Spatial distribution characteristics and health risk assessment of heavy metals in surface sediment of the Hai River and its tributaries in Tianjin, China

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ABSTRACT

To assess the spatial distribution characteristics and health risk of heavy metals (Cu, Zn, Ni, Cd, Pb, and Cr) in surface sediment of the Hai River and its tributaries in Tianjin, China, 32 surface sediment samples were collected. All the heavy metals mainly occurred in residue, except Cd. Cd primarily existed in the exchangeable fraction and posed a high risk to the aquatic environment. The mean values of pollution index followed a decreasing trend of Cu > Cd > Ni > Pb > Cr > Zn. The results of health risk assessment showed that the heavy metals were not a threat to local residents and Cr and Pb were the main contributors to the health risk. The carcinogenic risk posed by Cr was two orders of magnitude higher than that posed by Cd. A self-organizing map divided the 32 sites into three clusters and more attention should be paid to cluster 3. The results will be conducive to understanding the heavy metal pollution patterns and implementing effective and accurate management programs.

Key words: fraction, Hai River, health risk, heavy metals, self-organizing map, surface sediment

HIGHLIGHTS

- Cu, Zn, Ni, Pb, and Cr mainly occurred in residue.
- Cd primarily existed in exchangeable fraction.
- Based on the values, eight sites were moderately polluted.
- The health risk posed by Cr should not be ignored.
- The self-organizing map (SOM) divided the 32 sampling sites into three clusters and cluster 3 should be paid more attention.
1. INTRODUCTION

Every year, large amounts of contaminants are discharged into the aquatic ecological environment owing to the rapid global development of industries, agriculture, and urbanization (Zhang et al. 2017a; Al-Ananzeh 2021). Water pollution caused by heavy metals has drawn increasing attention worldwide owing to the persistence, non-degradability, toxicity, and bioaccumulation characteristics of heavy metals (Zhang et al. 2017c). Heavy metals enter the aquatic ecological environment from various natural (rock weathering, soil erosion, atmospheric deposition, volcanic eruption, and surface runoff) and anthropogenic (vehicle emissions, domestic sewage, industrial wastewater, agricultural fertilizer leachate, mining wastewater, and urban construction) sources (Wang et al. 2020b). After heavy metals enter the aquatic ecological environment, they would cause irreparable harm to aquatic organisms and human health when they are above certain concentrations. Heavy metals would enter the human body by ingestion, inhalation, and dermal contact, and thereafter injure human health (Zhao et al. 2019). The health risk assessment aims to reveal the correlation between human health and heavy metal pollution by relating each quantitative index to human health based on the three pathways (Zhang et al. 2017c; Neris et al. 2019). The human health risk assessment model suggested by the U.S. Environmental Protection Agency (USEPA) uses the total heavy metal concentration to evaluate the health risks posed to people living in the area (Shil & Singh 2019).

More than 85%, and in some cases 99%, of heavy metals entering aquatic systems accumulate in the sediment in various forms (Kang et al. 2020). Sediment-bound metals can be released into the overlying water by physical, chemical, and biological processes, and then become bioavailable and potentially toxic to aquatic organisms. Thus, sediments are both carriers of heavy metals and potential secondary sources, and can be used as an effective indicator for monitoring heavy metal pollution levels and pollution source apportionment (Zhang et al. 2017b). In sediment, heavy metals exist in different forms owing to multiple mechanisms associated with various chemical reactions, biological availability, mobility, and potential toxicity (Kang et al. 2019). Therefore, information about the total concentration of heavy metals may not be sufficient to reflect the physical and chemical behaviors in the aquatic ecological environment. The measurement of chemical fractions through sequential extraction is useful for source identification and toxicity assessments (Zhang et al. 2017a). The heavy metal fraction analysis was usually conducted using the sequential extraction protocols proposed by the Community Bureau of Reference (BCR), in which heavy metals in sediments were divided into exchangeable, reducible, oxidizable, and residual forms.
With the rapid development of the Circum-Bohai Sea Economic Zone, the Hai River Basin and Bohai Bay have suffered severe anthropogenic interferences and large amounts of pollutants produced by anthropogenic activities have been discharged into the water, thereby resulting in a series of heavy metal pollution problems. The Hai River and its tributaries mainly run through districts with well developed economies and high population densities that have faced serious pollution caused by industrial wastewater, municipal sewage, agricultural surface runoff, livestock agriculture, and atmospheric wet deposition (Kang et al. 2020). Therefore, the spatial distribution and health risks of heavy metals in the surface sediment of the Hai River and its tributaries need to be determined.

In this study, we investigated the heavy metal concentrations in the surface sediments of the Hai River and its tributaries to (1) investigate the distribution and speciation of Cu, Zn, Ni, Cd, Pb, and Cr; (2) evaluate the heavy metal pollution levels using the Nemerow Pollution Index ($P_n$); (3) assess the human health risk posed by the heavy metals; and (4) determine the potential element correlations of the heavy metals in the surface sediment using a self-organizing map (SOM).

## 2. MATERIALS AND METHODS

### 2.1. Study area

The Hai River, which is the largest river flowing toward Bohai Bay, and its tributaries have a drainage area of 1,352 km$^2$. The river mainly flows through districts with intense industrialization and urbanization and high population density. Large portion of the study area belongs to the Binhai New District, which is the first National Synthetically Reform Testing District. The automobile industry, petrochemical industry, metallurgical industry, and electronics industry have invested and settled in this area. These industries have brought considerable economic growth, whereas they have also created many environment problems. Large amount of pollutants has been discharged into the Hai River and its tributaries, and the Hai River and Bohai Bay face a severe heavy metal pollution problem.

The study area is characterized by a semi-arid and semi-humid continental monsoon climate. The annual precipitation ranges from 520 to 660 mm, with a mean of 550 mm and peaks from July to September. The average monthly air temperature is between –5.5 °C (January) and 26.6 °C (July). Industrial land, residential land, traffic land, and farmland are the four main types of land use, and other land use types, such as bare land, woodland, and grassland, are relatively fewer.

### 2.2. Sample collection and preparation

After careful analysis of the water depth, topography of the river bottom, and surrounding land use, in total 32 sampling locations were selected in the Hai River, its tributaries and Bohai Bay. The distribution and detailed information of the sampling sites were described in the previous study (Kang et al. 2020). The surface sediment (0–10 cm) can reflect the sedimentation of heavy metals in recent decades and is closely related to the overlying water quality. In addition, more chemical and biological activities occur in the superficial 10 cm layer than in deeper layers, and the heavy metal concentrations in the surface sediment (0–10 cm) are usually higher than those in the deeper layers (Zhang et al. 2017b). Three replicate surface sediment samples were collected at each site using a Peterson grab sampler (ETC-200, China). All the samples were immediately stored in sealed polyethylene bags after collection and sent to the laboratory for further analysis. Prior to the analyses, all the samples were air dried, ground in an agate mortar, and sieved through a 100-mesh nylon sieve. All the prepared samples were stored at 4 °C in clean polyethylene bags until further analysis.

### 2.3. Analysis of heavy metals

In order to determine the total concentrations of Cu, Zn, Ni, Cd, Pb, and Cr, the method reported by Liu et al. (2020) was used. The geochemical fractions of heavy metals in surface sediment samples were sequentially extracted based on the modified BCR three-step sequential sediment extraction procedure, and the details of the extraction processes were reported by Xu et al. (2017). This fractional method sequentially divided the heavy metals into exchangeable (F1), reducible (F2), oxidizable (F3), and residual (F4) fractions. The total and various fraction concentrations of heavy metals were determined using inductively coupled plasma-mass spectrometry (ICP-MS, Agilent Technologies 7,700 Series). To verify the sequential extraction procedure, an internal check was conducted by comparing the sum of the exchangeable, reducible, oxidizable, and residual fractions with the total metal concentration.

Standard reference samples (GBW07 sediment), which were obtained from the Center of National Standard Reference Material of China, were analyzed as part of the quality assurance and quality control procedures. The heavy metal concentrations of the three replicate surface sediment samples were within ±10% relative percent deviation. The recovery rates for
The solutions were prepared using ultrapure water and chemical reagents of analytical or guaranteed reagent grade. The experimental apparatuses were soaked in 5% (v/v) high purity nitric acid for 24 h, washed in ultrapure water three times, and then air dried.

### 2.4. Nemerow pollution index ($P_n$)

The Nemerow Pollution Index ($P_n$) is widely used to calculate the comprehensive sediment pollution status of heavy metals (Martinez-Guijarro et al. 2019). In this method, the single factor index ($P_i$) is first calculated, then the average value of ($P_i$) is obtained, and finally the maximum index ($P_{i,\text{max}}$) is selected and used to calculate the $P_n$ value, according to the following formulas:

$$P_n = \sqrt{\frac{P_i^2 + P_{i,\text{max}}^2}{2}}$$

$$P_i = \frac{C_i}{S_i}$$

where $P_n$ is the Nemerow Pollution Index, $P_i$ is the single factor index of the individual metal, $P_{i,\text{max}}$ indicates the average value of $P_i$, $C_i$ is the concentration of heavy metal i in the surface sediment sample, and $S_i$ is the environmental background value, which is referred to as the Class I Environmental Quality Standard for Soils (GB15618-1995) suggested by the State Environmental Protection Administration of China (Cu: 35.0 mg/kg; Pb: 35.0 mg/kg; Zn: 100.0 mg/kg; Ni: 40.0 mg/kg; Cd: 0.2 mg/kg; and Cr: 90.0 mg/kg) (SEPA 1995). Moreover, the $P_n$ classifies the surface sediment into five categories (Table S1 in Supplementary Information) (Martinez-Guijarro et al. 2019; Shil & Singh 2019).

### 2.5. Human health risk assessment

The human health risk assessment is a four-step process that includes data collection and analysis, exposure assessment, toxicity assessment, and risk characterization. It is used to present the potential adverse health effects in humans because of exposure to harmful environmental substances (Isa et al. 2015). For the management of contaminated areas, health risks for children and adults are calculated as non-carcinogenic risk and carcinogenic risk (CR) according to the USEPAB (USEPA 2004; Neris et al. 2019; Emenike et al. 2020). In this study, two main pathways of human exposure to different heavy metals (Cu, Zn, Ni, Cd, Pb, and Cr) were evaluated, namely ingestion, with the daily ingestion dose calculated by Equation (3), and dermal contact, with the daily absorption dose calculated by Equation (4) (Zhang et al. 2017c). The risk assessment was performed for children and adults considering a residential scenario. Heavy metals may cause non-carcinogenic and carcinogenic effects. The non-carcinogenic hazard quotient and potential for each heavy metal and for each exposure pathway were calculated by Equations (5)–(10) (Emenike et al. 2020):

$$D_{\text{ing}-i} = \frac{C_{i,\text{ing}} \times IR \times CF \times FI \times EF \times ED}{\text{BW} \times \text{AT}} \left(\frac{\text{mg}}{(\text{kg} \cdot \text{d})}\right)$$

$$D_{\text{der}-i} = \frac{C_{i,\text{der}} \times SA \times CF \times AF \times ABS \times EF \times ED}{\text{BW} \times \text{AT}} \left(\frac{\text{mg}}{(\text{kg} \cdot \text{d})}\right)$$

$$HQ_{\text{ing}-i} = \frac{D_{\text{ing}-i}}{RFD_{\text{ing}-i}}$$

$$HQ_{\text{der}-i} = \frac{D_{\text{der}-i}}{RFD_{\text{der}-i}}$$

$$HI_i = HQ_{\text{ing}-i} + HQ_{\text{der}-i}$$
THI = \sum HI

CR_i = D_{\text{ing-}i} \times SF_{\text{ing-}i} + D_{\text{der-}i} \times SF_{\text{der-}i}

TCRI = \sum CR

where $D_{\text{ing-}i}$ is the daily intake dose (mg/(kg·d)), $C_{\text{ing-}i}$ is the heavy metal concentration in the sediment (mg/kg), $D_{\text{der-}i}$ is the daily absorption dose (mg/(kg·d)), $\text{HQ}_{\text{ing-}i}$ is the non-carcinogenic hazard of ingestion, $\text{HQ}_{\text{der-}i}$ is the non-carcinogenic hazard of dermal contact; $HI_i$ is the sum of the HQ values for each exposure route, $THI$ is the sum of all the calculated $HI_i$ values for each heavy metal, $CR_i$ is the potential CR for each heavy metal, and $TCRI$ is the sum of all the calculated CR values for each heavy metal. Table S1 presents the meaning and values of the parameters used to perform the health risk calculations.

If the value of $HI$ or $THI > 1$, then the public may suffer from non-carcinogenic effects; if $HI$ or $THI < 1$, then there is no clear non-carcinogenic health risk. If the values of $CR$ or $TCRI$ surpass $1 \times 10^{-4}$, then they can be considered unacceptable and indicate a high risk of cancer in humans. If the values of $CR$ or $TCRI$ are within the range of $1 \times 10^{-6}$ to $1 \times 10^{-4}$, then it indicates an acceptable risk, and if $CR$ or $TCRI$ are below $1 \times 10^{-6}$, then it indicates no risk of cancer or adverse effects (Zhao et al. 2019).

### 2.6. Self-organizing map

The SOM is an unsupervised artificial neural network model with strong clustering and visualizing abilities to cluster the spatial distribution of similar neurons and dispose of nonlinear problems (Wang et al. 2020b). SOM can reduce the influence of outliers, missing data, sampling error, and measurement noise, project multi-dimensional distribution onto a two-dimensional grid, and define accurate cluster membership. The quality of an SOM is controlled by the quantization error (QE; the mean distance between every input vector) and topographic error (TE; the proportion of input vectors). The SOM Toolbox in MATLAB 2018b was used in this study to analyze the surface sediment profile data. In this study, the input data set consisted of 18 variables, including the total concentrations, the risk assessment code (RAC; defined as the percentage of $F_1$ to the total fraction), and the potentially mobile fraction (the sum of $F_1$, $F_2$, and $F_3$ to the total fraction) of the six heavy metals in the 32 surface sediment samples, and the output data were compared to the QE and TE, and an $8 \times 4$ neuron structure was selected to structure the SOM model where the QE and TE were 2.620 and 0.000, respectively.

### 3. RESULTS AND DISCUSSION

#### 3.1. Heavy metals fractions

Heavy metal speciation is of great importance to their potential toxicity and mobility, and determining the chemical fractions is necessary for assessing the potential toxicity and identifying the sources (Xu et al. 2017). The mean percentages of the four sequential extraction fractions for each heavy metal in the surface sediment samples from the Hai River and its tributaries are illustrated in Figure 1. The results showed that the distribution of the six heavy metals in the surface sediments differed greatly, except for Ni and Pb. The four geochemical fractions of Ni and Pb exhibited similar distribution patterns, and were in the following order: $F_4 > F_3 > F_1 > F_2$.

Exchangeable metals are supported by electrostatic adsorption or carbonate-bound, considered to be the weakest bounded metals in sediments and easily released into the overlying water, then absorbed by aquatic organisms (Liu et al. 2020). For $F_1$, the heavy metals followed the order of Cd (mean: 35.75%; 2.09–60.79%) > Zn (mean: 22.38%; 7.17–36.65%) > Pb (mean: 11.56%; 2.86–20.68%) > Ni (mean: 11.30%; 0.96–23.38%) > Cu (mean: 9.90%; 4.86–15.56%) > Cr (mean: 6.77%; 2.29–13.36%). Based on the RAC classification, the mean RAC values of Cr and Cu were less than 10% and they posed a low environmental risk; Zn, Pb, and Ni posed a medium risk; but the RAC value of Cd was greater than 30% and that means the Cd posed a high environmental risk. In this study, most of the Cd existed as $F_1$, especially at sites L4, L8, L18, and L25 where the percentages were greater than 50% indicating a high bioavailability, and Cd could be easily ingested and cause potential harm to organisms. The high amount of Cd in $F_1$ was mainly due to the anthropogenic activities, such as road traffic (wear of tires) and runoff from agricultural areas (Njenga et al. 2015). The amounts of Cu as $F_2$ and $F_3$ could not be ignored, which could cause adverse effects on organisms when the conditions changed, such as dissolved oxygen, pH (Kang et al. 2019).

Metals in the reducible fraction are associated with Fe-Mn oxy-hydroxides and can be released into the overlying water under reduction conditions. For $F_2$, the heavy metals followed the order of Cr (mean: 15.48%; 4.99–23.89%) > Cu (mean:
Figure 1 | Percentages of the four fractions for Cu, Zn, Ni, Cd, Pb and Cr, and the total concentrations of the six metals. F1: exchangeable fraction; F2: reducible fraction; F3: oxidizable fraction; and F4: residual fraction. (a) Cu. (b) Zn. (c) Ni. (d) Cd. (e) Pb. (f) Cr. (g) The total concentrations.
15.18%; 3.95–26.74%) > Cd (mean: 8.16%; 0.22–49.64%) > Pb (mean: 7.93%; 3.05–18.06%) > Zn (mean: 5.81%; 0.77–14.37%) > Ni (mean: 5.79%; 2.06–10.22%). In oxidizing conditions, Fe-Mn oxy-hydroxides have a large surface area to adsorb metal ions, however, under reduction conditions adsorbed metals can be liberated with the reduction of Fe$^{3+}$. Since the percentage of Cr in F2 was higher than the other metals, we speculated that Cr in the surface sediment was affected by anthropogenic activities, such as electroplating industry, metal processing industry and leather industry (Zhao et al. 2019).

Heavy metals in the oxidizable fraction are associated with various forms of organic matter such as living organisms and detritus, or exist as metal sulfides (Islam et al. 2015). For F3, the heavy metals followed the order of Cd (mean: 21.64%; 0.45–40.92%) > Pb (mean: 21.36%; 9.51–32.43%) > Cu (mean: 16.64%; 4.25–30.22%) > Ni (mean: 15.39%; 5.89–27.97%) > Zn (mean: 11.32%; 1.28–22.61%) > Cr (mean: 9.93%; 6.53–19.58%). With the decomposition of organic material, organic matter-bound heavy metals would be liberated, and metals existing as metal sulfides would be released when sulfides oxidize to sulfates. Thus, much more attention should be paid to reduce the concentrations of Cd and Pb.

The residual fraction, which exhibits the strongest association with crystalline structures of minerals, is considered to be biologically inactive and chemically stable, and regarded as a measure of the contribution by natural sources (Khadhar et al. 2020). For F4, the heavy metals followed the order of Ni (mean: 67.52%; 54.24–80.21%) > Cr (mean: 64.69%; 56.76–71.77%) > Cu (mean: 63.43%; 46.59–82.50%) > Zn (mean: 60.48%; 42.37–77.18%) > Pb (mean: 59.15%; 40.27–74.82%) > Cd (mean: 35.45%; 13.95–79.09%). All heavy metals were mainly found as the residual fraction, except for Cd. Most of the Ni was associated with the residual fraction, thereby showing that Ni was mostly present in minerals indicating a lower level of pollution (Wang et al. 2020a). Despite the fact that the dominant Zn fraction was residual in most of the sampling sites, the exchangeable fraction can be noticeable because Zn is easily absorbed by hydrous oxides, clay minerals, and carbonates owing to its relatively high mobility (Rodríguez et al. 2009).

### 3.2. Pollution degree assessment

The Nemerow Pollution Index ($P_n$) is used to clarify the integrated and comprehensive pollution levels of heavy metals in sediments, and the results are shown in Figure 2 and Table S2. The mean values of $P_i$ followed a decreasing trend of Cu > Cd > Ni > Pb > Cr > Zn. For Cu, 20 sites were moderately polluted, 11 sites were slightly polluted and only L32 was safe. The mean $P_i$ values of Pb, Ni, Cd, and Cr were between 1 and 2, indicating that these areas were slightly polluted. However, the $P_i$ value of Cd in L32 was as high as 2.39. The mean $P_i$ value for Zn was 0.894, and the $P_i$ values were greater than 1 only at sites L3, L4, L9, L10, L11, L28, and L30. Taking into account the $P_n$ values, all sampling sites were grouped into two groups. The calculated $P_n$ values at sites L3, L4, L5, L7, L8, L9, L10, and L12, which were mainly distributed in the Yuanjia River, Xijian River, and Hongni River, were between 2 and 3 indicating that they were moderately polluted and had a high metal load (Shil & Singh 2019). The remaining sites were slightly polluted ($1 < P_n < 2$).

### 3.3. Health risk assessment of heavy metals

The toxicity tolerance of children is much lower than that of adults, so the health risk posed by heavy metals for children is higher than that for adults (Zhao et al. 2019). The results of the health risk assessment are shown in Figure 3 and Table S3.

**Figure 2** | Nemerow Pollution Index.
The HI values of all sampling sites ranged from 0.05 to 0.08 for adults and from 0.45 to 0.77 for children, demonstrating that the heavy metals were not a threat to local residents (Figure 3(a) and Table S3a). A comparative analysis revealed that the non-CR of Cr was higher than the other five heavy metals. Of the six examined metals, Cr and Pb were the most important contributors to HI; the HI contribution of Cr was 54–77% for children and 57–79% for adults, and the HI contribution of Pb was 12–35% for children and 12–33% for adults. The average HI values were ranked as follows: Cr > Pb > Ni > Cu > Cd > Zn. The non-CR of Pb was second only to that of Cd owing to the effects from point and non-point sources, such as leaded petrol, municipal runoff, and atmospheric deposition (Jiang et al. 2020).

According to the calculation of the CRs of Cr and Cd, it was found that all the CR values were between $1 \times 10^{-6}$ and $1 \times 10^{-4}$, which indicates an acceptable risk (Figure 3(b)). Khan et al. (2015) had found that long-term exposure to low concentrations of Cr would produce carcinogenic and toxic effects in humans. In this study, the CR posed by Cr was two orders of magnitude higher than that posed by Cd, and the CR values for children were much higher than for adults (Table S3b).

Based on the results of the health risk assessment, the Cr pollution in the sediment should not be ignored. In order to reduce the risks for residents, it is necessary to strictly control and regulate the discharge of poorly treated wastewater into water bodies from industrial sources and runoff.

3.4. Classification of samples via the self-organizing map

The component planes of the 18 variables are displayed in Figure 4. Five color patterns were differentiated corresponding to different groups of variables. The first pattern showed that neurons were arrayed from the top to the bottom right in increasing order, and their representatives were Cu-F1, Cu-F123, TCu, Zn-F1, and Zn-F123. In the second pattern, neurons with a high

![Graph of HI values for adults and children](image)

**Figure 3** | Values of THI and TCR calculated for adults and children at the 32 sampling sites. (a) THI. (b) TCR.
Figure 4 | Component planes of the self-organizing map for the 18 input variables and the distribution of the sampling sites. Hexagons in the same section on different component planes correspond to the same map unit and the colors indicate the value of the component in the weight vector of each unit of the map according to the color bars on the right. Heavy metal-F1, means the percentage of F1 out of the total fraction; Heavy metal-F123, means the sum of F1, F2 and F3 out of the total fraction; T + heavy metal, means the total concentration of the heavy metal. Please refer to the online version of this paper to see this figure in colour: [doi:10.2166/wst.2021.322]
percentage were located on the bottom left and those with a low percentage were placed on the top right, and then Pb-F1, Pb-F123, and TNi belonged to this pattern. The third pattern showed that neurons were arranged from right to left in decreasing, and TPb, TZn, TCd, and Cr-F123 matched this pattern. Ni-F1, Ni-F123, and Cr-F1 agree with the fourth pattern; neurons on the top scored a low percentage, whereas neurons on the bottom had a high percentage. The fifth pattern exhibited a decrease to the top right, and Cd-F1, Cd-F123, and TCr matched this pattern.

The SOM neurons were grouped, and the sampling sites were classified into three clusters. Cluster 1, which was located at the upper part of the SOM, included 12 sites mainly in the Xingfu River (L14 and L16), Yueya River (L19, L20, and L21), Oldhai River (L22 and L24), Shuangqiao River (L26 and L27), Hai River (L30 and L31), and Bohai Bay (L32). The lowest concentration values of TCu, TZn, and TNi occurred in cluster 1, and the percentages of F1 for the heavy metals were the lowest, except for Cr. Cluster 2, which was placed at the middle of the SOM, included eight sites that were located in the Yuanjia River (L4), Xingfu River (L13 and L15), Weijin River (L17), Oldhai River (L23), Shuangqiao River (L25) and Machangjian River (L28 and L29). The remaining sites belonged to cluster 3, which had the highest percentages of Cu-F1, Cu-F123, Pb-F1, Pb-F123, Zn-F1, Zn-F123, Ni-F123, Cr-F1, and Cd-F1 and greatest TCu and TZn, indicating that the sites were heavily influenced by human activities and contaminated by heavy metals.

4. CONCLUSIONS

Heavy metal contamination is harmful to the aquatic ecological environment and pollution caused by heavy metals has become a hot topic worldwide. In this study, the spatial distribution and health risks of Cu, Zn, Ni, Cd, Pb, and Cr in surface sediment of the Hai River and its tributaries were investigated. All the heavy metals were mainly found in the residual fraction, except for Cd. Cd primarily existed in the exchangeable fraction, especially at sites L4, L8, L18, and L25, and posed a high risk to the aquatic ecological environment. Zn, Pb, and Ni posed a medium risk and Cr and Cu posed a low risk. According to the Nemerow Pollution Index, sites L3, L4, L5, L7, L8, L9, L10, and L12, which were mainly distributed in the Yuanjia River, Xijian River, and Hongni River, were moderately polluted and the remaining sites were slightly polluted. It is necessary to control Cr pollution in the sediment according to the health risk assessment. The SOM was implemented for the heavy metals dataset and divided the 32 sampling sites into three clusters. Much more attention should be paid to cluster 3, which was heavily influenced and polluted by human activities. The information obtained in this study contributes to the in-depth understanding of heavy metal pollution patterns and may be helpful for developing effective and accurate management programs to improve the aquatic ecological environmental quality.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This article does not contain any studies with human participants or animals performed by any of the authors.

CONSENT FOR PUBLICATION

We confirm that this manuscript has not been published previously and is not under consideration for publication elsewhere.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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AUTHORS’ CONTRIBUTIONS

Mengxin Kang: Conceptualization, Methodology, Writing-Original Draft, Writing – Review & Editing; Yimei Tian: Supervision, Methodology, Conceptualization; Haiya Zhang: Investigation, Writing – Review & Editing; Cheng Wan: Software.
DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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