Environ Geol (2007) 52:1467–1474
DOI 10.1007/s00254-006-0587-4

ORIGINAL ARTICLE

Combining geochemical and statistical methods to distinguish anthropogenic source of metals in lacustrine sediment: a case study in Dongjiu Lake, Taihu Lake catchment, China

Yanhong Wu · Xinhua Hou · Xiaoying Cheng · Shuchun Yao · Weilan Xia · Sumin Wang

Received: 3 August 2006 / Accepted: 16 November 2006 / Published online: 3 January 2007

Abstract Metals in lacustrine sediment have both anthropogenic and natural sources. Because of intensified human activities, the anthropogenic input of metal elements has exceeded the natural variability. How to distinguish the anthropogenic sources in lake sediments is one of the tasks in environmental management. The authors present a case study, which combined the geochemical and statistical methods to distinguish the anthropogenic sources from the natural background. A 56 cm core (core DJ-5) was collected from Dongjiu Lake, Taihu Lake catchment, China. The concentration distributions of Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, Sr, Ti, V and Zn in core DJ-5 indicated that Dongjiu Lake had serious Cd pollution, and the concentrations of Cr, Cu, Pb, Mn and Zn had also exceeded the Chinese State Standards of Soil Environmental Quality in the upper layer of the core. Using Al as a reference element, the other metals were normalized and compared with their baselines to calculate the enrichment factors (EFs). The principal component analysis (PCA) of metal concentrations was performed using ViSta6.4. The results of EFs and PCA indicated that the concentration variations of Cd, Cu, Pb, Mn and Zn were mainly caused by the anthropogenic sources, and the concentration variations of Cr and Ni were influenced by both the anthropogenic and natural factors, while the other metals were mainly derived from the natural sources. Intensified human activities within the lake catchment area resulted in the increase of heavy metal inputs directly and the acceleration of erosion which caused other metal elements to deposit in the aquatic environment. The results of this work will be useful in probing changes forced by humans in the lake environment and in adjusting human activity in restoring the lake environment.

Keywords Metal element · Principal component analysis · Enrichment factors · Human activity · Anthropogenic sources · Dongjiu Lake · China

Introduction

The concentration of metals in lake sediments has its background value mainly from the weathered mother rock or the soil. Since the last century with the rapid development of industry, the portion of metal inputs caused by human activity has exceeded that from the natural sources, which resulted in the increase of heavy metal load and the acceleration of widespread heavy metal pollution. The excess portion of total metal concentration is ascribed to the anthropogenic portion. One of the major tasks in environmental management is the sufficient and accurate assessment of human impact on the lake environment to propose some effective measures to environmental management. Distinguishing the anthropogenic inputs from the natural inputs is the basis of solving these problems.

Y. Wu (✉) · X. Hou · S. Yao · W. Xia ·
S. Wang
Key Laboratory of Lake Sedimentation and Environment,
Nanjing Institute of Geography and Limnology,
Chinese Academy of Sciences, Nanjing 210008, China
e-mail: yhwu@niglas.ac.cn

X. Cheng
The Key Laboratory of Industrial Biotechnology,
Ministry of Education, Southern Yangtze University,
Wuxi 214036, China

Due to the natural and anthropogenic inputs existing synchronously and varying unceasingly, they are difficult to distinguish in a given modified ecosytem. The changes of the grain-size composition, mineral components, organic matter content and sedimentary environment exacerbated the difficulty to distinguish the anthropogenic input from the natural background. One of the approaches is to normalize the metal concentration to grain-size distribution (Luoma and Bryan 1981; Horowitz et al. 1990; Szefer et al. 1996). This approach cannot reflect the enrichment characteristics of elements in the bulk sediment. The geochemical approach, which uses conservative elements, such as Al, Fe, Li and Rb to normalize the metals, is used to compensate for detecting and quantifying the anthropogenic input (Windom et al. 1989; Tam and Yao 1998; Green-Ruiz and Páez-Osuna 2001) under the presumption that the correlation with the conservative elements and other metal elements is relatively constant in the earth's crust.

The principal component analytical (PCA) method, which enables a reduction in data and description of a given multidimensional system by means of a small number of new variables, has been widely applied to judge the sources of sediments and soil materials, and to distinguish the natural and anthropogenic input (Tuncer et al. 2001; Loska and Wiechula 2003; Soto-Jiménez et al. 2003).

Taihu Lake has suffered serious pollution problems in recent years, and heavy metal pollution varies in different lake areas (Dai and Sun 2001). Seventy percent of the main pollutants in Taihu Lake come from the tributaries surrounding it. The pollutants carried by the Yili River accounted for the majority of the pollutants.[1] The heavy metal pollution is a more serious problem along the Yili River, especially Cd which has a much higher pollution index in certain sections of the river (Fan et al. 2002). Materials transported by Yili River are finally discharged into Taihu Lake passing through Dongjiu Lake.

Combining the statistical method with the geochemical normalization method, the anthropogenic input of heavy metals has been distinguished from their backgrounds in this work, which provides a foundation for further discussion on the human impact on environment deterioration of Taihu Lake.

General description of the research area

Dongjiu Lake is located in Yixing City, Jiangsu Province, connected with Xijiu Lake and Tuanjiu Lake, which are commonly known as Yixing Sanjiu. The area of Dongjiu Lake is 8.0 km^2 with the maximum depth of 5.8 m and the average depth of 1.85 m (Fig. 1).

Yili River is the main tributary of Taihu Lake, which collects water from the Yili mountain area, the southern Maoshan mountain area and the plains along the river valley. Since the 1970s, rapid urbanization and boosting of industry, especially the development of non-ferrous metalling (four companies), the galvanization industry and the printing and dyeing enterprise, increased the pollution load and accelerated the contamination of the water and soil environment (Xie and Chen 2002).

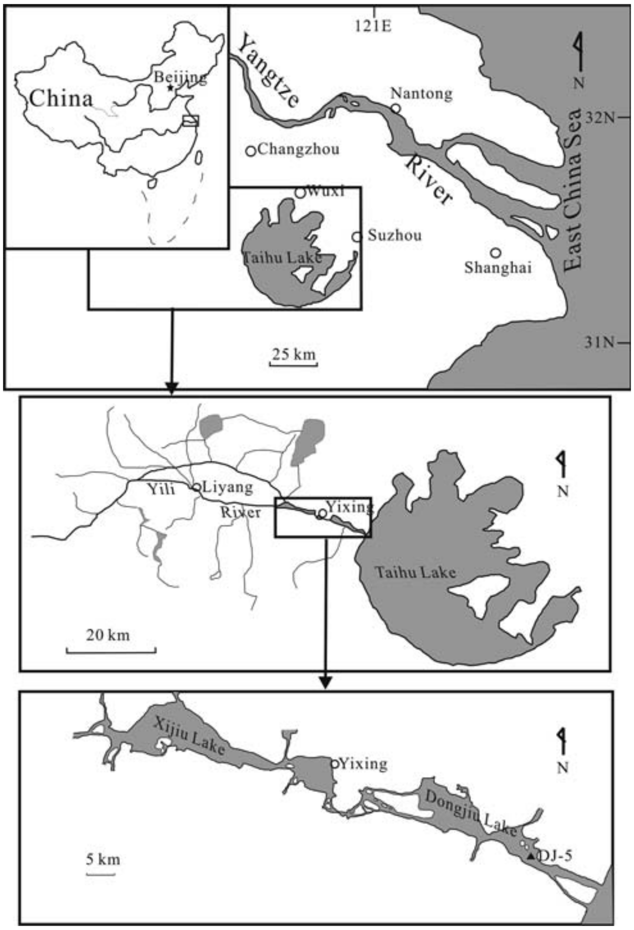

Fig. 1 Sketch map of Taihu Lake and location of the Yili River water sub-system with the through flow lakes Dongjiu Lake. Core DJ-5 was taken from Dongjiu Lake near the estuary of Taihu Lake with the gravity corer in September 2004

---

[1] Qin Boqiang, Fan Chengxin. Study on the relationship between economic development and ecologic environment in Taihu Lake catchment, the report of special project funded by Chinese Academy of Sciences. April, 2004 (unpublished)

Materials and methods

Sampling

A 56 cm core (DJ-5) was taken from Dongjiu Lake near the estuary of Taihu Lake (31°33′41.3″N, 119°90′08.5″E) (Fig. 1) with the gravity corer in September 2004. After discarding the sediments near the wall of the corer, the sediment was sliced with a plastic sheet. The upper 20 cm of the core was sampled with the intervals of 0.5 cm, while below 20 cm the sampling interval was enlarged to 1 cm. Finally, 76 samples were obtained.

Elementary analysis

Twenty metal elements including Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Li, K, Mg, Mn, Na, Ni, Pb, Sr, Ti, V, and Zn were determined using American LEEMAN LABS ROFILE Inductively Coupled Plasma-Atomic Emission Spectrograph (ICP-AES), after digested with the nitric acid—hydrofluoric acid—perchloric acid. Standard solution SPEX^{TM} from the US was used as the standard. Quality control was assured by the analysis of duplicate samples, blanks and reference materials (GSD-9 and GSD-11, Chinese geological reference materials).

Data analysis

The lake sediments, which mainly come from the lake drainage area, contain the inputs of the natural and the anthropogenic sources. The conservative elements such as Al are mainly from the weathering products. Al is often used as the reference element to normalize other metal elements to distinguish the anthropogenic portion from the natural background.

Due to intensive human activities, it is difficult to find uncontaminated mother rock or soil to obtain the background of metal elements in the Yili River watershed. The background values vary in different regions in Taihu Lake watershed; therefore, it is unsuitable to use the element concentrations in the soil of this area as the baseline of the Yili River (Sun and Huang 1993). The procedure of PIRLA (paleoecological investigation of recent lake acidification) study (Binford 1990) was applied to estimate the metal baseline from the elemental profile. This method calculates the mean (x) and the standard deviation (σ) of the apparently constant values found at the bottom of the core; if the next higher concentration was less than the mean value plus one standard deviation ($x + \sigma$), then this concentration was included in the set of constant values and standard deviation was recalculated. The procedure continued until the concentration in the next higher level was greater than $x + \sigma$. The asymptotic values estimated were assumed as the geochemical baselines for the different elements in the lake sediment (Table 1). For the core DJ-5, the authors could not obtain the asymptotic values for Cd, Fe, Mn and Na. Therefore, their global average concentrations in soil (Mason 1966) were used as the

Table 1 Metal concentration characteristics of DJ-5 core (unit: mg/kg)

Name of element	Global mean value in soil	Core DJ-5					
		Estimated baseline	Mean value below 43 cm	Mean value of upper 43 cm	Maximum value of whole core	Minimum value of whole core	Mean value of whole core
Al	69,300	57,190	57,216	64,797	75,463	49,494	63,647
Ba	445	374.2	374	454	504	337	442
Be	2.8	1.9	1.9	2.1	2.4	1.8	2.1
Ca	45,000	4,544	4,588	5,919	14,112	4,045	5,726
Cd	0.2			5.4	6.7		
Co	13	14.1	14.1	13.1	18.2	12.7	15.9
Cr	71	72.6	73	79	108	68	92.2
Cu	32	18.1	18	50.8	102	16.4	50.3
Fe	35,000		35,108	27,896	51,629	28,210	34,940
Li	25	35.4	32.1	40.9	50	33	40.1
K	24,000	13,780	13,783	14,823	15,943	13,098	14,670
Mg	16,400	5,590	5,574	6,050	6,478	5,270	5,978
Mn	720		748	836	1,839	286	825
Na	14,200		10,847	9,723	11,534	7,892	9,891
Ni	49	30.7	30.1	42.3	49	29	40.6
Pb	16	26.5	26.5	50.6	64	24	47.1
Sr	278	95.6	96	100	118	83	99.7
Ti	3,800	5,246	5,219	5,437	5,945	4,320	5,395
V	97	89.2	89	99.1	121	84	97.7
Zn	127	50.4	50.5	217	360	48	193.4

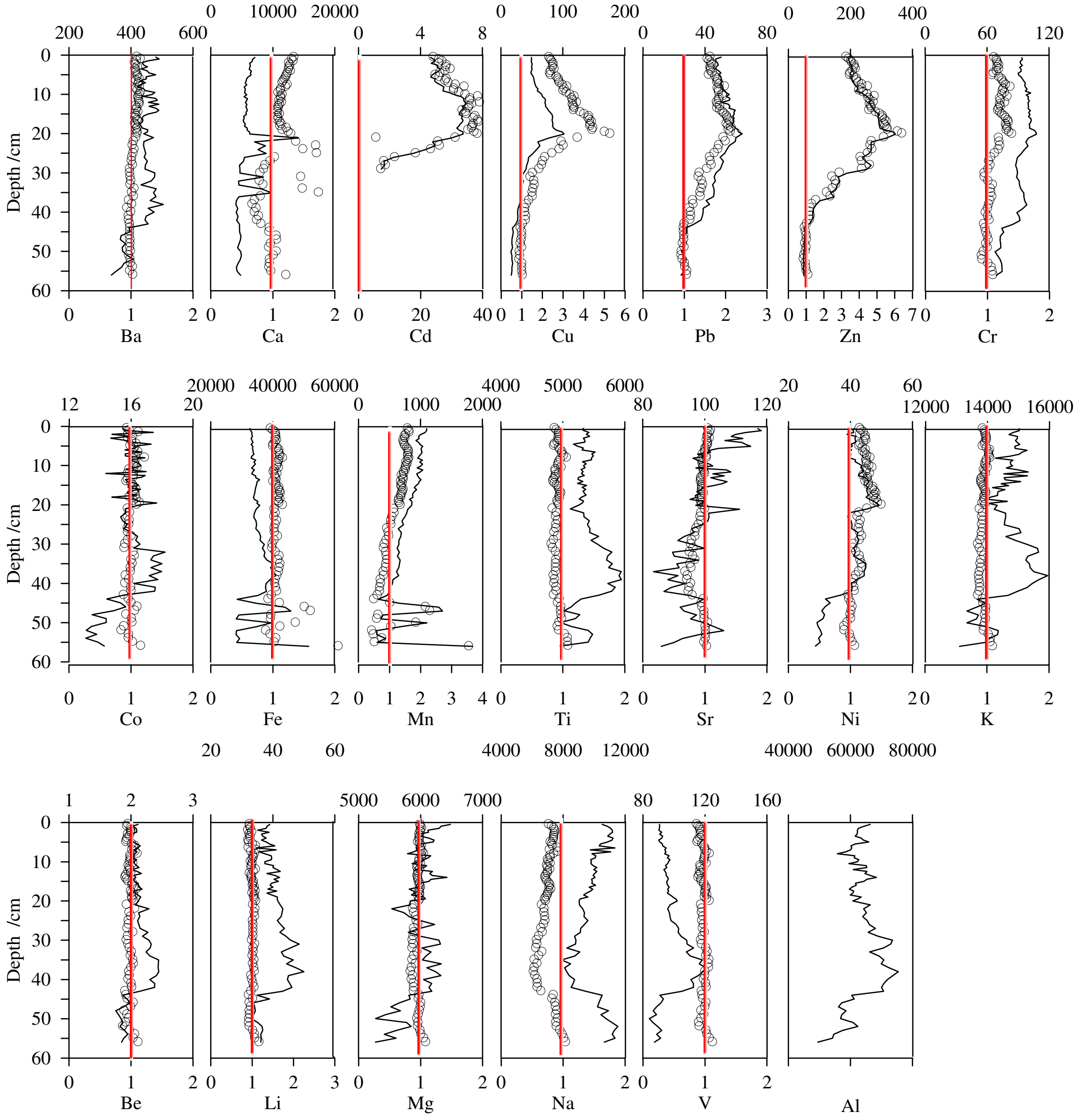

Fig. 2 Depth profiles for metal element concentrations (curves, unit: mg/kg), and the EFs (circles)

baselines to calculate the enrichment factor (EF) of each element in Donjiu Lake along core DJ-5. The EF was calculated according to the following function

$$\mathrm{EF} = (\mathrm{M}/\mathrm{Al})_{\mathrm{sample}}/(\mathrm{M}/\mathrm{Al})_{\mathrm{baseline}},$$

where M is the metal studied. Although the baselines of Cd, Fe, Mn and Na may differ from their global average concentrations in soil provided by Mason (1966), the enrichment factors (Efs) can still reflect the enrichment trends of Cd, Fe, Mn and Na.

The PCA analysis was performed using Vista 6.4. The principal components account for 85% of the total variance. The relevant components are those whose eigenvalue is higher than 1.

Results and discussion

Element concentrations of the sediments in Core DJ-5

All of the concentrations of studied elements changed distinctly around 43 cm in core DJ-5. Most had an obvious increase at 43 cm, except Na, which dropped at 43 cm. Fe and Mn fluctuated with a large extent below

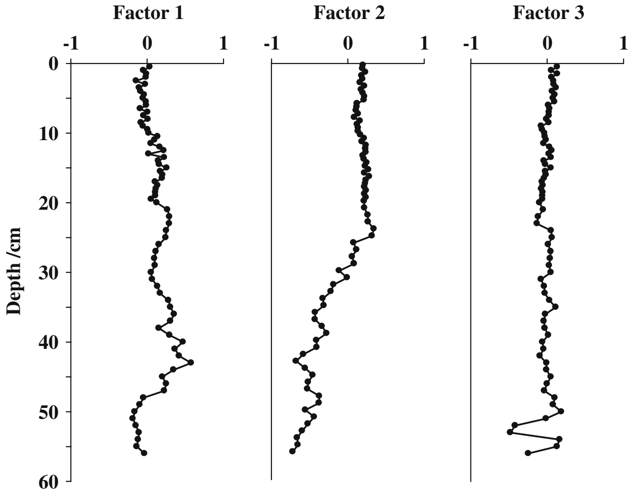

Fig. 3 Profile distribution of principal components

43 cm. According to the concentration variations in the upper 43 cm of Core DJ-5, the studied 20 elements can be divided into four groups (Fig. 2; Table 1).

The first group included Cd, Cu, Pb, Zn, Cr and Ni. Their concentrations increased obviously from 43 cm. Below 29 cm, Cd was under the detecting limit of instrument (e.g. 1 mg/kg), while it increased abruptly from 29 cm, came to its peak value 6.9 mg/kg at 20 cm, and then dropped gradually. The concentration of Cd above 29 cm was significantly higher than the Chinese Standards of Soil Environmental Quality.[2] Therefore, the Dongjiu Lake area had a serious Cd pollution problem. Cu, Pb and Zn had the same trends, and the concentrations increased from 43 cm, but dropped gradually from 20 cm where their peak values were located in the profile. The concentrations of Cr and Ni also increased rapidly from 43 cm, maintained the relative high values and then reached the maximums of 108 and 49 mg/kg, respectively, at 20 cm.

The second group included Ba, Co, Be, K, Ti, V, Al, Fe and Li, which had relatively high values from 43 to 33 cm and gradually decreased from 33 cm to the surface. The third group composed of Mn, Sr and Na, which had relatively high values below 43 cm, dropped rapidly around 43 cm and then increased continuously to the surface afterwards. The fourth group included Ca and Mg. The concentration of Ca had almost no variation along the whole profile, except some small peak values between 37 and 20 cm. The concentration of Mg varied with two stages from low value to high value; one was from the bottom to 20 cm and another from 20 cm to the surface (Fig. 2).

The PCA analysis using metal element concentrations of sediments in core DJ-5

Three significant components accounting for 84.7% of the variance were distinguished from the analyzed data (Fig. 4; Tables 2, 3).

Component 1 accounted for 40.8% of the total variance contribution. The main load variables included Al, Ba, Ca, Co, Fe, Li, K, Ni and V and the secondary variable included Cd, Cr, Cu and Ti, which indicated that the aluminosilicate weathering products were the main sources of the Dongjiu Lake sediments. The variation of factor score of the component 1 (Fig. 3) had the same trends with the concentrations of Al and Ba, which confirmed that component 1 mainly represented the materials from the weathering of the mother rock and soil erosion which controlled the distribution of the metal element concentrations in Dongjiu Lake sediments.

Component 2 accounted for 35.2% of the total variance. A high, positive loading was from Cd, Cu, Mn, Pb and Zn. Cr and Ni had also relatively high contribution. The second principal component mainly reflected the input of metal elements associated with human activities. The Mn score was only 0.06 in the first principal component, while 0.59 in the second principal component, which implied that the Mn in Dongjiu Lake sediments was mainly from an anthropogenic source, especially non-ferrous metal smelting in the Yili River catchment. Ni scored slightly higher in the first principal component than in the second principal component. Therefore, the source of Ni was mainly from the weathering products of the mother rock or soil in the basin, but the anthropogenic input of Ni increased with human activities in the past several decades. The variation of EF of Ni supported this conclusion. Cr had a positive score in the first and second principal components, but they were all relatively low. Therefore, Cr was affected by both the natural and anthropogenic factors. Cu, Cd, Pb and Zn scored much higher in the second component than in the first, indicating that the anthropogenic sources contributed more than the natural one. As a result, when the industries such as smelting and galvanization developed in this area, the concentrations of these metals increased quickly, while the concentrations decreased when these industrial scales were reduced since 1990 (Xie and Chen 2002). The variance contribution of principal components 3 accounted for 8.7% of the total, which correlated mainly with Al, Ba, Ca, K, Na, Sr and Ti.

The first and second principal components were lower below 43 cm of core DJ-5 (Fig. 3), which indi-

---

[2] Chinese Standards of Soil Environmental Quality (GB15618—1995).

Table 2 Correlation matrix for metal element concentrations

	Al	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	Li	K	Mg	Mn	Na	Ni	Pb	Sr	Ti	V	Zn
Al	1																			
Ba	0.76	1																		
Be	0.79	0.61	1																	
Ca	0.54	0.35	0.06	1																
Cd	–0.19	0.41	–0.12	0.36	1															
Co	0.61	0.65	0.71	0.09	0.15	1														
Cr	0.36	0.76	0.49	0.35	0.77	0.60	1													
Cu	–0.01	0.50	0.09	0.38	0.93	0.30	0.87	1												
Fe	0.66	0.08	0.37	–0.01	–0.25	0.40	0.01	–0.13	1											
Li	0.84	0.62	0.82	0.12	–0.17	0.58	0.43	0.09	0.34	1										
K	0.79	0.78	0.72	0.07	0.01	0.63	0.48	0.06	0.08	0.69	1									
Mg	0.29	0.22	0.24	–0.11	–0.12	0.15	0.09	–0.09	0.18	0.31	0.27	1								
Mn	–0.30	0.12	–0.19	0.19	0.54	0.17	0.29	0.41	0.46	–0.30	–0.13	–0.09	1							
Na	–0.73	–0.48	–0.80	–0.10	0.19	–0.61	–0.39	–0.10	–0.49	–0.86	–0.44	–0.21	0.24	1						
Ni	0.49	0.81	0.57	0.34	0.65	0.68	0.95	0.81	0.10	0.52	0.52	0.10	0.24	–0.51	1					
Pb	0.26	0.70	0.35	0.45	0.82	0.49	0.94	0.92	–0.06	0.32	0.35	–0.02	0.35	–0.29	0.91	1				
Sr	–0.08	0.37	–0.33	0.50	0.59	–0.10	0.26	0.39	–0.40	–0.35	0.08	–0.11	0.39	0.53	0.21	0.38	1			
Ti	0.53	0.28	0.67	–0.17	–0.32	0.41	0.15	–0.24	0.08	0.55	0.57	0.25	–0.44	–0.46	0.16	–0.07	–0.41	1		
V	0.81	0.49	0.88	–0.05	–0.35	0.66	0.31	–0.09	0.43	0.87	0.65	0.30	–0.37	–0.89	0.43	0.14	–0.56	0.70	1	
Zn	0.09	0.55	0.17	0.48	0.84	0.33	0.84	0.93	–0.11	0.18	0.16	–0.11	0.38	–0.17	0.81	0.96	0.40	–0.24	–0.03	1

Table 3 The metal element factor scores in every principal component

	Factor 1	Factor 2	Factor 3
Al	0.76	–0.45	0.21
Ba	0.88	0.14	0.22
Be	0.81	–0.46	–0.03
Ca	0.81	0.12	0.40
Cd	0.35	0.89	0.00
Co	0.80	–0.14	–0.22
Cr	0.35	0.46	0.01
Cu	0.55	0.77	–0.07
Fe	0.75	–0.34	–0.84
Li	0.79	–0.48	0.03
K	0.74	–0.28	0.33
Mg	0.23	–0.28	0.00
Mn	0.06	0.59	–0.64
Na	–0.73	0.18	0.24
Ni	0.90	0.45	–0.04
Pb	0.26	0.62	0.01
Sr	0.02	0.03	0.39
Ti	0.42	–0.63	0.26
V	0.71	–0.67	–0.06
Zn	0.20	0.72	–0.04
Eigenvalue	8.2	5.7	1.7
Component contribution (%)	40.8	35.2	8.7

cated that the metal element concentrations had been affected by other factors, except the aluminosilicate weathering products and human activities. Further work on mineral composition should be done before determining exact factors, which impacted the metal element concentrations below 43 cm of core DJ-5. The factor scores of the first and second principal components increased obviously around 43 cm, which reflected the increase of impact from the aluminosilicate, the weathering products and anthropogenic inputs. This fact indicated that the enhancing of human activities not only increased the metal element inputs, but also resulted in the acceleration of soil erosion, which brought more material from the mother rock and soil into the lake sediments.

The enrichment factors of metal elements in sediments of Core DJ-5

The correlation among the metal concentrations and their scores in the different principal components (Fig. 4; Tables 2, 3) showed that the elements of core DJ-5 were distributed mainly in two obvious clusters. Al, Be, Li and Fe were distributed in one cluster, and Cd, Cr, Cu, Pb, Mn and Zn in another cluster. Other elements dispersed outside these two clusters. Different clusters implied their different major source in the sediments. In general, Al, Be, Li and Fe mainly came from the weathering products of mother rock or soil

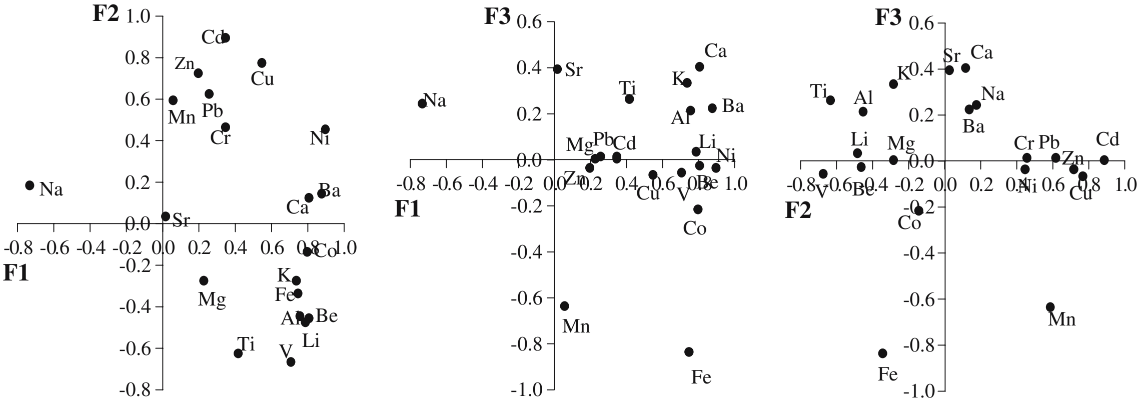

Fig. 4 Principal component loadings

(Soto-Jiménez et al. 2003; Szefer 1990). Al is an inert element, and if it is once deposited in sediments, it is difficult for it to migrate. Fe is an active metal and is apt to migrate. Be and Li concentrations are too low to be used as references to normalize other elements. Therefore, it was feasible to choose Al as the reference element to normalize the metals of Core DJ-5 and to gain their enrichment coefficients.

If the lake sediments completely originated from the initial soil or mother rock without the anthropogenic influence, the EF should be 1. When it is larger than 1, there should be another source besides a natural input which can be attributed to an anthropogenic input. The EFs of Cd, Fe, Mn and Na, which use global average concentrations as baselines, cannot quantitatively indicate the anthropogenic input variations; but they showed the variation trends of each element.

As shown in Fig. 2, the EFs of Ba, Co, Fe, Ti, Sr, K, Be, Li, Mg and V had almost no fluctuation from the bottom to the surface, which indicated that these elements in the lake sediments had little or no anthropogenic influence. The EFs of Cd, Cu, Pb, Zn, Cr and Ni kept the synchronous trends with their concentrations, which started to increase around 43 cm. This fact implies that these elements received more anthropogenic inputs from 43 cm in core DJ-5 than before. The anthropogenic input of Cd, Cu, Zn, Cr, Pb and Ni rapidly increased at 29 cm, and came to their peak values at 20 cm and decreased gradually afterwards. The anthropogenic input of metals in the Yili River catchment mainly came from the industrial sources, especially non-ferrous metal smelting, the galvanization and rolling industries (Xie and Chen 2002). As the industrial scale expanded, the heavy metal inputs to the sediments also increased. After 1990, with the limiting of heavy pollution-causing industries by the government the discharge amount of industrial wastewater reduced, resulting in a heavy metal pollutant decrease in lake sediments.

The variation of Mn concentration and its EF had the same pattern with that of Fe below 43 cm in core DJ-5. From 43 cm to the surface, the concentration of Mn increased, while Fe decreased. The EF of Mn continuously rose especially in the upper 20 cm, while the EF of Fe remained almost constant. It suggested that Mn received more anthropogenic impact than Fe although they have similar geochemical characteristics in lake sedimentary environment (Engstrom and Wright 1984; Boyle et al. 1999; Garrison and Wakeman 2000). The anthropogenic source of Mn did not decrease in the upper 20 cm while Cd, Cu, Zn, Cr, Pb and Ni decreased with the reduction of industrial scale and the limiting of polluting industries.

Conclusions

1. The metal element concentrations in the sediments of core DJ-5 reflected that Dongjiu Lake had suffered serious Cd contamination. Other heavy metals such as Cu, Cr, Pb, Zn and Mn were enriched in the upper layer of the core.
2. The results of PCA indicated that three significant components covered 84.7% of the total variances. The major contributors to the first principal component were Al, Ba, Ca, Co, Fe, Li, K, Ni and V, which represented the natural sources. The major contributors to the second principal component were Cd, Cu, Mn, Pb and Zn, which represented anthropogenic sources. The factor score of the first and second principal component had an obvious increase from 43 cm to the surface of core DJ-5, which suggested that the increase of metal inputs was the result of the enhancing of human activities

which not only elevated the input of heavy metal directly but also accelerated the soil erosion bringing more metal elements into the lake.

3. The results of EFs were coincidental with the results of PCA analysis. The EFs of Ba, Ca, Co, Fe, Ti, Sr, K, Be, Li, Mg and V fluctuated slightly, which indicated that their anthropogenic influence was slight. On the other hand, the EFs of Cu, Pb, Zn, Cr, Mn and Ni had an obvious increase from 43 cm to the surface of DJ-5, which implied that human activities, such as the galvanization and the non-ferrous metal smelting industries, which developed within the catchment, caused their obvious increase in input. In the upper 20 cm, the EFs of Cu, Pb, Zn, Cr and Ni decreased when the concentrations dropped which can be attributed to the limiting of polluting industries by the government. Mn is the exception of which the anthropogenic source did not decrease in the upper 20 cm.
4. Combining PCA and EF analysis, it can be concluded that of the 20 studied elements in the Dongjiu Lake sediments, the variation of concentrations of Cd, Cu, Pb, Mn and Zn were influenced mainly by the anthropogenic sources, while that of Cr and Ni were impacted by the natural and anthropogenic sources and the other metals were mainly influenced by the natural sources. All the inputs of metal elements were impacted by the enhancing of human activities, which resulted in a direct increase of heavy metal inputs and acceleration of the erosion causing other metal elements to deposit.

Acknowledgment This study was supported by the Chinese National Key Basic Research Project (Grant No. 2002CB412303) and the Chinese National Natural Science Foundation (Grant No. 40302022).

References

Binford MW (1990) Calculation and uncertainty analysis of ^{210}Pb dates for PIRLA project lake sediment cores. J Paleolimnol 3(3):253–267

Boyle JF, Rose N, Bennion H, Yang H, Appleby PG (1999) Environmental Impacts in the Jianghan plain: evidence from Lake sediments. Water Air Soil Pollut 112(1–2):21–40

Dai X, Sun Ch (2001) The characteristics of heavy metals distribution and pollution in sediments from Lake Taihu. Shanghai Environ Sci 20(2):71–74

Engstorm DR, Wright HE Jr (1984) Chemical stratigraphy of lake sediments as a record of environmental change. In: Haworth EY, Lund JWG (eds) Lake sediments and environmental history. University of Minnesota Press, Minneapolis, pp 11–68

Fan Ch, Zhu Y, Ji Zh, Zhang L, Yang L (2002) Characteristics of the pollution of heavy metals in the sediments of Yili River, Taihu Basin. J Lake Sci 14(3):235–241

Garrison PJ, Wakeman RS (2000) Use of paleolimnology to document the effect of lake shoreland development on water quality. J Paleolimnol 24(4):369–393

Green-Ruiz C, Páez-Osuna F (2001) Heavy metal anomalies in lagoon sediments related to intensive agriculture in Altata-Ensenada del Pabellon coastal system (SE Gulf of California). Environ Int 26(4):265–273

Horowitz AJ, Rinella FA, Lamothe P, Mlller TL, Edwards TK, Roche RL, Rickert DA (1990) Variations in suspended sediment and associated trace element concentrations in selected riverine cross sections. Environ Sci Technol 24(9):1313–1320

Loska K, Wiechula D (2003) Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik reservoir. Chemosphere 51(8):723–733

Luoma SN, Bryan GW (1981) A statistical assessment of the form of trace metals in oxidized estuarine sediments employing chemical extractants. Sci Total Environ 17:165–196

Mason B (1966) Principal of Geochemistry, 3rd edn. Wiley, New York

Soto-Jiménez M, Pánez-Osuna F, Ruiz-Fernández AC (2003) Geochemical evidences of the anthropogenic alternation of trace metal component of the sediments of Chiricahueto marsh (SE Gulf of California). Environ Pollut 125(3):423–432

Sun Sh, Huang Y (eds) (1993) Taihu. Ocean Press, Beijing, pp 229–230

Szefer P (1990) Mass-balance of metals and identification of their sources in both river and fallout fluxes near Gdansk Bay, Baltic Sea. Sci Total Environ 95:131–139

Szefer P, Szefer K, Glasby GP, Pempkowiak J, Kaliszan R (1996) Heavy-metal pollution in surficial sediments from the southern Baltic Sea off Poland. J Environ Sci Health 31A(10):2723–2754

Tam NFY, Yao MWY (1998) Normalization and heavy metal contamination in mangrove sediments. Sci Total Environ 216(1–2):33–39

Tuncer G, Tuncel G, Balkas TI (2001) Evolution of metal pollution in the Golden Horn (Turkey) sediments between 1912 and 1987. Mar Pollut Bull 42(5):350–360

Windom HM, Schropp SJ, Calder FD, Ryan JD, Smith RG Jr, Burney LC, Lewis FG, Rawlinson CH (1989) Natural trace metal concentrations in estuarine and coastal marine sediments of the southeastern United States. Environ Sci Technol 23(3):314–320

Xie H, Chen W (2002) Impacts of change of industrial structure on the water environment in Taihu Basin: a case study of Suzhou-Wuxi—Changzhou District. J Lake Sci 14(1):53–59