Bull Environ Contam Toxicol (2012) 89:1009–1015
DOI 10.1007/s00128-012-0784-7

Distribution and Risk Assessment of Metals in Sediments from Taihu Lake, China Using Multivariate Statistics and Multiple Tools

Yuan Zhang · Xiaona Hu · Tao Yu

Received: 30 April 2012 / Accepted: 7 August 2012 / Published online: 25 August 2012

Abstract Metals in the surface sediment and zoobenthos throughout Taihu Lake were investigated to explore their distribution, source and potential ecological risks. The result showed that the average metal concentration followed the order: Fe > Mn > Zn > Cr > Ni > Pb > Cu > Cd, with the highest value of 27.9 g/kg (Fe) and lowest value 0.54 mg/kg (Cd). Anthropogenic inputs were the major sources of metals, followed by geochemical processes, and organic matter is also a control for metals. Spatially, high metal concentrations were distributed in the northern lake and low concentrations in Gonghu Bay and the eastern part of the lake. Risk assessment showed that Pb had the highest ecological risk ($E_r = 10.32$), followed by Cu and Ni ($E_r = 8.77-8.81$), while Zn had the lowest risk ($E_r = 1.59$). Analysis indicated that *Corbicula* sp. was more suitable for biomonitoring than *Bellamya* sp.

Keywords Metals · Distribution · Sediment · Risk assessment · Taihu Lake, China

Metal pollution in soils and sediments has become a growing concern, especially in developing countries (including China) due to the use and discharge of toxic substances (Xia et al. 2011; Coulibaly et al. 2012). Sediments provide habitat for benthic fauna and food sources for man. Polluted sediments may contaminate aquatic organisms, endangering the health of both the aquatic organisms and human consumers of benthic animals. Thus, ecological risk assessment is a crucial step in water environment management.

Methods to distinguish anthropogenic contamination from natural background are important in risk assessment that drives pollution control and/or restoration. Characterization of metal pollution levels at different sites in a large water body is useful to understand anthropogenic impacts, and to separate them from the unavoidable natural variability of the sediment content. Multivariate statistics provides a method to do this. For assessment purpose, the geo-accumulation index and ecological risk index may be used to assess metal pollution and ecological risk posed by metals (Varol 2011; Yi et al. 2011).

Taihu Lake is the third largest freshwater lake with an area of approximately 2,350 km^2; it is hypereutrophic and is located in the downstream reaches of the Yangtze (Changjiang) River on the outskirts of the coastal city of Shanghai. With an average depth of 1.9 m, it plays an important role in water and fish supply for large riparian cities such as Wuxi and Suzhou. The rapid increase of population and development of industry and agriculture in this area has transformed this once meso-oligotrophic lake in the 1950s into its present hypereutrophic state (Otten et al. 2012), and resulted in increasing metal pollution from untreated or inadequately treated industrial discharges (Yu et al. 2012). These problems have become a significant hazard for aquatic life and humans who consume aquatic organisms. Some recent studies investigated metals in water and sediment in Taihu Lake (Yao and Xue 2010; Yu et al. 2012). However, these studies either focused on a local part of the lake or paid little attention to an ecological

Y. Zhang · X. Hu · T. Yu (✉)
State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
e-mail: yutao0325@sina.com

Y. Zhang · X. Hu · T. Yu
Laboratory of Riverine Ecological Conservation and Technology, Chinese Research Academy of Environmental Sciences, Beijing 100012, China

risk assessment for the entire lake. The source analysis of metals using multivariate statistics for this large lake has been rarely reported. In this study, we conducted a comprehensive investigation of sediment-related metals throughout Taihu Lake, using multivariate statistics, such as principal component analysis, cluster and correlation analysis, to distinguish different sources of metals in the lake sediment. The results support metal pollution monitoring and control for the lake.

Materials and Methods

Surface sediments (0–10 cm) were sampled using a sediment grab sampler (ZH2988 China) at 30 sites throughout the lake in September, 2010. Zoobenthic organisms were also collected using sediment grab and then selected and washed in-situ, with *Bellamya* sp. obtained at T1,T12,T20, T27 and *Corbicula* sp. obtained at T12, T14, T17, T21, T25, T26, T28 and T30 (Fig. 1). Two replicate sediment samples were taken at each site. Collected samples were then transported at 4°C in polythene bags to the laboratory for treatment and analysis.

The samples were first freeze-dried and then ground and stored in airproof polyethylene bags. All sediment samples (including replicates), of 0.5 mg were then digested using the National Standard Method (GB/T17140) with HCl-HNO_3-HF-$HCLO_4$ acid. All organism samples were weighed to 0.5 mg, and then digested using the National Standard Method (GB5009.12-2010). All processed samples were divided into two sub-samples for replicate analysis before digestion, so each metal had four test values with two replicate samples, upon which the

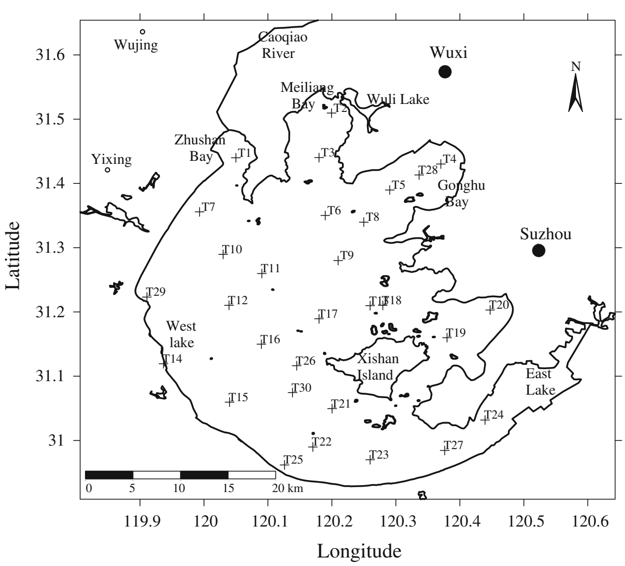

Fig. 1 Taihu Lake and sampling sites

calculations and statistics were conducted. After digestion, the extracted solution of each sample was tested for total concentration of metals using flame atomic absorbance spectrophotometry (AAS, Hitachi Z-2000, Japan) for Cu, Zn and Cr with the detection limit of ≤0.007 ppm; and using ICP-MS (Agilent, 7500 CX, USA) for Ni, Pb and Cd with the detection limit of ≤0.05 ppb. In sample treatment and measurement, sample blanks and the "National Certified Reference Material-lacustrine sediment" (GSD-10, with a known concentration of metal elements) were used for quality control. The relative standard deviation (RSD) for each group of replicate samples was 3 %–17 %. The recovery of the reference material for all metals was 88 %–105 %. Measured data were expressed as mean ± SD (standard deviation).

The index of geo-accumulation (I_{geo}) was calculated with:

$$I_{geo} = \log_2\left(\frac{C_{sn}}{K \times C_{Bn}}\right)$$

where, C_{sn} is the measured concentration of the heavy metal in the sediment; C_{Bn} is the geochemical background concentration of the heavy metal in Taihu lake sediment; K is the background matrix correction factor which takes account of the variation of the trace metal in the background materials due to lithospheric effects (K = 1.5). Pollution levels in terms of I_{geo} (Varol 2011) are listed in Table 1.

The potential ecological risk index (R_I) was calculated based on the toxicity of metals and organism response to the environment (Yi et al. 2011):

$$R_I = \sum E_r^i, E_r^i = T_r^i C_f^i, C_f^i = {C_s^i}/{C_n^i}$$

where R_I is calculated as the sum of all risk factors (E_r^i) for metals in sediments;E_r^i is the monomial potential ecological risk factor for metal i; T_r^i is the toxic-response factor for a given metal, which accounts for the toxicity and organism sensitivity to it (Cd = 30, Pb = 5, Cu = 5, Ni = 5, Cr = 2, Zn = 1, Yi et al. 2011); C_f^i is the contamination factor; C_s^i is the metal concentration in the sediment. C_n^i is the reference value (local background) for these metals. The risk factor R_I was proposed by Hakanson (1980) based on eight

Table 1 The pollution levels based on geo-accumulation index

Class	I_{geo} value	Pollution level
0	$I_{geo} \le 0$	Practically unpolluted
1	$0 < I_{geo} \le 1$	Unpolluted to moderately polluted
2	$1 < I_{geo} \le 2$	Moderately polluted
3	$2 < I_{geo} \le 3$	Moderately to heavily polluted
4	$3 < I_{geo} \le 4$	Heavily polluted
5	$4 < I_{geo} \le 5$	Heavily to extremely polluted
6	$5 < I_{geo}$	Extremely polluted

Table 2 Levels of potential ecological risk factor (E_r^i) and potential ecological risk index (R_I)

E_r^i value	R_I value	Ecological risk level
$E_r^i < 40$	$R_I < 55$	Low
$40 \le E_r^i < 80$	$55 \le R_I < 110$	Moderate
$80 \le E_r^i < 160$	$110 \le R_I < 220$	High
$160 \le E_r^i < 320$	$R_I \ge 220$	Very high
$320 \le E_r^i$	–	Extremely high

parameters (PCB, Hg, Cd, As, Pb, Cu, Cr, and Zn). In this study, PCBs, Hg and As were not considered. Based on the local background value for these elements, the adjusted assessment criterion for R_I (Yi et al. 2011) is listed in Table 2.

The analytical data were treated statistically using SPSS 13.0 (USA) software. Principal component analysis (PCA) was employed to identify the possible source of metals. The components were analyzed by correlation matrix without factor rotation and the eigenvalues over 1 were extracted as PCs. Cluster analysis (CA) was applied to identify different geochemical groups. CA was formulated according to the between-groups linkage method based on standardized data through z-scale transformation. A confidence level of 0.05 was used in this study.

Results and Discussion

The total metal concentration in bottom sediment from Taihu Lake is summarized in Table 3, and some international results and USEPA standards also listed in the table for comparison.

The mean metal concentrations from all sites combined followed the order: Fe > Mn > Zn > Cr > Ni > Pb > Cu > Cd. These concentrations were higher than the natural background values (except for Cd and Fe) of the Taihu area, but lower than the Chinese soil standards (GB15618-1995). Comparison with USEPA standards indicated that the concentrations of Mn, Cr and Ni were higher than the threshold effect concentration (TEC) values, but lower than the midpoint effect concentration (MEC) values. Zn, Cu, Pb and Cd were lower than TEC values. Compared with international results, metals in Taihu sediment were generally at the moderate level. However, Cu concentration in Taihu sediment was lower than the international results.

PCA was conducted to explain the measured parameters and to explore the source of metals in Taihu sediment. The results are given in Table 4.

The 11 variables for Taihu Lake sediments were summarized by three principal components (PCs), with eigenvalues of 5.143, 1.609, and 1.405, respectively. These three components explained 77.07 % of the total variance. PC 1

Table 3 Comparison of metal concentration in Taihu Lake sediment with international results and relevant standards (mg/kg, DW)

Country	Water	Fe (g/kg)	Mn	Zn	Cu	Cr	Pb	Ni	Cd	Reference
China	Taihu Lake	27.9 ± 3.16	668 ± 254	104 ± 43.3	27.0 ± 8.64	81.3 ± 71.5	32.4 ± 11.4	34.9 ± 12.4	0.54 ± 0.46	This study
Spain	Ebro River	–	–	72–290	34–96	150–490	16–52	–	0.66–8.4	Soto et al. (2011)
USA	Ontario Lake	23.1	830	147	34.5	52.5	60.0	30.3	1.30	Mckee et al. (1989)
Italy	Taranto Gulf	31.6	893	102.3	47.4	85.9	57.8	53.3	–	Buccolieri et al. (2006)
India	Mannar Gulf	12.5	305	73.0	57.0	177	16.0	24.0	0.21	Jonathan et al. (2004)
Egypt	The Suez Gulf	2.24	116	1,596	33.2	32.06	70.46	71.46	9.92	El Nemr et al. (2006)
China	Taihu background	34.3	396	65.1	15.4	71.8	15.7	19.8	1.99	Yu et al. (2012)
China	Soil Standards I	–	–	100	35.0	90.0	35.0	40.0	0.2	National soil quality standard (GB15618-1995)
	Soil StandardsII	–	–	250	50.0	300	300	50.0	0.6	
USA	TEC	–	460	121	31.6	43.4	35.8	22.7	0.99	Consensus-Based Sediment Quality Guidelines(2003)
	MEC	–	780	290	91.0	76.5	83.0	36.0	3.0	
	PEC	–	1,100	459	150	110	129	48.6	4.98	

TEC threshold effect concentration, *MEC* midpoint effect concentration, *PEC* probable effect concentration

Table 4 The results of principal component analysis

Item	PC 1	PC 2	PC 3
Cd	0.897	−0.059	−0.060
Cr	0.906	−0.111	−0.293
Cu	0.907	0.099	−0.097
Ni	0.889	0.060	−0.173
Pb	0.836	0.216	−0.083
Zn	0.885	−0.090	0.044
Fe	0.118	0.674	0.511
Mn	0.039	0.853	0.131
TOC	0.478	−0.450	0.577
OM	0.225	−0.303	0.782
pH	0.359	0.221	0.209

was characterized by a high loading of Cd, Cr, Cu, Ni, Pb, and Zn. This metal combination can be defined as anthropogenic components due to their high-level of presence in the sediment. It also indicates similar sources which are most likely industrial discharges, such as from electronics electroplating, and chemical plants around Taihu Lake (Li et al. 2009). PC 2 exhibited high positive loading for Mn (0.853) and Fe (0.674). Since Mn and Fe are macro-elements, the PC 2 may reflect geochemical composition by natural processes (Loska and Wiechula 2003) in this area. PC 3 accounted for 12.8 % of the total variance, having high loadings on organic matter (OM) and total organic carbon (TOC), which may explain a control factor for metal distribution (Loska and Wiechula 2003) in the lake. However, Table 5 showed that the correlation between OM and most metals was not significant. This may be because OM has a closer relationship with some species of the metals (e.g. exchangeable fraction) instead of the total metal measured in this study.

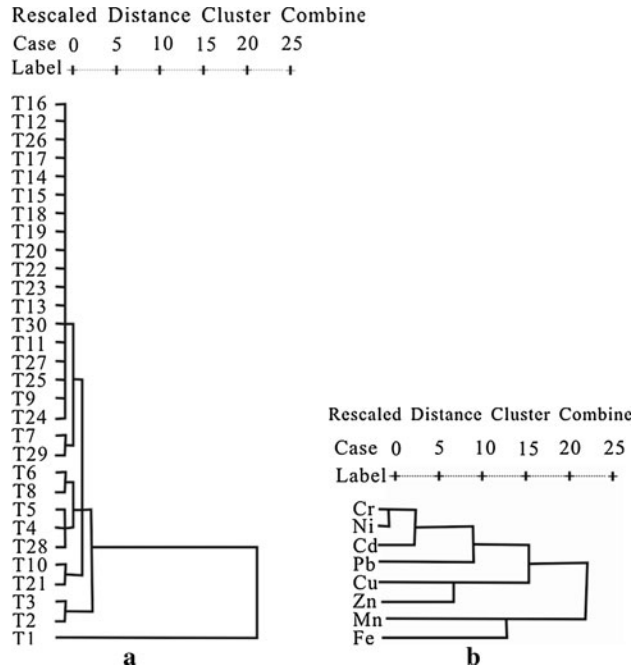

Fig. 2 Spatial cluster of sites (**a**) and metal cluster (**b**) for Taihu Lake sediment

Correlation analysis (Table 5) showed that significant relationship existed among these metals, indicating that they had similar sources. Cu, Ni, Cr, Pb and Cd were significantly correlated, and they are usually related to anthropogenic activities. For example, Cd is usually regarded as deriving from anthropogenic wastewater and fertilizers or pesticides, and Cr is usually connected to industrial discharges (Li et al. 2009).

Cluster analysis was applied to explore the spatial variation of sites and sediment metal combinations in Taihu Lake. The cluster result is shown in Fig. 2.

Table 5 Correlation coefficients between metals and sediment properties

	pH	OM	TOC	Cu	Cd	Cr	Ni	Pb	Zn	Mn	Fe
pH	1.00										
OM	0.04	1.00									
TOC	0.18	0.53*	1.00								
Cu	0.20	0.39	0.12	1.00							
Cd	0.23	0.29	0.05	0.86**	1.00						
Cr	0.23	0.37	0.13	0.72*	0.79*	1.00					
Ni	0.26	0.30	0.11	0.69*	0.84**	0.93**	1.00				
Pb	0.46	0.27	0.09	0.63*	0.71*	0.78*	0.74*	1.00			
Zn	0.22	0.45	0.19	0.95**	0.80**	0.69*	0.66*	0.62*	1.00		
Mn	0.02	−0.23	−0.04	−0.05	−0.05	0.14	0.08	0.21	−0.08	1.00	
Fe	0.17	0.08	0.06	0.16	−0.14	0.09	0.03	0.08	0.19	0.48	1.00

** Significant at the 0.01 level

* Significant at the 0.05 level (2-tailed)

Table 6 Values of geo-accumulation index (I_{geo}), potential ecological risk factor (E_r^i), and potential ecological risk index (R_I) in Taihu Lake sediments

	I_{geo}						E_r^i						R_I
	Cu	Cd	Cr	Ni	Pb	Zn	Cu	Cd	Cr	Ni	Pb	Zn	
T1	4.42	−0.10	6.19	4.69	4.40	3.41	21.68	27.44	12.42	23.05	21.59	3.36	109.55
T2	2.45	−0.06	0.60	2.04	2.80	1.26	12.69	28.04	2.53	11.07	14.15	1.67	70.15
T3	1.86	−0.54	1.20	2.36	1.76	0.76	10.40	22.01	3.25	12.32	10.06	1.36	59.39
T4	1.71	−1.35	1.02	1.15	2.48	2.35	9.86	14.17	3.02	7.98	12.81	2.46	50.30
T5	1.35	−1.55	0.36	0.69	2.18	2.85	8.64	12.66	2.27	6.60	11.61	2.87	44.65
T6	0.91	−2.03	0.24	1.03	1.63	2.52	7.23	9.50	2.15	7.60	9.59	2.59	38.66
T7	1.03	−2.98	0.06	1.70	3.68	0.62	7.58	5.28	1.98	9.82	18.06	1.28	43.99
T8	1.38	−1.88	0.32	0.36	2.14	2.60	8.73	10.40	2.24	5.68	11.48	2.66	41.20
T9	1.39	−1.55	0.33	1.17	1.90	0.80	8.74	12.66	2.24	8.03	10.56	1.38	43.62
T10	1.00	−4.26	−0.26	1.04	0.71	0.70	7.50	2.26	1.69	7.62	6.65	1.32	27.05
T11	1.04	−4.26	−0.53	0.89	0.76	0.26	7.64	2.26	1.47	7.16	6.78	1.08	26.40
T12	0.59	−3.38	−0.40	1.78	1.62	0.45	6.30	4.07	1.58	10.11	9.55	1.18	32.79
T13	1.13	−4.08	−0.03	1.04	1.69	0.78	7.92	2.56	1.90	7.62	9.77	1.37	31.14
T14	1.03	−3.43	−0.08	1.43	1.92	0.60	7.59	3.92	1.85	8.90	10.63	1.26	34.15
T15	1.50	−3.49	−0.34	1.32	1.50	0.60	9.14	3.77	1.63	8.52	9.12	1.26	33.44
T16	0.57	−3.91	−0.16	1.34	1.84	0.47	6.26	2.86	1.78	8.57	10.32	1.19	30.99
T17	0.93	−4.73	−0.62	2.11	1.34	0.43	7.29	1.66	1.41	11.36	8.57	1.17	31.46
T18	1.17	−2.77	−0.12	1.78	1.98	0.54	8.04	6.03	1.81	10.13	10.87	1.24	38.12
T19	1.30	−3.02	−0.29	1.36	−0.20	0.41	8.47	5.13	1.67	8.66	4.37	1.16	29.45
T20	1.54	−3.21	−0.16	1.20	0.15	0.35	9.28	4.52	1.78	8.13	5.17	1.13	30.03
T21	1.55	−2.89	−1.76	0.80	1.19	0.47	9.30	5.58	0.74	6.89	8.10	1.20	31.81
T22	1.10	−2.77	−0.76	0.82	1.13	0.48	7.80	6.03	1.31	6.95	7.92	1.20	31.21
T23	1.32	−2.77	−0.78	0.62	1.08	0.16	8.52	6.03	1.30	6.39	7.76	1.04	31.04
T24	0.62	−3.21	−0.12	0.70	0.77	1.34	6.38	4.52	1.82	6.60	6.82	1.72	27.85
T25	1.65	−2.29	0.12	0.82	2.21	0.66	9.64	8.14	2.03	6.97	11.74	1.30	39.82
T26	0.45	−3.69	−0.16	1.15	1.48	0.34	5.93	3.32	1.78	7.97	9.05	1.13	29.17
T27	1.54	−2.69	−0.45	0.95	1.26	1.24	9.26	6.33	1.54	7.34	8.33	1.65	34.45
T28	1.48	−1.32	1.11	1.04	2.78	3.05	9.04	14.47	3.14	7.61	14.04	3.04	51.35
T29	1.47	−3.76	−0.01	1.86	3.02	0.63	9.02	3.17	1.91	10.42	15.11	1.28	40.91
T30	0.95	−2.77	−0.30	1.20	1.50	0.37	7.34	6.03	1.66	8.14	9.12	1.14	33.44
Mean	1.35	−2.69	0.14	1.35	1.76	1.05	8.77	8.16	2.26	8.81	10.32	1.59	39.92

Table 7 Metal concentrations in zoobenthos and correlation of metals between zoobenthos and sediments

	Zoobenthos	Cu	Cd	Cr	Ni	Pb	Zn
Concentration (mg/kg, DW)	*Bellamya* sp. (n = 4)	77.8 ± 51.1	0.22 ± 0.06	3.92 ± 3.63	1.80 ± 1.31	2.51 ± 1.20	135 ± 4.84
	Corbicula sp (n = 8)	25.7 ± 14.0	2.96 ± 1.58	3.40 ± 1.75	1.67 ± 0.68	1.70 ± 1.28	175 ± 60.3
Correlation coefficient	*Bellamya* sp. (n = 4)	0. 970*	0.175	0.979*	0.990*	0.736	0.995**
	Corbicula sp (n = 8)	0.491	−0.077	0.388	−0.182	0.789*	−0.587

** Significant at 0.01 level

* Significant at 0.05 level (2-tailed)

Three clusters of the 30 sites were obtained, with 22 sites in the first cluster, 7 sites in the second cluster, and one (T1) in the third (Fig. 2a). These three clusters have clear spatial distinctions; cluster 1 represents most of the lake; cluster 2 represents Gonghu Bay, and cluster 3 represents Zhushan Bay. Also, the three clusters represent three areas of the lake that have characteristic water quality. Water quality in Gonghu Bay is relatively good as there are few river inputs to this bay. It is a drinking water source for local cities, therefore this part of the lake is well protected and wastewater discharges are prohibited. Consequently, metal concentrations in the area are generally low. Zhushan Bay tends to produce severe algal blooms, and has the worst water quality; the largest tributary of the lake—Caoqiao River, flows into this bay. This river receives a large amount of wastewater containing metals from local industries, resulting in relatively high metal concentrations in the water and sediment (Yu et al. 2012). Cluster 1 involved most sites, having similar water quality. However, for the sub-clusters in cluster 1, T2 and T3 had a closer relationship as they were both located in Meiliang Bay, also an algae bloom area, where metal concentrations are higher due to wastewater inputs.

For individual elements, three major clusters were obtained in terms of the distance of 10 (Fig. 2b). Cluster 1 included Cr, Ni, Cd, and Pb, which is related to chemical plant discharges. Cluster 2 contained Cu and Zn, also derived from human source but mainly from industrial discharges. Cluster 3 involved Fe and Mn, which was characterized by natural processes. This is consistent with our PCA results.

Risk assessment for the sediment metals was done using different tools and the calculated Geo-accumulation index and potential ecological risk index are listed in Table 6.

The mean value of I_{geo} followed an order of Pb > Cu > Ni > Cr > Zn > Cd in the entire lake. The potential ecological risk index (E_r^i) indicated that metal pollution in the sediment followed the order Pb > Cu > Ni > Cd > Cr > Zn. The I_{geo} value for Pb, Ni and Cu indicated an unpolluted to moderately polluted level (i.e., Class 1), while Cd, Cr and Zn were in the unpolluted level (i.e., Class 0). All E_r^i value indicated that the potential ecological risk of all metals in Taihu sediment was low. However, the highest value of I_{geo} and E_r^i at T1 showed that it was moderately polluted mainly in the north part due to inputs of a large amount of wastewater from township industries via the Caoqiao River. The mean R_I indicated that the potential ecological risk caused by metals was relatively low in Taihu sediments. Spatially, R_I values exhibited a distribution that followed the order: north lake > west lake > center > east lake. This spatial distribution is also related to the wastewater inputs mentioned above.

Zoobenthos can be good indicator for metal pollution in the sediment. The mean concentrations of metals in zoobenthos followed an order similar to that in the surface sediment (Zn > Cu > Cr > Ni > Pb > Cd). Correlations analysis showed that statistically significant correlations existed between *Bellamya* sp. and sediment for many metals, but not for *Corbicula* sp., with the exception of Pb (Table 7). Although some coefficients between *Corbicula* sp. and sediment were negative, they were not statistically significant, indicating no correlation probably due to the nature of *Corbicula* sp. This is because the *Bellamya* sp. is a tolerant species to pollution and it can survive in an environment with high metal concentration; while *Corbicula* sp. tend to live in a clean environment. This is consistent with our field observation that *Bellamya* sp. was generally obtained in the northern, such as Zhushan Bay. This finding may indicate that *Corbicula* sp. may be a more suitable bioindicator than *Bellamya* sp. based on population size, as it appears to be more sensitive to metal pollution.

Acknowledgments This work was financially supported by China's national basic research program ("973" program): "Water environmental quality evolution and water quality criteria in lakes" (2008CB418201). Two anonymous reviewers gave insightful comments to improve our manuscript. Dr. Edwin Ongley kindly edited the English language of whole text.

References

Buccolieri A, Buccolieri G, Cardellicchio N, Dell′Atti A, Di Leo A, Maci A (2006) Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, Southern Italy). Mar Chem 99:227–235

Consensus-Based Sediment Quality Guidelines (WT-7322003). Wisconsin Department of Natural Resources. Madison, USA

Coulibaly S, Atse BC, Koffi KM, Sylla S, Konan KJ, Kouassi NGJ (2012) Seasonal Accumulations of some heavy metal in water, sediment and tissues of black-chinned Tilapia *Sarotherodon melanotheron* from Biétri Bay in Ebrié Lagoon, Ivory Coast. Bull Environ Contam Toxicol 88:571–576

El Nemr A, Khaled A, El Sikaily A (2006) Distribution and statistical analysis of leachable and total heavy metals in the sediments of the Suez Gulf. Environ Monit Assess 118:89–112

Hakanson L (1980) An ecological risk index for aquatic pollution control: a sediment logical approach. Water Res. 14:975–1001

Jonathan MP, Ram-Mohan V, Srinivasalu S (2004) Geochemical variations of major and trace elements in recent sediments, off the Gulf of Mannar, the southeast coast of India. Environ Geol 45:466–480

Li JL, He M, Han W, Gu YF (2009) Analysis and assessment on heavy metal sources in the coastal soils developed from alluvial deposits using multivariate statistical methods. J Hazard Mater 164:976–981

Loska K, Wiechula D (2003) Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik Reservoir. Chemosphere 51:723–733

Mckee JD, Wilson TP, Long DT, Owen RM (1989) Geochemical partitioning of Pb, Zn, Cu, Fe and Mn across the sediment-water interface in Larger Lake. J Great Lakes Res 15:46–58

Otten TG, Xu H, Qin B, Zhu G, Paerl HW (2012) Spatiotemporal patterns and ecophysiology of toxigenic microcystis blooms in Lake Taihu, China: implications for water quality management. Environ Sci Technol 46:3480–3488

Soto DX, Roig R, Gacia E, Catalan J (2011) Differential accumulation of mercury and other trace metals in the food web components of a reservoir impacted by a chlor-alkali plant (Flix, Ebro River, Spain): implications for bio-monitoring. Environ Pollut 159:1481–1489

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
Xia XH, Chen X, Liu RM, Liu H (2011) Heavy metals in urban soils with various types of land use in Beijing, China. J Hazard Mater 186:2043–2050
Yao SC, Xue B (2010) Nutrients and heavy metals in multi-cores from Zhushan Bay at Taihu Lake, the largest shallow lake in the Yangtze Delta, China. Quart Inter 226:23–28
Yi YJ, Yang ZF, Zhang SH (2011) Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. Environ Pollut 159:2575–2585
Yu T, Zhang Y, Meng W, Hu XN (2012) Characterization of heavy metals in water and sediments in Taihu Lake, China. Environ Monit Assess 184:4367–4382