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Metals in Surface Sediments of Large Shallow Eutrophic Lake Chaohu, China

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Abstract Metal contents of surface sediments were analyzed temporally and spatially in Lake Chaohu, China. No obvious temporal variations were observed, which probably due to physio- and bio- mixing, e.g. wind and microbes, in this lake. Enrichment factor of some metals were generally greater than 1.0, suggesting significant anthropogenic impact on metal levels. Significantly positive correlations between concentrations of nutrient and metals indicated that the nutrients transported to this lake contributed, to some extent, to the enrichment of metals. The correlation between trace metals concentrations indicated the co-contamination of anthropogenically derived metal enrichment in surface sediment of Lake Chaohu.

Keywords Metal · Surface sediment · Lake Chaohu

Metals in sediments of aquatic ecosystems have natural and anthropogenic origin, and their distribution and accumulation are influenced by sediment texture, mineralogical composition, reduction/oxidation state, adsorption and desorption processes and physical transport (Manahan 2000). Recently, the introduction of waste water into aquatic ecosystem, especially those from industrial and population centers, led a significant increase in metal contamination (Buckley et al. 1995). Metals can be absorbed from the water column onto fine particles surfaces and move thereafter towards sediments. Sediment-associated metals pose a direct risk to detrital and deposit-feeding benthic organisms, and may also represent long-term sources of contamination to higher tropic levels (Eimers et al. 2001). Metals also can be participate in various biogeochemical mechanisms, subsequently affect the ecosystems through bio-accumulation and bio-magnification processes, and be potentially toxic for environment and for human life (Manahan 2000).

Lake Chaohu (Fig. 1), the fifth largest freshwater lake in China, is located in the delta of the Yangtze River. The

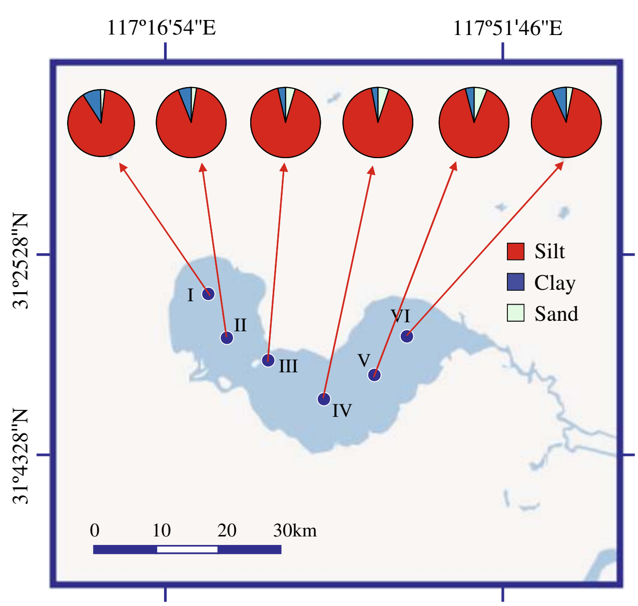

Fig. 1 Locations of sampling sites in Lake Chaohu, China. Grain size (% dw) of surface sediments in each site were also shown

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catchments' area is ca. 13,486 km^2. It has a mean surface area of 770 km^2, a mean depth of 2.7 m and a storage capability of 2.1 billion m^3 (Xu et al. 2005). The lake is an important drinking water source for the surrounding cities. It is also used for industrial and agricultural irrigation water source, flood prevention, fishery and tourism. Unfortunately, massive economic growth and urban development in its region has led to excessive release of waste into the lake, including metals from industrial and urban sources. However, despite these many possible inputs, the amounts of metals in the surface sediments of this lake have never been documented.

Base on these facts, we analyzed metal contents, including Al, Fe, Ca, Mg, Mn, As, Cd, Co, Cr, Cu, Ni, and Pb of surface sediments sampled from six sites in Lake Chaohu (Fig. 1). The primary aims of this work were to investigate spatial and temporal variations in metal contents of the surface sediments in this lake, to evaluate anthropogenic influence on metal contents by calculating the enrichment factor, and to test the correlations between metal and nutrient contents.

Materials and Methods

Sampling was conducted monthly from October 2002 to September 2003. Surface sediments (10 cm) were obtained using a hand driven stainless steel corer (100 cm long with an internal diameter of 3.9 cm). Twenty-one cores were collected at each site, and then grouped randomly into three parts (each part contained seven cores) and mixed thoroughly. In the laboratory, samples were air-dried, sieved through a 0.149-mm mesh, and digested by HF-$HClO_4$-HNO_3 in Teflon bombs. Concentrations of Al, Fe, As, Cd, Co, Cr, Cu, Mg, Mn, Ni, Pb were determined by ICP-OES (VARIAN VISTA-MPX). Detailed methods of digestion and analysis were reported elsewhere (Lu 2000). Concentration of calcium (Ca) was determined by atomic spectrophotometer (Perkin-ELMER 2280). Data of total Phosphorus (TP) and total nitrogen (TN) in surface sediments were cited from Zhang et al. (2006). Analysis of grain size was according to Lu (2000).

Results and Discussion

The surface sediments of our sampling sites were almost entirely comprised of silt (>88.2%), and the mean porosity of the surface sediment was slightly higher in the western (0.75, 0.74, 0.72 for sites I, II, III, respectively) than in the eastern areas (0.69, 0.70, 0.67 for sites IV, V, VI, respectively). The clay contents and concentrations of TP and TN in the surface sediments were generally higher in the western and eastern than in the central areas of the lake. Economic development and population increase have been proved to be the important factors for the relatively higher TP and TN concentrations in the western part of the lake, since massive sewages were discharged into this part of the lake from the surrounding cities (Xu et al. 2005; Zhang et al. 2006). Furthermore, grain sizes of the surface sediments were mainly affected by the organic matter recently induced by human activities around this lake (Zhang et al. 2006). Temporal variation of metals concentrations, including Al, Fe, Ca, Mg, Mn, As, Co, Cd, Cr, Cu, Ni, and Pb of the surface sediments were shown in Fig. 2. However, no obvious temporal variations were observed in this study. It is recently known that the surface sediment (about 5–10 cm) were relatively homogeneous due to physio- and bio-mixing, e.g. wind and microbes, in this lake (Zhang et al., unpublished data).

Therefore, it is not likely to see the seasonal changes because mixed surface sediments (10 cm) were analyzed in this study, even if there is any temporal variation in the sediments near the water-sediment interface. Spatial variations of the metals in surface sediments were presented in Fig. 3. Concentrations of Al, Fe, Mg, Mn, As, Cd, Cr, Cu, Ni and Pb were significantly higher at Sites I, II, III and VI than at Sites IV and V (Turkey t test $p < 0.05$), whereas concentrations of Ca and Co showed no obvious spatial variations in the present study (Turkey t test $p > 0.1$).

In order to evaluate anthropogenic influence on metals, enrichment factor (EF) was calculated following the equation: $EF = (Me/Al)_{sample}/(Me/Al)_{background}$, where $(Me/Al)_{sample}$ is the observed metal to aluminum ratio in

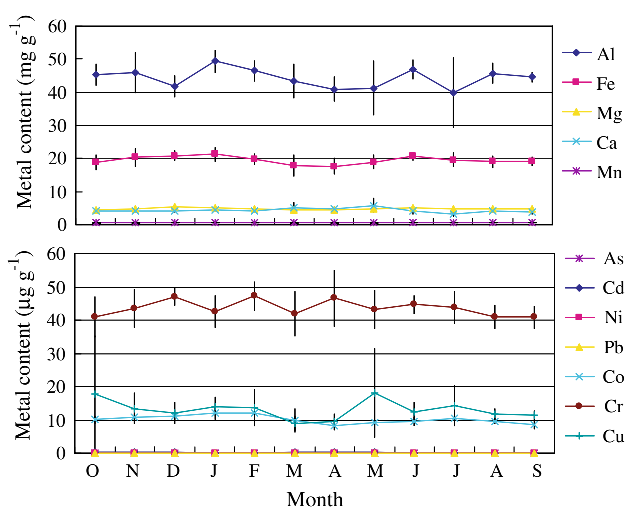

Fig. 2 Tamporal variations in metal contents of the surface sediments in Lake Chaohu ($n = 6$ for each sampling site)

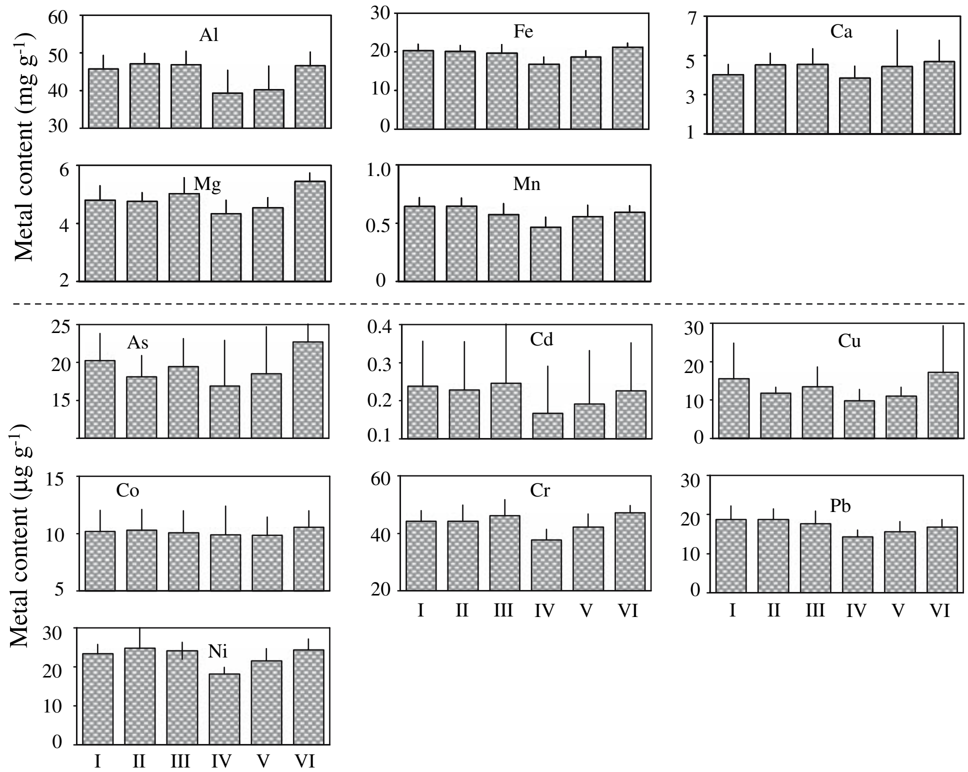

Fig. 3 Spatial variations in metal contents of the surface sediments in Lake Chaohu (n = 12 for each sampling site)

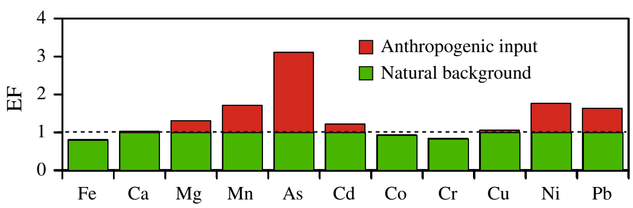

Fig. 4 Human impacts on metal distributions in terms of Enrichment Factors in the surface sediments from Lake Chaohu

the sample and $(Me/Al)_{background}$ is the background metal/Al ratio (Zhang and Liu 2002). Background values were from Tao et al. (1983). EF is a useful indicator reflecting the status of environmental contamination, and it has been suggested that, if EF value was lower than 1.0, the trace metals might be entirely from crustal materials and/or natural weathering processes (Zhang and Liu 2002). When EF > 1.0, it suggests that there are possible anthropogenic impacts on trace metal inputs in sediments (Olivares-Rieumont et al. 2005). Figure 4 showed the EF values for the metals, in which EF of Mg, Cd, As, Ni, Mn and Pb were generally greater than 1.0, suggesting significant anthropogenic impact on metal levels in the lake (Olivares-Rieumont et al. 2005), probably due to metal loads from waste water discharges, industrial-waste, agriculture, and high way storm water (O'Day et al. 2000).

In order to assess element associations and metal origins, Pearson correlation analysis has been carried out for the whole data set of the element concentrations in the surface sediment of Lake Chaohu. Table 1 showed the correlation matrix for metals and total nitrogen (TN) and phosphorus (TP) concentrations in surface sediments. There were significantly positive correlations between concentrations of nutrient and Fe, Mg, Mn, Cr, Ni and Pb, indicating that the nutrients transported to this lake contributed, to some extent, to the enrichment of metals (Qu et al. 2001). The correlation between trace metals concentrations has been used to demonstrate the co-contamination of anthropogenically derived metal enrichment in sediment (Olivares-Rieumont et al. 2005). Significant correlations between trace metal concentrations were observed in marine sediments (Presley et al. 1992). In the present study, the significantly positive correlations between the metals such as Fe, Mg, Mn, As, Co, Cr, Cu, Ni, Pb in the sediments indicated possible co-contamination from similar sources of waste input from the surroundings of Lake Chaohu. Alternately, no correlations were noted between Cadmium and other metals, suggesting that Cadmium contamination might be of different origin than other metals or has different sediment deposition characteristics (Olivares-Rieumont et al. 2005).

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Table 1 Correlation matrix of various parameters (TN, TP and metals) in the surface sediments from Lake Chaohu

	TP	TN	Al	Fe	Ca	Mg	Mn	As	Cd	Co	Cr	Cu	Ni	Pb
TP	1.00													
TN	**0.52**	1.00												
Al	**0.44**	**0.44**	1.00											
Fe	**0.71**	**0.62**	**0.66**	1.00										
Ca	–0.04	–0.02	–0.05	0.02	1.00									
Mg	**0.58**	**0.49**	**0.55**	**0.87**	0.15	1.00								
Mn	**0.75**	**0.70**	**0.58**	**0.88**	–0.04	**0.61**	1.00							
As	0.20	0.18	0.28	**0.35**	**0.34**	**0.46**	0.17	1.00						
Cd	–0.11	–0.15	0.10	0.09	0.18	0.06	–0.03	0.15	1.00					
Co	0.15	**0.33**	**0.34**	**0.45**	0.00	**0.39**	**0.34**	–0.01	0.03	1.00				
Cr	**0.48**	**0.47**	**0.37**	**0.68**	0.13	**0.66**	**0.60**	**0.36**	0.15	**0.27**	1.00			
Cu	**0.28**	0.21	0.16	**0.31**	0.00	**0.28**	0.16	**0.27**	0.19	0.12	**0.25**	1.00		
Ni	**0.49**	**0.38**	**0.37**	**0.44**	0.23	**0.36**	**0.45**	0.22	0.08	0.23	**0.65**	**0.40**	1.00	
Pb	**0.67**	**0.62**	**0.45**	**0.75**	0.04	**0.52**	**0.88**	0.03	0.09	0.32*	**0.59**	0.12	**0.43**	1.00

Bold represents correlation is significant at $p < 0.05$

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