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Pollution Assessment and Sources Identification of Heavy Metals in Surface Sediments from the Nantaizi Lake, Middle China

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Abstract. The total contents of heavy metal elements including Cr, Cd, Cu, Zn, Pb and As were investigated in sediments from the Nantaizi Lake in Hanyang district of Wuhan. The heavy metal pollution level of Nantaizi Lake was calculated by potential ecological risk index and the main sources of pollutants were researched by correlation analysis and principal component analysis. The results show that heavy metal concentration of Nantaizi Lake sediments is within the Chinese Environmental Quality Standard for Soils (GB 15618-1995) level-II standard limitation. According to the result of potential ecological risk index, ecological hazard rank of heavy metal element of Nantaizi Lake sediments is: Cd>Cu>As>Pb>Zn>Cr, and whole water environment of lake is slightly polluted. Through correlation analysis and principal component analysis, it is found that industrial sewage and domestic wastewater in human activities are the main contributors to heavy metal sources of Nantaizi Lake, and chemical processes, such as endogenous microbial activities of lake etc., also affect heavy metal sources in sediments simultaneously.

1. Introduction

Heavy metals can enter into river system through hydrological cycle. The vast majority of heavy metal pollutants entering into waters will transform from water phase to solid phase through physical, chemical and biological effect etc. of a certain period, and combine with suspended solids and sediments in waters to become water pollution endogenesis, which causes lasting damage to water environment and may enter into human dining-table, directly affecting human health [1-2]. Main sources of heavy metal of lake environment are divided into human activities and natural sources [3-4]. In recent years, with rapid development of urbanization and industrialization, artificial sources, such as wastewater discharge, mining and fossil fuel combustion etc., and natural sources, such as geological structure activity, erosion and weathering etc., have caused entry of a great deal of heavy metal pollutants into waters, and made them gathered at lake sediments, which causes huge damage to urban lakes and threatens urban resident health [5-8]. As important constituent part of urban ecological system, urban lakes play an irreplaceable role in many respects [9]. Therefore, analyzing heavy metal pollution source by researching heavy metal pollution distribution of urban lake environment sediments is of great importance to protect urban lake environment and maintain urban ecological safety.

Wuhan is called as “city of hundreds of lakes”, and its lake area occupies 25% of total area. Because of ecological pressure caused by population explosion and pollution by-product generated by rapid development of industry, many lakes of Wuhan are polluted in different degree, which arouses the attention of many scholars. Research of Qiao Shengying et al. [10] shows that the bottom mud heavy metal content of lakes within Wuhan is greater than that of lakes at suburb. Yu Jinsong et al. [11] researched the migration of heavy metal of main lake environment of Wuhan. Zhi Fengyang et al. [12] made analysis aimed at sediment heavy metal pollution degree of Wuhan Yangtze river basin and lake environment. Zhang Hailin et al. [13] analyzed 8 main lakes of Wuhan by utilizing lake eutrophication model. Through monitoring analysis to 6 representative sample sites of river system of Nantaizi Lake, and based on potential ecological risk index model, correlation analysis principle and principal component analysis, the author evaluates heavy metal pollution in Nantaizi Lake environment sediments and judges its main pollution source, to provide related data and evidences proving pollution condition of Nantaizi Lake to Wuhan Municipal Government.

2. Methods and Materials

2.1. Study Area

Nantaizi Lake (114°10′E to 114°13′E, 30°29′N to 30°30N) is located within Hanyang District of Wuhan. Hanyang is the earliest industrial area in Wuhan, and has been developed into the largest industrial park of Wuhan currently [14]. In July of 2015, Nantaizi Lake of Wuhan Economic and Technological Development Zone was suddenly polluted, with lake water presenting black brown and a great deal of dead fish floating on lake. Within one month, gross of dead fish appearing turned to be 75000kg roughly. Before this, large area of dead fish has appeared in water area of Nantaizi Lake because of serious pollution for 4 continuous years, which causes serious economic losses to local fishermen and threatens health of adjacent residents simultaneously.

2.2. Sampling and Analysis

According to distribution characteristics of sewage pipe of Nantaizi Lake, 6 representative sample sites are selected for stationing sampling in Figure 1. ZYA-0204 sludge sampler is used to collect sediments sample, 0~10 cm sediments at surface layer of lake is collected as sample, and 3 samples are collected at each sample site, and placed into clean PVC bag after blending

Sediment samples are naturally dried at laboratory with residual body of flora, fauna and stone removed. Then, sediments were grinded and sieved through 200-mesh nylon mesh. Next, all sediments were kept in plastic bottles and were numbered before analysis.

Weigh and take 0.2500 g of screened sediments sample correctly with TE124S electronic scales and place it into polytetrafluoroethylene digestion tank, and then prepare it into solution to be measured after digestion with HNO_3-HF-$HClO_4$. Samples were handled under the reference preprocessed steps according to NY/T 1121.10-2006. The total contents of heavy metal Cr, Cd, Cu, Zn and Pb were all detected by atomic absorption spectrometer (ZEEnit-700P). In addition, the concentration of As were measured by full-automatic dual-channel atomic fluorescence photometers

(AFS-9730). Guarantee accuracy and correctness of experimental result through repeated analysis and standard sample analysis to sample. Take 10% of sample as duplicate samples, and when analytical error of duplicate sample is lower than 5%, analysis result would be reliable. Experimental process conforms to the Chinese Technical Specifications for Soil Environmental Monitoring HJ/T 166-2004.

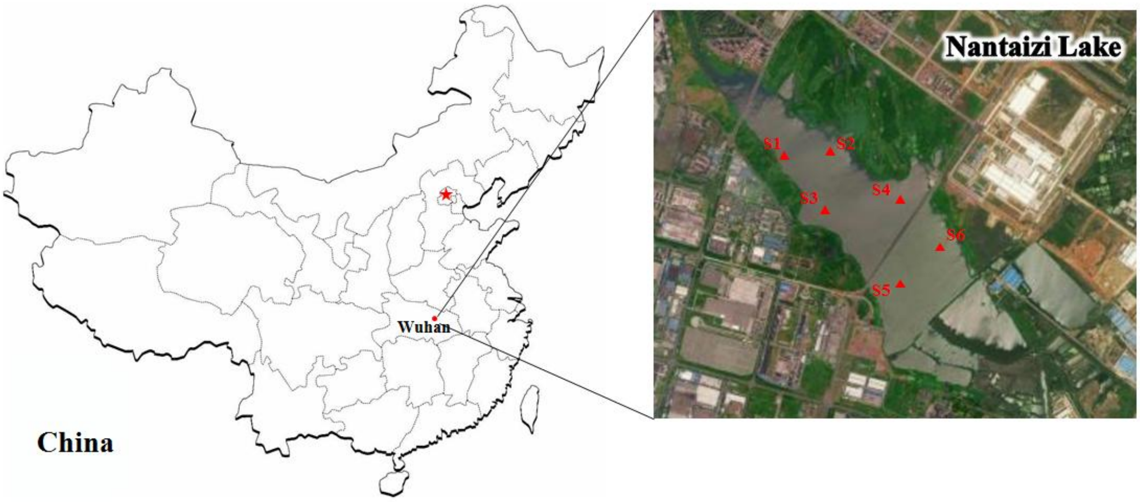

Fig. 1 The location of Nantaizi Lake and sampling sites

2.3. Potential Ecological Risk Index

Swedish scientist Hakanson [15] proposed potential ecological risk index method in 1980. This method is widely applied to evaluation of sediment heavy metal pollution, which mainly makes evaluation from perspective of toxicological effect of heavy metal, and its computational formula is as follows:

$$E_r^i = T_r^i \times C_f^i = T_r^i \times C^i / C_i \tag{1}$$

In the formula, C_f^i is enrichment factor of overlying sediment heavy metal *i*; C^i is measured content of sediment heavy metal element *i*, mg•kg^{-1}; C_i is reference value of element *i*, mg/kg, and the highest background value of heavy metal in sediments before industrialization is taken as reference value, and see Table 1; T_r^i is toxicity response coefficient of heavy metal *i* in the Table 1; E_r^i is potential ecological risk coefficient of heavy metal *i*.

Table 1. Reference value (C_n^i) and toxicity coefficient (T_r^i) of heavy metal in sediments

Element	Cr	Cu	Zn	Pb	Cd	As
C_n^i(mg/kg)	86	30.7	83.6	26.7	0.17	12.3
T_r^i	2	5	1	5	30	10

Integrated potential ecological risk degree of numerous heavy metals in sediments, Hakanson [15] method, is represented by ecological risk index *RI*:

$$RI = \sum_{i=1}^{n} E_r^i \tag{2}$$

Corresponding pollution level can be judged according to potential ecological risk index value obtained, which is as shown in Table 2.

Table 2. Division on level of ecological pollution degree of sediment heavy metals

Scope of potential ecological risk index of single heavy metal	Potential ecological risk degree of single heavy metal	Scope of potential ecological risk index (*RI*) of Hakanson	Potential ecological risk degree of heavy metal
<40	Level 1, low risk	<150	Level 1, low risk
40~80	Level 2, intermediate risk	150~300	Level 2, intermediate risk
80~160	Level 3, considerable risk	300~600	Level 3, considerable risk
160~320	Level 4, high risk	>600	Level 4, high risk
>320	Level 5, very high risk		

3. Results and Discussion

3.1. Heavy Metal Distribution of Sediments in Nantaizi Lake

Table 3 shows heavy metal content of sediments on the surface of Nantaizi Lake. According to the results of Table 3, average content values of Cr, Cu, Zn, Pb, Cd and As in Nantaizi Lake surface sediments are respectively 40.11, 27.86, 86.21, 20.03, 0.23 and 5.19 mg/kg; referring to Environmental Quality Standard for Soils (GB15618-1995), 6 kinds of heavy metal contents in sediments shall be within class II standard limit. According to arrangement condition of heavy metal concentrations in sample sites, it can be found out clearly that heavy metal contents in sediments shall increase from half northern part and half southern part of lake to central area of lake.

Table 3. Detection result for total heavy metals in Nantaizi Lake sediments

Items		Concentration/(mg/kg)					
		Cr	Cu	Zn	Pb	Cd	As
Sample sites	S1	7.94	20.45	60.53	17.61	0.13	2.50
	S2	55.43	24.18	78.38	20.87	0.30	6.07
	S3	58.66	35.61	118.78	22.64	0.38	7.35
	S4	56.64	29.43	91.49	21.02	0.20	7.19
	S5	34.89	30.89	100.43	21.70	0.19	4.65
	S6	27.09	26.60	67.67	16.34	0.19	3.39
	Average value	40.11	27.86	86.21	20.03	0.23	5.19
Class II standard limit (GB 15618-1995)		350	100	300	350	0.6	20

3.2. Potential Ecological Hazards Assessment

In order to characterize the ecological pollution degree of heavy metals in Nantaizi Lake sediments, the results calculated by potential ecological risk index were in Table 4, it can be seen clearly that ecological pollution degree in all sample sites of Nantaizi Lake sediments is slight. Analyzed from all sample sites that ecological risk in sample site S3 index RI is higher than other sample sites; analyzed from all aspects of heavy metals, heavy metal element Cd is main contributor of ecological harm index and its ecological harm index is far higher than that of other elements, where Cd ecological harm coefficient of sample site S2 and S3 exceeds 40, which belongs to middle ecological pollution and shows that ecological harm degree of Cd in Nantaizi Lake is relatively high. 6 kinds of heavy metal elements in Nantaizi Lake were sorted according to ecological harm coefficient of average value of heavy metal elements: Cd>Cu>As>Pb>Zn>Cr.

Table 4. Potential risk Index evaluation results for heavy metals in Nantaizi Lake sediments

E_r^i	Cr	Cu	Zn	Pb	Cd	As	*RI*	Ecological pollution degree
S1	0.18	3.33	0.72	3.30	23.68	2.03	33.25	Slight
S2	1.29	3.94	0.94	3.91	52.56	4.94	67.57	Slight
S3	1.36	5.80	1.42	4.24	66.92	5.98	85.72	Slight
S4	1.32	4.79	1.09	3.94	35.03	5.84	52.01	Slight
S5	0.81	5.03	1.20	4.06	32.82	3.78	47.72	Slight
S6	0.63	4.33	0.81	3.06	33.45	2.75	45.04	Slight
Average value	0.93	4.54	1.03	3.75	40.75	4.22	55.22	Slight

3.3. Pollution Sources Analysis

According to the correlation analysis between all heavy metals in Nantaizi Lake sediments listed in Table 5. Table 5 shows that there is relatively remarkable positive correlation between heavy metal elements in sediments: Cu-Zn, Pb-Zn and Pb-As, which shows that there is similar geochemical property in all heavy metals in Nantaizi Lake environment sediments Cu, Zn, Pb and As, which may have certain homology. Besides, there is significant correlation in As and Cr, which shows that they are closely related.

Table 5. Pearson's correlation matrix of heavy metals in Nantaizi Lake sediments

Items	Cr	Cu	Zn	Pb	Cd	As
Cr	1					
Cu	0.648	1				
Zn	0.706	0.945**	1			
Pb	0.769	0.701	0.884*	1		
Cd	0.775	0.619	0.690	0.646	1	
As	0.972**	0.695	0.774	0.827*	0.743	1

** Significant correlation (both sides) under $P < 0.01$.

* Significant correlation (both sides) under $P < 0.05$.

Principal Component Analysis (PCA) is to reflect weight of all factors by dividing variables factors by utilizing dimension reduction technology and by representing correlation degree between different factors with different main components based on displaying original data to the maximum [16].Urban inland lake waters has reflected that lake waters are polluted by heavy metals, of which contents and sources have recorded influence of human activity and natural change on environment [17]. Pollution source of heavy pollution can be divided into main source and secondary source according to sources. Based on PCA, by simplifying and extracting original variables factors, independent heavy metal elements can be combined to form a new variable, so as to judge and analyze heavy metal sources in water environment sediments [16]. Therefore, PCA has been implemented for characteristics values of heavy metals of 6 sample sites of Nantaizi Lake water system. It can be shown from results of PCA (Table 6) that characteristics value of the first principal component is 4.824 and its variance contribution rate reaches 80.392%; characteristics value of the second principal component is 0.591 and its variance contribution rate is 9.848% and accumulated contribution rate of the first principal component and the second principal component occupies for 90.239% of total variance, which shows that extracted principal component can better reflect large part of information of all data.

Table 6. Principal component analysis of heavy metal data in Nantaizi Lake sediments

Principal component	Initial factor solution			Extracted original solution		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.824	80.392	80.392	4.824	80.392	80.392
2	.591	9.848	90.239	.591	9.848	90.239
3	.341	5.691	95.931			
4	.223	3.715	99.646			
5	.021	.354	100.000			
6	-7.02E-17	-1.17E-15	100.000			

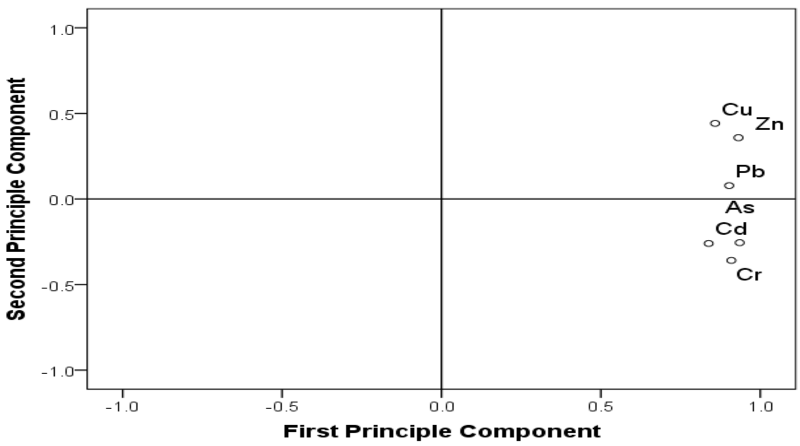

Fig. 2 Figure of main component load

Based on Table 6 and Figure 2, the contribution rate of the first principal component in the total variance is far higher than other principal components, where Cu, Zn, Pb, As, Cd and Cr are relatively higher than positive load. According to research of Tang Zhenwu [18], heavy metal elements Cd, Cu, Pb and Zn, etc. in the first principal component of heavy metals in lake sediments in Hanyang industrial area have relatively large load and Cd, Cu, Pb and Zn contents are higher than that of other lakes, which is basically consistent with result of the experiment. Nantaizi Lake is located in Hanyang High-new Technical Park, where there are many industrial enterprises, such as chemical industry, metallurgy and plating, etc.; at the same time, because of rapid development of Wuhan economy, transfer of industry and enterprises drive removal of population, which leads to closed communities and buildings near Nantaizi Lake [19]. By referring to relevant materials on line, the Author has known that sewage from Longyang Lake and Moshui Lake, etc. have been discharged to Nantaizi Lake for several times because disposal capacity of sewage disposal factory is limited within Hanyang Industrial Park, which has caused severe damage to Nantaizi Lake environment. It is judged comprehensively that Cu, Zn, Pb, As, Cd and Cr may be related to human activities. Therefore, according to analysis of 6 kinds of heavy metals Cd, Cu, Pb, Zn, Cr and As and combined with relevant materials, it can be known that the first principal component represents influence of industrial sewage and domestic sewage on lake environment. It can be known from Table 5 that there is relatively strong correlation between contents of heavy metals Cd, As and Cr; therefore, it can be known that the first principal component mainly reflects sources of heavy metals Cd, As and Cr in lake sediments and at the same time, it also reflects sources of Cu, Pb and Zn.

Heavy metals, of which the second principal component is positive load are Cu, Zn and Pb. Content of the 3 kinds of heavy metals in crust is not high, mainly in mineral [20]. There is a lot of rainfall in plum rain season in Wuhan annually, which brings quantities of street rubbish and residual tailings to lake and will accumulate in lake sediments. Under certain condition, metabolic activity of microorganism in lake environment will lead to that heavy metal in sediments will be released and generate “secondary pollution” [21]. It can be inferred that Cu, Zn and Pb may come from the release of inner source pollution of lake sediments. Therefore, the second principal component has mainly reflected influence of inner source pollution of lake on heavy metal contents.

4. Conclusion

Average values of Cr, Cd, Cu, Zn, Pb and As contents in Nantaizi Lake sediments are within GB 15618—1995 class II standard limit. According to potential ecological risk index, except for that heavy metal Cd content in lake sediments belong to middle ecological pollution, rest heavy metal contents belong to slight ecological pollution. 6 kinds of heavy metal elements of Nantaizi Lake shall be ranked according to ecological harm coefficient of mean value of heavy metals: Cd>Cu>As>Pb>Zn>Cr. Therefore, general ecological pollution degree of Nantaizi Lake belongs to slight pollution. Based on correlation analysis and principal component analysis, the sources of heavy metals on Nantaizi Lake surface mainly comes from two main components: the first principal component is industrial pollution discharge in human activities and point-source pollution generated by domestic sewage, which has decided the sources of Cd, As and Cr and has partly dominated the sources of Cu, Pb and Zn; the second principal component is inner source pollution generated by microbial degradation of minerals in natural environment and the sources of Cu, Pb and Zn mainly depend on second principal component.

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