Pollution Level and Potential Ecological Risk of Heavy Metals in Surface Sediment of A Severe Polluted River in Nanjing

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Abstract. Black and smelly water bodies are generally caused by the enrichment and release of large amount of pollutants such as organic matter and heavy metals in sediments. Surface sediments at 11 sections of a severe polluted urban river in Nanjing were monitored to assess the pollution level and potential ecological risk. Results show that surface sediments were seriously polluted by heavy metals and contents of heavy metals were all higher than respective background values. Cd and Hg were major pollutants with relative high contents, following by Ni, As, and Zn. Comprehensive pollution load index of the river reached 4.1, indicating a “Progressive deteriorate” pollution level, with a contribution degree order of Cd>Hg>Pb>Zn>Cu>Ni>Cr>As. Most sections of the river exhibited high potential ecological risk with a contribution order of Cd>Hg>Pb>Cu>Ni>As>Zn>Cr. Additionally, there are significant positive correlations between Cu and organic matter (r=0.947, p<0.01), and between Cu and nitrogen and phosphorus (r=0.866 and 0.860, p<0.01). Cd and Hg contributed most to the high ecological risk of sediment and possibly came from similar anthropogenic sources due to significant correlations. Ecological dredging and disposal methods for the sediments should be seriously considered when comprehensively rehabilitating such a river.

1. Introduction

With rapid development of China's economy and gradual increase of population, discharge loads of urban domestic sewage and industrial wastewater increased largely in recent decades and deteriorated water environment of urban rivers. In general, as content of organic pollutants in the water increases, oxygen in the water is greatly consumed when organic matter decomposes, and then the water environment gradually turns to be anoxic or anaerobic state [1]. Under anoxic and anaerobic conditions, some metal ions rich in sediment such as iron and manganese usually react with sulphur ions, forming ferrous sulphide and manganese sulphide compounds. These darken metal compounds easily release into overlying water and are then absorbed by suspended particles in water. A large quantity of fuscous compounds makes the water body blacken. Additionally, organic matter rich in surface sediment and overlying water continually degenerate and decompose, producing malodorous gaseous substances such as ammonia, hydrogen sulphide, sulphur alcohol, alkyl sulphide, organic amines, and organic acids. These smelly gases gradually release from sediment into the water and atmosphere [2]. More and more urban rivers were seriously polluted and have become “black and smelly”, affecting the city's water supply, impression, and living environments.
Generally sediments, on the one hand, tend to adsorb and keep a large quantity of pollutants acting as a pollution sink of water body, on the other hand, release pollutants into overlying water acting as a source [3]. Heavy metals discharged into water usually deposit into sediment along with suspended particles and degraded slowly in sediment due to the difficulty of degradation [4]-[5]. Water and sediment of severe polluted rivers are usually under long-term anaerobic conditions and their other indexes (e.g., pH, EC, and Eh) are changed comparing to unpolluted rivers. For example, dissolved oxygen contents and redox potentials of a serious polluted river are significantly lower than those of other rivers, and the water body exhibits to be weakly alkaline (pH>7). These changes further affect transport and transformation of heavy metals and other pollutants near water-sediment interface, and even lead to ecological risks to water bodies [6]-[9]. Previous studies [6]-[7] have reported that alkaline conditions (pH>7) promoted release of Zn, Cu, Cr, Cd, and Pb in sediments, and there was a significant positive correlation between release rates and pH values. Effect of DO content on the release of heavy metals varies with proportion of heavy metals undergoing redox reaction. Relative low DO contents and ORP values promote release rate of heavy metals such as Cd [8], and increase release capacity of heavy metals in sediments [9]. In addition, relative low DO content causes changes in physical and chemical environmental indicators such as pH and ORP, which weaken adsorption of heavy metals on inorganic substances [10]. Heavy metal pollution in sediments has received increasing attention around the world [11]-[12].

Most important and priority measure for treatment of severe polluted rivers and restoration of water ecology is to remove polluted sediment. However, disposal of sediment is related to the ecological restoration of the river and surrounding environment. Pollution characteristics and potential environmental hazards of sediment should be mastered firstly. To provide scientific guides for ecological remediation and disposal of sediment of a severe polluted urban river, Nanhe River in Nanjing was selected to analyze pollution level and potential ecological risk by analyzing content and distribution of heavy metals in sediment and comparing with other similar polluted rivers. Furthermore, potential source of heavy metals in the sediment and their correlation with nutrients were discussed.

2. Materials and methods

2.1. Study Area

Nanhe River locates in the upper Qinhuai River and connected with it (Figure 1). The length of Nanhe River is about 9.4 km with an average width of 5-8 m. Water depth of the river gradually increases from about 0.8 m at upstream to 3.5 m at downstream. Water quantity and water level in this river were artificially controlled by gates at the two ends of the river. Flow velocity in the river ranges between 0.01 to 0.10 m/s and gradually decreases from upstream to downstream. There are 4 rainwater and several sewage outlets discharging into the river. Many residential areas distribute on both sides of Nanhe River. Domestic sewage from these areas directly discharges into the river in the past. In recent decades, with the development of the economy and the increase of population, many self-employed workshops and small business establishments (such as restaurants, barbecue bars, machine power factories, garages, steel mills, and machinery processing and electroplating factories) have appeared on both sides of Nanhe River. Increased discharge of waste water has resulted in serious pollution of the water body. In addition, discarded solid rubbish from both side lands gradually narrowed the water width, intensified the siltation, and influenced the instability of river banks, then further deteriorated water environment. A large amount of organic pollutants, heavy metals, and persistent organic pollutants accumulated in sediments due to low flow velocity and gradually released into overlying water, resulting in that the water of Nanhe River had become “black and smelly”. Almost no thorough dredging was carried out in the past 50 years, thus silt sediment at the downstream even reached more than 2 m in depth. Seriously contaminated sediment has been considered a key restrict factor to restore the water environment of Nanhe River.
2.2. Sampling and Analysis

Along the river from upstream to downstream, 11 monitoring sections were selected (Figure 1) to monitor the water and surface sediment quality in April 2016. About 10 cm surface sediment samples were collected using a Grab silt collector and were transported to the laboratory, frozen at –20 °C. Debris such as gravel, animal, and plant residues were removed. All samples were placed in black bags and prepared for measurement.

Total nitrogen (TN), total phosphorus (TP), and organic matter (OM) in sediment samples were measured by using Kjeldahl method in HJ171-2014, acid-molybdenum-ruthenium anti-colorimetric method [13], and an elemental analyzer, respectively. Heavy metal elements (Cr, Ni, Cu, Zn, As, Cd, Hg, and Pb) in sediment samples were analyzed by using ICP-MS (inductively coupled plasma mass spectrometry). Main procedure introduced briefly here. 0.5 g of the sediment sample was digested in a Teflon crucible. Soil samples were firstly diluted with distilled water, 10 mL concentrated hydrochloric acid was next added to heat (control temperature at 90 °C) to a viscous state, then concentrated nitric acid and 10 mL of hydrofluoric acid were added again to heat until solution became viscous, and finally high chlorine was added. The solution was heated until white smoke was exhausted. The digested sample was rinsed with water and filtered, and this operation was repeated for twice. Finally, the funnel was rinsed with distilled water and diluted to 50 mL with distilled water, then shuck up well for testing. Digestion procedure was repeated for 3 times.

2.3. Evaluation Method

Heavy metal contents in surface sediment were assessed according to Grade II standard value of Chinese Soil Environmental Quality Standard (GB15618-1995), representing the soil possibly being fit for agricultural cultivation (Table 1).

**Table 1.** Soil environmental quality standard (SEQS), reference value ($C_{ref}^h$), and toxicity effect coefficient ($T_{ref}^h$) of heavy metals in sediment.

| Heavy metal | Cr  | Ni  | Cu  | Zn  | As  | Cd  | Hg  | Pb  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| SEQS (mg/kg)| 300 | 50  | 100 | 250 | 25  | 0.3 | 0.5 | 300 |
| $C_{ref}^h$ (mg/kg) | 77.80 | 26.70 | 22.30 | 62.60 | 10.00 | 0.13 | 0.29 | 26.20 |
| $T_{ref}^h$ | 2   | 5   | 5   | 1   | 10  | 30  | 40  | 5   |
Potential ecological risk (PER) index method was used to comprehensively evaluate the sediment risk, which comprehensively considers the toxicity, ecological and environmental effects of heavy metals in sediment [14]. PER coefficient \( E_i^r \) of the \( i^{th} \) metal in sediment in a region, and the comprehensive PER index \( RI \) of all considered heavy metals are expressed as:

\[
E_i^r = T_i^r \times C_i^r = T_i^r \times \frac{c_i}{c_i^{th}}, \quad RI = \sum_{i=1}^{n} E_i^r
\]

Where \( C_i^r \) is pollution enrichment coefficient of a heavy metal \( i \); \( C_i \) is measured content of heavy metal \( i \) in sediment (mg/kg); \( C_i^{th} \) is reference value of the corresponding heavy metal \( i \) (mg/kg). Here, background values of soil heavy metals in Jiangsu Province [15] were considered as the reference value (Table 1); \( T_i^r \) is toxicity response coefficient of heavy metal \( i \) (Table 1). PER index was obtained according to \( E_i^r \) and \( RI \) values (Table 2) [14].

**Table 2.** Classification of potential ecological risk (PER) level of heavy metals in sediment.

| PER level | Low | Moderate | Considerable | High | Very High |
|-----------|-----|----------|--------------|------|-----------|
| \( E_i^r \) | <40 | (40,80] | (80,160] | (160,320] | \( \geq 320 \) |
| \( RI \) | <150 | [150,300) | [300,600) | \( \geq 600 \) |

Pollution load index (PLI) method [16] was used to classify heavy metal pollution level, directly reflecting the contribution of each heavy metal to pollution and the spatial trend of heavy metals. The calculation method is as follows:

\[
C_{F_i} = \frac{C_i}{C_{oi}}, \quad PLI = \sqrt[n]{CF_1 \times CF_2 \times \cdots \times CF_n}, \quad PLI_{zone} = \sqrt[m]{PLI_1 \times PLI_2 \times \cdots \times PLI_m}
\]

Where \( C_i \) is measured value of element \( i \), \( C_{oi} \) is evaluation standard of element \( i \), \( n \) is number of evaluation elements, \( m \) is number of sampling points, \( CF \) is pollution coefficient of element \( i \), and \( PLI \) is pollution load index at a certain point. \( PLI_{zone} \) is a regional \( PLI \). Degree of pollution was listed in Table 3, corresponding to calculated \( PLI \) values [17].

**Table 3.** Class and degree of sediment pollution corresponding to pollution load index (PLI).

| PLI | Degree of pollution |
|-----|---------------------|
| <1  | No pollution        |
| 1   | Baseline level of pollution |
| 1–6 | Progressive deterioration |
| \( \geq 6 \) | High contamination |

Data statistics were carried out using SPSS 19.0, including variation coefficient \( CV \) for characterizing heavy metal content, and Pearson’s correlation analysis between heavy metals and nutrients in sediment.

3. Results and Discussion

3.1. Distribution of Heavy Metals in Surface Sediment

Heavy metal contents in sediment of Nanhe River differed with sampling sections (Figures 2 and 3). Contents of Cr, Ni, Cd, Hg, and Zn exceeded the corresponding Grade II standard values of the Chinese Environmental Quality Standard for Soils (Table 1), indicating the surface sediment was unfitted for agricultural cultivation. Particularly, contents of Cr at sections 7# (418.0 mg/kg), 8# (118.0 mg/kg), and 10# (541.0 mg/kg) exceeded largely the standard value of 300 mg/kg. Contents of Ni peaked at section 4# (325.9 mg/kg), following by section 10# (201.6 mg/kg), exceeding the standard value of 200 mg/kg. Contents of Cu at sections 7# (116.5 mg/kg), 8# (166.1 mg/kg), and 11# (154.5 mg/kg) slightly exceeded the standard value of 100 mg/kg. Contents of As in each section were relatively low, except for that at 8# section exceeded the standard value of 25 mg/kg. Contents of Cd at all sections exceeded the standard value (0.3 mg/kg), peaked at section 3# (14.6 mg/kg) following by section 7# (7.0 mg/kg) and 4# (3.7 mg/kg). Similarly, contents of Hg at all sections exceeded the standard value of 0.5 mg/kg, and peaked at section 11# (16.9 mg/kg) following by section 2# (13.3 mg/kg). Content of Pb at section 7# (651.4 mg/kg) exceeded the standard value (300 mg/kg), and that
at section 2# approached the standard value. Similar to Cd and Hg, content of Zn at most sections (1#, 2#, 3#, 4#, 5# and 11#) exceeded the standard value of 250 mg/kg, and peaked at section 4# (552.7 mg/kg) following by sections 5# (511.9 mg/kg) and 3# (452.1 mg/kg).

Figure 2. Distribution of heavy metals in surface sediment of Nanhe River.

Figure 3. Statistics of heavy metal contents in surface sediment of Nanhe River.

In summary, surface sediments of Nanhe River were seriously polluted by heavy metals. Mean contents of Cr, Ni, Cu, Zn, As, Cd, Hg, and Pb in surface sediment were 178.5, 93.7, 79.4, 301.3, 15.3, 4.3, 5.2, and 185.3 mg/kg, respectively. Among them, Cd and Hg contributed great to the sediment pollution, whose mean contents reached about 14.3 and 10.4 times to corresponding standard values, respectively. Coefficients of variation ranged between 38.0% and 115.2% (Figure 3), and those of Cr, Ni, Cd, and Hg were relatively high (85.8%, 96.6%, 109.5%, and 115.2%, respectively).

Compared with content of heavy metals in sediment of rivers in other cities of China (Table 4), it is found that contents of Cr and Ni in the Shanghai urban areas, suburbs and Hangzhou urban rivers around Nanjing were much lower than those in sediment of Nanhe River. This result indicated Cr and Ni pollution in the surface sediment of Nanhe River was more serious. Contents of Cd and Pb were also high, while contents of Cu and As were lower than those of other urban rivers in China (Table 4), indicating that Nanhe River was less polluted by Cu and As.

Table 4. Mean content of heavy metals in surface sediment of other urban rivers in China.

| Study areas | Mean content of heavy metal (mg/kg) | References |
|-------------|------------------------------------|------------|
|             |                                    |            |
3.2. Assessment of Heavy Metal Pollution in Sediment

3.2.1. Potential Ecological Risk Analysis. Potential ecological risk (PER) assessment results (Table 5) show that Cd in surface sediment had a highest potential ecological risk coefficient ($E_i$) with a mean of 1003, particularly at sections 2#, 1#, and 7#, indicating a “High” or “Very High” PER of Cd. Hg in the surface sediment showed a relatively high mean $E_i$ value of 719, suggesting a “Very High” PER. Mean $E_i$ values of Ni and Zn exhibited a “Low” PER (Table 5). PER of the heavy metals detected in surface sediment was ordered as: Cd>Hg>Pb>Cu>Ni>As>Zn>Cr. Similarly, PER of heavy metals in surface sediment of a suburb river in Shanghai [3] was ordered as Cd>As>Hg>Cu>Pb>Ni>Zn>Cr. Cd had a highest PER and Cr had the least impact, but the ecological hazard of Hg and Pb in Nanhe River should be received more attention. Overall PER levels of surface sediment in Nanhe River were very high (mean $RI = 1818$) and showed relatively high at both upstream (e.g., sections 1# and 2#) and downstream (e.g., section 11#) (Table 5), suggesting surface sediments at almost all sections of Nanhe River were seriously polluted by heavy metals. Heavy metal pollution of Nanhe sediment was far more serious than that of an urban river in Shanghai (Chaoyang River [20], $RI = 157.1$), Qinhua River ($RI = 357.6$) [18], and Suzhou Creek Network ($RI = 55.8$) [19], particularly the great contributions of Cd and Hg in Nanhe River.

Table 5. Potential ecological risk (PER) of heavy metals in surface sediment of Nanhe River.

| Section          | Cr   | Ni   | Cu   | Zn   | As   | Cd   | Hg   | Pb   | $E_i^i$ | $RI$ | PER   |
|------------------|------|------|------|------|------|------|------|------|---------|------|--------|
| 1#               | 2    | 7    | 11   | 5    | 11   | 2705 | 1749 | 53   | 4543    | Very High |
| 2#               | 2    | 8    | 15   | 5    | 13   | 3377 | 1831 | 57   | 5298    | Very High |
| 3#               | 2    | 7    | 8    | 7    | 13   | 427  | 380  | 15   | 859     | Very High |
| 4#               | 4    | 61   | 17   | 9    | 17   | 862  | 566  | 27   | 1563    | Very High |
| 5#               | 3    | 13   | 10   | 8    | 11   | 185  | 118  | 11   | 359     | Considerable |
| 6#               | 3    | 8    | 15   | 2    | 16   | 510  | 78   | 19   | 651     | Very High |
| 7#               | 11   | 12   | 26   | 4    | 5    | 1619 | 381  | 124  | 2182    | Very High |
| 8#               | 3    | 13   | 37   | 2    | 27   | 409  | 87   | 29   | 607     | Very High |
| 9#               | 3    | 8    | 13   | 1    | 19   | 250  | 285  | 14   | 593     | Considerable |
| 10#              | 14   | 38   | 10   | 3    | 20   | 152  | 109  | 9    | 355     | Considerable |
| 11#              | 4    | 18   | 35   | 7    | 17   | 531  | 2328 | 31   | 2971    | Very High |
| Mean             | 4.6  | 17.5 | 18   | 4.8  | 15   | 1003 | 719  | 35   | 1818    | Very High |
| PER              | Low  | Low  | Low  | Low  | Low  | Very High | Very High | Low | Very High |

Note: PER values were calculated using the formula: $PER = E_i^i / E_i$.
3.2.2. Pollution Load Index. Pollution load index (PLI) calculation (Table 6) showed that mean pollution coefficient $CF$ of Cd in surface sediments of Nanhe River was highest ($CF = 33.4$), followed by Hg (18). Contribution degree of each heavy metal to pollution was ordered as follows: Cd > Hg > Pb > Zn > Cu > Ni > Cr > As. PLI values of heavy metals peaked at section 11# (6.6), following by section 4# (6.4). Additionally, PLI values at sections 2# (6.3) and 7# (6) also reached the level of “High contamination” (Table 3), whereas PLI values at sections 1#, 3#, 5#, 6#, 8#, 9#, and 10# exhibited as a level of “Progressive deteriorate”. Comprehensive PLI zone of surface sediment of Nanhe River reached 4.1, suggesting a pollution level of “Progressive deteriorate” for the entire river. It is obvious that the PLI zone value of Nanhe River was higher than other similar urban rivers, for example, PLI zone was 4.0 [21] of a river in Kaifeng city. High PLI zone value of Nanhe River was mainly contributed by Cd, Hg, and Pb.

Table 6. Heavy metal pollution load index (PLI) of surface sediment along Nanhe River

| Section | $CF_i$ | Ni | Cu | Zn | As | Cd | Hg | Pb | PLI | PLI zone |
|---------|--------|----|----|----|----|----|----|----|-----|---------|
| 1#      | 1.1    | 1.4| 2.2| 4.8| 1.1| 90.2| 43.7| 10.5| 5.4 |         |
| 2#      | 1.2    | 1.6| 3.0| 5.3| 1.3| 112.6| 45.8| 11.4| 6.3 |         |
| 3#      | 1.0    | 1.4| 1.5| 7.2| 1.3| 14.2| 9.5 | 3.0 | 3.1 |         |
| 4#      | 1.9    | 12.2| 3.5| 8.8| 1.7| 28.8| 14.1| 5.4 | 6.4 |         |
| 5#      | 1.3    | 2.6| 1.9| 8.2| 1.1| 6.2 | 2.9 | 2.3 | 2.6 |         |
| 6#      | 1.4    | 1.6| 2.9| 1.6| 1.6| 17.0| 1.9 | 3.9 | 2.6 |         |
| 7#      | 5.4    | 2.5| 5.2| 3.5| 0.5| 54.0| 9.6 | 24.9| 6.0 | 4.1     |
| 8#      | 1.5    | 2.6| 7.4| 2.0| 2.7| 13.6| 2.2 | 5.7 | 3.6 |         |
| 9#      | 1.5    | 1.5| 2.5| 1.4| 1.9| 8.3 | 7.1 | 2.8 | 2.7 |         |
| 10#     | 7.0    | 7.6| 2.0| 3.3| 2.0| 5.1 | 2.7 | 1.8 | 3.4 |         |
| 11#     | 2.0    | 3.6| 6.9| 6.9| 1.7| 17.7| 58.2| 6.1 | 6.6 |         |
| Mean    | 2.3    | 3.5| 3.6| 4.8| 1.5| 33.4| 18.0| 7.1 | 5.5 |         |

3.3. Correlation between Heavy Metals and Nutrients in Sediment

Contents of total nitrogen (TN), total phosphorus (TP), and organic matter (OM) in surface sediment of Nanhe River were relatively high (Figure 4), with average values of 2768.1 mg/kg, 1895.2 mg/kg, and 4.86% (1.87%-11.96%). Contents of TN and OM peaked at section 11# (6229.2 mg/kg and 11.96%), following by section 8# (4836.5 mg/kg and 9.2%). It is apparent that the surface sediment of Nanhe River has accumulated a large amount of OM, N, and P as well as heavy metals, suggesting a great potential threat to water quality of Nanhe River and downstream connected Qinhuai River.
Furthermore, relatively high contents of nutrients in sediment perhaps play important roles on the activity and migration of some heavy metals [27]. Cu in sediment of Nanhe River had significantly positive correlation with OM (Table 7), indicating that OM combining with Cu might form some complex metal compounds (e.g., \([\text{Cu(OH)}_4]^2–\)), which tend to be stably remained in sediment [26]. Cu also significantly correlated with N \((r=0.866, p<0.01)\) and P \((r=0.860, p<0.01)\), indicating that they might be more likely to interact each other and then remain in sediment. Other 7 heavy metals did not show a significant correlation with OM, indicating that they interact with OM weakly and possibly tend to be separately adsorbed in sediment [28]. Previous studies have reported that chelation and complexation usually occur in sediment/soil when metal elements and humus, nitrogen, and phosphorus coexist. Generated complex compounds by nutrients and metals further form complicate polymers by combining with OM and colloids [25]. In general, OM in sediment is one of important colloids for adsorption, allocation, and complexation of heavy metals. Varied OM content usually changes the chemical form of heavy metals and affects the migration and transformation of heavy metals in sediment/soil [29].

**Table 7.** Pearson correlation analysis between heavy metals and nutrients in surface sediment of Nanhe River.

| Pollutant | Cr     | Ni     | Cu     | Zn     | As     | Cd     | Hg     | Pb     |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|
| TN        | −0.170 | −0.075 | 0.866b | −0.043 | 0.452  | −0.239 | 0.383  | −0.051 |
| TP        | −0.080 | −0.003 | 0.860b | −0.098 | 0.531  | −0.260 | 0.353  | −0.098 |
| OM        | −0.041 | −0.053 | 0.947b | −0.122 | 0.355  | −0.164 | 0.353  | 0.165  |
| Cr        | 1      | 0.374  | 0.781a | −0.229 | −0.089 | −0.160 | −0.264 | 0.302  |
| Ni        | 1      | 0.017  | 0.400  | 0.230  | −0.227 | −0.129 | −0.180 |        |
| Cu        | 1      | −0.169 | 0.351  | −0.076 | 0.223  | 0.324  |        |        |
| Zn        | 1      | −0.359 | 0.068  | 0.327  | 0.772  |        |        |        |
| As        | 1      | −0.46  | −0.224 | −0.621a|        |        |        |        |
| Cd        | 1      | 0.623a | 0.601  |        |        |        |        |        |
| Hg        | 1      | 0.241  |        |        |        |        |        |        |
| Pb        | 1      |        |        |        |        |        |        |        |
a significant correlation at the level of 0.05.

Significantly positive correlation between Cu and OM, TN, and TP indicated that Cu has similar pollution sources with nutrients [26]-[30]. Nutrients usually play important roles on the accumulation of heavy metals in sediment [30]. In addition, there is a significant correlation between Cu and Cr, and Pb and As in surface sediment of Nanhe River. According to the previous evaluation, the 4 heavy metals exhibited low ecological risks (Table 5). They were mainly derived from natural geochemical processes. Hg and Cd were the major pollutants in sediment of Nanhe River with relatively high contents and had a significantly positive relationship ($r = 0.623$, $p < 0.05$), might be mainly from anthropogenic pollution sources [31]. Similarly in a river of Suzhou City, correlations between Cr, Cu, Zn and Pb in sediments were also significant [19], indicating that these metals came from same pollution sources. Many metallic material and electroplating factories and garages, located along Nanhe River, possibly contributed greatly to the heavy metal pollution in sediment, as well as other small processing factories. However, As in sediment of Nanhe River showed a negative relationship with Pb ($r = -0.621$, $p < 0.05$).

4. Conclusion

Heavy metals and nutrients in surface sediment of Nanhe River in Nanjing were investigated for further comprehensively management of water environment. Contents of heavy metal in surface sediment of Nanhe River were significantly higher than soil background values and Grade II Threshold of Chinese Soil Environmental Quality Standard, indicating the sediment possibly being unfit for agricultural cultivation. Cd and Hg were the major pollutants with relatively high contents, contributing great to the pollution level of sediment. Comprehensive pollution load index of Nanhe River indicated an extremely high pollution level. Heavy metals in sediments exhibited high potential ecological risk, particularly at both the upstream and downstream of Nanhe River, with an order of Cd$>$Hg$>$Pb$>$Cu$>$Ni$>$As$>$Zn$>$Cr. Additionally, significantly positive correlation was found between Cu and OM ($r = 0.947$, $p < 0.01$), and between Cu and N ($r = 0.866$, $p < 0.05$), and C and P ($r = 0.860$, $p < 0.05$), indicating similar pollution sources and complexation reactions. Severe polluted sediment of Nanhe River and its potential ecological risk to the overlying water should receive more attention in the future. Furthermore, ecological dredging and disposal methods for the sediments should be seriously considered when comprehensively rehabilitating the water environment of Nanhe River.

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