Journal of Environmental Sciences Vol.17,No.4,pp.672—675,2005

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2005)04-0672-04 **CLC number**: X131.3;X53 **Document code**: A

Heavy-metal contents in suspended solids of Meiliang Bay, Taihu Lake and its environmental significances

ZHU Guang-wei[1], CHI Qiao-qiao[1,2], QIN Bo-qiang[1,*], WANG Wen-min[3]

(1. Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China. E-mail: qinbq@niglas.ac.cn; 2. Graduate School of Chinese Academy of Sciences, Beijing 100039, China; 3. Jiangxi Agricultural University, Nanchang 330045, China)

Abstract: Surface water was taken from river mouth to the central area of Meiliang Bay, Taihu Lake, a large shallow eutrophic lake in China. Suspended solids were condensed by centrifugation 25 L surface water samples from each selected site. Suspended solids and surface sediments were further freeze-dried and microwave digested before determining the metals by ICP-AES. Among the metals analyzed in suspended solids and sediments, contents of Cr, Cu, Mn, Ni, and Zn in suspended solids were significantly higher than those in sediments while contents of Al, Ba, Be, Ca, Co, Fe, K, Mg, Pb, and V in suspended solids were 10%—30% higher than those in sediments. Sr and Ti contents in suspended solids and sediments were very similar. Na content in suspended solids was lower than that in sediments. Heavy metals were significantly accumulated in suspended solids. From the river mouth to the center of Meiliang Bay, contents of Cr, Cu, Pb, and Zn in suspended solids showed a gradual decreasing trend indicating the river (Zhihugang River) still discharged large quantity of heavy metals to Meiliang Bay. The study suggests that the geochemical behaviors and ecological effects of heavy metals in suspended solids may serve as a good indicator for the pollution of lake.

Keywords: shallow lakes; suspended solids; heavy metals; Taihu Lake

Introduction

Heavy metals are important environmental indicators for the impact of human activities on natural ecosystems. Lakes may serve as the main sink of anthropogenic pollutants from terrestrial ecosystems. Heavy metals produced by human activities are indirectly or directly transported into lakes in particulates and/or dissolved states. Generally, particulate state is the main form of heavy metals in the freshwater bodies. Heavy metals can also be transported in the particulate form and settled in sediment. Moreover, the heavy-metal contents in suspended solids(SS) are generally several times higher than those of bottom sediments, and are hundreds times higher than those of dissolved state in the water body (He, 2003; Zhu, 2001; Cui, 2000). Understanding the environmental behaviors of heavy metals in SS could help to realize the environmental impact of heavy metals on the ecosystems of water bodies.

Generally, SS contents in shallow lakes are appreciablly higher than those in deep lakes. They are greatly influenced by storm-wave disturbance and phytoplankton abundance. SS also plays an essential role on migration and on the ecological behavior of heavy metals in shallow lakes. Nevertheless, studies on the relations between the SS and heavy-metal behaviors have been mainly concentrated on rivers. Few studies concentrated have focused on shallow lakes.

Taihu Lake is the third largest freshwater lakes in China. It is also a shallow and eutrophic lake, strongly influenced by human activities, with an area of 2338.1 km^2 and a maximum depth of 3 m(Qin, 2004). Its phytoplankton is transitional between those of lakes and rivers (Chen, 2004). A lot of researches have been carried on the pollution of Taihu Lake and its catchment(Zhang, 2001; Dai, 2001; Fan, 2002; Wang, 2002; Yuan, 2002; Liu, 2004; Yan, 2004), but most of them considers the issue of sediments pollution.

The objective of this paper was to present a study on the heavy-metal pollution characteristics of SS in river mouth of the large pollution source river and lake center of Taihu Lake. In particular, we sought to determine current levels of metals delivered to the lakes and their geochemical behaviors within the lake itself.

1 Materials and methods

Before 2001, pollution of Meiliang Bay mainly came from the Zhihugang and Liangxi Rivers, the outfalls of which are located at the northwest and northeast corners of the bay, respectively(Fig.1)(Qin, 2004). As a result of the pollution control projects carried out at Wuli Lake, Liangxi River, pollution has been effectively controlled since 2001. Today, Zhihugang River is the most important source of pollutants to Meiliang Bay.

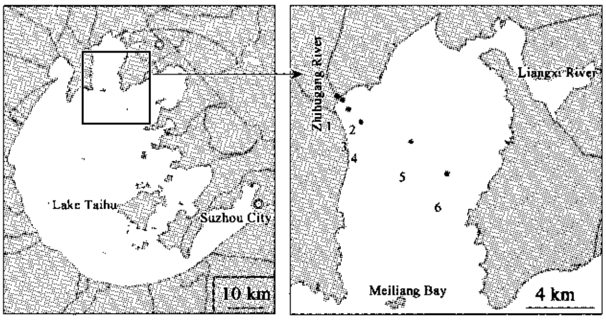

Fig.1 Locations of sampling sites in Taihu Lake

On July 10, 2004, water and sediment samples were taken at 6 sites from the mouth of Zhihugang River to the center of Meiliang Bay(Fig.1). The 5 cm top-layer sediment was sampled using a sediment-core sampler. The sediment core was immediately cut into 1 cm slices on boat. These were labeled as S1 (0—1 cm sediment), S2 (1—2 cm sediment), and S3 (2—3 cm sediment), stored in a cold cooler(4℃) and returned to laboratory for further analysis. In addition, 25 L surface water was pumped at each site and sieved through 63 μm nylon mesh. The filtered water was taken back to the laboratory within 2 hours for SS collections.

Foundation item: The National Natural Science Foundation of China (No. 40203007) and the Key Project of Chinese Academy of Sciences (KZCX1-SW-12); * Corresponding author

The 25 L surface water was centrifuged at 5000 r/min for 10 min and the precipitate was collected as SS. SS and sediment samples were freeze-dried and ground. Approximately 0.120—0.125 g of SS and sediment samples were weighted into polytetrafluoroethylene (PTFE) tubes, followed by 4.0 ml of concentrated nitric acid, 0.5 ml of hydrochloric acid, and 3.0 ml of hydrofluoric acid into the tube, and digested the sample in Berghofmws-3 microwave system. Then all materials were transferred into PTFE beaker, adding 0.5 ml perchloric acid, heating, evaporating, and dried. Then, 2.5 ml 1:1 nitric acid, 3—5 ml pure water and 0.25 ml hydrogen peroxide solution was added. After low-temperature heating, the solution was transferred to 25 ml colorimetric tube, and was adjusted to 25 ml and submitted to analysis. 19 kinds of metallic elements were determined using inductively coupled plasma atomic emission spectrometry (ICP-AES) (LEEMAN LABS INC, Profile DV, USA), such as Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr, Ti, V, and Zn, etc. Cd contents were lower than method detection limit in all samples. As contents were also lower than detection limit of 50 mg/kg. 18 kinds of other elements contents were in the detection range. To analyze the quality control, sedimentary and soils standard of Chinese National Geological Certified Materials GSD-11, GSS-4, GSS-8 were determined with the samples. The analysis results agreed with the standard values.

2 Results

2.1 Heavy metal content in sediments and SS

Contents of 18 elements in SS and 0—1 cm top layer sediments (S1) are presented in Table 1. Heavy-metal contents in SS were notably higher than those in the top layer sediment, notably those of Cr, Cu, Mn, Ni, and Zn. Contents of Al, Ba, Be, Ca, Co, Fe, K, Mg, Pb, and V in SS were 10%—30% higher than those in the top layer sediments. Contents of Sr and Ti in SS were similar to those in sediments. However, Na content in SS was markedly lower than that in the sediment. It could be concluded that the polluting heavy-metal elements were mainly riches in SS. With the exception of Pb and Co, other polluting heavy-metal elements (Cu, Zn, Cr, Ni) were considerably enriched in SS.

Table 1 Metal element contents in suspended solids (SS) and surface sediments (S1)

Sample site	1		2		3		4		5		6	
	SS	S1	SS	S1	SS	S1	SS	S1	SS	S1	SS	S1
Al, mg/g	79.6	55.4	78.5	74.3	66.6	54.3	80.1	67.1	84.0	61.1	85.3	72.5
Ba, mg/kg	517	377	516	438	516	379	521	404	562	422	535	401
Be, mg/kg	2.5	1.8	2.5	2.2	2.3	1.7	2.7	2.1	2.8	1.9	2.9	2.1
Ca, mg/g	8.6	6.1	7.1	6.4	9.1	7.7	12.7	4.7	30.9	6.2	21.0	6.0
Co, mg/kg	17.0	9.1	17.2	11.9	20.1	10.1	17.8	12.8	18.9	13.4	20.1	16.3
Cr, mg/kg	533	69	413	93	307	167	134	66	119	76	109	70
Cu, mg/kg	327	29	228	39	149	149	60	23	47	37	43	22
Fe, mg/g	47.6	23.2	49.3	46.5	43.9	29.9	46.7	41.0	47.4	37.8	48.9	44.0
K, mg/g	17.0	14.2	16.6	15.7	15.0	14.1	17.3	14.6	17.3	15.2	18.2	14.3
Mg, mg/g	8.4	4.5	7.9	5.2	7.2	5.1	8.0	4.6	8.3	5.6	8.2	5.5
Mn, mg/kg	1516	270	2543	595	3750	575	1417	652	1049	728	824	454
Na, mg/g	7.3	10.0	6.2	7.5	2.8	10.8	4.1	8.2	2.9	9.7	2.9	8.2
Ni, mg/kg	184	28	152	44	189	66	92	33	89	48	85	38
Pb, mg/kg	66	27	65	32	63	41	61	35	56	43	58	30
Sr, mg/kg	105	91	93	92	71	106	82	81	92	95	80	90
Ti, mg/kg	4519	4380	4412	4821	3192	4219	4013	4879	3731	5086	3589	4658
V, mg/kg	109	71	113	100	118	71	120	91	120	90	126	94
Zn, mg/kg	851	93	614	126	532	359	272	64	231	129	213	71

With the exception of Pb, heavy-metal contents in SS rapidly decreased from the mouth of Zhihugang River to the center of Meiliang Bay (Fig.2) indicating that heavy-metal pollution in river mouth was more serious than in the center of Meiliang Bay. Zhihugang River was still the main source of heavy metals in Meiliang Bay. However, heavy-metal contents in sediments did not reflect the current trend of pollution in the water body. Except at point 3, heavy-metal contents gradually decrease from the top layer downwards, while at 3 cm below the surface, the heavy metals content is similar at sites. Because Zhihugang River is the major pollution source to Meiliang Bay, the SS pollution trend is as expected. Thus, it could be concluded that the environmental information record in the sediments must be distorted. The strong wind-wave disturbance and transportation and the enormous human activities may be implied.

The geological accumulation index (I_{geo}) of the SS and the surface sediments was calculated as following equation (Fan, 2002):

$$I_{geo} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{C_i}{S_i}\right]^2}.$$

Here, C_i is the heavy-metal content in SS or sediments. Co, Cr, Cu, Ni, Pb, and Zn are chosen for evaluation. S_i is the background value of these metals in the soil of the basin of Taihu Lake, which are 18.6 mg/kg, 71.8 mg/kg, 15.4 mg/kg, 19.8 mg/kg, 15.7 mg/kg, and 65.1 mg/kg for Co, Cr, Cu, Ni, Pb, and Zn, respectively. The I_{geo} of heavy metals in SS were significantly higher than those in top layer sediments (Table 2). Certainly, I_{geo} showed a decreasing trend from site 1 to site 6.

Table 2 Geological accumulation index of heavy metals in SS and surface sediments

Sample site	1	2	3	4	5	6
I_{geo}(ss)	11.4	8.3	6.9	3.5	3.1	3.0
I_{geo}(sediment)	1.4	1.9	5.0	1.4	2.0	1.4

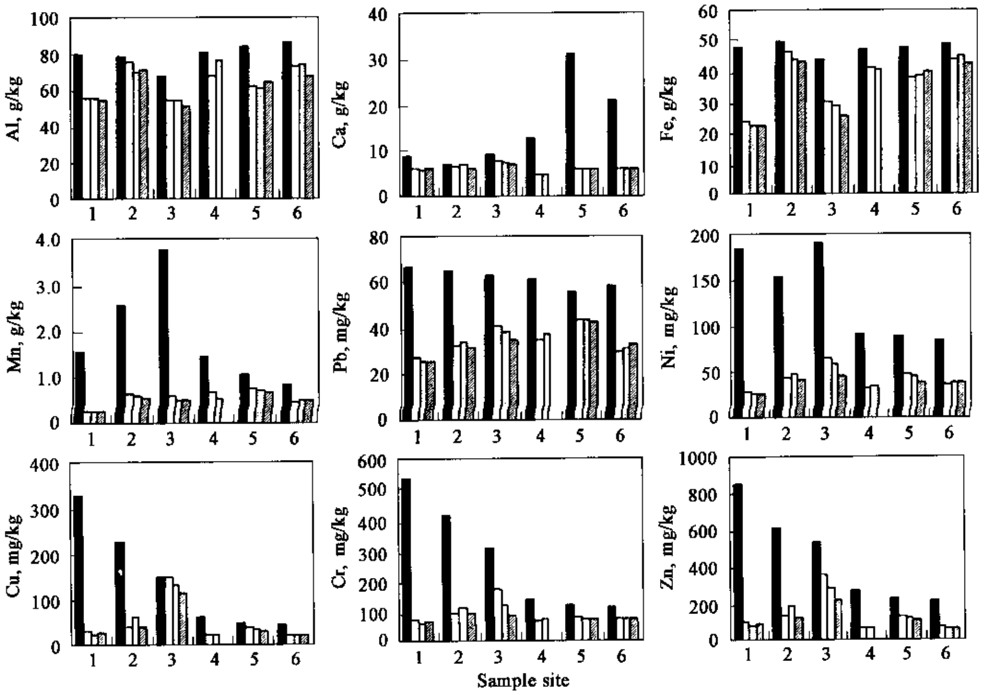

Fig.2 Contents of heavy metals in SS, S1, S2 and S3.
Black bar denote SS, blank bar denote S1, grey bar denote S2, and stripe bar denote S3

From river mouth to the center of Meiliang Bay, contents of Al and Fe in SS varied little but the amount of Ca notably increased.

2.2 Correlation between heavy metal contents of SS

Contents of Cr, Cu, Ni, Pb, and Zn in SS were significantly correlated (Table 3). The similarity indicates that most of them are from Zhihugang River input. However, there was no correlation between Co contents and the other heavy metals in SS owing to no significant Co pollution detected in SS. The background value of Co in soil of the catchment of Taihu Lake was 18.6 mg/kg. However, the Co contents in SS of the 6 sites were between 17.0 and 20.1 mg/kg, with a mean value of 18.5 mg/kg. There was any Co pollution in SS.

It should be emphasized that there was no significant correlation among heavy-metal contents and Al, Fe, and Mn contents in SS (Table 3). Moreover, there was no significant correlation among the contents of heavy-metal with Ca in SS, indicating that hydroxides were not the major sites of metal adsorption.

Table 3 Correlationship between metal contents in SS

	Al	Ca	Fe	Mn	Co	Cr	Cu	Ni	Pb	Zn	Sr
Ca	0.609										
Fe	0.801	0.166									
Mn	-0.958**	-0.633	-0.624								
Co	-0.190	0.432	-0.407	0.128							
Cr	-0.388	-0.736	0.028	0.435	-0.600						
Cu	-0.314	-0.709	0.076	0.351	-0.640	0.955**					
Ni	-0.763	-0.747	-0.410	0.758	-0.226	0.875*	0.836*				
Pb	-0.519	-0.943**	-0.069	0.552	-0.596	0.914*	0.900*	0.840*			
Zn	-0.427	-0.740	-0.050	0.445	-0.573	0.995**	0.992**	0.897*	0.914*		
Sr	0.458	-0.034	0.556	-0.408	-0.794	0.569	0.629	0.156	0.329	0.543	
Ti	0.369	-0.367	0.621	-0.283	-0.955**	0.599	0.651	0.157	0.549	0.560	0.868*

Notes: * denote significantly correlation($P < 0.05$); ** denotes extremely significantly correlation($P < 0.01$)

3 Discussion

3.1 Heavy metal pollution in Taihu Lake

During the last 25 years, Changjiang Delta has been one of the rapidest developing areas in China. With dense population and rapid industrialization of the catchment, water quality of Taihu Lake has been deteriorated seriously since 1970s (Qin, 2004). Heavy metal pollution in Lake Taihu first became a concern during the 1980s. Investigation had shown heavy-metal pollution in Taihu Lake was mainly come from the northern part of Meiliang Bay (Yuan, 2002). Pollution history was initiated in the 1970s (Liu, 2004). However, as a large and shallow lake, heavy-metal pollution did not affect the lake uniformly. Pollution was confined to several river mouths. However, the heavy-metal contents in water were very low, often difficult to determine precisely. Therefore, most of the research work on heavy-metal pollution associated with Taihu Lake was direct to investigation of sediments (Zhang, 2001; Dai, 2001; Fan, 2002; Wang, 2002; Yuan, 2002; Liu, 2004; Yan, 2004). However, being strongly influenced by wind-induced waves and currents, the bottom sediment distribution of Taihu Lake is quite heterogeneous: one third of the lake bed is without any soft mud cover (Luo, 2004a). Furthermore, there is an obvious current paralleling the direction of the bank in the northwest of Meiliang Bay (Luo, 2004b), which must influence the sedimentation of SS entering from Zhihugang River. Therefore, it is in fact difficult to utilize information of sediments to estimate the recent heavy-metal pollution of Taihu Lake being the restriction of sediment erosion, perturbation, and dredging activities. In addition, contents of heavy metals in the sediments of Taihu Lake were generally similar to the background value of the catchment materials, except that in the vicinities of the several river inflows.

Result of the SS investigation failed to reflect the current water pollution in Meiliang Bay. SS was a better indicator of today's water pollution than the sediments. Although a series of countermeasures to the eutrophication of Taihu Lake has been implemented, the impact of these countermeasures needed to be evaluated. From the SS investigation, it can be concluded that heavy-metal pollution has not been effectively controlled and Zhihugang River still acted as the main contributor of heavy metals of Meiliang Bay.

3.2 Environmental significances of SS heavy-metal investigation

Dissolved, particulate, and sediment are the three generalized locations of heavy metals in water bodies. Usually, sediments contain a pollution history for the lake. Heavy-metal investigation of sediment is also predictive of internal release potential and the likely toxicity of sediment to benthic organisms. Therefore, sediment investigations were generally first carried out as a past of heavy-metal pollution surveys in water bodies. As for dissolved heavy metals in the water body, there have been seldom surveyed because of the low concentrations and often have analytical problems, although their importance to aquatic ecosystems is not disputed. As for particulate heavy-metal in water body, the investigation has been hampered by a lack of the authorized standard methods for sampling and analysis.

Heavy-metal contents in SS were generally obviously higher than those in the top layer sediment. For example, contents of Cu, Pb, Cd and Zn in SS of Yellow River were generally as twice as higher than those in top layer of sediment (He, 2003). Heavy metal contents in SS of main stream of Changjiang River were also higher than those in bottom sediments (Zhu, 2001). This phenomenon could be the results of the following reasons: (1) particle size of SS is generally finer than that of sediment, and heavy metals tend to adsorb onto the fine particles (Chen, 1994; Fu, 2000); (2) organic matter contents in SS are generally higher than those in sediments, and usually heavy metals are accumulated in organic matter present in natural water bodies; (3) SS generally contain more inorganic colloidal matter than sediments, which is also favorable to the accumulation of heavy metals in water bodies.

In shallow lakes, wind-induced wave action frequently disturbs the water-sediment interface and serves as mixing action. In this condition, SS may be a good alternative indicator for heavy-metal pollution survey. There are some advantages to use SS as heavy-metal pollution indicator: (1) The relatively high contents of heavy metals in SS can reduce the precision demanded of the detecting instrument; (2) comparing with the investigation on the sediment, SS survey can reflect the real-time status of water pollution; (3) heavy metals in SS will produce more direct impacts on aquatic ecosystems than sediment. Therefore, it may be a good choice to investigate heavy-metal pollution of SS in the shallow lakes as a proxy for environmental pollution and the study of pollution of aquatic ecosystems by toxic substances.

Acknowledgements: The authors would like to thank Sun Xiaojing, Zhu Yuxin, Gao Guang, Ji Jiang and Zhang Lu for their help on the experimental design, sample taking and chemical analysis used in this work.

References:

Chen J S, Wang F Y, Chen J L, 1994. Relation of aquatic particulate grain size to heavy metals concentrations in eastern Chinese rivers[J]. Acta Scientiae Circumstantiae, 14: 419—425.

Chen Y W, HU Y H, Dokulil M T, 2004. Phytoplankton photosynthesis and plankton community respiration in a large shallow lake, Taihu Lake, China [C]. Abstract book of 29th Congress of International Association of Theoretical and Applied Limnology. 102.

Cui H M, 2000. Study on adsorption of heavy metals by suspended sediment of Juma River[J]. Water Resources Protection, 20: 25—28.

Dai X L, Sun C, 2001. The characteristics of heavy metals distribution and pollution in sediment from Lake Taihu [J]. Shanghai Environmental Sciences, 20: 71—74.

Fan C X, Zhu Y X, Ji Z J *et al.*, 2002. Characteristics of the pollution of heavy metals in the sediments of Yilihe River, Taihu Basin[J]. Journal of Lake Sciences, 14: 235—241.

Fu R B, He Q, Sun Z B, 2000. The distributive character of heavy metals in the south passage of Changjiang Estuary[J]. China Environmental Science, 20: 357—360.

He J, Wang X W, Li C X *et al.*, 2003. Pollution character of heavy metals in the water-sediment system from Baotou section of the Yellow River[J]. Acta Scientiae Ciruemstantiae, 23: 53—57.

Liu E F, Shen J, Zhu Y X *et al.*, 2004. Source analysis of heavy metals in surface sediments of Lake Taihu[J]. Journal of Lake Sciences, 16: 113—119.

Luo L C, Qin B Q, Zhu J W, 2004a. Sediment distribution pattern mapped from the combination of objective analysis and geostatistics in the large shallow Taihu Lake, China[J]. Journal of Environmental Sciences, 16: 908—911.

Luo L C, Qin B Q, 2004b. Three-dimensional numerical simulation of wind-induced circulation in Lake Taihu[J]. Journal of Hydrodynamics, 18: 686—691.

Qin B Q, Hu W P, Chen W M, 2004. Processes and mechanisms of water environment in Lake Taihu[M]. Beijing: Science Press.

Wang H, Wang C X, Wang Z J, 2002. Speciations of heavy metals in surface sediment of Taihu Lake[J]. Environmental Chemistry, 21: 430—435.

Wang X Q, Zheng L P, Sun W M, 2004. The distribution characteristics of heavy metals in the pore water of sediments, Dianshan Lake [J]. China Environmental Science, 24: 400—404.

Yan H T, Zhu T X, Hu S Y *et al.*, 2004. Magnetic studies on heavy metal pollution and multivariate analysis in West Tiaoxi Basin [J]. China Environmental Science, 24: 385—389.

Yuan X Y, Chen J, Ji J F *et al.*, 2002. Characteristics and environmental changes of pollution elements in Taihu sediments and soil near the lake[J]. Acta Sedimentologica Sinica, 20: 427—434.

Zhang Y P, Qu W C, 2001. Determination of heavy metal contents in the sediments from Taihu Lake and its environmental significance[J]. Rock and Mineral Analysis, 20: 34—36.

Zhu S Q, Zang X P, 2001. On heavy metal pollution along Yangtze River stretches of urban areas in major cities[J]. Yangtze River, 32: 22—24.

(Received for review November 29, 2004. Accepted January 18, 2005)