Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 4	pp. 1417-1425	2016

Original Research Paper

Spatial Distribution, Ecological Risk Assessment and Source Identification for Nutrients and Heavy Metals in Surface Sediments from Tangxun Lake, Wuhan, Central China

Shaolin Zhao*, Ye Li*, Dongbin Liu*, Bo Li*, Huafeng Xiao*, Wei Cheng*, Ang Li* and Joel Chong**
*Resources and Environmental Engineering, Wuhan University of Technology, Wuhan 430070, China
**Oriental Link Holdings Pty Ltd, Unit 8, 24 Parkland Road, Osborne Park, Australia
†Corresponding author: Ye Li

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 11-06-2016
Accepted: 15-07-2016

Key Words:
Tangxun lake sediment
Nutrients
Heavy metals
Environmental risk

ABSTRACT

The nutrient and heavy metal contents of sediments in the largest urban lake in Wuhan City in China are determined through a detailed analysis of the present condition of Tangxun Lake pollution. Total nitrogen (TN) and total phosphorus (TP) contents in vertical change are experimentally analysed by using the geoaccumulation index (Igeo) and potential ecological risk index to evaluate the heavy metal pollution in Tangxun Lake. Results reveal that the nutrient content in the surface sediment of Tangxun Lake decreases as depth increases. The maximum concentrations of TN and TP in the surface layer reach 0 cm to 6 cm in depth, and different pollution levels of heavy metals are detected in the sediments. The heavy metal contents along the vertical direction are similar, and the degree of pollution exhibits the following order: Cd > As > Zn > Cu > Cr > Pb. The potential ecological harm index is evaluated, and the following ecological risk degree of heavy metals is obtained: Cd > As > Pb > Cu > Cr > Zn. Multivariate statistical analyses suggest that Pb, Cu, Cr, and Zn are mainly from natural sources, Cd and As are from anthropogenic sources, and TN and TP are from urban sewage and fisheries. This study provides significant insights into the pollution treatment of Tangxun Lake in China.

INTRODUCTION

China has experienced rapid industrialization, urbanization, and agricultural modernization. With rapid industrialization and urbanization, heavy metals highly accumulate in soil, water, sediment, street dust, and organisms in urban areas (Chaudhari et al. 2012, El-Hasan et al. 2002, Hou et al. 2013, Hu et al. 2013, Li et al. 2013, Wei et al. 2010). Urban lakes, including those scattered in satellite city areas surrounding the central city, are mainly located in built-up areas with high population density (Yang et al. 2015). Urban lake environment is closely related to the quality of the urban environment and implicated in climate regulation, ecological balance maintenance, and lake environment quality. The improvement of lake environments is also an important factor affecting sustainable urban development (Chowdhury et al. 2013, Li et al. 2014). However, urban and suburban lakes, such as Chaohu Lake in Anhui Province, Dianchi Lake in Yunnan Province, and Hangzhou West Lake, are severely polluted to varying degrees (Cheng et al. 2015a). With the continuous monitoring of exogenous pollution, endogenous pollution has been considered a relevant factor influencing the lake water body environment.

The presence of TN and TP in the nutrient cycle of surface sediments greatly affects the eutrophication of lake water body and sediment, which may become a dominant factor of eutrophication over time. Nutrient enrichment severely degrades aquatic ecosystems and impairs the use of water for drinking, industry, agriculture, recreation, and other purposes. Eutrophication caused by N and P over-enrichment is a widespread problem in rivers, lakes, and reservoirs (Varol et al. 2012).

The effects of metals on sediment quality in individual lakes have been well documented. Most heavy metals loaded in aquatic ecosystems are associated with sediments, especially bottom sediments (Wang et al. 2015, Zahra et al. 2014). Sediments contaminated with heavy metals enter aquatic environments through several pathways, including atmospheric deposition, industrial activities, and agricultural activities (Tang et al. 2010). In aquatic systems, heavy metals exhibit a high affinity for particulate matter and thus accumulate in surface sediments (Sundaray et al. 2011, Wang et al. 2015). In aquatic systems, heavy metals exhibit a high affinity for particulate matter and thus accumulate in surface sediments (Lalah et al. 2008, Li et al. 2013). Heavy metals in urban sediments may have originated from industrial discharge, traffic emission, and municipal wastes. Sediments can accumulate heavy metals even at low concentrations in aquatic environments (Yang et al. 2014, Christophoridis et al. 2009). Lake sediment data can indicate the source, migration episodes, and transformation patterns of various pollutants caused by industrial production and human activity. Therefore, the ecological effects of heavy metals on sediments have been extensively investigated.

The distribution of heavy metals in urban lakes should be monitored and its relationship with the regional development of China should be compared. Moshui Lake in Wuhan is selected in this study (Liu et al. 2008). Tangxun Lake, which is the largest urban lake in China and boundary to growing industries, is chosen as a case study to understand the effects of human activities and industrialization on the ecosystem around the sampled points. This research is conducted to examine the surface sediment in Tangxun Lake in Wuhan City by conducting a layered test of pollutant contents (total nitrogen, total phosphorus, and heavy metals) and analyzing the extent of eutrophication and sediment heavy metal pollution status. Correlation analysis and principal component analysis (PCA) are also performed to identify the sources of heavy metals in surface sediments from Tangxun Lake. This study provides a technical basis for the mechanism research and ecological protection of Tangxun Lake.

OVERVIEW OF THE STUDY AREA

Wuhan is the largest city in central China, a megalopolis in the Yangtze River Basin. The city contains abundant freshwater resources. Tangxun Lake is located in the southeast of Wuhan (114°15' to 114°35' E, 30°30' to 30°22' N) (Fig. 1). In 2010, it has become the biggest urban lake in China. The water area of this lake is 47.62 km^2, and the storage capacity is 1.15×10^8 m^3 (Lv et al. 2011). The lake consists of 11 other lakes, and more than 70% belong to Jiangxia District and the rest are in the high-tech development district and Hongshan district. It is a backup source of drinking water and the largest pristine lake in Wuhan. It occupies 36.2% of the 39 lake area of the central urban area. The average water depth is 1.85 m. As such, this lake is described as typical shallow.

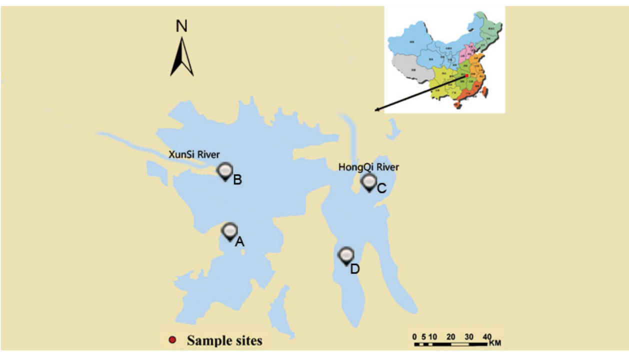

Fig. 1: Distribution of sampling sites in Tangxun Lake.

Tangxun Lake has a subtropical humid monsoon climate. Topography belongs to monadnock alluvial plains of rivers and lakes, terrain is lying flat, rainfall is plentiful, rain and heat are in the same season, and plenty of sunshine and rainfall occurs in June and August. The annual average, extreme high and extreme low temperatures are 16.9, 42.2, and -18.1 °C, respectively. The average pH is 8.21. The water quality of the Tangxun Lake has deteriorated as inferior V class in 2014, belonging to the area within the scope of the typical lakes. Thus, a study on the cause of water deterioration, governance feasibility, and restoration implementation is urgently needed.

Tangxun Lake has two parts, and four sampling points located using Google Earth software were set. Sediment samples were collected in mid-June 2015. Table 1 shows the position of the sampling points and the environment nearby, and Fig. 1 illustrates the sample distribution.

MATERIALS AND METHODS

Sample collection and pretreatment: The vertical profile samples of sediment were placed into the polyethylene barrels using the sampler without gravity disturbance. Sampling tube ends were closed using a plastic cover to reduce the mud sample contact with air, and samples were taken back to the lab. Each cylindrical sample is about 20 cm with a diameter of approximately 5 cm, and columnar sample stratification intervals from top to bottom were 3, 3, 5, and 5 cm. Each sample was subjected to precipitation, natural air drying, debris removal, and agate bowl grinding and sieving. Using four-point sampling, a part of the sample was placed in a sealed bag and left to stand, whereas the other part of the sample was refrigerated at 4°C for storage and use in later experiments.

Experiment methods and instrument analysis: *The indicators of the nutrient analysis:* TN and TP were determined using the semi-micro kelvin and perchloric acid-sulphuric acid methods, respectively.

Test project of heavy metal: All samples, including Cd, As, Cu, Zn, Pb, and Cr, were analysed using inductively coupled plasma mass spectrometry (ICP-MS) after microwave acid digestion with concentrated HNO_3-HCl-HF-$HClO_4$ (Cuong et al. 2006, Ra et al. 2011).

RESULTS AND ANALYSIS

Vertical Analysis of the Surface Sediment Nutrient Content from Tangxun Lake

Table 1: The basic information of the sample points.

Sample point	Longitude	Latitude	Environment nearby
A	114°20'18.68"	30°24'44.92"	Fishing village
B	114°20'12.39"	30°26'11.58"	Entrance of the patrol
C	114°23'40.74"	30°26'11.02"	Entrance of the canal
D	114°22'45.94"	30°24'24.27"	Residential areas

Analysis of total nitrogen: According to the four-sample-point data, the TN content in the surface sediment of Tangxun Lake fluctuated between 1500 and 3000 mg/kg, and the average TN of all the samples was 2093.13 mg/kg. This value is below the TN content in Wei Mingrong's reports on Wuhan South Lake sediment (Wei et al. 2010). In the vertical direction, the highest TN content of samples A and C appeared at 3 cm to 6 cm, respectively, between 2990 and 1870 mg/kg. For samples B and D, the highest TN content appeared at 0 cm to 3 cm, respectively, between 2640 and 2360 mg/kg. According to Fig. 2, the TN content is maximum at 0 cm to 6 cm fluctuations. Moreover, the N content was significantly higher than at the bottom 6 cm to 16 cm. As the sediment depth increased, the N content gradually decreased then stabilized.

Analysis of total phosphorus: The TP content in the four samples fluctuated between 400 and 1200 mg/kg, and the mean TP content of the samples was 716.46 mg/kg, which is similar to that described by Jianxin Wang (2013) where the TP is between 674 and 820 mg/kg (Wang et al. 2013). According to Fig. 3, in addition to column A, the maximum TP contents of B, C, and D three-column samples appeared at 3 cm to 6 cm, respectively, with values of 1156.49, 371.50, and 589.83 mg/kg. However, the high TP content of column A appeared at 0 cm to 3 cm in the surface, and the value was 1119.62 mg/kg. The average TP contents of samples A and B were 809.12 and 860.55 mg/kg, which were significantly higher than that of points C (663.57 mg/kg) and D (532.58 mg/kg). These results showed that the sediment TP pollution nearby sample points A and B was more severe than in other sites.

Figs. 2 and 3 illustrate that both TN and TP contents gradually decrease with increasing depth, indicating that the Tangxun Lake has suffered severe pollution in recent years. The average TN and TP contents of sediments A and B were higher than that of sediments C and D, suggesting that contaminants are greater in the outside lake than in the inside lake, which has great relation to developments and aquaculture in the neighbouring areas in the coming years. Donghua Yang (2009) evaluated the present eutrophication status of Tangxun Lake by using the trophic status index in 2009 and concluded that the water eutrophication in Tangxun Lake is mesotrophic and nutrient salt in the lake mainly comes from aquatic farms and high-density residential zones (Yang et al. 2009). According to government data, the fish-farming area is 10.27 km^2, which accounts for about 21.57% of the lake area. Moreover, 5000 t fish feeds with TN and TP were thrown in the lake to increase the production per year. Assuming that the utilization rate is 50%. Thus, 2500 t fish feeds and fish excrements sank to the lake bed. Feeds and excrements contain large amounts of N and P and consequently cause severe lake bed pollution.

Assessment of the Present Status of Heavy Metal Pollution

Sediment, as one of the water ecosystem components, acts as a reservoir of heavy metals. Hence, it can reflect the status of water polluted by heavy metals (El-Sayed et al. 2015). Numerous indices have been developed to assess the environmental risk of heavy metals in lake surface sediment based on the total content, bioavailability, and toxicity (Yang et al. 2009). Ecological risks posed by heavy metals in sediments include enrichment factor (EF), pollution load index (PLI), and geoaccumulation index (Igeo), which further elucidate the heavy metal contamination status and risk in lake sediments (Asa et al. 2013, Guo et al. 2015, Tiwari et al. 2013). The geoaccumulation index by German scholar Muller and the potential ecological risk index (PERI) by Hakanson were applied in this study to evaluate the present status of heavy metal pollution and potential ecological risk of Tangxun Lake.

Heavy metals in lake sediment: The concentrations of heavy metals in different depth surface sediments of the Tangxun Lake are summarized in Fig. 4. The concentration of metals at 0 cm to 10 cm was higher than that reported by Shengying Qiao (Qiao et al. 2007). This study indicated that the heavy metal concentrations in the surface sediment in Wuhan urban lake were higher than the recorded values of heavy metals in previous reports (Table 3). This was especially true for the cases of Cd and As, which were 2.4 and 1.9 times higher than their recorded values, respectively. Compared with the corresponding recorded values in sediments from the Tangxun Lake, the degree of enrichment of the six heavy metals decreased in the order of Cd > As > Zn > Cu > Cr > Pb. The contents of heavy metals in the

Table 2: Classes of geoaccumulation index and description of sediment quality.

Index Value	Class	Description of sediment quality
Igeo ≤ 0	0	Uncontaminated
0 < Igeo < 1	1	Uncontaminated to moderately contaminated
1 < Igeo < 2	2	Moderately contaminated
2 < Igeo < 3	3	Moderately to strongly contaminated
3 < Igeo < 4	4	Strongly contaminated
4 < Igeo < 5	5	Strongly to extremely contaminated
Igeo > 5	6	Extremely contaminated

Table 3: The background value of heavy metals in Wuhan lake (mg/kg).

Metal	Cd	Zn	As	Cu	Pb	Cr
Content	0.2	79	14.3	32.2	34.5	88

sediments increased at different levels, showing the varying degrees of heavy metal pollution in recent years.

The assessment and result of index of geo accumulation: Igeo or Muller index takes into account the impact of natural geological process and human activities on heavy metal contamination. Igeo is a common criterion used for quantifying the intensity of heavy metal contamination in terrestrial, aquatic, and marine environments (Ozkan et al. 2012, Tijani et al. 2009). Therefore, the index does not only reflect the natural evolving process of the distribution of heavy metals but also determines the human impact on the environment, which is the major parameter to distinguish the influence of human activities. Igeo was estimated using the following formula:

$$Igeo = Log_2\left[\frac{C_i}{1.5B_i}\right]$$

Where C_i is the measured concentration of heavy metal in sediments, and B_i is the geochemical background concentration of the same metal in average scale. The factor 1.5 is introduced to minimize the effect of possible variations in the background values which might be attributed to lithological variations in the sediments (Hu et al. 2013). The degree of heavy metal contamination in lake sediments was determined based on the Igeo classes (Table 2).

In general, the average elemental composition of the data acquired from sampled area in the surveyed lake should be compared with reference values. Hence, the recorded values in Wuhan Lake were used as reference point (Table 3). The reference point data were obtained from the Geological Survey Institute of Hubei Province (Wuhan Geochemistry Survey Department).

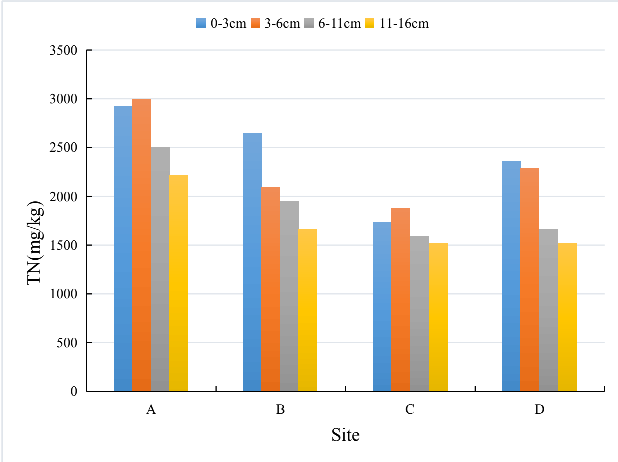

Fig. 2: The vertical distribution of total nitrogen of column sample.

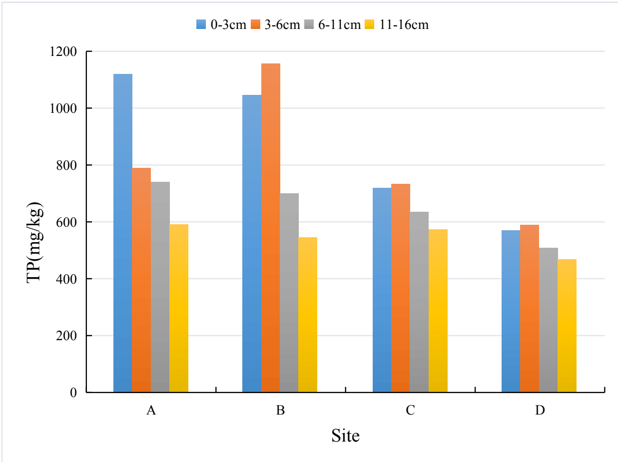

Fig. 3: The vertical distribution of total phosphorus of column sample.

In Table 4, Igeo, and a series of Igeo in each sampling site, the contents of heavy metals from the sediment vary widely in different regions. Pb was absent in sample point A, and the Igeo accumulation of Cu, Zn, and Cr was 1 N-Mod, whereas Cd and As reached to moderate pollution. In the entrance of Xunsi River (sample A), the Igeo accumulation of Cu, Cr, and Pb was 1 N-Mod, whereas that of Zn and Cd was 2, indicating moderate pollution. No pollution was recorded in the entry of Hongqi Qu except As and Cd with an Igeo of 1. In the residential area, the Igeo accumulation values were all 1 but were null for Pb.

The heavy metals in the sampled sediment showed little variation with depth, and this was the case with all other sampled points. The degree of pollution based on the analysis is in the following order: Cd > As > Zn > Cu > Cr > Pb.

Potential ecological risk assessment of heavy metals and results: Heavy metal PERI evaluation method proposed in

Table 4: I_{geo} and series of I_{geo} in each sampling site (mg/kg).

Sample number	Layers (cm)	Cu		Zn		Cd		Cr		Pb		As	
		Igeo	Class	Igeo	Class	Igeo	Class	Igeo	Class	Igeo	Class	Igeo	Class
A1	0-3	0.13	1	0.53	1	1.11	2	0.17	1	-0.13	0	1.09	2
A2	3-6	0.22	1	0.60	1	0.95	1	0.08	1	-0.13	0	1.11	2
A3	6-11	0.07	1	0.99	1	1.16	2	-0.28	0	-0.08	0	0.73	1
A4	11-16	0.42	1	0.85	1	1.71	2	0.03	1	0.26	1	1.00	2
B1	0-3	0.48	1	1.55	2	1.37	2	0.11	1	0.21	1	0.98	1
B2	3-6	0.30	1	1.25	2	1.22	2	0.07	1	0.01	1	0.82	1
B3	6-11	0.39	1	1.46	2	1.32	2	0.23	1	0.12	1	0.97	1
B4	11-16	1.07	2	1.69	2	1.92	2	0.47	1	0.71	1	1.32	2
C1	0-3	-0.24	0	0.46	1	2.42	3	-0.11	0	-0.12	0	1.05	2
C2	3-6	-0.49	0	-0.13	0	0.73	1	-0.32	0	-0.45	0	0.70	1
C3	6-11	-0.32	0	-0.14	0	0.24	1	-0.33	0	-0.42	0	0.75	1
C4	11-16	-0.47	0	-0.06	0	0.65	1	-0.30	0	-0.39	0	0.96	1
D1	0-3	0.15	1	0.49	1	0.94	1	0.08	1	-0.17	0	0.92	1
D2	3-6	0.07	1	0.40	1	0.88	1	-0.03	0	-0.23	0	0.88	1
D3	6-11	0.04	1	0.37	1	1.31	2	-0.07	0	-0.29	0	0.83	1
D4	11-16	0.10	1	0.42	1	0.94	1	0.04	1	-0.26	0	0.84	1

Table 5: Toxicity coefficient of heavy metal (T_r^i) and Reference ratio (C_n^i).

Element	Cd	Zn	As	Cu	Pb	Cr
C_n^i	0.5	80	15	30	25	60
T_r^i	30	1	10	5	5	2

1980 by Hakanson, a Swedish scientist, takes into account the ecological risk index which makes use of the degree of enrichment of the heavy metals in sediments relative to the highest background value of pre-industrial sediments and the corresponding coefficient of ecological toxicity of heavy metals-weighted sum. It is calculated as follows:

$$E_r^i = T_r^i \times \frac{C_s^i}{C_n^i}$$

$$RI = \sum_{i=1}^{n} E_r^i$$

Where C_s^i is the measured concentration of element i in lake surface sediment; C_n^i is the local background value of heavy metals in sediment. The highest background value of heavy metals in sediment before industrialization; T_r^i is the toxicity coefficient of the heavy metal i, which mainly reflects the toxicity level of heavy metal and sensitive degrees of biological pollution of heavy metals. Table 5 gives toxicity coefficient of heavy metal (T_r^i) and reference ratio (C_n^i). Table 6 shows the division standard of heavy metals in sediment.

Potential ecological hazard assessment results (Table 7) showed that heavy metals in the sediments of Tangxun Lake posed a low risk. Only the ecological risk of Cd at the entrance of the river reached a moderate level and spanned through the other sampled points. The ecological risk coefficient of Cd was higher, suggesting that Tangxun Lake is heavily polluted with Cd. PERI showed that the ecological hazard index at the entrance of the patrol division (sampling point) was between 100 and 150, which was the highest, whereas other sampling points were between 50 and 100 (low ecological risk). The ranking of the ecological hazard of heavy metals according to the ecological factor arrangement of Tangxun Lake is Cd > As > Pb > Cu > Cr > Zn.

Identification of Sources of the Nutrient and Heavy Metals in Surface Sediments

The heavy metals in the sediments reflect great danger to the lives of aquatic animals and humans. Therefore, the sources of pollution should be analysed and controlled. PCA and correlation analysis were conducted to evaluate the extent of heavy metal contamination in the study area (Facchinelli et al. 2001, Yi et al. 2011). The results revealed that heavy metals were provided by Xunsi River because Tangxun Lake is downstream of the river. Heavy metals may have also been produced by the active and uncontrolled industrial waste dumps from the cement factory upstream of the lake. SPSS software and Pearson's correlation analysis were carried out to determine the relationship among the heavy metal, TN, and TP contents, and PCA was performed to determine the most common pollution sources.

Correlation analysis: Elements exhibiting high correlations may share common sources and analogous behaviour during transformation and migration under certain physi-

Table 6: Division standard of heavy metals in sediment.

E_r^i	Grades of ecological risk of single metal (i)	RI	Grades of potential ecological risk of whole lake
$E_r^i < 40$	Low risk	RI < 150	Low risk
$40 \le E_r^i < 80$	Moderate risk	150 d” RI < 300	Moderate risk
$80 \le E_r^i < 160$	High risk	300 d” RI < 600	High risk
$160 \le E_r^i < 320$	Very high risk	RI e” 600	Very high risk
$E_r^i \ge 320$	Extremely high risk		

Table 7: Potential ecological risk factors (E_r^i) and risk indices (RI) of heavy metals in surface sediments from Tangxun Lake.

Sample number	Layers (cm)	E_r^i						RI
		Cu	Zn	Cd	Cr	Pb	As	
A1	0-3	8.8	2.1	38.8	5.0	9.5	30.3	94.5
A2	3-6	9.4	2.3	34.8	4.6	9.5	30.8	91.4
A3	6-11	8.5	2.9	40.3	3.6	9.8	23.7	88.9
A4	11-16	10.8	2.7	58.8	4.5	12.4	28.7	117.8
B1	0-3	11.2	4.3	46.5	4.8	12.0	28.1	106.9
B2	3-6	9.9	3.5	42.0	4.6	10.4	25.3	95.7
B3	6-11	10.5	4.1	44.9	5.2	11.2	28.0	103.9
B4	11-16	16.9	4.8	68.2	6.1	17.0	35.6	148.5
C1	0-3	6.8	2.0	96.6	4.1	9.5	29.7	148.7
C2	3-6	5.7	1.4	29.9	3.5	7.6	23.3	71.4
C3	6-11	6.4	1.3	21.3	3.5	7.7	24.0	64.4
C4	11-16	5.8	1.4	28.2	3.6	7.9	27.7	74.6
D1	0-3	8.9	2.1	34.4	4.7	9.2	27.0	86.3
D2	3-6	8.4	2.0	33.2	4.3	8.8	26.4	83.1
D3	6-11	8.3	1.9	44.8	4.2	8.4	25.5	93.0
D4	11-16	8.6	2.0	34.6	4.5	8.6	25.6	84.0

Table 8: Correlation coefficients between different heavy metal elements in sediment from Tangxun Lake.

	TN	TP	Cu	Zn	Cd	Cr	Pb	As
TN	1							
TP	0.595*	1						
Cu	0.142	0.046	1					
Zn	0.177	0.311	0.864**	1				
Cd	-0.120	0.008	0.380	0.391	1			
Cr	0.200	0.130	0.896**	0.753**	0.365	1		
Pb	0.073	0.059	0.956**	0.867**	0.540*	0.811**	1	
As	0.181	0.031	0.703**	0.493	0.546*	0.780**	0.734**	1

*Significant correlation at the 0.05 level (two-tailed); **Significant correlation at the 0.01 level (two-tailed).

cochemical circumstances (Wang et al. 2012). Pearson's correlation analysis was employed to explore the correlations between heavy metals and nutrients from Tangxun Lake. The result is shown in Table 8.

Table 8 depicts the correlation coefficient matrix, listing the Pearson product moment correlation coefficients. Concentrations of TN and TP were insignificantly correlated with any of the studied heavy metals. Concentration of Cd was insignificantly correlated with TN, TP, Cu, Zn, and Cr. However, a significantly positive correlation at $P < 0.01$ was found between several elemental pairs: Cr-As (0.780), Cu-As (0.703), Pb-As (0.734), Pb-Cu (0.956), Cr-Pb (0.811), Zn-Cu (0.864), Zn-Pb (0.867), Zn-Cr (0.753), and Cr-Cu (0.896). Three elemental pairs, TN-TP (0.595), Cd-Pb (0.540), and Cd-As (0.546), showed a significantly positive correlation at $P < 0.05$. Furthermore, a positive correlation between Zn, As, Cu, Cr, and Pb was observed, suggesting a common source for these heavy metals. Relatively strong positive correlations were observed between As, Pb, Cr, Cu, and Zn, but Cd was insignificantly correlated with these

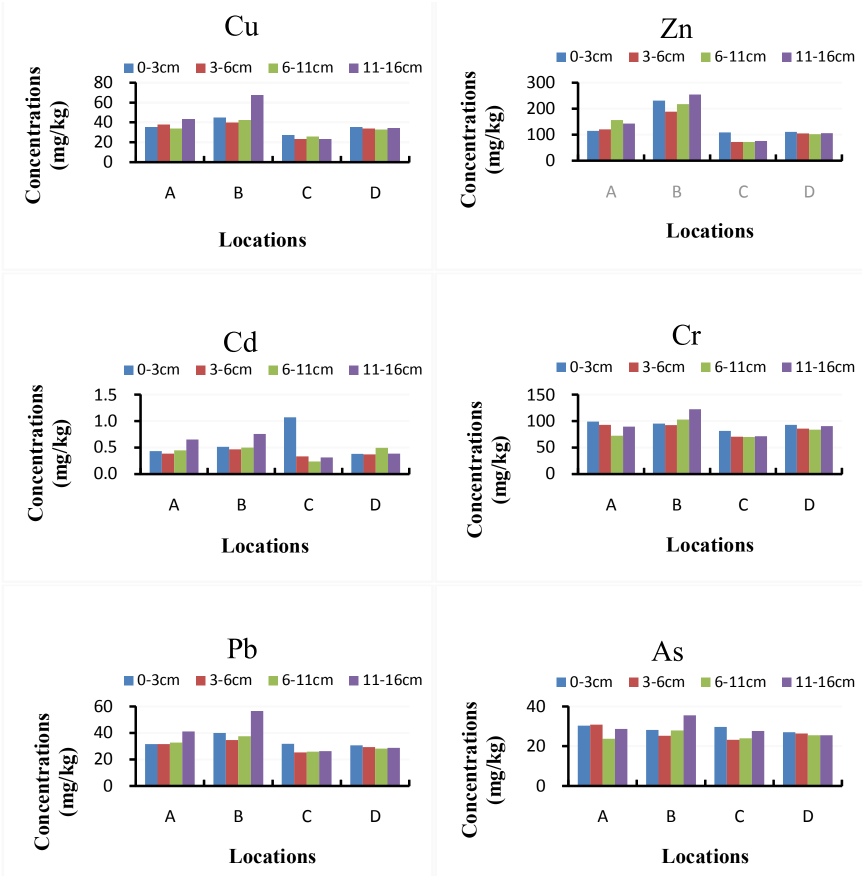

Fig. 4: Content of heavy metals in the sediment from Tangxun Lake.

metals (Table 9). As, Pb, Cr, Cu, and Zn were grouped together, indicating that the anthropogenic sources of these heavy metals were closely related in the sediments of the study area, but correlations between Cd and other heavy metals were very low, suggesting that the pollution sources of Cd were different from those of the other metals.

PCA: PCA was performed to further assist in the identification and analysis of nutrient and heavy metal sources in surface sediments from Tangxun Lake. PCA has been applied to determine the degree of pollution by heavy metals from lithogenic action and anthropogenic sources (Wang et al. 2012). The results of PCA for heavy metal contents are listed in Table 9.

According to these results, these factors elucidated a relatively large extent of the total variance (86.15%) of the eight variables used in this analysis. As, Pb, Cr, Cu, and Zn showed a strong association with the first factor (PC1; 56.20%), whereas Cd showed a moderate association, implying that Cd presented a quasi-independent behaviour within the group. The second factor (PC2) accounted for 20.28% of the total variance with high loading on TN and TP. The third factor (PC3) correlated strongly with Cd (0.735), accounting for 9.67% of the total variance. TN and TP were distributed in PC2, suggesting that some of the TN and TP may have originated from a common source (e.g., fisheries). Accordingly, emissions from anthropogenic sources have resulted in a large amount of nutrient deposited and accumulated in lake sediments through river flow or atmospheric deposition (Cheng et al. 2015b). The parent materials of the sediments might partly control the concentrations of Pb, Cr, Cu, and Zn. This result was consistent with the correlation analysis. However, Cd also showed moderate loading in PC1 (Table 10), indicating that it may have its contribution from anthropogenic sources besides its influence from natural sources.

CONCLUSIONS

The spatial distribution, pollution ecological risk assessment, and nutrient and heavy metal sources in surface sediments from Tangxun Lake were thoroughly investigated

Table 9: Rotated component matrix for principal component analysis loading for heavy metals in surface sediments from Tangxun Lake.

Elements	Component		
	PC1	PC2	PC3
TN	0.210	0.858	0.026
TP	0.185	0.846	0.261
Cu	0.950	-0.068	-0.264
Zn	0.876	0.124	-0.149
Cd	0.566	-0.318	0.735
Cr	0.915	0.014	-0.184
Pb	0.957	-0.133	-0.072
As	0.821	-0.106	0.181
Eigen value	4.50	1.62	0.77
% of variance	56.20	20.28	9.67
% of cumulative	56.20	76.48	86.15

in this study to examine the distribution of pollutants in sediments and pollution condition of Tangxun Lake. The following conclusions were obtained.

1. In the vertical direction, the maximum contents of TP and TN in the nutrients are found in the surface layer between 0 and 6 cm depths. These contents significantly decrease as the depth increases from 6 cm. This finding indicates that Tangxun Lake eutrophication has exacerbated and should thus be the focus of future governance. The contents of Zn, Cu, Cd, Cr, Pb, and As in the sediments of Tangxun Lake are higher and Zn, Cr, and Cd pollutants are greater than the background values of elements in urban lakes in Wuhan City as depth increases.

2. The Igeo values of the sediment analysis revealed that the degree of heavy metal pollution of Tangxun Lake is mostly between low and moderate risks. As and Cd near the small fishing village reach a moderate pollution level, and Zn and Cd at the entrance of XunSi River yield a moderate pollution level. The degree of pollution exhibits the following order: Cd > As > Zn > Cu > Cr > Pb. The potential contamination indices of the sediment samples indicated that the heavy metal pollution in the sediments of Tangxun Lake causes a low ecological risk, but the potential ecological hazard coefficients of Cd and As are relatively high and should thus be extensively investigated. The hazard degree and ecological risk of various pollutants in Tangxun Lake are observed in this order: Cd > As > Pb> Cu > Cr > Zn.

3. Correlation analysis and PCA revealed that heavy metals in the surface sediment of Tangxun Lake may originate from natural and anthropogenic sources. Cd and As originate mainly from industrial activities, and Cu, Pb, and Zn are from natural sources. Cd is produced by a mixed source of anthropogenic and natural processes. The nutrients provided by Xunsi River and fisheries are primary TN and TP sources for the surface sediment of lake.

The rate of developmental advancement in the community contributes to the devastating ecological challenges in the environment. As such, drastic measures should be implemented to control the areas with moderate or near-moderate pollution intensity. Wuhan City should enforce strict policies on the disposal of industrial wastewater and domestic sewage within the community. Industries must employ a registered environmental analyst to ensure that wastewater is safe before discharging into lakes, rivers, and lands. Agricultural non-point source pollution must be controlled to decrease the ecological risks of Cd pollution. Industrial wastewater may be relevant in other industries and sectors. Hence, wastewater storage and disposal should be encouraged to reduce environmental pollution or hazards.

REFERENCES

Asa, S.C., Rath, P., Panda, U.C. et al. 2013. Application of sequential leaching, risk indices and multivariate statistics to evaluate heavy metal contamination of estuarine sediments: Dhamara Estuary, East Coast of India. Environmental Monitoring and Assessment, 185(8): 6719-6737.

Chaudhari, P.R., Gupta, R., Gajghate, D.G. et al. 2012. Heavy metal pollution of ambient air in Nagpur City. Environmental Monitoring and Assessment, 184(4): 2487-2496.

Cheng, H., Li, M., Zhao, C. et al. 2015a. Concentrations of toxic metals and ecological risk assessment for sediments of major freshwater lakes in China. Journal of Geochemical Exploration, 157: 15-26.

Chowdhury, F., Lant, C. and Dziegielewski, B. 2013. A century of water supply expansion for ten U.S. cities. Applied Geography, 45(5): 58-76.

Christophoridis, C., Dedepsidis, D. and Fytianos, K. 2009. Occurrence and distribution of selected heavy metals in the surface sediments of Thermaikos Gulf, N. Greece. Assessment using pollution indicators. Journal of Hazardous Materials, 168(2-3): 1082-1091.

Cuong, D.T. and Obbard, J. P. 2006. Metal speciation in coastal marine sediments from Singapore using a modified BCR-sequential extraction procedure. Applied Geochemistry, 21(8): 1335-1346.

El-Hasan, T., Al-Omari, H. and Jiries, A. et al. 2002. Cypress tree (*Cupressus semervirens* L.) bark as an indicator for heavy metal pollution in the atmosphere of Amman City, Jordan. Environment International, 28(6): 513-519.

El-Sayed, S.A., Moussa, E.M.M. and El-Sabagh, M.E.I. 2015. Evaluation of heavy metal content in Qaroun Lake, El-Fayoum, Egypt. Part I: Bottom sediments. Journal of Radiation Research and Applied Sciences, 136(3): 276-285.

Facchinelli, A., Sacchi, E. and Mallen, L. 2001. Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. Environmental Pollution, 114(3): 313-324.

Guo, W., Huo, S. and Xi, B. et al. 2015. Heavy metal contamination in sediments from typical lakes in the five geographic regions of China: Distribution, bioavailability, and risk. Ecological Engineering, 81: 243-255.

Hou, D., He, J. and Lü, C. et al. 2013. Distribution characteristics and potential ecological risk assessment of heavy metals (Cu, Pb, Zn, Cd) in water and sediments from Lake Dalinouer, China. Ecotoxicology and Environmental Safety, 93(4): 135-144.

Hu, B., Li, G. and Li, J. et al. 2013. Spatial distribution and ecotoxicological risk assessment of heavy metals in surface sediments of the southern Bohai Bay, China. Environmental Science and Pollution Research, 20(6):4099-4110.

Hu, Y., Liu, X. and Bai, J. et al. 2013. Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization. Environmental Science and Pollution Research, 20(9): 6150-6159.

Lalah, J. O., Ochieng, E. Z. and Wandiga, S. O. 2008. Sources of Heavy Metal Input Into Winam Gulf, Kenya. Bulletin of Environmental Contamination and Toxicology, 81(3): 277-284.

Li, F., Huang, J. and Zeng, G. et al. 2013. Spatial risk assessment and sources identification of heavy metals in surface sediments from the Dongting Lake, Middle China. Journal of Geochemical Exploration, 132(3): 75-83.

Li, F., Ye, Y.P. and Song, B.W. et al. 2014. Assessing the changes in land use and ecosystem services in Changzhou municipality, Peoples Republic of China, 1991-2006. Ecological Indicators, 42(1): 95-103.

Li, H.,Wei, H.U. and Wang, Y. et al. 2013. Chemical speciation and human health risk of trace metals in urban street dusts from a metropolitan city, Nanjing, SE China. Science of The Total Environment, 456-457C(7): 212-221.

Liu, H., Li, Li, Qing., Yin, Cheng, qing. et al. 2008. Fraction distribution and risk assessment of heavy metals in sediments of Moshui Lake. Journal of Environmental Sciences (China). 20: 390-397.

Lv, J., Wu, H. and Chen, M. 2011. Effects of nitrogen and phosphorus on phytoplankton composition and biomass in 15 subtropical, urban shallow lakes in Wuhan, China. Limnologica-Ecology and Management of Inland Waters, 41(1):48-56.

Ozkan, E.Y. and Buyukisik, B. 2012. Geochemical and statistical approach for assessing heavy metal accumulation in the Southern Black Sea sediments. Ekoloji, 21(83): 11-24.

Ra, K., Bang, J.H. and Lee, J. M. et al. 2011. The extent and historical trend of metal pollution recorded in core sediments from the artificial Lake Shihwa, Korea. Marine Pollution Bulletin, 62 (8): 1814-1821.

Sundaray, S.K., Nayak, B.B. and Lin, S. et al. 2011. Geochemical speciation and risk assessment of heavy metals in the river estuarine sediments - A case study: Mahanadi basin, India. Journal of Hazardous Materials, 186 (2-3): 1837-1846.

Tang, W., Shan, B. and Hong, Z. et al. 2010. Heavy metal sources and associated risk in response to agricultural intensification in the estuarine sediments of Chaohu Lake Valley, East China. Journal of Hazardous Materials, 176(1-3): 945-951.

Tijani, M.N. and Onodera, S. 2009. Hydrogeochemical Assessment of Metals Contamination in an Urban Drainage System: A Case Study of Osogbo Township, SW-Nigeria. Journal of Water Resource and Protection, 3(3): 164-173.

Tiwari, M., Sahu, S.K. and Bhangare, R. C. et al. 2013. Depth profile of major and trace elements in estuarine core sediment using the EDXRF technique. Applied Radiation and Isotopes, 80C(7): 78-83.

Varol, M. and Sen, B. 2012. Assessment of nutrient and heavy metal contamination in surface water and sediments of the upper Tigris River, Turkey. Catena, 92(1): 1-10.

Wang, H., Wang, J. and Liu, R. et al. 2015. Spatial variation, environmental risk and biological hazard assessment of heavy metals in surface sediments of the Yangtze River estuary. Marine Pollution Bulletin, 93(1-2): 250-258.

Wang, X.J. and Wang, S. 2013. Phosphorus fractions and the influence of PH on the release of phosphorus from sediments in the Donghu Lake, Tangxun Lake and Liangzi Lake. Ecology and Environmental Sciences, 22(5): 810-814.

Wang, Y., Hu, J. and Xiong, K. et al. 2012. Distribution of Heavy Metals in Core Sediments from Baihua Lake. Procedia Environmental Sciences, 16(4): 51-58.

Wang, Y., Yang, L. and Kong, L. et al. 2015. Spatial distribution, ecological risk assessment and source identification for heavy metals in surface sediments from Dongping Lake, Shandong, East China. Catena, 125: 200-205.

Wei, B. and Yang, L. 2010. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchemical Journal, 94(2): 99-107.

Wei, M. R., Jiang, Y. H. and Zhou, Y. E. et al. 2010. Research on vertical distribution and release potential of contaminants in sediment of Nanhu lake. Journal of Wuhan University of Technology, 32(8): 68-71.

Yang, B. and Ke, X. 2015. Analysis on urban lake change during rapid urbanization using a synergistic approach: A case study of Wuhan, China. Physics and Chemistry of the Earth, 89:127-135.

Yang, H.D., Yuan, W.H. and Ouyang, X. J. et al. 2009. Current Situation and Countermeasures on the Eutrophication of the Tangxun Lakes in Wuhan City. Journal of Water Resources and Water Engineering, 20: 34-38.

Yang, J., Chen, L. and Liu, L.Z. et al. 2014. Comprehensive risk assessment of heavy metals in lake sediment from public parks in Shanghai. Ecotoxicology and Environmental Safety, 102(1): 129-135.

Yang, Z., Ying, W. and Shen, Z. et al. 2009. Distribution and speciation of heavy metals in sediments from the mainstream, tributaries, and lakes of the Yangtze River catchment of Wuhan, China. Journal of Hazardous Materials, 166(2-3): 1186-1194.

Ying, Q.S., Ye, J.J. and Wu, X. et al. 2007. Heavy metals pollution in lakes of Wuhan City. Water Resources Protection, 23:45-48.

Yi, Y., Yang, Z. and Zhang, S. et al. 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. Environmental Pollution, 159(10): 2575-2585.

Zahra, A., Hashmi, M.Z. and Malik, R.N. et al. 2013. Enrichment and geo-accumulation of heavy metals and risk assessment of sediments of the Kurang Nallah-Feeding tributary of the Rawal Lake Reservoir, Pakistan. Science of The Total Environment, 470-471C(2): 925-933.