is in the residual fraction (45%–80%) and Fe-Mn oxide bound fraction (10%–40%) (Figure 3). The dominance of the residual fraction for Pb is largely dependent on the continental origin of the element [26].

3.2.2. Metal Speciation in Fuwai Street. As shown in Figure 4, the Cu that bound to the organically bound and residual fractions is 45%–70% and 25%–55%, respectively. This phenomenon may be explained by the easy formation of high stability constants of organic-Cu compounds [25]. As

FIGURE 3: The fractionation distribution of metals Cu, Zn, Cd, and Pb in six functional areas: (I) old residential area, (II) comprehensive area, (III) new residential area, (IV) pedestrian only commercial area, (V) educational area, and (VI) business area. Note: E, C, Fe-Mn, O, and R represent exchangeable fraction, carbonate bound fraction, Fe-Mn oxide bound fraction, organically bound fraction, and residual fraction, respectively.

reported in earlier studies on polluted sediment, extractable Cu is mainly associated with the organic phase and is likely to occur as organically complexed metal species [27]. Even though Cu is generally adsorbed to a greater extent than other metals, the high affinity of Cu^{2+} ions for soluble organic ligands may greatly increase their mobility in sediments [25].

For Zn, the residual fraction (65%–85%) is the most dominant in the sediment from all sites, followed by the Fe-Mn oxide bound and organically bound fractions, with the combined ranges of 10%–30%. The association of Zn with residual fraction can be regarded as the contribution by nature sources and is relatively stable in the environment [28].

FIGURE 4: The fractionation distribution of metals Cu, Zn, Cd, and Pb at Fuwai Street. Note: E, C, Fe-Mn, O, and R represent exchangeable fraction, carbonate bound fraction, Fe-Mn oxide bound fraction, organically bound fraction, and residual fraction, respectively.

The metal that associated with the Fe-Mn oxide bound and organically bound fractions can be mobilized when environmental conditions changed by reduction or oxidation [28].

The fractional distribution of Cd on Fuwai Street is relatively different between sampling sites. At site F1, Cd primarily bound to the carbonate bound fraction, and similar result has been reported by Yao et al. [29] and Yao [30]

for Dongting Lake in central China. At sites F2, F3, and F4, Cd mainly bound to the residual fraction, while at F5, it is dominated by Fe-Mn oxide bound fraction. As Cd has a predominate presence and is readily released in the surface sediment, the sediment in Fuwai Street may become bioavailable.

Pb mainly bound to the exchangeable fraction (40%–60%) and is followed by Fe-Mn oxide bound and residual

FIGURE 5: The fractionation distribution of metals Cu, Zn, Cd, and Pb at Chegongzhuang Street. Note: E, C, Fe-Mn, O, and R represent exchangeable fraction, carbonate bound fraction, Fe-Mn oxide bound fraction, organically bound fraction, and residual fraction, respectively.

fractions. Our result is different from those in regions influenced by industrial effluents, including coastal sediment in Spain [31] and marine sediment in Singapore [11], where Fe-Mn oxide bound fractions are found to be the main carrier sediment. This variation indicates different pollution sources, as Fuwai Street is influenced more by high volume traffic.

3.2.3. Metal Fractionation on Chegongzhuang Street. The organically bound fraction of Cu dominated all sampling

sites (75%–80%, Figure 5), which is probably due to its more pronounced tendency for complexation with organic matter, thus showing low bioavailability [32]. Similar findings are observed in Nainital Lake, India [33].

The residual fraction of Zn is the largest proportion at all sampling sites, with percentages of 40%–60%, which indicate that it is incorporated into the mineral phase and is therefore of natural geochemical origin [34]. In addition, a moderate amount of Zn exists in the carbonate bound, Fe-Mn oxide

TABLE 1: The E_r^i and R_I values of the heavy metals.

Sampling sites	E_r^i				R_I
	Cu	Zn	Cd	Pb	
I	73.79	2.73	298.77	21.04	396.33
II	31.06	1.24	250.00	20.73	303.03
III	24.03	1.03	173.53	5.83	204.42
IV	48.72	1.54	545.09	25.11	620.46
V	20.48	1.23	472.75	12.75	507.21
VI	38.05	1.73	248.58	14.60	302.96
F1	46.58	1.43	375.00	24.18	447.19
F2	23.51	1.63	625.00	33.39	683.53
F3	24.40	1.95	899.00	23.03	948.38
F4	48.80	1.82	875.00	24.64	950.26
F5	39.93	0.98	250.00	26.49	317.40
C1	37.27	1.30	375.00	19.35	432.92
C2	39.93	1.11	312.50	20.73	374.27
C3	48.80	1.17	262.50	21.84	334.31
C4	35.49	1.69	250.00	22.99	310.17
Mean value	38.72	1.50	414.18	21.11	475.52

(I) old residential area, (II) comprehensive area, (III) new residential area, (IV) pedestrian only commercial area, (V) educational area, and (VI) business area; Chegongzhuang Street (C1 to C4) and Fuwai street (F1 to F5).

bound, and organically bound fractions, with the proportions of 7%–20%, 10%–20%, and 18%–20%, respectively. Metals in the carbonate bound and Fe-Mn oxide bound fraction are labile and may enter the food chain [33].

In terms of Cd, 60%–90% is associated with carbonate bound and Fe-Mn oxide bound fractions and can be easily remobilized by changes of environmental conditions.

The fractional distribution of Pb indicates that a major portion (>60%) of Pb is associated with organically bound and residual fractions at all sites. The metal associated with these fractions cannot be remobilized under normal conditions. A significant amount (about 30%) of Pb is also found to be associated with the Fe-Mn oxide bound fraction, which may indicate dominance of human sources through municipal discharges, and similar result is found in the sediment from Xiangjiang River [12].

3.3. Pollution Assessment

3.3.1. Pollution Assessment of Total Metals. In this study, the sediment background values for sediment of Beijing are chosen as the background values to calculate the R_I value (Cd: 0.12 mg/kg, Cu: 11.27 mg/kg, Pb: 21.71 mg/kg, and Zn: 76.8 mg/kg) [18]. The E_r^i and R_I values are typically classified as follows: low risk ($E_r^i < 40$; $R_I < 150$); moderate risk ($40 \leq E_r^i < 80$; $150 \leq R_I < 300$); considerable risk ($80 \leq E_r^i < 160$; $300 \leq R_I < 600$); high risk ($160 \leq E_r^i < 320$; $R_I \geq 600$); very high risk ($E_r^i \geq 320$).

The E_r^i and R_I values for the metals studied are presented in Table 1. As a whole, the metals show significantly different

TABLE 2: Pollution grades of potential ecological risk of heavy metals.

Risk assessment code	Criteria (%)
No risk	<1
Low risk	1–10
Medium risk	11–30
High risk	31–50
Very high risk	>50

E_r^i values ($P < 0.05$), with the ranking of average E_r^i being as follows: Cd > Cu > Pb > Zn. The average E_r^i value of Cd is 414.80, which is ranked as “very high risk,” with individual values falling into high and very high risk categories especially in the commercial area (IV) and Fuwai Street. The high Cd concentration in these areas with a higher population density may be attributed to complicated human factors. The average E_r^i value for Zn is 1.50, which is ranked at “no risk to low risk” level. Cu and Pb both ranked at “low risk” level. In addition, the average R_I value is 475.52, suggesting that the study areas are heavily contaminated by the four metals; especially the commercial area (IV) and three sites of Fuwai Street (F2, F3, and F4) even reach the level of “very high risk.”

3.3.2. Risk Assessment of Metal Speciation. Although the total concentration of heavy metals in the sediment is a useful parameter that indicates the degree of contamination, it cannot predict the fate of any of the metals and their effects on the environment [35]. Studies have shown that the geochemical properties of the sediment are critical to metal bioavailability [13]. Metals bound to different phases behave differently in the sedimentary environment and therefore have different potentials for remobilization and the uptake by biota. It is evident from the results of the speciation study that the metals in the sediment bound to different fractions with different strengths. The strength values can therefore give a clear indication of sediment reactivity, which in turn can measure the risks connected to the metals.

The risk assessment code given below is rated as the risk of metals released in exchangeable and carbonate bound fractions (Table 2). Less than 1% of the total metal is considered safe for the environment. On the contrary, more than 50% of the total metal is considered highly dangerous and can enter the food chain [15].

The 1–2% of Cu at Chegongzhuang Street and the 1–3% of Zn at Fuwai Street in the exchangeable fractions are therefore of low risk according to the risk assessment. The 10–25% of Cd at six functional areas indicates medium risk. The 40–60% of Pb at Fuwai Street existing in the exchangeable fractions is of high to very high risk and may enter the food chain. The association of these metals with exchangeable fraction may also have deleterious effects on aquatic life. The sum of the metals (Cu, Zn, Cd, and Pb) associated with exchangeable, carbonate bound, and Fe-Mn oxide bound fractions is also quite high, especially Cu (30–70%), Zn (45–60%), and Cd (70–90%) in functional areas, Pb (75–80%) at Fuwai Street,

and Cd (60–90%) at Chegongzhuang Street. In general, the sum of these three fractions is extremely important because it represents the proportion of heavy metals that can be remobilized by changes in environmental conditions such as pH, redox potential, and salinity [36].

4. Conclusions

The concentrations, distribution, accumulation, and pollution assessment of the heavy metals (Cu, Zn, Cd, and Pb) in sewer sediment from six different functional areas and two streets in Xicheng District, Beijing, are studied in this paper. The concentrations of Cu, Zn, Cd, and Pb vary between 50 and 175, 80 and 180, 0.75 and 2.5, and 20 and 110 mg/kg, respectively in the six functional areas. At Fuwai Street, most metals highly accumulated in the middle while having similar concentrations among sampling sites at Chegongzhuang Street. In terms of fractional distribution, the Fe-Mn oxide bound fraction is significant for all metals with the values of 10–60% at functional areas, while Cu, Zn, Cd, and Pb are dominated by different fractions at two streets. The concentrations of Cu, Zn, Cd, and Pb in most study sites are higher than the local sediment background values, indicating that the pollution may result from human factors, such as vehicle exhaust, building construction, and waste incineration.

The assessment performed by potential ecological risk index indicates that the pollution levels of the heavy metals are as follows: $Cd > Cu > Pb > Zn$, and Cd could be considered as heavily contaminated. During the risk assessment, Zn is ranked at “no risk to low risk” level and Cu and Pb is ranked at the “low risk” level. The high Cd concentration at six areas however fell into the “high to very high risk” category and may enter into the food chain. The sum of the metals (Cu, Zn, Cd, and Pb) associated with exchangeable, carbonate bound, and Fe-Mn oxide bound fractions is quite high; however, these three fractions represent the proportion of heavy metals that can be remobilized by changes in environmental conditions. In summary, the results from this study can provide information on sewer sediment management.

Competing Interests

The authors declare no competing interests regarding the publication of this paper.

Acknowledgments

This study was supported by the Beijing Municipal Natural Science Foundation (no. 8142013). The authors are also grateful to Beijing Outstanding Talent Project for Excellent Youth Team (no. 2015000026833T0000) and Pyramid Talent Cultivation Project of Beijing University of Civil Engineering and Architecture (21082716011).

References

- [1] B.-G. Wei and L.-S. Yang, “A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China,” *Microchemical Journal*, vol. 94, no. 2, pp. 99–107, 2010.
- [2] V. Rocher, S. Azimi, R. Moilleron, and G. Chebbo, “Hydrocarbons and heavy metals in the different sewer deposits in the ‘Le Marais’ catchment (Paris, France): stocks, distributions and origins,” *Science of the Total Environment*, vol. 323, no. 1–3, pp. 107–122, 2004.
- [3] M. Chen, X. Qin, G. Zeng, and J. Li, “Impacts of human activity modes and climate on heavy metal ‘spread’ in groundwater are biased,” *Chemosphere*, vol. 152, pp. 439–445, 2016.
- [4] E. Manno, D. Varrica, and G. Dongarrà, “Metal distribution in road dust samples collected in an urban area close to a petrochemical plant at Gela, Sicily,” *Atmospheric Environment*, vol. 40, no. 30, pp. 5929–5941, 2006.
- [5] A. G. El Samrani, B. S. Lartiges, and F. Villières, “Chemical coagulation of combined sewer overflow: heavy metal removal and treatment optimization,” *Water Research*, vol. 42, no. 4–5, pp. 951–960, 2008.
- [6] J. Houhou, B. S. Lartiges, E. Montarges-Pelletier, J. Sieliechi, J. Ghanbaja, and A. Kohler, “Sources, nature, and fate of heavy metal-bearing particles in the sewer system,” *Science of the Total Environment*, vol. 407, no. 23, pp. 6052–6062, 2009.
- [7] J. H. Park, D. Lamb, P. Paneerselvam, G. Choppala, N. Bolan, and J.-W. Chung, “Role of organic amendments on enhanced bioremediation of heavy metal(loid) contaminated soils,” *Journal of Hazardous Materials*, vol. 185, no. 2–3, pp. 549–574, 2011.
- [8] M. Chen, P. Xu, G. Zeng, C. Yang, D. Huang, and J. Zhang, “Bioremediation of soils contaminated with polycyclic aromatic hydrocarbons, petroleum, pesticides, chlorophenols and heavy metals by composting: applications, microbes and future research needs,” *Biotechnology Advances*, vol. 33, no. 6, pp. 745–755, 2015.
- [9] W. B. Achiba, N. Gabteni, A. Lakhdar et al., “Effects of 5-year application of municipal solid waste compost on the distribution and mobility of heavy metals in a Tunisian calcareous soil,” *Agriculture, Ecosystems & Environment*, vol. 130, no. 3–4, pp. 156–163, 2009.
- [10] A. Tessier, P. G. C. Campbell, and M. Blsson, “Sequential extraction procedure for the speciation of particulate trace metals,” *Analytical Chemistry*, vol. 51, no. 7, pp. 844–851, 1979.
- [11] D. T. Cuong and J. P. Obbard, “Metal speciation in coastal marine sediments from Singapore using a modified BCR sequential extraction procedure,” *Applied Geochemistry*, vol. 21, no. 8, pp. 1335–1346, 2006.
- [12] B.-F. Jiang and W.-L. Sun, “Assessment of heavy metal pollution in sediments from Xiangjiang River (China) using sequential extraction and lead isotope analysis,” *Journal of Central South University*, vol. 21, no. 6, pp. 2349–2358, 2014.
- [13] K. Nemati, N. K. A. Bakar, M. R. Abas, and E. Sobhanzadeh, “Speciation of heavy metals by modified BCR sequential extraction procedure in different depths of sediments from Sungai Buloh, Selangor, Malaysia,” *Journal of Hazardous Materials*, vol. 192, no. 1, pp. 402–410, 2011.
- [14] X.-D. Li, C.-S. Poon, and P. S. Liu, “Heavy metal contamination of urban soils and street dusts in Hong Kong,” *Applied Geochemistry*, vol. 16, no. 11–12, pp. 1361–1368, 2001.
- [15] H.-M. Li, X. Qian, W. Hu, Y. Wang, and H. Gao, “Chemical speciation and human health risk of trace metals in urban street dusts from a metropolitan city, Nanjing, SE China,” *Science of the Total Environment*, vol. 456–457, pp. 212–221, 2013.
- [16] K. L. Rule, S. D. W. Comber, D. Ross, A. Thornton, C. K. Makropoulos, and R. Rautiu, “Diffuse sources of heavy metals

- entering an urban wastewater catchment," *Chemosphere*, vol. 63, no. 1, pp. 64–72, 2006.
- [17] J. Gasperi, S. Garnaud, V. Rocher, and R. Moilleron, "Priority pollutants in wastewater and combined sewer overflow," *Science of the Total Environment*, vol. 407, no. 1, pp. 263–272, 2008.
- [18] Z.-Q. Xu, S.-J. Ni, X.-G. Tuo et al., "Calculation of heavy metals' toxicity coefficient in the evaluation of potential ecological risk index," *Environmental Science & Technology*, vol. 2, article 29, 2008 (Chinese).
- [19] P. E. Rasmussen, C. Levesque, M. Chénier, H. D. Gardner, H. Jones-Otazo, and S. Petrovic, "Canadian House Dust Study: population-based concentrations, loads and loading rates of arsenic, cadmium, chromium, copper, nickel, lead, and zinc inside urban homes," *Science of the Total Environment*, vol. 443, pp. 520–529, 2013.
- [20] T. T. T. Duong and B.-K. Lee, "Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics," *Journal of Environmental Management*, vol. 92, no. 3, pp. 554–562, 2011.
- [21] G. Shi, Z. Chen, S. Xu et al., "Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China," *Environmental Pollution*, vol. 156, no. 2, pp. 251–260, 2008.
- [22] X.-W. Lu, L.-J. Wang, K. Lei, J. Huang, and Y. Zhai, "Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China," *Journal of Hazardous Materials*, vol. 161, no. 2-3, pp. 1058–1062, 2009.
- [23] P. A. Tanner, H.-L. Ma, and P. K. N. Yu, "Fingerprinting metals in urban street dust of Beijing, Shanghai, and Hong Kong," *Environmental Science and Technology*, vol. 42, no. 19, pp. 7111–7117, 2008.
- [24] A. D. K. Banerjee, "Heavy metal levels and solid phase speciation in street dusts of Delhi, India," *Environmental Pollution*, vol. 123, no. 1, pp. 95–105, 2003.
- [25] P. Rath, U. C. Panda, D. Bhatta, and K. C. Sahu, "Use of sequential leaching, mineralogy, morphology and multivariate statistical technique for quantifying metal pollution in highly polluted aquatic sediments—a case study: Brahmani and Nandira Rivers, India," *Journal of Hazardous Materials*, vol. 163, no. 2-3, pp. 632–644, 2009.
- [26] S.-H. Guo, X.-L. Wang, Y. Li, J.-J. Chen, and J.-C. Yang, "Investigation on Fe, Mn, Zn, Cu, Pb and Cd fractions in the natural surface coating samples and surficial sediments in the Songhua River, China," *Journal of Environmental Sciences*, vol. 18, no. 6, pp. 1193–1198, 2006.
- [27] X.-J. Yu, Y. Yan, and W.-X. Wang, "The distribution and speciation of trace metals in surface sediments from the Pearl River Estuary and the Daya Bay, Southern China," *Marine Pollution Bulletin*, vol. 60, no. 8, pp. 1364–1371, 2010.
- [28] S. K. Sundaray, B. B. Nayak, S. Lin, and D. Bhatta, "Geochemical speciation and risk assessment of heavy metals in the river estuarine sediments—a case study: Mahanadi basin, India," *Journal of Hazardous Materials*, vol. 186, no. 2-3, pp. 1837–1846, 2011.
- [29] Z. Yao, Z. Bao, and P. Gao, "Environmental assessments of trace metals in sediments from Dongting Lake, Central China," *Journal of China University of Geosciences*, vol. 17, no. 4, pp. 310–319, 2006.
- [30] Z.-G. Yao, "Comparison between BCR sequential extraction and geo-accumulation method to evaluate metal mobility in sediments of Dongting Lake, Central China," *Chinese Journal of Oceanology and Limnology*, vol. 26, no. 1, pp. 14–22, 2008.
- [31] J. Morillo, J. Usero, and I. Gracia, "Heavy metal distribution in marine sediments from the southwest coast of Spain," *Chemosphere*, vol. 55, no. 3, pp. 431–442, 2004.
- [32] W.-F. Zhang, X.-P. Liu, H.-F. Cheng, E. Y. Zeng, and Y. Hu, "Heavy metal pollution in sediments of a typical mariculture zone in South China," *Marine Pollution Bulletin*, vol. 64, no. 4, pp. 712–720, 2012.
- [33] C. K. Jain, D. S. Malik, and R. Yadav, "Metal fractionation study on bed sediments of Lake Nainital, Uttarakhand, India," *Environmental Monitoring and Assessment*, vol. 130, no. 1-3, pp. 129–139, 2007.
- [34] H. A. El-Azim and K. M. El-Moselhy, "Determination and partitioning of metals in sediments along the Suez Canal by sequential extraction," *Journal of Marine Systems*, vol. 56, no. 3-4, pp. 363–374, 2005.
- [35] M. J. Mahanta and K. G. Bhattacharyya, "Total concentrations, fractionation and mobility of heavy metals in soils of urban area of Guwahati, India," *Environmental Monitoring and Assessment*, vol. 173, no. 1-4, pp. 221–240, 2011.
- [36] N. Zaaboub, M. V. A. Martins, A. Dhib et al., "Accumulation of trace metals in sediments in a Mediterranean Lagoon: usefulness of metal sediment fractionation and elutriate toxicity assessment," *Environmental Pollution*, vol. 207, pp. 226–237, 2015.