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Fractionation and potential risk of heavy metals in surface sediment of Nansi Lake, China

Zhi jian Li[a,b], Qin yan Yue[a]*, Heng Ni[c], Bao yu Gao[a]

[a]*Shandong Key Laboratory of Water Pollution Control and Resource Reuse, School of Environmental Science and Engineering, Shandong University, Jinan, 250100, China*
Tel. +86 531 88365258; Fax +86 531 88364832; email: qyyue@sdu.edu.cn
[b]*School of Light Chemistry and Environment Engineering, Shandong Institute of Light Industry, Jinan, 250353, China*
[c]*Investigating Department, State Nuclear Electric Power Planning Design & Research Institute, Beijing, 100094, China*

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ABSTRACT

Fractionation of heavy metals in sediments can provide information on potential hazards of heavy metals. In this paper heavy metal pollution and release risk have been investigated by comparing total concentrations and fractionation of heavy metals (Cd, Cr, Cu, Fe, Pb, Mn and Zn) in Nansi Lake and the adjacent river sediments. Five chemical fractionations were extracted using Tessier's sequential extraction technique. The percentage of carbonate and exchangeable fractions to the total content in sediment metals were measured. The data denoted that most sediment in Nansi Lake suffered certain pollution from heavy metals to some extent. The average concentrations of metals showed that the sediment was severely impacted by Cr and Zn, moderately impacted by Cd, Pb, Cu and Mn, and then slightly impacted by Fe. According to the risk assessment code, when carbonate and exchangeable fractions are 31–50% or more than 50%, the sedimentary metal presented a high or very high risk, respectively. The results indicated that Cd, Pb, Zn and Cr are potentially more mobile and at high or very high risk. In contrast, most Cu and Mn (65.38% and 53.85%) showed a medium risk, while iron was dominantly associated with residual fractions, therefore was immobile and most appeared no risk (61.54%) or low risk (34.62%).

Keywords: Heavy metals; Sediment; Total content; Fractionation; Pollution; Potential risk

1. Introduction

In modern times, human activities have resulted in chemical inputs that are reflected in sediments. Many of the natural events and human activities can affect the distribution of chemical species in the environment [1]. Heavy metals, due to their cumulative build up, long life, high toxicity and hard degradation, are of special concern worldwide. Metals have many sources from which they can flow into the water body; natural sources from rocks and soil, through metal ores mining and processing, domestic wastewater which contains substantial quantities of metals, agricultural sources of fertilizers and pesticides which contains metals, mine runoff and solid waste disposal areas [2].

Sediments act as recorders of metal pollution events, but are potential sources of pollution for the surrounding water should remobilization occur through any disturbance [3–5]. Heavy metals are present in various forms in sediment. The chemical forms of heavy metals associated with the settled solids can influence their fate [6].

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* Corresponding author.

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Different forms of heavy metals have different mobility and bioavailability. Heavy metal contamination of sediments can critically degrade aquatic systems [7]. Their release from the sediment can make them enter the aquatic ecosystems and bring about severe problems [8]. The need for continuous scientific research to assess the potential risk posed by these elements in our environment seems inevitable [2].

Determination of total metal content in sediments provides important information about pollution level if the background concentration is known. However, to understand the mobilization of heavy metals and assess the bioavailability, the total concentration is not enough [9,10]. It has been found that the speciation of a metal, rather than its total concentration, is the key to understand its effect on the biota [11], as well as its biogeochemical transformation and ultimate fate [12]. Therefore, it is vital to perform chemical fraction studies of heavy metals in the sediments to accurately assess the toxic potential [10].

It is quite useful to apply some significant guidelines to assess metal pollution and potential risk in sediment. Like the New York State Department of Environmental Conservation (NYSDEC, 1999) guideline [13], it proposed the lowest effect screening levels (LEL) for Fe, Cd, Cr, Cu, Pb, Zn and Mn, of 2.0%, 0.6, 26, 16, 31, 120 and 460.0 mg/kg, respectively, and severe effect screening levels (SEL) of 4.0%, 9.0,110, 110, 110, 270 and 1100.0 mg/kg, respectively. The pollution extent was assessed by two threshold values of LEL and SEL. If the LEL was exceeded, the metal could moderately impact biota health. If the SEL was exceeded, the metal could severely impact biota health [14]. The other guideline was Risk Assessment Code (RAC) classification based on the percentage of metal in the carbonate and exchangeable fractions [15,16].

The RAC demonstrates that the metals in sediments are bound with different strengths to different fractions. The RAC assesses the availability of metals in solution by applying a scale to the percentage of sediments that can reduce metals in the exchangeable and carbonate fractions [10,17]. With the aim of achieving a broader assessment of metal pollution in Nansi Lake in terms of ecological risk, a quantitative approach has been made.

In previous years, there were few reports on the distribution and species of heavy metal in the sediments of Nansi Lake. But since Nansi Lake functioned as a reserving lake on the East Route of the South-to-North Water Diversion Project in 2001, in order to meet the requirement of transferring water quality, external sources of pollution due to industrial drainage have been limited or reduced in recent years, therefore, the equilibrium between the water column and the sediment was disturbed. The potential release of heavy metal from sediment became a topic worth to researching immediately.

However, hardly any systematic study has been carried out so far to asses the behavior characteristics and release risk of heavy metals in the sediments of Nansi Lake using sequential extraction technique and statistical method.

The objectives of the study are to investigate the total contents, species and their correlations of the major heavy metals in sediment, distribution patterns and behaviors of the heavy metals, thereby, to advance the understanding of metal interactions between water and sediment in an aquatic ecosystem. All of the work will provide reference and guide for the water pollution prevention and lake ecological management.

2. Materials and methods

2.1. Study area and sediment sampling

Nansi Lake (116°34′E–117°21′E, 34°27′–35°20′N) lies in the southwest of Shandong, and is the largest freshwater lake in Shandong province, China. The lake is divided into four connected lakes, including Nanyang Lake, Dushan Lake, Zhaoyang Lake, and Weishan Lake from the upstream to the downstream with the dam in the middle of Nansi Lake. Nansi Lake is a shallow lake with an average depth of 1.46 m; it is 126 km long, 0.005–0.251 km wide, and approximately 30,453 km^2 in water area, fed by 29 inflow rivers. Nansi Lake plays a significant role in the local industry, agriculture, fishery and entertainment. Jining City and Weishan County are two regions adjacent to Nansi Lake. Jining is an important industrial city, located at the upper reaches of Nansi Lake, with 8,300,000 people. Large numbers of industries and enterprises were widespread around the lake, such as paper making, medicine, steel, building materials, cement, textile and dyeing, as well as coal mining and shipping, ship building and electronic industry. While, Weishan County is situated at the downstream area, has a population of 680,000, and the economic of downstream area is less developed compared with the upstream area.

The lake along with its tributaries forms the major drainage in the local area. A large amount of wastewater and sewage was discharged into the lake each year. The major sources of pollution include municipal wastewater, urban runoff, and industrial effluents. Plenty of contaminants, especially, heavy metals have been silted due to large deposits of suspended solids.

The monitoring and sampling work covered a wide range of the study areas at key locations during April 2008 to April 2009. Twenty six sediment cores were sampled by the help of a handed corer (with acryl tubes 6-cm diameter by 50 cm long) on a boat in March and April 2009. The samples were taken from the upper 5 cm of the sediments and collected in polyethylene bags and brought to the laboratory as soon, and air dried at well-ventilated room in two weeks and stored in refrigerator for further analysis.

The sampling sites in the upstream section were named U1, U2 to U13, and meanwhile, 13 sampling sites in the downstream section were numbered D1, D2 to D13 in sampling time sequence. The stations are depicted in Fig. 1. The sample area covered the sections of four consecutive lakes and the entrances at the river flowing into Nansi Lake. Twenty six sampling sites were selected to provide representative data on the spatial distribution of heavy metals in surface sediment in Nansi Lake. Among them, sample U1, U2, U3, U4, D5, D6, D9, D10 and D13 were located in the inflows, the others were in the lake area. In these sampling sites, U5, U6 and U7 were located at Nanyang Lake; U8, U9, U10 at Dushan Lake; U11, U12, U13, D8 at Zhaoyang Lake, and the others, D1, D2, D3, D4, D7, D11 and D12 at Weishan Lake.

2.2. Analytical methods

The air dried sediment samples were ground and sieved through a 200-mesh nylon sieve to obtain 80 μm sediment fraction. Organic material was defined as the material lost by burning about 2 g of dry sample at 550°C for 4 h (data are reported in % loss in terms of the sample dry weight at 105°C) [10].

In order to provide a complete picture for predicting the metal distribution, mobility, and bioavailability in settled solids, the employment of sequential extraction may be of great value [18]. The sequential extraction proposed by Tessier et al. [19] was used to determine five metal fractions of sediments. The detailed scheme is as follows:

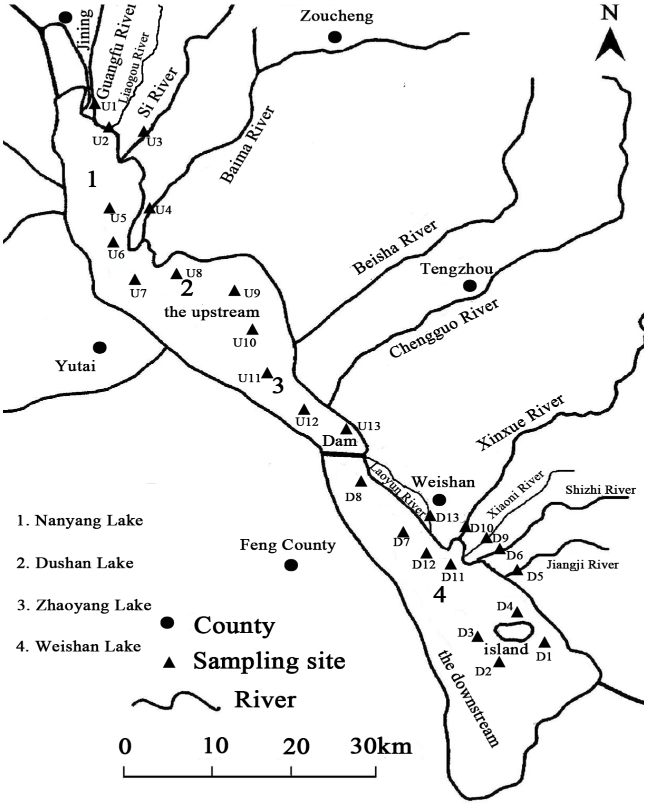

Fig. 1. Sketch of sampling sites of Nansi Lake.

(1) Fraction A. Exchangeable fraction: 1.0 g sediment sample was extracted at room temperature for 1 h with 10 ml of 1.0 M $MgCl_2$ (pH 7.0) with continuous agitation.

(2) Fraction B. Bound to carbonates: The residue obtained from step (1) was leached at room temperature with 10 ml of 1.0 M sodium acetate adjusted to pH 5.0 with acetic acid. The mixture was agitated for 5 h.

(3) Fraction C. Bound to Fe–Mn oxides: The residue obtained from step (2) was refluxed at about 96±3°C with 20 ml of 0.04 M $NH_2OH.HCl$ in 25% (v/v) acetic acid for 6 h.

(4) Fraction D. Bound to organic matter: To the residue obtained from step (3), 3 ml of 0.02 M HNO_3 and 5 ml of 30% H_2O_2 were added and pH adjusted to 2.0 with HNO_3. The mixture was refluxed at 85±2°C for 2 h. A second 3 ml aliquot of 30% H_2O_2 (pH 2 with HNO_3) was then added and the sample was heated again to 85±2°C for 3 h with intermittent agitation. After cooling, 5 ml of 3.2 M ammonium acetate in 20% (v/v) HNO_3 was added. The sample was diluted to 50 ml and agitated continuously for 30 min. The addition of ammonium acetate is designed to prevent adsorption of extracted metals onto the oxidized sediment.

(5) Fraction E. Residual fraction: The residue obtained from step (4) was digested with a HF–$HClO_4$ mixture as per procedure followed for the analysis of trace elements.

The total metals or residual metals were extracted from the sediment samples using an acid digestion mixture (HF + $HClO_4$ + HNO_3) in an open system. The 0.5 g of sediment sample was treated with 10 ml HF and 2 ml $HClO_4$ and heated on hot plate up to dryness. The residue was further treated first with 5 ml perchloric acid and then with 5 ml HNO_3 and heated up to dryness. Then the residue was finally dissolved in 1:1 HCl [17] to analyze for trace metals.

The extractions from (1)–(5) were conducted on centrifuge tubes, and the suspension was centrifuged immediately at 5000 rpm for 10 min, then the supernatant was collected with a pipette and determined for trace metals by atomic absorption spectrophotometry.

3. Results and discussion

3.1. Characteristics of the sediments

pH and organic matter (OM) are important factors that control the availability of heavy metals in the soil [20]. Raising the soil OM can increase the soil CEC, a factor that may affect both soluble and exchangeable metal levels [21,22].

The pH of the water and sediment varies from 7.66 to 10.62 and 7.2 to 7.69, indicating alkaline nature of the water and the neutral to slight alkaline property of the sediment. The organic content of the sediment was of the order of 1.36–15.13% at most of the sites except U1 (in Guangfu River), U10 (in Dushan Lake), D7 (in Weishan Lake), D5 (Xiaoni River) and D9 (JiangJi River) where organic content was found to be 15.13, 11.96%, 11.19%, 12.45% and 16.65%, respectively. The high values of organic content were occurred at the four heavily polluted inflow rivers and lake due to discharge of huge amount of industrial sewage and wastes.

3.2. *Total content of heavy metal in surface sediments*

The statistics on total content of heavy metal is presented in Table 1. Concentration amounted 35.55–144.44 mg/kg for Cu (mean 58.2), 3.15–8.00 mg/kg for Cd (mean 5.04), 25.77–73.67 mg/kg for Pb (mean 47.46), 145.10–1262.2 mg/kg for Zn (mean 284.58), 0.66–174.52 mg/kg for Cr (mean 107.63), 8.63–23.31 mg/g for Fe (mean 14.2) and 169.93–1826.95 mg/kg for Mn (mean 645.24). The values of Fe were much higher than those of the other heavy metals. The world average of Fe in uncontaminated soils is much higher than other metals being 46 g/kg [23,24] indicating geological occurrence of this metal in quite high concentrations. Followed by, Mn showed a relative high concentration, owing to its high background levels in sediments, analogous to Fe. Except Fe and Mn, Zn showed the highest concentration levels among trace metals, being only slightly lower at the middle of the lake. Cr, Cu, and Pb accumulated in the sediments of Nansi Lake and should be classed as belonging to a moderate to strong contaminated levels. Cd was found at relatively low concentrations at most sites along the lake.

The coefficient of variation (CV) most varied from 25% to 34%, with relatively low variation, except for that of Zn and Mn with higher variation 80% and 54%, respectively. The CVs usually presented as a form of percentage, can be used to compare the variability of same property under similar values of variances and different means situations in relative terms [25]. Based on the CVs of the metals at the 26 sites given in Table 1, the total metal loads showed a significant spatial variation followed the order of Zn > Mn > Cu > Pb > Cr > Cd > Fe. This was related to the local industries distribution and different resources of metals.

According to the NYSDEC (1999) [13] guideline, sediment is considered contaminated if either criterion is exceeded. If both criteria are exceeded, the sediment is considered to be severely impacted. If only the LEL criterion is exceeded, the impact is considered moderate. It was found that the total concentrations of heavy metals in sediment were higher than the SEL (Tables 1 and 2), except total Cd, Fe, and Pb. The total and fraction distribution of heavy metal is shown in Fig. 2. Maximum Zn enrichment was 1262.25 mg/kg observed at site U1, 10.5 and 4.7 times as much as the LEL and SEL values respectively. Additionally, Zn concentration was highest at sampling points U2, D1 and D9–D13, where several industries existed, like paper mill, coal mine and other power plant in upstream area, from which sewage was discharged into the upper lake; whilst, some villages were located on the island adjacent to D1 and shipbuilding, painting, mining and coal shipping were the main industries. It suggested an anthropogenic origin.

The maximum Cu and Cr existing at site U1 were 9.0 and 6.7 times as the SEL, 1.31 and 1.59 times the LEL respectively. The highest Cd content, 8 μg/g, occurred at sample site U10, and it was approximately 13.3 times the LEL but 0.6 times the SEL. High Cu content were observed in upper lake, like U1, U2, U5, U8, U9 and U10. Further, higher Cd concentrations can be seen at sampling points U2, U4, U8, U9, U10 and U11; Cr concentration in the sediments was found to be much higher at U1, U5–U9, U12, which correspond to sites influenced by urban discharges and industrial activity. This may be attributed to several industrial units dealing with steelmaking, ferrous alloy, building materials, cement, chemical and painting. As shown in Fig. 2, the upper lakes suffered more

Table 1
Descriptive statistics on total content of heavy metals in surface sediments from Nansi Lake[a,b]

Heavy metal	Min.	Max.	Mean	SE	SD	CV (%)
Cd	3.15	8.00	5.04	0.26	1.34	27
Cr	70.66	174.52	107.63	5.92	30.17	28
Cu	35.55	144.44	58.20	3.87	19.76	34
Fe	8.63	23.31	14.20	0.69	3.51	25
Pb	25.77	73.67	47.46	2.66	13.56	29
Mn	169.93	1826.95	645.24	68.03	346.91	54
Zn	145.10	1262.25	284.58	44.78	228.34	80

[a]The units are (mg/kg) except that of Fe is (mg/g); [b]Min, minimum; Max, maximum; SE, standard error; SD, standard deviation; CV, coefficient of variation.

Table 2
Technical guidance for screening contaminated sediment[a]

Metals	Lowest effects level (LEL) [1 2] (μg/g)	Severe effects level (SEL) (μg/g)
Cadmium	0.6 (P)	9.0 (L)
Chromium	26.0 (P)	110.0 (P)
Copper	16.0 (P)	110.0 (P)
Iron (%)	2.0% (P)	4.0% (P)
Lead	31.0 (P)	110.0 (L)
Manganese	460.0 (P)	1100.0 (L)
Zinc	120.0 (P/L)	270.0 (L)

[a] An "L" following a criterion means that it was taken from Long and Morgan (1990); a "P" following a criterion indicates that it is from Persaud et al. (1992). The units are μg/g, or ppm, except for iron, which is listed as a percentage.

pollution from Cu, Cr, Pb and Cd than the downstream. However, there was only little difference in Zn, Fe and Mn contamination in the upper and lower reaches of Nansi Lake, except of a few sample sites.

Comparing the mean of total metal the Nansi Lake sediments with LEL and the SEL (Table 2), the result indicates that Nansi Lake sediments can be severely impacted by Cr and Zn, meanwhile, the impact from Cd, Cu, Pb and Mn may be considered moderate, while, there is just very low impact from Fe. Based on the above analysis from metal distribution, in the whole, the upstream lake suffered more severe pollution from heavy metal. This is in accordance with the more industries, more developed cities and such high-dense population in the upstream.

3.3. Fractions of heavy metal in surface sediments

In sediments, heavy metals can be present in a number of chemical forms, and generally exhibit different physical and chemical behaviors in terms of chemical interaction, mobility, biological availability and potential toxicity risk.

The fractions introduced by man's activity include the adsorptive and exchangeable and bound to carbonates fractions, which are considered to be weakly bound and may equilibrate with aqueous phase thus becoming more rapidly bioavailable [26,27]. The Fe–Mn oxide and organic matter have a scavenging effect and may provide a sink for heavy metals. The release of the metals from this matrix will most likely be affected by the redox potential and pH. The metal present in the detrital and primary mineral phases can be regarded as a measure of the contribution by natural sources [15,28].

The metal concentrations associated with different phases in Nansi Lake at different sites are presented in Fig. 2.

Fraction A. The amount of metals in this phase indicated the environmental conditions of the overlying water bodies. About 2.83–55.52% of Cd, 1.34–31.12% of Pb, 0.02–56.49% of Cr, 1.05–6.42% of Zn, 0.11–26.24% of Cu, 2.13–14.97% of Mn and 0.07–0.27% of Fe were found in the exchangeable phase (Fig. 2). Pb and Cd have special affinity for clay mineral structure due to their ionic radius, which are very similar to those of K primarily associated with clay minerals [29]. The fractionation profile for Cd indicated that it was mostly bound to exchangeable, carbonate and residual fractions, the rest being present in Fe–Mn oxide fraction and organic fraction. Tessier et al. [30] reported that a large amount of cadmium was found in the exchangeable and carbonates fractions in Yamaska and St. Francois River sediments. Similar situations were also found in our observations. Second, Cr existed in exchangeable forms in most downstream sediments and part of upper locations, like U11–U13 close to lower reaches. The major fraction of Cd in carbonate form would imply that an appreciable percentage of cadmium would have been remobilized becoming readily available following a slight lowering of pH [17].

Fraction B. The fraction bound to carbonate phase. There are high percentages of Cd (1.43%–30.01%), Pb (17.65%–52.90%) and Zn (1.56%–69.15%), Cr (1.34%-42.56%) in comparison to Cu (4.58%–37.90%), Mn (1.17%–77.70%) and Fe (0.02%–11.76%) associated this phase. Zn and Pb had quite high content in carbonate forms, followed by Cd and Cu and part of Cr (D9–D13) and Mn (upstream). This is because some of them (like Cd, Pb and Cr) have a special affinity with carbonate and may co-precipitate with carbonate minerals at high pH [31].

Fraction C. The trace metal content in the Fe/Mn oxide phase, which has been proved to be sensitive to anthropogenic inputs [30], there are about 0–29.97% of Cd, 0.04%–33.52% of Cr, followed by Zn 0.5%–90.16%, Pb 1.07%–44.26%, Mn 0.51%–70.35%, and Fe 9.33%–36.44%, Cu 0.97%–6.83% in the Fe/Mn oxide phase. Most of Mn in downstream Nansi Lake, and most Fe in all site were present in Fe–Mn oxide fraction in sediments, however, Mn was found more in carbonate forms in the upstream, therefore, which tended more easily to release than in the downstream.

Fraction D. The proportion range of the organic phase are: Cu (0.42%–44.93%), Zn (0.88%–13.49%), Pb (1.44%–13.46%), Cr (0.12%–40.19%), Fe (0.02%–27.91%), Mn (2.08%–11.87%) and Cd (0–9.17%). Cu covered more percent in organic fraction than other metals in this form. The combination of both organic matters bound and residual Cu forms dominated in all the sediment. The similar result was observed in other researches, like Liu et al. [16] and Filgueiras et al. [32].

Fraction E. Metals found in the geochemical phase-the residual fraction: these are expected to be chemically stable and biologically inactive. Cu (27.67–79.84%, mean 60.67%), Cr (6.91–96.19%), Fe (50.11–89.57%, mean 71.07%), Cd (1.51–76.25%, mean 34.26%), Zn (0.69–71.82%,

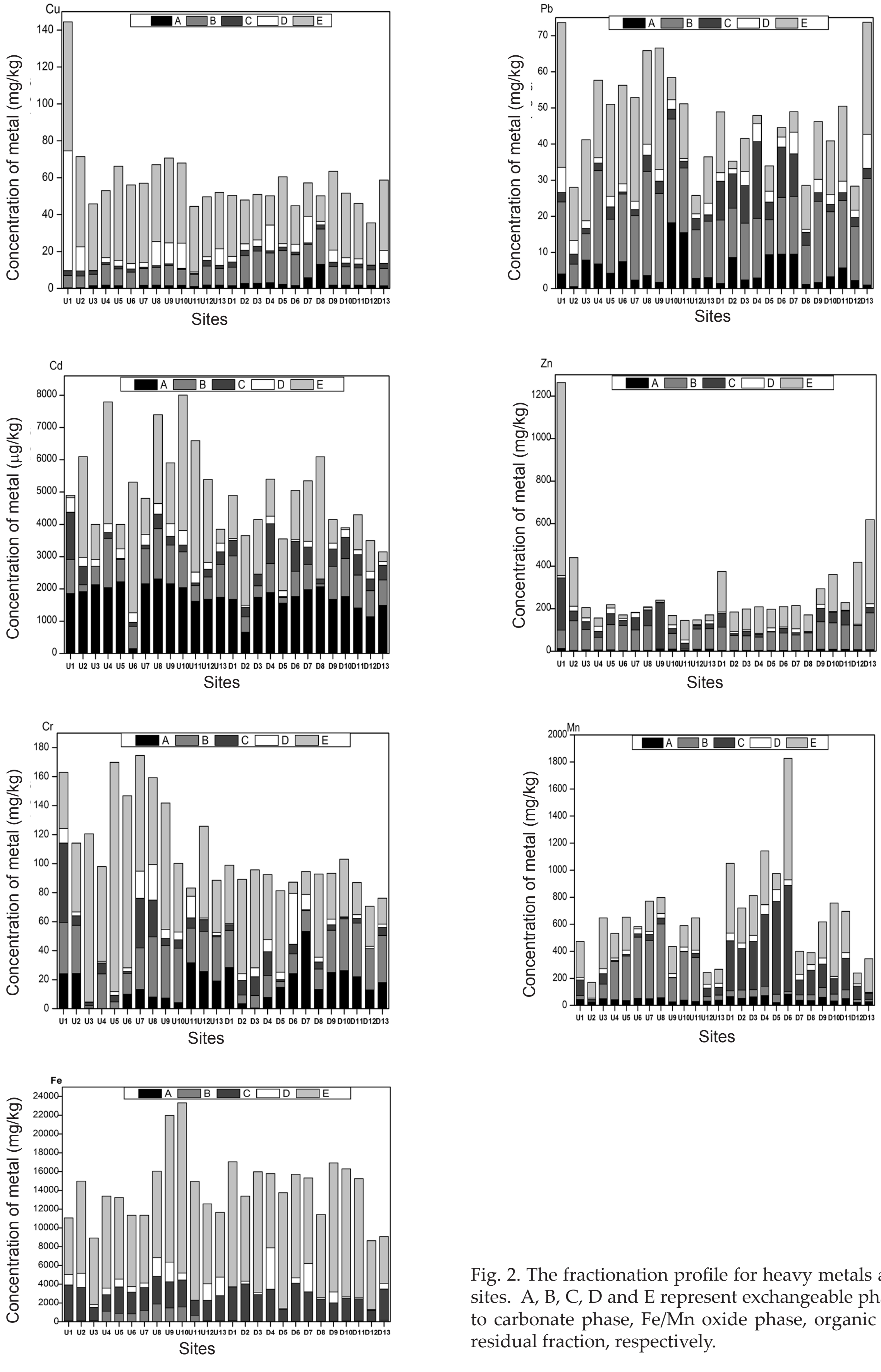

Fig. 2. The fractionation profile for heavy metals at different sites. A, B, C, D and E represent exchangeable phase, bound to carbonate phase, Fe/Mn oxide phase, organic phase and residual fraction, respectively.

35.99%), Pb (4.85–54.43%, mean 33.13%), and Mn (2.96–72.27%, mean 39.7%) were associated with the residual fraction. Trace metals in this form are not soluble under experimental conditions and may therefore be considered as tightly bound and a guide to the degree of contamination of the fluvial system. It is assumed that trace metals in these sediments are to a great extent derived from geochemical background rather than anthropogenic inputs.

Results revealed that the residual fraction was predominant for Cu and Fe in most sites, accounting for about 60.67% and 71.07% of total at average level, which suggesting an insignificant anthropogenic. Besides, quite a few Zn and Mn were associated with residual fraction, so did part of Cr at U3–U6, U9, D2, D3, D5 and D8, as well Pb at middle of the lake. For Zn and Mn, residual contents were higher in the downstream than the upstream, indicating the downstream suffered little human input in comparison with the upstream. This accorded with the above analysis with NYSDEC guideline. Similar results were reported for Cu, Cr and Pb in [32,33].

There are also considerable concentrations associated with carbonate and reducible phases. The above results are in accordance with those reported by Jain [17], Pardo et al. [27] and Tessier et al. [30].

Above all, more easily mobilized forms (exchangeable or carbonate fractions) were predominant for Cd, Cr and Pb, in contrast, the largest amount of Fe, Mn and Zn, were associated with the iron/manganese oxide, while Cr, Pb and Cu in organic matter fractions. Cadmium is widely used in electroplating, chemical,electronic industry and etc. the contamination of cadmium was due to the dense distribution of such industries around the lake.

According to the previous studies, pollution of Cu was located adjacent to cities due to the use of electrical equipment, alloys, and antifouling paint for ships [34]. They were also main industries in the local area, hence, were major pollution sources. Cr and Zn came either from anthropogenic pollution or from lithogenous materials. Chromium primarily came from local metal processing, chrome plating and leather producing. Lead mainly comes from coal-fired power plants, automobile exhaust, chemical raw materials, industrial waste and type prints, while for Fe and Mn, the predominant source might be natural impacts [35].

3.4. Risk assessment of heavy metal in surface sediments

Great deal of study proved that the metals in sediment are bound to different fractions with different strengths. The strength values can give a clear indication of sediment reactivity, which in turn assess the risk connected with the presence of metals in an aquatic environment. This criteria (RAC) was used to assess the potential risk of sediment metals in many researches [16,17], which indicates that a sediment which can release in exchangeable and carbonate fractions, less than 1% of the total metal will be considered safe for the environment; the sediment with 1–10% carbonate and exchangeable fractions was low risk, but sediment with the same fractions up to 11%–30%, 31–50% and more than 50% would be at medium risk, high risk and very high risk to the environment, respectively. Especially, the latter two have to be deemed to be highly dangerous and can easily enter the food chain [36].

The percentages of 7 heavy metals contributed to different risk levels from 26 sites in Nansi Lake are given in Table 3. According to the Risk Assessment Code, when carbonate together with exchangeable fractions reach 31%–50% or more than 50% of the total content of heavy metal, the sedimentary metal presents a high or very high risk, respectively. The results indicated that above 95% of Cd and Pb, 76.92% of Zn and 57.69% of Cr were in high or very high risk, and 65.38% of Cu and 53.85% of Mn showed a medium risk, while iron was dominantly associated with residual fractions, therefore, Fe was immobile and most appeared no risk (61.54%) or low risk (34.62%). Cd, Pb, Zn and Cr were potentially more mobile.

4. Conclusion

The comprehensive analysis on total content and fractionation of heavy metal can give a good and detailed evaluation on metal pollution and toxicity risk in the sediment and aquatic environment. The results denote that

Table 3
Mobility and risk of heavy metal in sediment of Nansi Lake

Metal	No risk	Low risk	Medium risk	High risk	Very high risk
Cd	0%	0%	3.85%	30.77%	65.38%
Pb	0%	0%	3.85%	50%	46.15%
Zn	0%	11.54%	11.54%	46.15%	30.77%
Cr	0%	19.23%	23.08%	19.23%	38.46%
Cu	0%	7.69%	65.38%	23.08%	3.85%
Mn	0%	15.38%	53.85%	3.85%	26.92%
Fe	61.54%	34.62%	3.85%	0%	0%

most sediments in Nansi Lake suffer certain pollution from heavy metals to some extent. The results showed that the sediment was severely impacted by Cr and Zn, moderately impacted by Cd, Pb, Cu and Mn, and then slightly impacted by Fe. The upper lakes suffered more pollution from Cu, Cr, Pb and Cd than the downstream; However, there was only little difference in Zn, Fe and Mn contamination in the upper and lower reaches of Nansi Lake, except of a few sample sites.

There was considerable enrichment of metals at inflows and lake area. Amongst the different metals, Cd concentration was the lowest but a major portion (30%–65%) was contained in mobile fraction (either exchangeable or carbonate bound), therefore, it was of great risk to enter the food chain. About 46%–50% of Pb in sediment existed in exchangeable or carbonate fraction and thus exert a potential risk for the aquatic environment. Followed this, Cr and Zn were relatively easy to mobile. Most Cu and Mn were in immobile fraction in Nansi Lake, just little part was found in carbonate fraction thus posing medium risk for the aquatic environment. Fe concentration was the highest but with lowest enrichment, thus showed only low risk for the aquatic environment. The potential risk of these 7 metals followed the order: Cd > Pb > Cr > Zn > Cu > Mn > Fe.

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