Original Research

Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in
Journal of Environmental Biology
JEB™

ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/38/4/PRN-129

Analysis of heavy metals in the surface sediments of shallow lakes in Nanjishan (Poyang Lake) Natural Wetland in China

Authors Info

J. Yong[1]*, Z. Jie[1, 2, 3], Z. Liwei[4], L. Xiaoli[1, 5], W. Dingding[1], L. Jiali[1] and L. Jing[1, 3]

[1]School of Hydraulic and Ecological Engineering, Nanchang Institute of Technology, Nanchang-330099, China

[2]College of Environmental, Hohai University, Nanjing-210098, China

[3]Key Laboratory of Water Science and Engineering, Nanjing Hydraulic Research Institute, Nanjing- 210029, China

[4]JiangXi Water Resources Institute, Nanchang-330013, China

[5]Water Resource and Eco-system Environmental Research Center for Poyang Lake, Nanchang- 330029, China

*Corresponding Author Email : jiyong@nit.edu.cn;

Key words

Ecological risk assessment,
Heavy metals,
Lake Poyang,
Nanjishan wetlands,
Surface sediments

Publication Info

Paper received : 26.02.2016
Revised received : 05.08.2016
Re-revised received : 04.11.2016
Accepted : 07.01.2017

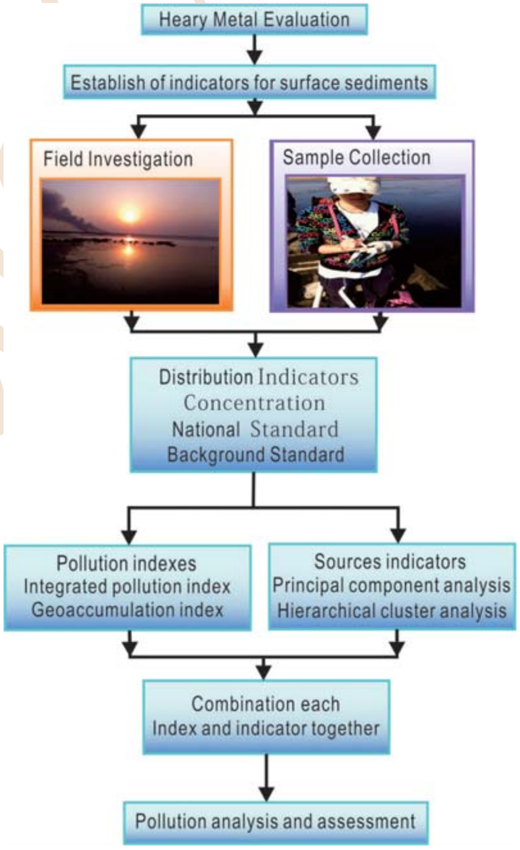
Abstract

Aim: The land between aquatic and terrestrial systems is defined as wetland where heavy metals accumulate and deposit in sediments more easily due to natural as well as anthropogenic activities. The main objective of the present study was to investigate the distribution characteristics, pollution degree and potential source of heavy metals in the surface sediments of Nanjishan Wetland Nature Reserve.

Methodology: Surface sediments samples from three representative shallow lakes (Lake Nanshen, Lake Dong and Lake Chang) were collected, and heavy metals were estimated in terms of content characteristics, spatial features and correlations. Integrated pollution indexs (PI and IPI), geoaccumulation indices (I_{geo}) combined with geostatistical methods were used to calculate the degree of heavy metals, evaluate the ecosystem risks and identify the potential sources.

Results: Indicators like PI, IPI and I_{geo} indicated that heavy metals in research areas exist widely and were mainly dominated by Zn, Pb, Cd and Cr at higher concentration than the permissible limit standards. Statistical analysis revealed two main sources of pollutants; first due to discharge of mixed-origin domestic wastewater emissions and other due to terrigenous sediments.

Interpretation: Human activities, such as traffic, aquaculture, municipal and industrial wastewater and hydrological exchange can significantly influence the spatial variation of heavy metals in wetlands.



Introduction

Among various organic and inorganic pollutants, heavy metals are widely distributed in air, water, soil and various forms of organisms due to their non-degradable nature (Dalal *et al.,* 2013; Li *et al.,* 2014). Some of them, such as copper, zinc, lead, cadmium, chromium and arsenic, generally exist at low concentrations but can cause serious pollution and damage to the aquatic ecosystem when their concentrations exceed permissible limit (Singh *et al.*, 2005; Ahmad *et al.*, 2015). Metals can deposit in aquatic systems through different pathways, such as atmospheric particulate matter, decomposing dead organic matter, rocks directly exposed to surface waters and surges of anthropogenic activities including discharge of various treated and untreated liquid into water bodies (Förstner and Salomons, 1980). Wetlands are defined as transitional lands between aquatic and terrestrial systems, where water table is usually at or near the surface or where land is covered by standing water that does not exceed six meters (Pechmann *et al.*, 1989). In the real world, wetlands are usually located in low areas where heavy metals accumulate more easily due to the influence of human activities and natural environment (Madkour *et al.*, 2015). In wetland systems, heavy metals mainly exist in sediments and plants or other organisms. Several researches have reported various types of hazardous and toxic substances accumulated in the mud of enclosed and semi-enclosed areas (Jaiswar *et al.*, 2015). Wetland sediments receive and absorb pollutants mainly from natural erosion and anthropogenic activities. Sediments are indicators for monitoring contaminants in the aquatic environment because they can act as a sink and a carrier for pollutants (Truu *et al.*, 2009). Thus, sediment is usually selected as a key section in evaluating the pollution status of wetland systems because the contaminated sediments have great ecological impact on the organisms.

Wetlands can offer a variety of important resources for human beings, so heavy metals in wetlands can ultimately jeopardize human health (Swinton *et al.*, 2007). This may happen directly through human consumption of food and water in daily life, as well as indirectly through a long-term, gradual accumulation in the ecological chain (Mok *et al.*, 2015). Therefore studies on the distribution of heavy metals in wetland sediments are of great importance. To date, a great number of studies have reported the distribution of heavy metals in sediment or plant tissues, as well as metal enrichment mechanism of many wetland plant species (Bai *et al.*, 2011). These studies have evaluated the ecological risk of heavy metals. However, most of these studies have mainly focused on various forms of constructed wetlands, not on natural wetlands (Vymazal and Svehla, 2013). Therefore, distribution of heavy metals in sediments of natural wetlands need further exploration.

Heavy metal pollution is a serious problem in China due to industrilization (Li *et al.*, 2014; Xin *et al.*, 2014; Zhou *et al.*, 2015). Previous studies have reported heavy metals in Lake Poyang, in China, (Ji *et al.*, 2014; Ji *et al.*, 2015). The heavy metal content in sediments Nanjishan natural wetland has not been reported. In light of this, the objective of the present study was to investigate the spatial distribution of heavy metals in surface sediment and analyze the integrated pollution index (IPI) of shallow lakes in Nanjishan Natural Wetland sediments.

Materials and Methods

Study sites : As shown in Fig. 1 and Table 1, Nanjishan Wetland Nature Reserve (NWNR) lies in the southwest of Lake Poyang's main body. In the present study, three seasonal hydrological lakes (Lake Chang, Lake Nanshen and Lake Dong) in NWNR were selected, based on the historical consideration of plant distribution, pollution, transportation and location in this region along the water gradient. These three lakes are distributed on the southern side, downstream of the River Ganjiang, one of the five main branches of Lake Poyang. A country road passes through middle of three lakes during dry season and ends east of Lake Nanshen. Among three lakes, Lake Chang is smallest, with its north side close to one branch of the River Ganjiang, while southern boundary is near the country roadside. Lake Nanshen, a medium-sized lake, is located north of the two other lakes and is parallel to one branch of the River Ganjiang's northwest side. Lake Dong, the largest lake among the selected three lakes, is directly connected with the main body of Lake Poyang and has not been used commercially.

Sample collection and preparation : A global positioning system receiver(Magellan 315 GPS) was used to record the location of each sampling site. A total of 28 surface sediment samples were collected from three sampling lakes using Hydro-Bios' stainless steel grab sample and wrapped in polyethylene plastic bags (Fig.1). Among the samples, ten (C1-C10) sites were located in Lake Chang, ten (D1-D10) in Lake Dong and eight (N1-N8) in Lake Nanshen respectively. At each site, four or five samples were taken to reflect the heavy metal contamination. All the samples were extracted from the upper layer (0-20 cm) of the sediment. After collection, samples were put polyethylene bags, brought to laboratory and then left to air dry in Petri dishes at room temperature. After that, the sediments were crushed and ground with a mortar and pestle until all the particles passed through a 200-mesh nylon sieve. These were stored at ambient temperature before analysis of heavy metals.

Sample analysis : For analysis of total heavy metal content , one gram of homogenized dry sample was microwave-digested in acid-cleaned Teflon vessels for 30-40 min at 200 °C with 5 ml of HCl, HNO_3 : and HF in 3:1:1 ratio (MLS-1200 MEGA high-performance microwave digestion). After cooling, one ml of boric acid was added into the vessels to dissolve the precipitates of fluoride in the microwave digestion system for additional 20 min. After that, the samples were transferred to graduated plastic test tubes with additional 0.5 ml of HF and made up to the volume of 50 ml with Milli-Q water. The concentration of Cu, Zn, Pb, Cd, Cr and As in the acid digests were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES, Thermo 6300) by sequential chemical extraction method (Tessier *et al.*, 1979). Sampling duplicates, method blanks and standard reference materials (GSD-9 and GSD-11, supplied by the Chinese Academy of Geological Sciences) were used to control the analysis quality. Under the selected test conditions, the analytical precision was better than 10% and detection limit ranged from 0.010 to 0.050 mg·kg. The linear correlation coefficient of calibration standards of each heavy metal was $\geq$ 0.999. The percentage of recovery ranged from 95.3 to 104.8 %. The results met the accuracy demand of Technical Specification for Soil Environmental Monitoring HJ/T 166-2004.

Statistical analysis : Correlation analysis was performed on all the datas to identify the relationship among heavy metals. Multivariate analyses including multiple linear regression, principal component analysis (PCA) and hierarchical cluster analysis (HCA) were used to distinguish the natural and anthropogenic sources of sediment heavy metals. Data analysis was performed using geostatistical methods. All data analysis in the present study was carried out using SPSS 17.0 for Windows and ArcGIS version 10.0. Two-way ANOVA was used to compare the spatial and temporal variations of heavy metals at significance level of $P < 0.05$.

Results and Discussion

The concentration of heavy metals, Cu, Zn, Pb, Cd, Cr and As, in twenty eight sampling sites is shown in Fig. 2. The concentration range ($mg \cdot g^{-1}$) of heavy metals in these areas were as follows: Cu: 4.83-26.07 (12.25); Zn: 31.95-248.61 (79.45); Pb: 6.97-53.14 (27.81); Cd: 0.00-2.32 (0.42); Cr: 25.70-231.19 (105.77); As: 3.28-11.52 (6.69). As shown in Fig. 2 and Table 2, generally, sampling sites close to the Ganjiang River and residential areas had higher concentrations of heavy metals. The highest concentration metals were usually found in mud flats located close to Ganjiang River, local towns and some special areas. Among these polluted areas, Lake Dong usually had high concentration of heavy metals, especially Cu, Cd and As. As for Lake Nanshen, N1, N2 and N3 were identified as the highest polluted areas. In the past, these areas were used for aquaculture. While Lake Chang is still relatively clear compared with the other two lakes, however this does not hold true for the Cr level. Overall, level of the heavy metals in Lake Dong, excluding Cd and As, was higher than the other two lakes. Generally, Lake Chang had a minimum value for almost all the heavy metals. Collectively, sampling sites with high metal level are directly affected by wastewater, human activities or exchange with other water coming from Lake Poyang (Yuan *et al.*, 2011).

Table 1: Description of study area

Location	Sites	Vegetation community	Description
Lake Dong	D1, D4, D5, D6, D7	No submerged plants	Lake Dong located within the protection zone of open water is directly connected with the main lake of Lake Poyang and has not been used for aquaculture
	D2, D10	*Hydrilla verticillata*	
	D3, D8, D9	*Vallisneria spiralis* and *Hydrilla verticillata*	
Lake Chang	C2, C3	No submerged plants	Lake Chang is a natural lake. The northern side is close to one branch of River Ganjiang, while the southern boundary is closer to traffic road.
	C7, C8	*Vallisneria spiralis*	
	C1, C4, C5, C6, C9, C10	*Vallisneria spiralis* and *Hydrilla verticillata*	
Lake Nanshen	NS1, NS3, NS6, NS8	No submerged plants	The southern part of Lake Nanshen close to Nanjixiang town is being used for aquaculture. Meanwhile, the western part is pretty close to one branch of River Ganjiang.
	NS2, NS7	Vallisneria spiralis	
	NS4, NS5	*Vallisneria spiralis* and Hydrilla verticillata	

Table 2 : Mean concentrations of heavy metals in sediments of different sampling sites

Sampling sites	Cu	Zn	Pb	Cd	Cr	As
Lake Dong	14.20	98.47	44.24	0.45	138.08	6.51
Lake Chang	9.64	69.63	18.08	0.19	134.93	6.62
Lake Nanshen	13.29	74.05	24.41	0.63	50.77	6.90
Mean	12.25	79.45	27.81	0.42	105.77	6.69
Coefficient Variation	42.37	51.24	52.26	127.05	58.74	29.19
National Averages(Gong *et al.*, 2006)	20.70	68.00	23.50	0.14	57.30	9.60
Background Values(Gong *et al.*, 2006)	4.75	45.75	12.50	0.75	29.65	13.37

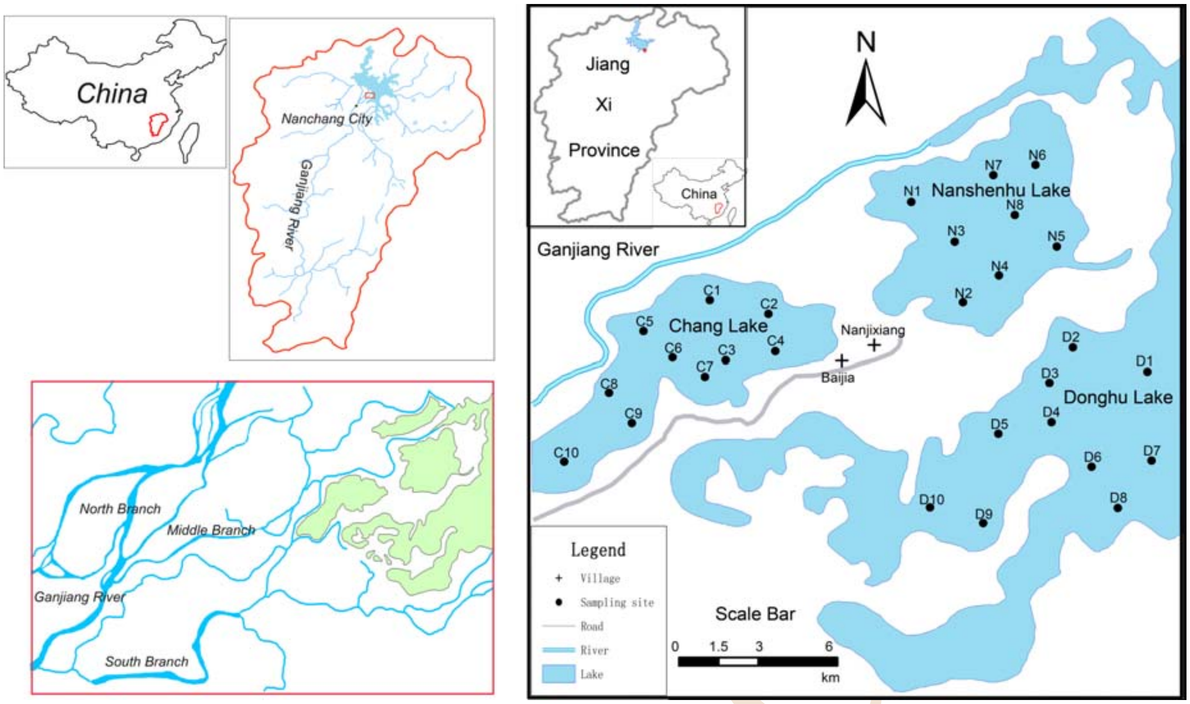


Fig. 1: Location of three study areas and sampling locations of sediments

As shown in Table 2, the spatial distribution of different elements was assessed by Coefficients of Variation (CV). Among these studied elements, Cd had the highest CV values, indicating that Cd was generally discharged due to anthropogenic activities. In contrast, other elements had lower CV values and were less affected by anthropogenic activities. Compared with national averages, almost all the heavy metals estimated in the present study, excluding As and Cu, were significantly higher than their corresponding averages. The average values for Cd, Pb, Cr and Zn were 3.00, 1.18, 1.85 and 1.17 times greater, than their corresponding national average values. In particular, Cd and Zn in Lake Dong and Lake Nanshen were far higher than their corresponding national average values. Taking background values of Lake Poyang (Gong *et al.*, 2006) as standard, the soils in both Lake Dong and Lake Nanshen sampling sites were moderately polluted by Cu, Pb, Cr and Zn. The average heavy metals in all the three lakes were found to be 2.58, 2.22, 3.57 and 1.74 times higher than their corresponding background values. Nevertheless, the data analyzed in the present study were obviously lower than the published data of Raohe River, one of the heaviest polluted rivers in Lake Poyang (Zeng *et al.*, 2011).

In the present study, the pollution index (PI) and integrated pollution index (IPI) for each sampling site were calculated to assess the degree of pollution for six selected heavy metals. Normally, PI is defined as the ratio of heavy metal concentration to the geometric mean of background concentration. Correspondingly, IPI of selected six heavy metals for each sampling site is defined as the mean value of metal's PI by the equation mentioned in reference (Sun *et al.*, 2010). IPI is the integrated pollution index for each sampling site. As listed in Table 3, Cu and As exhibited lower values ranging from 0.14 to 0.74 and 0.26 to 0.90, respectively. The mean pollution indices for Pb and Cd were slightly higher than those of Cu and As, ranging from 0.18 to 1.35 for Pb and 0.00 to 3.09 for Cd. These data indicate that Pb and Cd contamination existed at few sampling sites. In particular, the maximum PI value for Pb was found in Lake Nanshen (1.35) and that for Cd was found in Lake Dong, (3.09.) Furthermore, Pb and Cd were found at higher level at the same sampling sites. The pollution indices of Zn and Cr were much higher, ranging from 0.43 to 3.36 for Zn and 0.51 to 4.57 for Cr. It can be concluded that Zn and Cr pollution were widespread in the Nanjishan wetlands. The IPIs of all the sampling sites varied from 0.36 to 2.07 (Table 3). There were only ten sites with IPI less than 1.0, seventeen sites with value ranging IPI between 1 and 2, and only one site with IPI greater than 2.0. All these data demonstrated that lakes in the Nanjishan wetlands are widespread in suffering low-degree contamination by heavy metals. Significant heavy metal pollution existed in some parts of wetlands, such as N2 and N4.

Based on location, the mean PI and IPI values of six heavy metals in Lake Nanshen were much higher than those in the Lake Chang and Lake Dong (Fig. 2). The concentration of

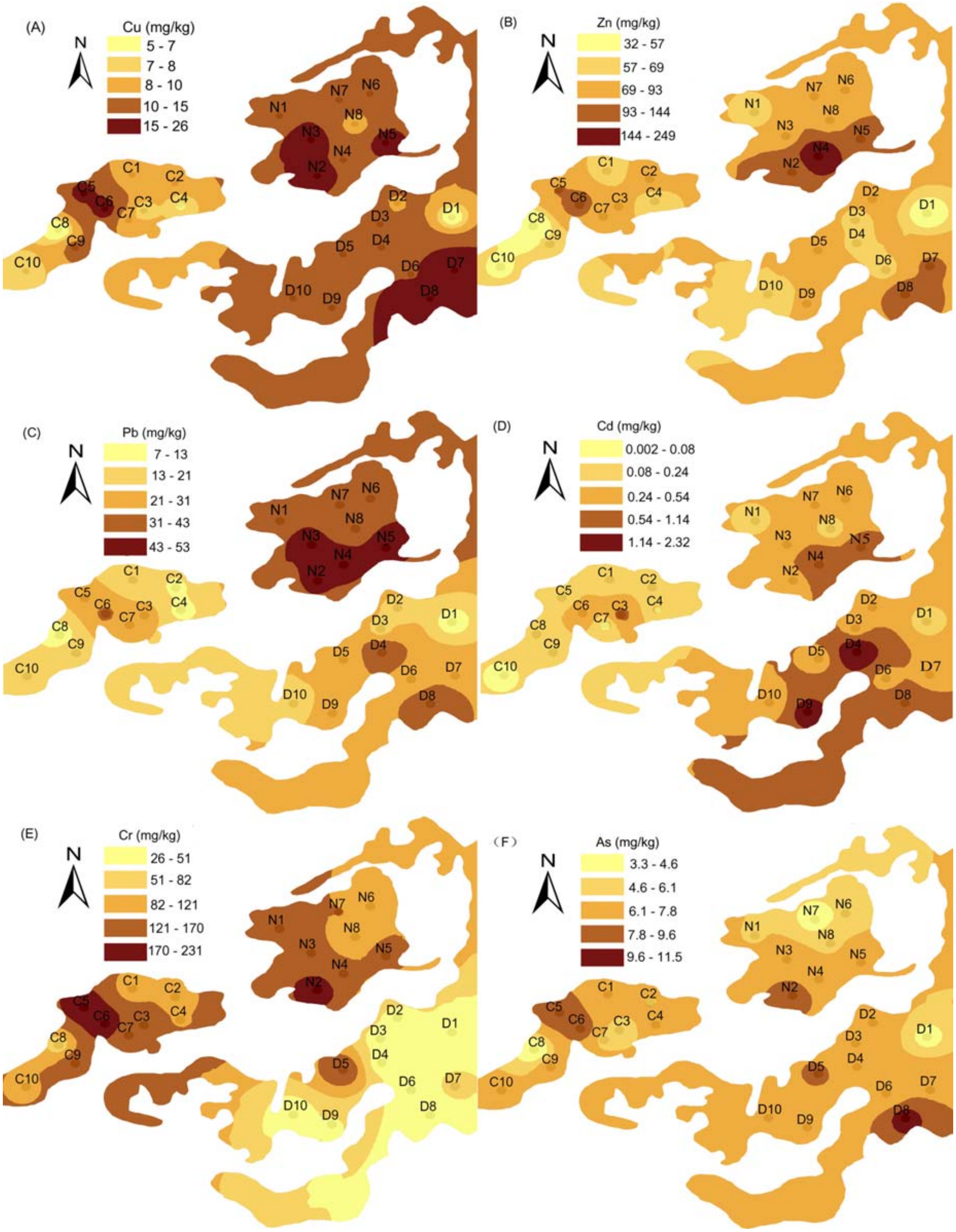


Fig. 2 : Distribution of metals in Lake Chang, Lake Nanshen and Lake Dong in Nanjishan Wetlands

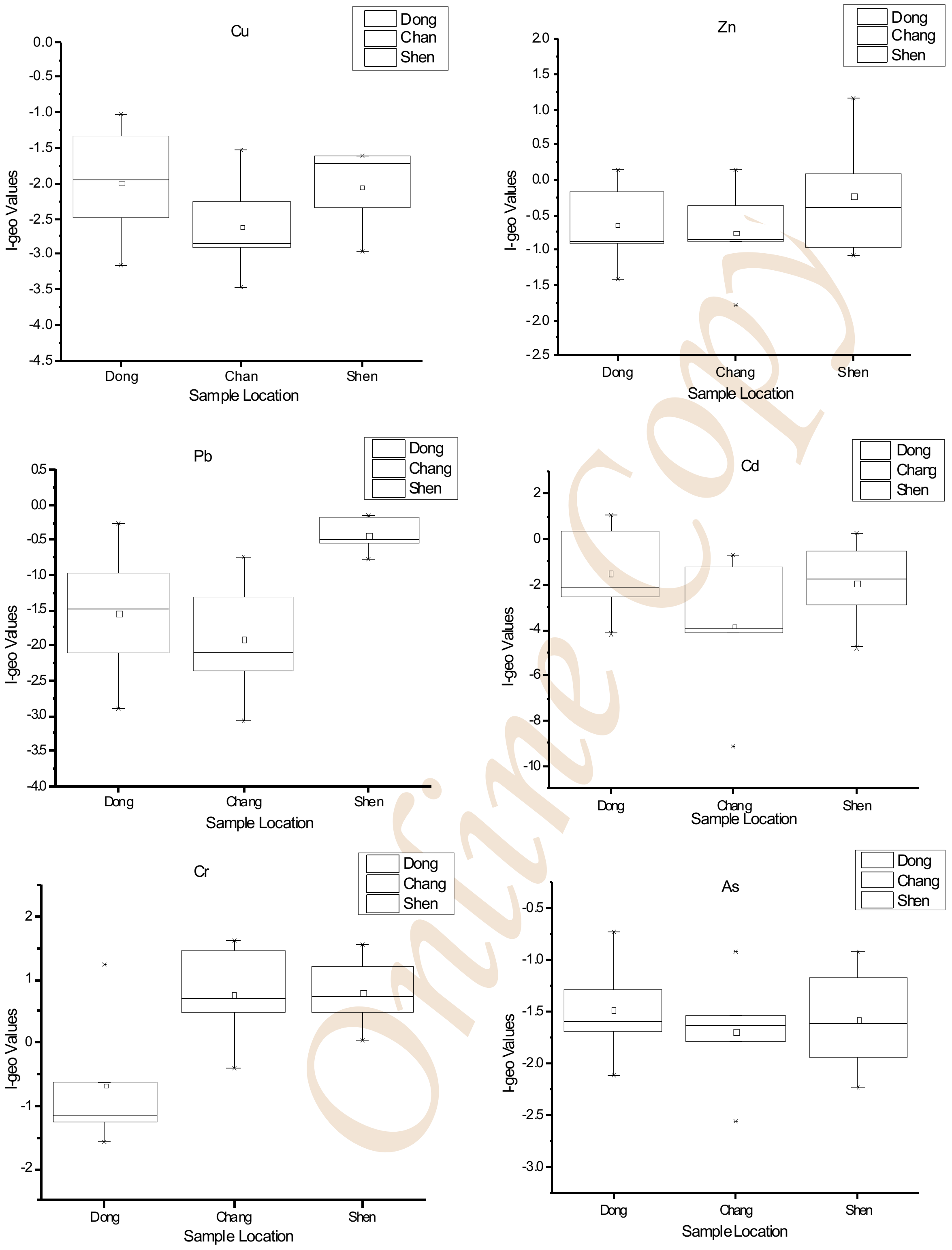


Fig. 3 : Distribution of box-plots of index of geoaccumulation (I_{geo}) of Cu, Zn, Pb, Cd, Cr and As in surface soils

Table 3 : Statistical results of PI and IPI of heavy metals in surface sediment of Nanjishan wetland

Lake		PI						IPI
		Cu	Zn	Pb	Cd	Cr	As	
Dong	Min	0.17	0.56	0.20	0.08	0.51	0.35	0.36
	Max	0.74	1.64	1.24	3.09	3.52	0.90	1.59
	Mean	0.38	1.00	0.62	0.83	1.00	0.54	0.86
Chang	Min	0.14	0.43	0.18	0.00	1.13	0.26	0.52
	Max	0.52	1.66	0.89	0.93	4.57	0.79	2.07
	Mean	0.27	0.94	0.46	0.25	2.67	0.52	1.21
Nanshen	Min	0.19	0.72	0.88	0.05	1.55	0.32	0.82
	Max	0.50	3.36	1.35	1.83	4.41	0.79	1.98
	Mean	0.40	1.33	1.12	0.60	2.73	0.51	1.42

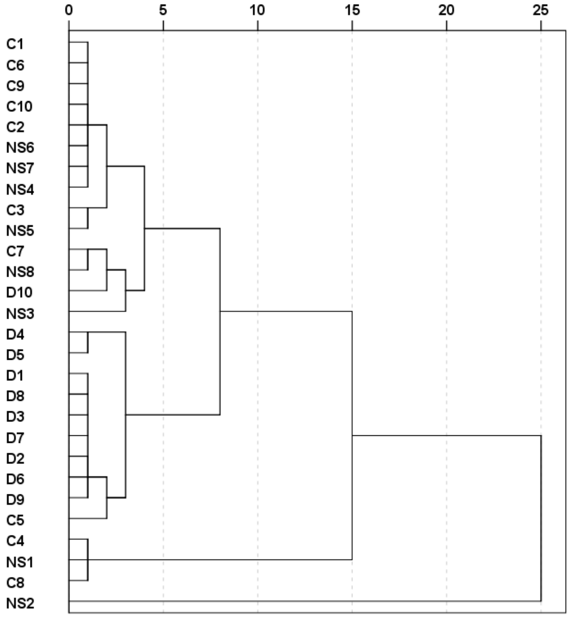


Fig. 4 : Dendrogram of hierarchical cluster analysis of heavy metal concentrations in sampling Lakes

Zn and Pb in Lake Nanshen was slightly higher than other two lakes. In particular, seven of eight sampling sites with high PI for Pb was found in Lake Nanshen, while all of the sampling sites with high PI for Cr were found in Lake Nanshen and Lake Chang. Normally, the sampling sites with high PI and IPI values were close to a branch of the Ganjiang River or traffic on the main country road. Traffic activities, human activities and other sources coming from upstream are important factors in determining the deposition of heavy metals in wetlands (Bai *et al*., 2011). Chen *et al*., (2005) reported that the concentration of Cu, Zn, Pb and Cd in the surface sediments close to main roads often exceeded the standards. The results from another study found that the normal activity and deterioration of vehicles on the roads emited heavy metals in the air (Martin *et al*., 1998). Therefore, high concentration of heavy metals in the inland lakes of Nanjishan Wetlands may be related to traffic and aquaculture. Additionally, the location of sampling sites is one of the important factor determining the extent of heavy metal deposition, particularly Zn and Pb.

The geoaccumulation index (I_{geo}), defined by Müller, is a common criterion to assess the heavy metal pollution in sediments and soils (Müller, 1969). Since late 1960s, I_{geo} has widely been used in terrestrial, aquatic, and marine environments to evaluate contamination in sediments (Abrahim and Parker, 2008; Cevik *et al*., 2009), and has also been applied in the cities to measure soil and dust pollution (Förstner *et al*., 1993; Yaqin *et al*., 2008; Kumar and Edward, 2009; Hasan *et al*., 2013). In general, the I_{geo} values showed strong positive relation with corresponding heavy metal concentrations. As shown in Table 4 and Fig. 3, the average I_{geo} values of Pb was highest in Lake Nanshen, indicating different sources of pb. Lake Chang showed lowest I_{geo} values among three lakes.

The maximum I_{geo} value for Zn revealed that the surface sediments from all three lakes ranged between uncontaminated and moderately contaminated. The highest I_{geo} (1.17) value was recorded in Lake Nanshen, while the maximum I_{geo} value of Zn in Lake Dong and Lake Chang was lower than 1.0, and the average I_{geo} values were negative. All the I_{geo} values of Cd in the surface sediments was below 1.0 (Class 1), but the maximum values were approximately 1.0 in Lake Dong, indicating moderate contamination. In contrast, Cr had the highest concentration in surface sediments, with I_{geo} values ranging from class 0 to class 2. Generally, not including Cr, Lake Dong and Lake Nanshen recorded higher I_{geo} values compared to Lake Chang. In most cases, Lake Chang was clear.

As a first step in considering the findings as a whole, all three sampled lakes were taken into account as Part I, and Lake Nanshen was calculated individually as Part II, (Table 5). In general, all the heavy metals showed significant correlation, excluding Cr, which indicates that these heavy metals had similar sources to some degree even though they had different transport

Table 4 : Geoaccumulation index (I_{geo}) of heavy metals in sediments

		Cu	Zn	Pb	Cd	Cr	As
Lake Dong	Min	-3.16	-1.42	-2.90	-4.17	-1.56	-2.12
	Max	-1.02	0.13	-0.27	1.04	1.23 -	0.74
	Mean	-2.12	-0.65	-1.47	-1.74	-0.86	-1.53
Lake Chang	Min	-3.46	-1.80	-3.08	-9.16	-0.41	-2.55
	Max	-1.54	0.14	-0.75	-0.69	1.61	-0.92
	Mean	-2.58	-0.76	-1.87	-3.69	0.73	-1.61
Lake Nanshen	Min	-2.96	-1.07	-0.78	-4.79	0.05	-2.22
	Max	-1.60	1.17	-0.15	0.29	1.56	-0.92
	Mean	-1.96	-0.36	-0.43	-1.90	0.80	-1.62

behaviors in aquatic environments. For Part I, the correlation coefficients between Cu, Zn and Pb was 0.542, 0.620 and 0.537, respectively. Cd also had a strong positive relationship with Cu, Zn and Pb. In Part II, a similar trend was observed. Cu, Zn, Pb and Cd showed significant correlation with the following coefficients 0.724 for Cu and Pb, 0.721 for Zn and Pb, 0.944 for Zn and Cd and 0.823 for Pb and Cd. In both Part I and Part II, Cr did not show any significant relation with other heavy metals, which indicates different sources of Cr.

In the present study, principal component analysis (PCA) was used to analyze the concentration of selected heavy metals to identify trace elements' potential sources and possible relationship between these variables (Micó *et al.*, 2006). Under Kaiser criterion, the components with eigenvalues larger than 1.0 showed dominant influence. As listed in Table 5, two main factors were obtained from factor analysis (FA). The first two factors with eigenvalue greater than 1.0 of Part I and Part II accounted for 72.78% and 85.88% of the total variance. Factor 1 and Factor 2 in both Part I and Part II showed high similarity, although Lake Nanshen has historically been used for aquaculture and fertilizer has also been used widely in this areas for improved productivity. In both Parts, Factor 1 was characterized by almost all heavy metals, accounting for 49.60% and 55.04% of the total variance for Part I and Part II, respectively. Factor 2, mainly dominated by Cr and As, accounted for 23.18% and 30.84% of the total variance. All of the above results indicate that the heavy metal concentration is likely influenced by multiple factors. Factor 1 could be derived from industrial sources because it is mainly composed of all types of heavy metals, which are commonly detected in industrial wastewater (Micó *et al.*, 2006). In fact, the Ganjiang River, the main branch of Lake Poyang carries domestic wastewater from upstream, passes through the research area and connects together within the three sample lakes during flooding season. Factor 2 could be associated with soil erosion and agricultural areas through rainfall runoff (Quinton and Catt, 2007).

In most research studies, hierarchical cluster analysis (HCA) is undertaken on individual variables rather than on cases (Mummullage *et al.*, 2016). However, in the present study, HCA was performed to identify the similarities in heavy metal contents between the analyzed sediment samples. In this case, the Ward method, which uses the squared Euclidean distance as a similarity measure was used to calculate the data for HCA. As shown in Fig. 4 this basis, it was obvious that a total of four groups were distinguishable in this research. They were fourteen sites in cluster 1 (including seven sites in Lake Chang, six sites in Lake Nanshen and one site in Lake Dong), ten sites in cluster 2 (nine sites in Lake Dong and one site in Lake Chang), three sites in cluster 3 (two sites in Lake Chang and one site in Lake Nanshen), and only one site in cluster 4 (N2). It could be concluded that sediments from different sampling sites showed an apparent trend for grouping, which might be attributed to the various origin of heavy metals and disturbances due to human activities (Guo *et al.*, 2015). Therefore, on the basis of similar metals sources, the most heavily polluted cluster 3 (N1, C4 and C8), dominated by Cr, and cluster 4 (N2) with high Zn, Cd and As levels were considered the most heavily polluted sites. N2 was close to administration office used to guard and feed Lake Nanshen, while cluster 2 was dominated by Lake Dong, which was connected directly with the main body of Lake Poyang. Pollutants in this cluster may come from the backwater effect of Poyang Lake and historic anthropogenic activities, such as discharge from industrial wastewater and domestic sewage (Ji *et al.*, 2014). The largest region, Cluster 1 consisting of fourteen sites reflected the most lightly polluted area in the study. Due to the sites located far from polluted sources, the pollution risk and heavy metal concentrations in these sites were inevitably lower. Consequently, it could be concluded that human activities have significantly influenced the pollution and spatial variation of heavy metals, especially the municipal and industrial wastewater of cities and towns (Zhou *et al.*, 2015).

In general we can conclude that the accumulation of heavy metals in these seasonal lakes in the Nanjishan Wetland Reserve is the results of anthropogenic activities and the hydrological processes in the main Lake Poyang. This study also demonstrates that a combined assessment by sediment quality values, pollution indexes and statistical analyses gives a more integrated view to identify the potential sources of heavy metals and evaluate the ecological risks.

Table 5 : Statistical results of principal components analysis

Total I (n=28)

Matrix to be factored

	Cu	**Zn**	**Pb**	**Cd**	**Cr**	**As**
Cu	1.00	0.542*	0.620*	0.275	0.252	0.727*
Zn		1.00	0.537*	0.402*	0.303	0.438*
Pb			1.00	0.580*	0.305	0.283
Cd				1.00	-0.209	0.064
Cr					1.000.	441*
As						1.00

	Rotated loading matrix		**Percent of total variance explained**	
	1	2	1	2
Cu	0.860	0.087	2.976	49.60
Zn	0.785	-0.096	1.391	72.78
Pb	0.802	-0.314		
Cd	0.489	-0.789		
Cr	0.463	0.670		
As	0.724	0.453		

Lake Nanshen (n=11)

Matrix to be factored

	Cu	**Zn**	**Pb**	**Cd**	**Cr**	**As**
Cu	1.00	0.263	0.724*	0.335	0.616	0.491
Zn		1.00	0.721*	0.944*	0.030	0.169
Pb			1.00	0.823*	0.350	0.461
Cd				1.00	-0.064	0.075
Cr					1.00	0.737*
As						1.00

	Rotated loading matrix		**Percent of total variance explained**	
	1	2	1	2
Cu	0.769	0.358	3.302	55.04
Zn	0.752	-0.571	1.851	85.88
Pb	0.953	-0.147		
Cd	0.766	-0.638		
Cr	0.533	0.764		
As	0.605	0.620		

Significant values ($p < 0.05$) are marked with an asterisk(*); Significant values ($p < 0.01$) are marked with double asterisks(**)

Acknowledgments

This study was supported by National Natural Science Foundation of China (51369024; 51469017; 51579127), Ministry of Water Resources (201401039), Project of Jiangxi Provincial Technology Department (20142BBF60012; 20142BAB213024; 20133DDH80028), Open Research Fund Program of Key Laboratory of Water Science and Engineering, Nanjing Hydraulic Research Institute (YK914014) and Open Research Fund Program of Water Resource and Eco-system Environmental Research Center for Poyang Lake, Ministry of Water Resources(KFJJ201401).

References

Abrahim, G.M. and R.J. Parker: Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. *Environ. Monit. Assess.,* **136,** 227-238 (2008).

Ahmad, Z., K.A. Al-Ghanim, H.F.A.K. Al-Balawi, F. Al-Misned, S. Maboob and E.A.M. Suliman: Accumulation of heavy metalss in the fish, *Oreochromis niloticus* and *Poecilia latipinna* and their concentration in water and sediments of dam lake of Wadi Namr, Saudi Arbia. *J. Environ. Biol.*, **36,** 295-299 (2015).

Bai, J., B. Cui, B. Chen, K. Zhang, W. Deng, H. Gao and R. Xiao: Spatial distribution and ecological risk assessment of heavy metals in surface sediments from a typical plateau lake wetland, China. *Ecol. Model.,* **222,** 301-306 (2011).

Çevik, F., M.Z.L. Göksu, O.B. Derici and Ö. Fındık : An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. *Environ. Monit. Assess.,* **152,** 309-317 (2009).

Chen, T., Y. Zheng, M. Lei, Z. Huang, H. Wu, H. Chen, K. Fan, K. Yu, X. Wu and Q. Tian: Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. *Chemosphere,* **60,** 542-551 (2005).

Dalal, P., D. Chaudhry and V. Shukla: Analysis of heavy metals concentration in ambient air and in human population of Rohtak, India. *J. Environ. Biol.,* **34,** 945-949 (2013).

Förstner, U., W. Ahlf and W. Calmano: Sediment quality objectives and criteria development in Germany. *Wat. Sci. Technol.,* **28,** 307-316 (1993).

Förstner, U. and W. Salomons: Trace metal analysis on polluted sediments: Part I: Assessment of sources and intensities. *Environ. Technol.,* **1,** 494-505 (1980).

Gong, X.F., C.L. Chen, W.B. Zhou, M.F. Jian and Z.H. Zhang: Assessment on heavy metal pollution in the sediment of Poyang Lake. *Environ. Sci.,* **27,** 732-736 (2006, in Chinese).

Guo, W., S. Huo and W. Ding: Historical record of human impact in a lake of Northern China: Magnetic susceptibility, nutrients, heavy metals and OCPs. *Ecological Indicators,* **57,** 74-81 (2015).

Hasan, A., S. Kabir, A. Reza, M. Zaman, A. Ahsan and M. Rashid: Enrichment factor and geo-accumulation index of trace metals in sediments of the ship breaking area of Sitakund Upazilla (Bhatiary–Kumira), Chittagong, Bangladesh. *J. Geochem. Explor.,* **125,** 130-137 (2013).

Jaiswar, S., M.A. Kazi and S. Mehta: Bioaccumulation of heavy metals by freshwater algal species of Bhavnagar, Gujarat, India. *J. Environ. Biol.,* **36,** 1361-1366 (2015).

Ji, Y., J. Zhang, X.P. Huang, C.R. Bai and X. Chen: Investigation and assessment of heavy metals in surface sediments of Ganjiang River, China. *J. Environ. Biol.,* **35,** 1173-1179 (2014).

Ji, Y., J. Zhang, R.H. Li, B.Z. Pan, L.W. Zhang and X. Chen: Distribution and partitioning of heavy metals in sediments of the Xinjiang River in Poyang Lake Region, China. *Environ. Progre. Sustai. Energy,* **34,** 713-723 (2015).

Kumar, S. and J. Edward: Assessment of metal concentration in the sediment cores of Manakudy estuary, south west coastal of India. *Indian. J. Mar. Sci.,* **38,** 235-248 (2009).

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

Madkour, H.A., M.A.K. Abdelhalim, K.A. Obirikorang, A.W. Mohamed, A.E.N. Ahmed and A. El-Taher: Environmental implications of surface sediments from coastal lagoons in the Red Sea coast. *J. Environ. Biol.,* **36**, 1421-1427 (2015).

Martin, A., V. Rivero and M. Marin: Contamination by heavy metals in soils in the neighborhood of a scrapyard of discarded vehicles. *Sci. Tot. Environ.,* **212**, 142-152 (1998).

Micó, C., L. Recatalá, M. Peris and J. Sánchez: Assessing heavy metal sources in agricultural soils of an European Mediterranean area by multivariate analysis. *Chemosphere,* **65**, 863-872 (2006).

Mok, J.S., J.Y. Kwon, K.T. Son, W.S. Choi, P.H. Kim, T.S. Lee and J.H. Kim: Distribution of heavy metals in internal organs and tissues of Korean molluscan shellfish and potential risk to human health. *J. Environ. Biol.,* **36**, 1161-1167 (2015).

Mummullage, S., P. Egodawatta, G.A. Ayoko and A. Goonetilleke: Use of physico chemical signatures to assess the sources of metals in urban road dust. *Sci. Tot. Environ.,* **541,** 1303-1309 (2016).

Müller, G.: Index of geoaccumulation in sediments of the Rhine River. *Geol. J.,* **2**, 108-118 (1969).

Pechmann, J.H., D.E. Scott, J.W. Gibbons and R.D. Semlitsch: Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. *Wetl. Ecol. Manage.,* **1**, 3-11 (1989).

Quinton, J.N. and J.A. Catt: Enrichment of heavy metals in sediment resulting from soil erosion on agricultural fields. *Environ. Sci. Technol., **41**,* 3495-3500 (2007).

Singh, K.P., D. Mohan, V.K. Singh and A. Malik: Studies on distribution and fractionation of heavy metals in Gomti river sediments - a tributary of the Ganges, India. *J. Hydrology,* **312,** 14-27 (2005).

Sun, Y., Q. Zhou, X. Xie and R. Liu: Spatial, sources and risk assessment of heavy metal contamination of urban soils in typical regions of Shenyang, China. *J. Hazard. Mater.,* **174**, 455-462 (2010).

Swinton, S.M., F. Lupi, G.P. Robertson and S.K. Hamilton: Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecolo. Econom.,* **64**, 245-252 (2007).

Tessier, A., P.G. Campbell and M. Bisson: Sequential extraction procedure for the speciation of particulate trace metals. *Analyt. Chemis.,* **51**, 844-851 (1979).

Truu, M., J. Juhanson and J. Truu: Microbial biomass, activity and community composition in constructed wetlands. *Sci. Tot. Environ.,* **407**, 3958-3971 (2009).

Vymazal, J. and J. Švehla: Iron and manganese in sediments of constructed wetlands with horizontal subsurface flow treating municipal sewage. *Ecological. Engineering,* **50,** 69-75 (2013).

Xin, K., X. Huang, J. Hu, C. Li, X. Yang and S.K. Arndt: Land use change impacts on heavy metal sedimentation in mangrove wetlands - A case study in Dongzhai Harbor of Hainan, China. *Wetlands,* **34**, 1-8 (2014).

Yaqin, J., F. Yinchang, W. Jianhui, Z. Tan, B. Zhipeng and D. Chiqing: Using geoaccumulation index to study source profiles of soil dust in China. *J. Environ. Sci.,* **20**, 571-578 (2008).

Yuan, G.L., C. Liu, L. Chen and Z. Yang: Inputting history of heavy metals into the inland lake recorded in sediment profiles: Poyang Lake in China. *J. Hazard. Mater.,* **185**, 336-345 (2011).

Zeng, F.P., C. Xin, H.Y. Xiao and W.B. Zhou: Distribution and fractions of heavy metals in Poyang Lake at inlet of Raohe River. *Environ. Monit. Admin. Techno.,* **23,** 19-22 (2011, in Chinese).

Zhou, X.D., C.L. Zhao, T.B. Qu, Y. Wang, T.J. Guo and X.G. Sun: Characteristics and evaluation on heavy metal contamination in Changchun municipal waste landfill after closure. *J. Environ. Biol.,* **36**, 857-863 (2015).