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Sources identification and pollution evaluation of heavy metals in the surface sediments of Bortala River, Northwest China

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A B S T R A C T

The current study focused on the Bortala River – a typical inland river located in an oasis of arid area in northwestern China. The sediment and soil samples were collected from the river and drainage basin. Results showed that: (1) the particle size of the sand fraction of the sediments was 78–697 μm, accounting for 78.82% of the total samples; the average concentrations of eight heavy metals fell within the concentration ranges recommended by the Secondary National Standard of China, while the maximum concentrations of Pb, Cd, and Hg exceeded these standards; (2) results from multivariate statistical analysis indicated that Cu, Ni, As, and Zn originated primarily from natural geological background, while Cd, Pb, Hg and Cr in the sediments originated from human activities; (3) results of the enrichment factor analysis and the geo-accumulation index evaluation showed that Cd, Hg, and Pb were present in the surface sediments of the river at low or partial serious pollution levels, while Zn, Cr, As, Ni, and Cu existed at zero or low pollution levels; (4) calculation of the potential ecological hazards index showed that among the eight tested heavy metals, Cd, Pb, Hg, and Cr were the main potential ecological risk factors, with relative contributions of 25.43%, 22.23%, 21.16%, and 14.87%, respectively; (5) the spatial distribution of the enrichment factors (EF_S), the Geo-accumulation index (I_{geo}), and the potential ecological risk coefficient (E_r^i) for eight heavy metals showed that there was a greater accumulation of heavy metals Pb, Cd, and Hg in the sediments of the central and eastern parts of the river. Results of this research can be a reference for the heavy metals pollution prevention, the harmony development of the ecology protection and the economy development of the oases of inland river basin of arid regions of China, Central Asia and also other parts of the world.

1. Introduction

Heavy metals are an important class of pollutants which can produce considerable harm to the environment when they are above certain concentrations (Varol, 2011; Gao et al., 2014; Zhang et al., 2012, 2015a,b). After heavy metals enter into a water body, they can harm aquatic organisms, and through the processes of chemical adsorption and physical precipitation, heavy metals can accumulate in the sediments of the water environment. When environment conditions such as pH, electrical conductivity (EC), oxidation reduction potential (ORP), and chemical oxygen demand (COD) change in the water or sediments, these elements can be released from the sediments and cause continual harm to the water environment (Ndimele, 2012; Li et al., 2014a; Zheng et al., 2013; Dong et al., 2014a; Fu et al., 2014). Heavy metal contents of the surface sediments are generally significantly higher compared with those in the water body, so it is very important to explore the heavy metal contents in the surface sediments as well as in the water body including rivers, lakes, and bays worldwide (Sundaray et al., 2011; Djordjević et al., 2012; Leung et al., 2014; Wang et al., 2014).

Rapid economic development and exogenous input of heavy metals from human activities are the main sources of heavy metals in the sediments of the water bodies, with the highest concentrations often measured in rivers, lakes, and the reservoirs located in the cities, and near industrial parks and towns with various human activities. Since the Industrial Revolution that began in Britain in the mid-19th century, approximately 40% of the rivers and lakes have been affected by human activities (Li et al., 2014b). Sediments are the main heavy metals accumulation places, and the heavy metals pulled into the water body of rivers, lakes and bays, eventually accumulated in the sediments (Scheibye et al.,

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2014). By statistics, about 85% of heavy metals eventually accumulated in the surface sediments (Zahra et al., 2014; Zhang et al., 2015a). In recent years, the heavy metal pollution of sediments of rivers in North America, Europe, and Asia has been widely studied, including the Mississippi River in the United States (Staley et al., 2015), the Ruhr and Rhine Rivers in Germany (Förstner and Prosi, 2013), the Mithi River in Mumbai, India (Singare et al., 2012), and the Yellow River (Ma et al., 2015) and the Yangtze river (Dong et al., 2014b) in China.

Inland rivers, such as the Tarim River in northwest China (Xiao et al., 2014), the Chari River in Africa (Moser et al., 2014), and Amu Darya and Syr Darya in central Asia (Barber et al., 2005) were formed by rain and snow runoff from inland mountains. Previous research showed that heavy metal accumulation in the inland rivers can cause continual harm to the environment due to its closure (Abuduwaili et al. 2015). The water environment of the inland rivers was very fragile, and once they suffered from heavy metals contamination, it was very difficult to remediate (Li et al., 2014b).

After the start of “The Development of the West Regions of China” in 2000, the economy of the oases in arid regions in northwestern China experienced rapid progress, as well as serious heavy metal pollution in water bodies (Zhang et al., 2012, 2013, 2015a). However, there has been limited research regarding heavy metal pollution and the potential ecological risk to the inland rivers and the rump lakes. Abuduwaili et al. (2015) found that with the economic development of the drainage basin, emissions from the petroleum chemical industry, agriculture production, and the agricultural and sideline products of the drainage basin have resulted in accumulation of the heavy metals Hg, Cd, and Cr, which were above moderate pollution levels. The high contents of these heavy metals in the river as well as in the farmland soil increased the heavy metal contents in the rump lake downstream, which reached heavy pollution levels.

The Bortala River is a typical inland river located in the Xinjiang oases of northwestern China. The river has no marine outfall and eventually flows into the rump lake, Aibi Lake (Fig. 1). Since the 1990s, the industrial structures of these regions were greatly altered with the “West to East Gas Pipeline Construction”, the Second Asia–Europe Continental Bridge Construction, the establishment of the port free trade zone of Alataw Pass, and the development of the petroleum chemical, the salt chemical, and transportation industries, and the environments of the rivers in the

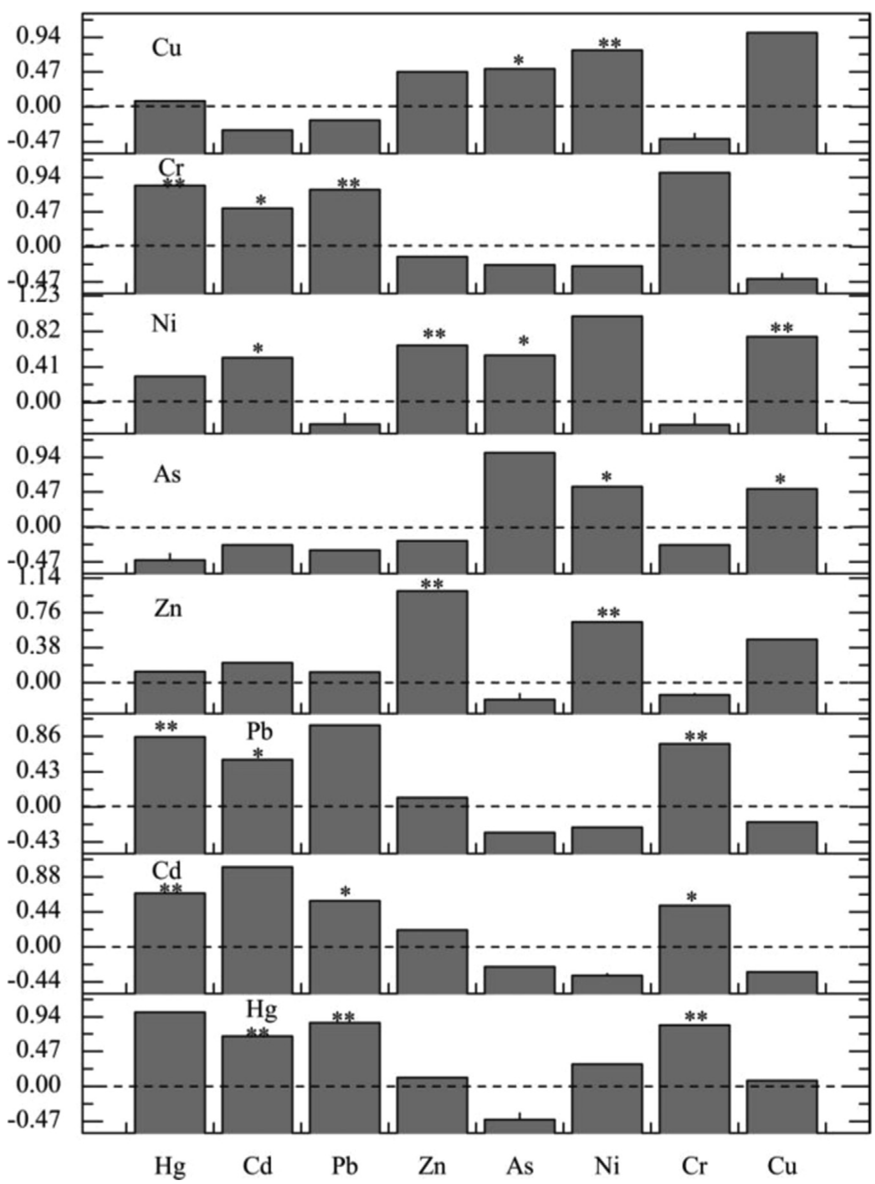

Fig. 1. Correlation coefficients of heavy metals in surface sediments of Bortala River. Note: * is significant at $p < 0.05$; ** is significant at $p < 0.01$.

basin have been significantly influenced (Abuduwaili et al., 2015).

In the current study, by analyzing the collected surface sediments samples of Bortala River and the nearby farmland, we aim to reveal if the sediments of Bortala River have been polluted by heavy metals and characterize the pollution status of Bortala River. We also want to identify which heavy metal has the most potential ecology risk and explore the contribution of agriculture production to the heavy metal pollution of the River.

2. Materials and methods

2.1. Research area

Bortala River is a typical inland river located in the northwestern part of Xinjiang province, northwest China (79°53′–83°53′, 44°02′–45°23′). The river originates from the Boluokenu Mountains, flows through Wenquan County, Bole city, and Jinghe County, and then flows into Aibi Lake. The length of the river is 252 km, and the total area of the watershed is 1.14×10^4 km^2 (Li et al., 2015). The basin is characterized by long winter and summer and short spring and autumn seasons. The annual maximum temperature of the study area is 44 °C, the annual minimum average temperature is −36 °C and the annual average temperature ranges 3.7–7.4 °C. The river is supplied mainly by snow and ice runoff, rainfall, and groundwater.

Bortala River is also the main water source for irrigation of Wenquan County, Bole City, and the “Production and Construction Groups” of the drainage basin of Xinjiang province. The total irrigation area for the whole basin is approximately 4.7×10^4 hectares (XBS, 2013). Dynamic changes in the water quantity and quality of the river play important roles in the development of agriculture, industry, urban living, and the ecology of the basin. Excess use of fertilizer and pesticides in agriculture and the pollution from industry, urban living, and transportation in the basin adversely affect water quality. The total Gross Domestic Product (GDP) of this area is 22.8 billion Dollars, and the assets of industries in the area exceed 158.7 thousand Dollars.

2.2. Sampling and testing

After careful analysis of the water depth and topography of the bottom of Bortala River, we used ArcGIS 10.0 software to produce a grid of sediment sampling points, and obtained 41 groups of sediment samples at an interval of 2 km. The sediments samples were collected during May 4–5th, 2015, and the water temperature of the river was 8.6–13.2 °C, the pH value of the river was 7.62-8.93, and the total salt content of the river was 0.36–1.83 g kg^{-1}. During field sampling, the wind speed was <3.5 m/s, and the temperature was 15.5-28.6 °C from 6:00 am to 10:00 pm, and the number of sites was adjusted based on the actual water depth of the river with all samples collected at sediment depths of 0–20 cm. Three sediment samples were collected from each sampling site, and the mean values of these three tests were presented. The weight of each sample was >400 g, and all the samples were wet. The samples were placed into clean polyethylene plastic bags, and labeled with collection site, date, and the color of the samples.

In this research, soil samples were also collected from the typical farmland and the mountain area, and ArcGIS 10.0 was used to produce a grid of interval of 200 m. During May 6–8th, 2015, a total of 81 groups of samples were obtained from farmland and 51 groups of samples from the mountain area. The primary planting crops for the cultivated farmland were cotton and corn, the soil texture was brown desert soil, the average pH of the area was 7.89, and the average total salt content of the soil was 1.56 g kg^{-1}. The mountain soil was classified as desert, with an average pH of 8.54 and average total salt content of 2.38 g kg^{-1}. The sampling depth of the soil was 0–10 cm. During the sampling process, the wind speed of the research was <3.7 m/s, and the temperature was 16.3–28.5 °C from 6:00 am to 10:00 pm. In the research, the weight of each sample was >300 g, and they were all dry. After the samples were collected, they were placed into clean polyethylene plastic bags, and labeled with collection site, date, and the color of the samples.

The surface sediments and soil samples were taken back to the laboratory and air dried and pushed through a 100 mesh nylon sieve (0.25 mm) to prevent contamination. Samples were stored in plastic bottles.

The total contents of heavy metals in all the surface sediments and the soil samples were tested as follows: a 0.5 g sample was placed into an Anton PVC digestion tank (Anton Paar GmbH, AT) with a mixture of HF–HNO_3. An inductively coupled atomic spectrum emission spectrometer 7500 (ICAP 7500, Dionex Corporation, USA) was used to determine the concentrations of Pb, Ni, Cd, Cu, Zn, and Cr. An atomic fluorescence spectrometer (Atomic Fluorescence Spectrometry, AFS) was used to determine the concentrations of Hg. The standard curves were obtained using separate solutions containing known concentrations of each heavy metal (GSS Series, PMC Engineering, Danbury, CT, USA) diluted with deionized water. During the testing, the blank tests were performed as the Standard Material of China (GSS). In order to verify the accuracy of these measurements, 25% of the sediment and soil samples were measured in duplicate. The accuracy or precision of the measurements was determined to be 93.85–96.82%. Prior to analysis, glassware was soaked in 5% HNO_3 for 24 h, rinsed by ultrapure water and then dried. All reagents were of analytical grade and were used without further purification. All solutions were prepared with Milli-Q water.

In this research, a Mastersizer 2000 (Melvin laser particle size analyzer, Malvern, UK) was used to determine the particle size of the sediments and soil by the following steps: 0.5 g of each sediment sample was combined with 30% H_2O_2 and HCl to remove carbonates. Ultrapure water was added and the solutions were allowed to stand in order for pH to stabilize between 6.5 and 7.0. Sodium Hexametaphosphate (SHMP) was then added and the samples were ultra-sonicated for 30 s. The range of particles measured by the instrument was 0.02–2000 μm. Measurements were conducted in triplicate and averaged, with measuring errors less than 5%.

The organic matter content of the sediments samples was determined using the potassium dichromate oxidation-colorimetric method. The nitrogen content of the sediments and soil samples were determined by the alkali solution diffusion method (Lu, 2000), and the phosphorus content was determined using a sodium bicarbonate extraction-spectrophotometry method. The potassium content of the sediments and soil samples were determined by ammonium acetate extraction-flame photometry method (Lu, 2000). The pH was determined using a glass electrode method (Lu, 2000). All analytical tests were conducted in triplicate and the quality control analysis showed that error was less than 5%.

2.3. Statistical analysis

2.3.1. Descriptive and multivariate statistical analysis

In this research, the descriptive statistics were used for analysis of organic matter, pH, and heavy metals in the sediment samples, which included range, mean, standard deviation, coefficient of variation, kurtosis, and skewness. The Pearson correlation analysis and the Principal Component analysis (PCA) that based on the rotation of the characteristic value of 1 were used to process the data and identify the sources of heavy metal contamination of the sediments. Analyses were conducted using SPSS 19.0 (IBM, NYC, USA).

2.3.2. Enrichment factor (EF) method

The EF index has been widely used to determine the pollution status and the sources of heavy metals in sediments of rivers, lakes and bays. EF is calculated as (Brady et al., 2014; Gao et al., 2014):

$$EF=(c_i/c_{ref})_{samples}/(B_i/B_{ref})_{baseline} \quad (1)$$

where EF is the enrichment level of a certain heavy metal, C_i is the measured concentration of i heavy metal in the sediment, C_{ref} is the measured concentration of the reference element, B_n is the background value of the local region and B_{ref} is the background concentration of the reference element of the soil in the same region.

The background values of Cd, Cr, Cu, Hg, Ni, Pb and Zn in the local region (B_n) were determined from the supra-crust of western Jounggar region, Xinjiang. The background values (B_{ref}) of Cd, Cr, Cu, Hg, Ni, Pb and Zn in the basin were 0.08, 26.49, 32.37, 9.27, 14.25, 11.19, and 110.6 mg kg^{-1}, respectively (SEPA, 1990).

2.3.3. Geo-accumulation index (I_{geo})

The geo-cumulative index method (I_{geo}), which was first described by Muller (1969), is widely used to estimate the heavy metal pollution status of sediment in water body. This method provides a direct measure of the degree of enrichment of heavy metals in sediment. Geo-accumulation index (I_{geo}) is calculated as:

$$I_{geo} = \mathrm{Log}_2[C_i/1.5\,B_i] \quad (2)$$

where C_i is the measured concentration of metal in sediment, B_i is the geochemical background value of a particular heavy metal. Fe was used in this study due to its high abundance in the crust, low solubility in neutral and alkaline environments, resistance to leaching and migration, low bioavailability, and high stability. The average values in global shale were used as background reference values. The background concentrations of Cd, Cr, Cu, Hg, Ni, Pb, and Zn were 0.3, 90, 45, 0.017, 26.7, 26.6, and 19.4 mg kg^{-1}, respectively (Horn and Adams, 1966).

2.3.4. Potential ecological risk index (RI)

The Hakanson potential ecology risk method (RI) was proposed by Hakanson (1980) and can be used to evaluate the potential ecological risk posed by heavy metals in sediments (Cui et al., 2014; Maanan et al., 2015). This comprehensive method considers four factors: concentration, type of pollutant, toxicity level, and the sensitivity of the water body to metal contamination in sediments. The potential ecological risk index (RI) is calculated as:

$$RI=\sum_{I}^{M} E_r^i = \sum_{I}^{M} T_r^i \times C_r^i = \sum_{I}^{M} T_r^i \times \frac{c^i}{c_n^i} \quad (3)$$

where E_r^i is the potential ecological risk coefficient of a particular heavy metal, T_r^i is the toxicity coefficient of specific single pollutant and reflects the toxicity, pollution levels, and sensitivity of the environment to heavy metals, C_r^i is the pollution factor, c^i is the tested value of heavy metal i, and c_n^i is the reference value of heavy metal i. To facilitate comparisons between the backgrounds values measured in Xinjiang in northwest China, the background values of Xinjiang (SEPA, 1990) were used as reference values. The toxicity coefficients of Pb, Ni, Cd, Hg, Cu, Zn and Cr based on results from previous studies were determined to be 5, 5, 5, 40, 5, 5 and 2, respectively (Xu et al., 2008).

3. Results

3.1. Descriptive statistical analysis of sediments properties

The minimum (maximum) values of organic matter (OM) content, nitrogen content, phosphorus content, and potassium content, and the pH values of all the surface sediment samples of the river were 1.01(4.62), 0.011(0.043), 0.002(0.012), 0.01 (0.09) mg kg^{-1} and 6.21(8.36), respectively (Table 1).

The coefficients of variation (CV) for OM, potassium content, and pH were 12.49%, 14.86%, and 11.37%, respectively, indicating that the variability of these measurements was considered low variation (CV < 15%). The average CVs for nitrogen content and phosphorus content were 26.36% and 31.51%, respectively, which fell under moderate variation (15% < CV < 36%) (Zhang et al., 2015b).

Results of the particle size distribution tests showed, the sand fraction of the sediments with a size range of 78–697 microns was 78.82%, while particles less than 5 microns in size (clay fraction) accounted for 3.69%, and silt particles (6–77 microns) accounted for 17.49% of the total.

The minimum (maximum) values of As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn in the sediments of Bortala River (Table 1) were found to be 3.27(10.34), 0.01(0.78), 32.34(215.64), 28.21(87.33), 0.01(1.69), 2.81(49.55), 11.77(373.61), and 65.34(207.61) mg kg^{-1}, respectively. Results from this analysis indicate that the average values of the eight tested heavy metals all fell within the Secondary National Standard of China (SEPA, 1995), but except As and Ni, the

Table 1
Descriptive statistics of OM, pH, and heavy metals elements contents in sediment of Bortala River.

Elements	Ranges (mg kg^{-1})	Mean (mg kg^{-1})	SD (mg kg^{-1})	CV(%)	Kurtosis	Skewness	BV (mg kg^{-1})	NSS (mg kg^{-1})
OM	1.01–4.62	0.82	0.12	12.49	32.28	29.17	–	–
N	0.011–0.043	0.005	0.004	26.36	24.6	14.23	–	–
P	0.002–0.012	0.006	0.001	31.51	26.71	18.61	–	–
K	0.01–0.09	0.02	0.09	14.83	25.92	19.17	–	–
pH	6.21–8.36	7.92	0.21	11.37	38.32	32.16	–	–
Zn	65.34–207.61	99.19	11.32	32.13	21.27	12.56	68.8	300
Pb	11.71–373.61	31.98	5.61	104.37	42.36	35.66	19.4	350
Cr	32.34–215.64	51.55	1.28	28.65	22.57	15.39	49.3	250
As	3.27–10.34	9.67	1.01	19.25	21.11	14.55	11.2	25
Ni	2.81–49.55	22.32	9.62	22.34	19.83	12.39	51.3	60
Cu	28.21–87.33	30.09	2.18	30.37	15.57	10.68	26.7	100
Cd	0.01–0.78	0.17	0.21	89.56	35.66	28.61	0.12	0.6
Hg	0.01–1.69	0.018	2.03	80.61	46.37	31.75	0.017	1.0
Fe	1556.38–2281.16	1882.33	–	–	–	–	–	–

Footnotes(a): OM is the organic matter, N is the Nitrogen, P is the Phosphorus, K is the potassium, SD is the standard deviation, CV is the variable coefficient, BV is the background values of the heavy metals, and NSS is the secondary national soil standard values.

maximum values of the other six heavy metals all exceeded the background values of Xinjiang (SEPA, 1990), and the maximum values of Pb, Cd, and Hg all exceeded the Secondary National Standard of China (SEPA, 1995), which were Pb(373.61), Cd(0.78), and Hg(1.69) mg kg^{-1}, respectively. The CVs of Cr, As, Ni, Cu, and Zn were 28.65%, 19.25%, 22.34%, 30.37%, and 32.13%, respectively, which were characterized as medium variation ($15\% < CV \le 36\%$). In contrast, the CVs for Hg, Cd, and Pb were 80.61%, 89.56%, and 104.37%, respectively, which fell under high variation ($CV > 36\%$). The CVs for these heavy metals were higher than those of other tested elements, suggesting that they were unevenly distributed and likely influenced by artificial sources (Abuduwaili et al., 2015). The skewness of the heavy metals followed the order of Pb > Hg > Cd > Cr > As > Zn > Ni > Cu. The skewness values for Pb, Hg and Cd were also higher than those of the other metals, suggesting that heavy metal levels in sediments may be influenced by human activities, resulting in positive skewness (Zhang et al., 2013).

3.2. *Multivariable statistics analysis*

3.2.1. *Correlation analysis*

The results of the Pearson correlation analysis are presented in Fig. 1, and indicate that complex correlations exist among the eight heavy metals in the sediments of Bortala River. The correlation coefficients for the pairs Pb–Hg, Pb–Cr, and Pb–Cd were calculated to be 0.857, 0.771, and 0.877 ($p < 0.01$), respectively. The correlation coefficients for Cr–Cd, Pb–Cd, and Cr–Hg were 0.588, 0.577, and 0.517 ($p < 0.05$), respectively, which were significant correlations. The correlation coefficients of Ni–As, Ni–Zn, and Ni–As (99.99% significance level) were 0.847, 0.661 and 0.761, respectively. The correlation coefficients of Cu–Zn, As–Cu, and As–Ni were 0.561, 0.515, and 0.547 ($p < 0.05$), respectively, which were also significant correlations. Corrections coefficients among Pb, Cd, Hg, Cr, and As, Cu, Zn, Ni were generally negative. For example, correlation coefficients for Cu–Cd, Ni–Cd, Hg–As, Cr–Ni, and Pb–As were determined to be −0.317, −0.361, −0.451, −0.257, and −0.317, respectively, indicating that these metal pairs likely originated from different sources. A principal component and cluster analysis was used to further investigate the relationships among these elements and their primary sources.

3.2.2. *Principal components analysis*

The results of the PCA that based on the rotation of the characteristic value of 1 showed that eight heavy metals in the surface sediments of Bortala River can be identified as three principal components, contributing to 44.38%, 22.69%, and 14.57% of the total variance, respectively, and the accumulating contribution of them was 91.47% (Fig. 2). For the first principal component, heavy metals Zn, Cu, Ni, and As had high loads. In the second principal and third components, Cr exhibited high loads of 0.664 and 0.714, and for the third principal component, Cd, Pb, and Hg had larger loads than others.

3.3. *Enrichment factor analysis*

The EF analysis (Table 2) gave average EF values for Cd, Pb, Hg, and Cr of 8.24, 7.32, 8.05, and 5.94, respectively. Since these values were all higher than 5, these elements were considered highly enriched. The average EF values of As, Ni, and Cu were determined to be 0.83, 0.89, and 1.05, respectively. In all samples, the average EF value for Zn was determined to be 2.88.

3.4. *Geo-accumulation index evaluation (I_{geo}) of heavy metals*

Geo-accumulation index (I_{geo}) values for Cd, Hg, and Pb ranged from 0 to 4, suggesting low to partial serious pollution levels

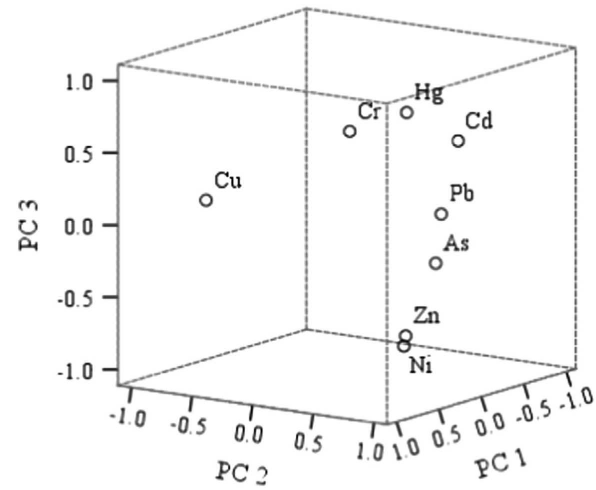

Fig. 2. Principal Component analysis results of heavy elements in sediments of Bortala River.

(Table 3). Cd exhibited the highest pollution level, while Pb displayed low to moderate pollution. I_{geo} values for Ni, Zn, Cr, As, and Cu were 0.38, 0.51, 0.62, 0.21, and 0.27, respectively (Table 3), indicating no pollution status. Five heavy metals (Ni, Zn, Cr, As, and Cu) can be categorized as no pollution. The mean pollution levels for the eight tested heavy metals followed the order of Cd > Hg > Pb > Cr > Zn > Ni > Cu > As, among which Cd, Hg, and Pb were significantly high, and there were 44.6%, 42.2%, and 37.5% of all samples with the I_{geo} values of heavy metals Pb, Hg, and Cd above 1, but the I_{geo} values of other elements all lower than 1.

3.5. *Potential ecological risk assessment (RI) of heavy metals in surface sediment and the soil*

The potential ecological harm of single heavy metal and the potential ecological hazard index (RI) of multiple heavy metals (Eq. (3), Table 4, and Fig. 3) were calculated and the results indicated that Cd, Pb, Hg, and Cr contributed the majority of ecological risk in the Bortala River. The single ecological risk factor (E_r^i) contribution to the potential hazard index (RI) for these heavy metals was 25.43%, 22.23%, 21.16% and 14.87%, respectively, while the contribution ratio for Zn, Cu, As, and Ni to the RI was only 16.31%. The single ratio for the eight tested heavy metals to the total potential ecological hazard followed the order of Cb > Pb > Hg > Cr > Cu > Zn > As > Ni.

The E_r^i values for Cu, Ni, Zn, and As in the surface sediments of Bortala River were all less than 40, suggesting a low ecological risk (Table 4). The average E_r^i value for Cd was 73, indicative of moderate pollution. Approximately 37.7% of all sediment samples displayed a moderate ecological risk. The average value of E_r^i for Hg was 78 (moderate pollution level) and 34.5% of all samples displayed moderate potential ecological risk. The average E_r^i values of Ni, As, Cu, and Zn fell under low potential ecological risk level. Based on the ecological hazard index for multiple heavy metals (Table 4), 97.5% of the total samples exhibited low ecological risk.

4. Discussion

4.1. *Pollution levels of the heavy metals of the sediments of Bortala River*

The EF analysis showed that the average EF values for Cd, Pb, Hg, and Cr were all higher than 5, and these elements were all

Table 2
Enrichment factor (EF) of heavy metals in surface sediment of Bortala River.

	Cd	Pb	Zn	Hg	Cu	As	Ni	Cr
Mean	8.24	7.32	2.88	8.05	1.05	0.83	0.89	5.94
Pollution Degree	Significant Enrichment	Significant Enrichment	Moderate Enrichment	Significant Enrichment	Weak Enrichment	No Enrichment	No Enrichment	Significant Enrichment

Footnotes(b): when EF < 2, there is no enrichment and pollution of heavy metals; when EF falls between 2 and 10, there is moderate enrichment significant pollution of heavy metals; when EF > 10, there is a significant enrichment and serious pollution of heavy metals (Sutherland, 2000).

Table 3
Geo-accumulation index (I_{geo}) assessment of heavy metals in surface sediments of Bortala River.

I_{geo}	Classifications	Degree	Accounting (%)							
			Hg	Pb	Cd	Ni	As	Zn	Cr	Cu
$I_{geo} \le 0$	0	No pollution	/	/	/	81.1	82.5	62.1	57.3	85.4
$0 < I_{geo} \le 1$	1	Low pollution	56.8	62.3	55.4	18.9	17.5	37.9	43.7	14.6
$1 < I_{geo} \le 2$	2	Partial median	12.5	11.8	13.4	/	/	/	/	/
$2 < I_{geo} \le 3$	3	Median	14.2	15.1	14.8	/	/	/	/	/
$3 < I_{geo} \le 4$	4	Partial Serious	15.5	10.6	16.4	/	/	/	/	/
$4 < I_{geo} \le 5$	5	Serious	/		/	/	/	/	/	/
$I_{geo} > 5$	6	Sever	/	/	/	/	/	/	/	/
Average values	/	/	1.32	1.07	1.41	0.38	0.21	0.51	0.62	0.27

Footnotes(c): $I_{geo} \le 0$ shows a clean status, and no pollution; $0 \le I_{geo} \le 1$ shows a slight pollution status; $1 \le I_{geo} \le 2$ shows a partial pollution status; $2 \le I_{geo} \le 3$ shows a moderate pollution status; $3 \le I_{geo} \le 5$ shows a serious pollution status; $I_{geo} > 5$ shows a severe pollution status (Bai et al., 2012).

considered highly enriched; the average EF values of As, Ni, and Cu were determined considerably lower; in all samples, the average EF value for Zn belonged to moderate enrichment. From the whole, the values of eight heavy metals were all within 10, which were obviously lower than those of the heavy metals in the sediments of lakes in other places of the world, such as the EFs of heavy metals in the sediments of Lake Pamvotis, Greece (Ioannides et al., 2015), and the EFs of heavy metals in the sediments of Chao Lake, China (Huo et al., 2014).

The analysis also showed that the values of $I_{geo,}$ and E_r^i of heavy metals Cr, Cu, Hg, As, Ni, Zn, Cb, and Pb in the surface sediments of Bortala River were relatively low and the pollution levels of these heavy metals were also very low. From the comparison, we can get that the concentrations of these eight heavy metals in the surface sediments of Bortala River were lower than those in the rivers located in more developed areas of the world, such as Mississippi in United States (Santschi et al., 2001), the Ruhr and Rhine Rivers in Germany (Gocht et al., 2001), and the Mithi River in Australia (Singare et al., 2012). This research also showed that the pollution status and the concentrations of heavy metals in the surface sediments of Bortala River were also generally lower than those measured in the more developed regions in central and eastern parts of China, such as Yellow River (Zhang et al., 2009), Songhua River (Zhu et al., 2014), and the Yangtze River (Dong et al., 2014b). From the whole, we can get that the pollution status and levels of eight heavy metals in Bortala River are relatively low, though the pollution status and levels of some heavy metals such as Pb, Hg, and Cd were obviously higher than others.

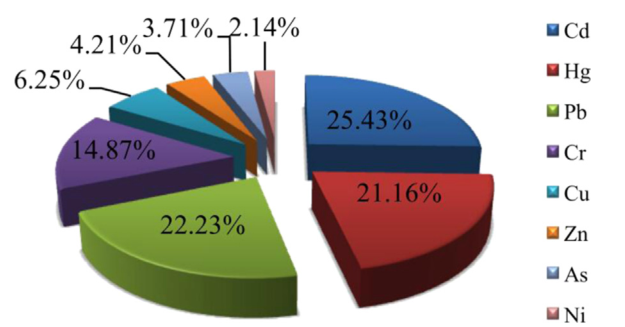

Fig. 3. Contribution of different heavy metals to potential ecological risk indices in sediments of Bortala River.

4.2. Sources identification of the heavy metals in the surface sediments of Bortala river

In this research, the multivariate statistical analysis showed that heavy metals Zn, Cu, Ni, and As had high loads in the first component, and the correlations among these elements were also strong, and the measurements showed that sediment samples that contained high levels of Cu, Ni, Zn, and As were primarily distributed in the western and northeastern parts of Bortala River,

Table 4
Potential ecology risk coefficient (E_r^i) and potential ecological hazard index (RI) of heavy metals in sediments of Bortala River.

Indicators	Elements								RI	Classification
	Pb	Ni	Cd	Hg	As	Cu	Zn	Cr		
E_r^i	95	36	73	78	23	21	30	54	142	Low
Proportion (%)	40.5	100	37.7	35.5	100	100	95.2	100	97.5	

Footnotes(d): the potential ecological risk coefficient (E_r^i) ≤ 40 shows a low ecology risk of certain heavy metal; $40 \le E_r^i \le 80$ shows a moderate ecology risk; $80 \le E_r^i \le 160$ shows a high ecology risk; $160 \le E_r^i \le 320$ shows a serious ecology risk; $320 \le E_r^i$ shows a severe ecology risk. The risk indices of all heavy metals (RI) ≤ 150 shows a low potential ecological hazard; 150 ≤ RI ≤ 300 shows a moderate potential ecological hazard; 300 ≤ RI ≤ 600 shows a high potential ecological hazard; 600 ≤ RI shows a serious potential ecological hazard (Yuan et al., 2014).

where the main land use types were desert, bare land and alkaline soil. Combined with the former research, we can conclude that in the research area, Cu, Ni, Zn, and As in the sediments may mainly originate from high natural geological background in the river bed and basin (Abuduwaili et al., 2015; Zhang et al., 2015b).

In the second and third principle components, Cr had a significantly higher content than the first principle components, and the average concentrations of the elements in all samples significantly exceeded the background values present in Xinjiang. Measurements showed that the sediment samples which contained high levels of Cr were primarily distributed in the western parts of the river watershed, and the distribution patterns were similar to those of Cd, Pb, and Hg in the surface sediments of the lake. Correlation analysis showed that the corrections between Cr and Pb, Cd, Hg in all samples were significant ($p < 0.01$ and 0.05). Previous studies showed that the pollution emissions from the township and industries (silicon chemical factories in Bortala River) also significantly contributed to accumulation of the Cr in the environment (Zhang et al., 2015a,b). The third principal components, Cd, Pb, and Hg, had large loads and measurements, and the concentrations of these three elements were higher than the background values in Xinjiang. Correlations among these three elements were also found to be significant. Additionally, the sampling records showed that samples containing high concentrations of Cd, Pb, and Hg primarily distributed in sediments located in the central and eastern parts of Bortala River, where the land types are mostly classified as farmland and urban construction land with high populations and economic activity.

In this research, a correlation analysis was used to evaluate the correlations among 12 elements both in the surface sediments and the farmland soil. Results showed that OM, nitrogen, phosphorus, and potassium were closely correlated with each other in both locations, among which, the correlation coefficient between the OM in the sediments and soil was 0.979, and the correlation coefficient between P in the sediments and the soil was 0.993, the correlation coefficient between the K in the sediments and soil was 0.956, and the correlation coefficient between the N in the sediments and soil was 0.994 ($p < 0.01$).

The analysis also showed that the levels of these same compounds and elements in both the sediments and farmland soil were significantly different ($p < 0.01$ and 0.05), among which, the correlation coefficients between Hg, Pb and OM in the sediments and farmland soil were 0.906 and 0.971, respectively ($p < 0.01$), the correlation coefficients between the Pb, Cr, and phosphorus were 0.714 ($p < 0.05$), and 0.868 ($p < 0.01$), respectively, the correlation coefficients between the Cr, Zn, Ni and K were 0.688, 0.754, and 0.747, respectively ($p < 0.05$), and the correlation coefficients between the Pb, Cr, Zn and N were 0.766, 0.842, and 0.764, respectively ($p < 0.05$). In the soil, the correlation coefficients between Hg, Pb, Cr and OM were 0.801, 0.788 ($p < 0.05$), and 0.813 ($p < 0.01$), respectively, the correlation coefficients between Pb, Zn, Cr and N were 0.766, 0.764 ($p < 0.05$), and 0.842 ($p < 0.01$), respectively, the correlation coefficients between Hg, Pb, Cr and P were 0.748, 0.710 ($p < 0.05$), and 0.868 ($p < 0.01$), respectively, the correlation coefficients between Hg, Pb, Cr and K were 0.698, 0.756, and 0.688 ($p < 0.05$), respectively, indicating that OM, N, P, and K in both the sediments and the soil significantly influence the accumulation of eight heavy metals, especially Hg, Pb, Cd, and Cr.

This analysis showed that heavy metals contents in the sediments and farmland soil were closely correlated, among which, the correlation coefficient between Hg in the sediments and in soil was 0.967 ($p < 0.01$), the correlation coefficient between Pb in the sediments and in soil was 0.939 ($p < 0.01$), the correlation coefficient between Cu in the sediments and in soil was 0.871 ($p < 0.01$), the correlation coefficient between Cd in the sediments and in soil was 0.883 ($p < 0.01$), the correlation coefficient between Zn in the sediments and in soil was 0.898 ($p < 0.01$), the correlation coefficient between Ni in the sediments and in soil was 0.951 ($p < 0.01$), and the correlation coefficient between Cr in the sediments and in soil was 0.911 ($p < 0.01$). Results of the analysis also showed close corrections between Cd, Pb, Hg, and Cr in the sediments and farmland soil ($p < 0.01$ and 0.05), indicating that these heavy metals particularly in the sediments were influenced by levels present in the farmland.

This research showed that four different heavy metals Pb, Hg, Cd, and Cr, resulted in high values of EF_S, I_{geo}, and E_r^i in the central and eastern parts of the river in Bole city, Jinghe County. Mi et al. (2010) found that the heavy metals contents in sediments were relatively higher, particularly for As, Hg, Pb, and Cd, indicating that the economic development in recent years had negative influence on the accumulation of the heavy metals. In this research we found that the development of agriculture production in recent years had negative influence on the heavy metal accumulation in the environment, such as the excess use of pesticide and fertilizer. In future research, soil samples from the urban area should be collected, and the contents of heavy metals as well as the particle organic matter (OM), nitrogen, phosphorus, and potassium should be tested, then statistical analysis methods such as fitting analysis method and multivariate statistical analysis should be conducted to accurately reveal the contributions of the man-made pollution such as urban lives, industries, etc.

5. Conclusions

From this research we can get the follow conclusions:

(1) Descriptive statistics analysis showed that the average values of eight heavy metals were all within the Secondary National Standard of China, but the maximum values of Pb, Cd, and Hg all exceeded this standard, and in addition to As and Ni, the maximum values of the other six heavy metals all exceeded the background values of Xinjiang.
(2) Multivariate statistical analysis showed that there were three main factors influencing the amounts of the eight heavy metals in the sediment of the lake. PC1, consisting of Cu, Ni, As, and Zn, were primarily influenced by the natural geological background, while PC2 and PC3 consisting of Cr and Cd, Pb, Hg and Zn, were primarily influenced by man-sources.
(3) Geo-accumulation index evaluation (I_{geo}) and potential ecological risk assessment (RI) showed that Cd, Pb, Hg, and Cr were the main pollution factors of the surface sediments of Bortala River and posed the greatest potential ecological risks than the other heavy metals.
(4) This research revealed the rapid development of the economy progress of the typical river drainage of Bortala River had negative influence on the heavy metals accumulation in the soil and the sediments of the river drainage. The results of this research can be a reference for the heavy metals pollution prevention of the inland river of northwest China and the harmony development of the ecology protection and the economy development of the oases of inland river basin of arid regions of China and also other parts of the world.

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References

Abuduwaili, J., Zhang, Z.Y., Jiang, F.Q., 2015. Assessment of the distribution, sources and potential ecological risk of heavy metals in the dry surface sediment of Aibi Lake in Northwest China. PLoS One 10 (3), e0120001.

Bai, J.H., Xiao, R., Zhang, K.J., Gao, H.F., 2012. Arsenic and heavy metal pollution in wetland soils from tidal freshwater and salt marshes before and after the flow-sediment regulation regime in the Yellow River Delta, China. J. Hydrol. 450, 244–253.

Barber, D.S., Betsill, J.D., Mohagheghi, A.H., Passell, H.D., Yuldashev, B., Salikhbaev, U., Solodukhin, V., 2005. The Navruz experiment: cooperative monitoring for radionuclides and metals in Central Asia transboundary rivers. J. Radioanal. Nucl. Chem. 263 (1), 213–218.

Brady, J.P., Ayoko, G.A., Martens, W.N., Goonetilleke, A., 2014. Enrichment, distribution and sources of heavy metals in the sediments of Deception Bay, Queensland, Australia. Mar. Pollut. Bull. 81 (1), 248–255.

Cui, J., Zang, S.Y., Zhai, D.L., Wu, B., 2014. Potential ecological risk of heavy metals and metalloid in the sediments of Wuyuer River basin, Heilongjiang Province, China. Ecotoxicology 23 (4), 589–600.

Djordjević, L., Živković, N., Živković, L., Djordjević, A., 2012. Assessment of heavy metals pollution in sediments of the Korbevačka river in Southeastern Serbia. Soil Sedim. Contam.: Int. J. 21 (7), 889–900.

Dong, C.Y., Zhang, W.G., Ma, H.L., Feng, H., Lu, H.H., Dong, Y., Yu, L., 2014a. A magnetic record of heavy metal pollution in the Yangtze River subaqueous delta. Sci. Total Environ. 476, 368–377.

Dong, X., Wang, C., Li, H., Wu, M., Liao, S., Zhang, D., Pan, B., 2014b. The sorption of heavy metals on thermally treated sediments with high organic matter content. Bioresour. Technol. 160, 123–128.

Förstner, U., Prosi, F. 2013. Heavy metal pollution in freshwater ecosystems. Biological Aspects of Freshwater Pollution: Proceedings of the Course Held at the Joint Research Centre of the Commission of the European Communities. 5–9 June 1978. Ispra, Italy, pp. 129.

Fu, J., Zhao, C., Luo, Y., Liu, C., Kyzas, G.Z., Luo, Y., Zhu, H., 2014. Heavy metals in surface sediments of the Jialu River, China: their relations to environmental factors. J. Hazard. Mater. 270, 102–109.

Gao, C., Lin, Q., Bao, K., Zhao, H., Zhang, Z., Xing, W., Wang, G., 2014. Historical variation and recent ecological risk of heavy metals in wetland sediments along Wusuli River, Northeast China. Environ. Earth Sci. 72 (11), 4345–4355.

Gocht, T., Moldenhauer, K.M., Püttmann, W., 2001. Historical record of polycyclic aromatic hydrocarbons (PAH) and heavy metals in floodplain sediments from the Rhine River (Hessisches Ried, Germany). Appl. Geochem. 16 (15), 1707–1721.

Hakanson, L., 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res. 14 (8), 975–1001.

Huo, S., Xi, B., Zan, F., Yu, X., Zhao, G., Su, J., Yeager, K.M., 2014. Assessment of distribution characteristics and contamination with heavy metals in surface sediments of lake Chaohu, China. Environ. Eng. Manag. J. 13 (3), 669–680.

Horn, M.K., Adams, J.A.S., 1966. Computer-derived geochemical balances and element abundances. Geochim. Cosmochim. Acta 30 (3), 279–297.

Ioannides, K., Stamoulis, K., Papachristodoulou, C., Tziamou, E., Markantonaki, C., Tsodoulos, I., 2015. Distribution of heavy metals in sediment cores of Lake Pamvotis (Greece): a pollution and potential risk assessment. Environ. Monit. Assess. 187 (1), 1–16.

Leung, H.M., Leung, A.O.W., Wang, H.S., Ma, K.K., Liang, Y., Ho, K.C., Yung, K.K.L., 2014. Assessment of heavy metals/metalloid (As, Pb, Cd, Ni, Zn, Cr, Cu, Mn) concentrations in edible fish species tissue in the Pearl River Delta (PRD), China. Mar. Pollut. Bull. 78 (1), 235–245.

Li, M., Zang, S., Xiao, H., Wu, C., 2014a. Speciation and distribution characteristics of heavy metals and pollution assessments in the sediments of Nashina Lake, Heilongjiang, China. Ecotoxicology 23 (4), 681–688.

Li, Y., Zhang, H., Chen, X., Tu, C., Luo, Y., Christie, P., 2014b. Distribution of heavy metals in soils of the Yellow River Delta: concentrations in different soil horizons and source identification. J. Soils Sedim. 14 (6), 1158–1168.

Li, R., Zhang, F., Zhou, M., Li, X.H., Wang, D.F., 2015. Assessment of water resources carrying capacity in Bortala Mongol autonomous prefecture based on principal component analysis. China Rural Water Hydropower 4, 65–69 (In Chinese).

Lu, R.K., 2000. Soil Agricultural Chemical Analysis Methods. China's Agricultural Science and Technology Press, Beijing (In Chinese).

Ma, X., Zuo, H., Tian, M., Zhang, L., Meng, J., Zhou, X., Liu, Y., 2015. Assessment of heavy metals contamination in sediments from three adjacent regions of the Yellow River using metal chemical fractions and multivariate analysis techniques. Chemosphere 144, 264–272.

Maanan, M., Saddik, M., Maanan, M., Chaibi, M., Assobhei, O., Zourarah, B., 2015. Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. Ecol. Indic. 48, 616–626.

Mi, Y., Chang, S.L., Shi, Q.D., Gao, X., Huang, C., 2010. Study on the effect of agricultural non-point source pollution to water environment of the Ebinur Lake Basin during high flow period. Arid Zone Res. 27, 278–283.

Moser, W., Greter, H., Schindler, C., Allan, F., Ngandolo, B.N., Moto, D.D., Zinsstag, J., 2014. The spatial and seasonal distribution of Bulinus truncatus, Bulinus forskalii and Biomphalaria pfeifferi, the intermediate host snails of schistosomiasis, in N'Djamena, Chad. Geospatial Health 9 (1), 109–118.

Muller, G., 1969. Index of geo-accumulation in sediments of the Rhine River. Geojournal 2 (3), 108–118.

Ndimele, P.E., 2012. The effects of water hyacinth (Eichhornia crassipes [l//Iart.] Solms) infestation on the physico-chemistry, nutrient and heavy metal content of Badagry Creek and Ologe Lagoon, Lagos, Nigeria. J. Environ. Sci. Technol. 5 (2), 128–136.

Santschi, P.H., Presley, B.J., Wade, T.L., Garcia-Romero, B., Baskaran, M., 2001. Historical contamination of PAHs, PCBs, DDTs, and heavy metals in Mississippi river Delta, Galveston bay and Tampa bay sediment cores. Mar. Environ. Res. 52 (1), 51–79.

Scheibye, K., Weisser, J., Borggaard, O.K., Larsen, M.M., Holm, P.E., Vammen, K., Christensen, J.H., 2014. Sediment baseline study of levels and sources of polycyclic aromatic hydrocarbons and heavy metals in Lake Nicaragua. Chemosphere 95, 556–565.

Singare, P.U., Mishra, R.M., Trivedi, M.P., 2012. Sediment contamination due to toxic heavy metals in Mithi River of Mumbai. Adv. Anal. Chem. 2 (3), 4–24.

Staley, C., Johnson, D., Gould, T.J., Wang, P., Phillips, J., Cotner, J.B., Sadowsky, M.J., 2015. Frequencies of heavy metal resistance are associated with land cover type in the Upper Mississippi River. Sci. Total. Environ. 511, 461–468.

Sundaray, S.K., Nayak, B.B., Lin, S., Bhatta, D., 2011. Geochemical speciation and risk assessment of heavy metals in the river estuarine sediments-a case study: Mahanadi basin, India. J. Hazard. Mater. 186 (2), 1837–1846.

Sutherland, R.A., 2000. Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environ. Geol. 39 (6), 611–627.

The State Environmental Protection Administration (SEPA), 1990. China's Soil Element Background Values. China Environmental Science Press, Beijing (In Chinese).

The State Environmental Protection Administration (SEPA), 1995. The national standard of soil environmental quality standard of the People's Republic of China (GB15618-1995). The People's Republic of China State Environmental Protection Agency, Beijing (In Chinese).

Varol, M., 2011. Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. J. Hazard. Mater. 195, 355–364.

Wang, J., Liu, R., Zhang, P., Yu, W., Shen, Z., Feng, C., 2014. Spatial variation, environmental assessment and source identification of heavy metals in sediments of the Yangtze River Estuary. Mar. Pollut. Bull. 87 (1), 364–373.

Xiao, J., Jin, Z., Wang, J., 2014. Geochemistry of trace elements and water quality assessment of natural water within the Tarim River Basin in the extreme arid region, NW China. J. Geochem. Explor. 136, 118–126.

Xinjiang Bureau of Statistics (XBS), 2013. Xinjiang Statistical Yearbook, 2013. China Statistics Press, Beijing (In Chinese).

Xu, Z.Q., Ni, S.J., Tuo, X.G., Zhang, C.J., 2008. Calculation of heavy metals' toxicity coefficient in the evaluation of potential ecological risk index. Environ. Sci. Technol. 31 (2), 112–115 (In Chinese).

Yuan, G.L., Sun, T.H., Han, P., Li, J., Lang, X.X., 2014. Source identification and ecological risk assessment of heavy metals in topsoil using environmental geochemical mapping: typical urban renewal area in Beijing, China. J. Geochem. Explor. 136, 40–47.

Zahra, A., Hashmi, M.Z., Malik, R.N., Ahmed, Z., 2014. Enrichment and geo-accumulation of heavy metals and risk assessment of sediments of the Kurang Nallah—feeding tributary of the Rawal Lake Reservoir, Pakistan. Sci. Total. Environ. 470, 925–933.

Zhang, W.G., Feng, H., Chang, J.N., Qu, J.G., Xie, H.X., Yu, L.Z., 2009. Heavy metal contamination in surface sediments of Yangtze River intertidal zone: an assessment from different indexes. Environ. Pollut. 157 (5), 1533–1543.

Zhang, Z.Y., Abuduwaili, J., Jiang, F.Q., Tud, M., Wang, S.P., 2012. Contents and sources of heavy metals in surface water in the Tianshan Mountain. China Environ. Sci. 32 (10), 1799–1806 (In Chinese).

Zhang, Z.Y., Abuduwaili, J., Jiang, F.Q., 2013. Determination of occurrence characteristics of heavy metals in soil and water environments in Tianshan Mountains, Central Asia. Anal. Lett. 46 (13), 2122–2131.

Zhang, Z.Y., Abuduwaili, J., Jiang, F.Q., 2015a. Heavy metal contamination, sources, and pollution assessment of surface water in the Tianshan Mountains of China. Environ. Monit. Assess. 187 (2), 1–13.

Zhang, Z.Y., Abuduwaili, J., Jiang, F.Q., 2015b. Sources, Pollution Statue and Potential Ecological Risk of Heavy Metals in Surface Sediments of Aibi Lake. Northwest China Environ. Sci. 36 (2), 490–496.

Zheng, S.S., Wang, P.F., Wang, C., Hou, J., Qian, J., 2013. Distribution of metals in water and suspended particulate matter during the resuspension processes in Taihu Lake sediment, China. Q. Int. 286, 94–102.

Zhu, H., Zhu, L.L., Yan, B.X., Guan, J.N., 2014. Accumulation of lead, zinc, and copper in scalp hair of residents in a long-term irrigation area downstream of the second Songhua River, northeast China. Hum. Ecol. Risk Assess.: Int. J. 20 (1), 137–149.