Sediment Pollution of Heavy Metal and Potential Ecological Risk Assessment in Baiyangdian Lake, China

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ABSTRACT: Baiyangdian Lake, the largest freshwater lake in North China, is known as "Pearl of North China" and "kidney of North China" for its abundant products and multiple ecological services. However, from the 1970s, due to the ever-increasing discharge of polluted water from upstream rivers, it has been severely polluted. Sediment investigation and analysis were conducted on contents of heavy metal (Cu, Zn, Cd and Pb) from Baiyangdian Lake in June 2004. Results showed that pollution situation at downriver regions are more serious than that of upstream regions. The seriously polluted spots are access of Fuhe River, original wastewater reservoir of Tanghe River, densely populated Chunshui Village and Wangjiazhai Village. By using method of the potential ecological risk assessment, the heavy metal evaluation of polluted sediment has been conducted. The results showed that the contents of Cd and Pb were very high in sediment of Baiyangdian Lake. There were extremely stronger ecological risk for Cd and slight-medium ecological risk for Pd. According to the current situation of Baiyangdian Lake, countermeasures and suggestions have been put forward.
Keywords: sediment, heavy metal, geoaccumulation, ecological risk, Baiyangdian Lake

1 INTRODUCTION

Before the 1970s, the sediment is simply regarded as "sink" of pollutants in aquatic environment. In company with stepwise effective control of point pollution source in aquatic environment, the polluted sediment begins to become one of the nonnegligible non-point sources (Li, 1998). Sediment has become sink and source of the transfer and transformation of various pollutants (Chu, et al., 1999). In recent years, people have paid general attention to improvement and regulation of water body polluted by heavy metal and organic pollutants, and water body of eutrophication. Measures of biologic rectification, pollution control technology and diluting effect of water transfer have improved the water quality obviously, but contents of each element in sediment are still increasing year by year. It counts for much to estimate the distributive status, variation of contents and pollution tendency of nutrient elements and heavy metals in sediment.

The shallow water lakes of Baiyangdian in North China, was chosen as study areas in this paper in order to study the sediment. Sediment investigation and analysis were conducted on contents of heavy metal (Cu, Zn, Cd and Pb) from Baiyangdian Lake in June 2004. By using method of the potential ecological risk assessment, the heavy metal evaluation of polluted sediment has been conducted.

2 STUDY AREA AND METHOD

Baiyangdian Lake lie in north latitude 38° 44 ' - 59 38° ', east longitude 115° 45 ' - 116° 06 ', located in 40 km east of Baoding City, Hebei Province, 130 km south of Beijing, the largest natural freshwater body in North China Plain, with a surface area of 366 km^2. Accepting waters from different rivers including Zhulong, Xiaoyi, Tanghe, Fuhe, Caohe, Puhe and Pinghe (these are the southern tributary rivers of the Daqing River), this natural fan-shaped river net is formed by multiple rivers and brooks flowing from the west to the east and from the south to the north. There are 143 lakelets of different size including Zhengdian, Mapengdian, Shaochedian and Zaozhadian as well as over 3700 water channels and ditch in the whole Baiyangdian Lake. Reed fields occupy 8000 hm^2, accounting for 22 % of the lake area. A unique landscape of lake in lake, channels intercrossed with channels and farmlands intersected with waters is therefore formed (Region Office of Anxin, 1996).

With the rapid social and economic development, typical shallow water lakes at suburb of cities both in the South and North pass through pollution of water body and sediment to different extent. For many years, precipitation at Baiyangdian Lake has decreased, loss of water and soil in upstream, reservoir heads off stream, intake of sewage discharged by cities and industries, as well as runoff water from agricultural non-point pollution sources, for all these reasons, this lake is shallowing, and its area is shrinking, contents of nutrient elements in lake water and sediment has risen, the lake is in the course of swamp ecotype, declination and contabescence (Liu, 2004). Based on the lake classification criterion which is constituted by OECD, and widely adopted in international now, Baiyangdian Lake has fallen into eutrophication type.

On June 2004, 41 sediment samples at 21 spots were collected in an all-round way in Baiyangdian Lake, divided 0-10 cm, 10-20 cm. All the samples were contained in polyethylene bags and transported to the laboratory for analysis. In the laboratory, each sample was homogenised and sieved through a 0.16-mm plastic sieve for the analytical programmes after being air dried. The position of collected samples is showed in Fig 1.

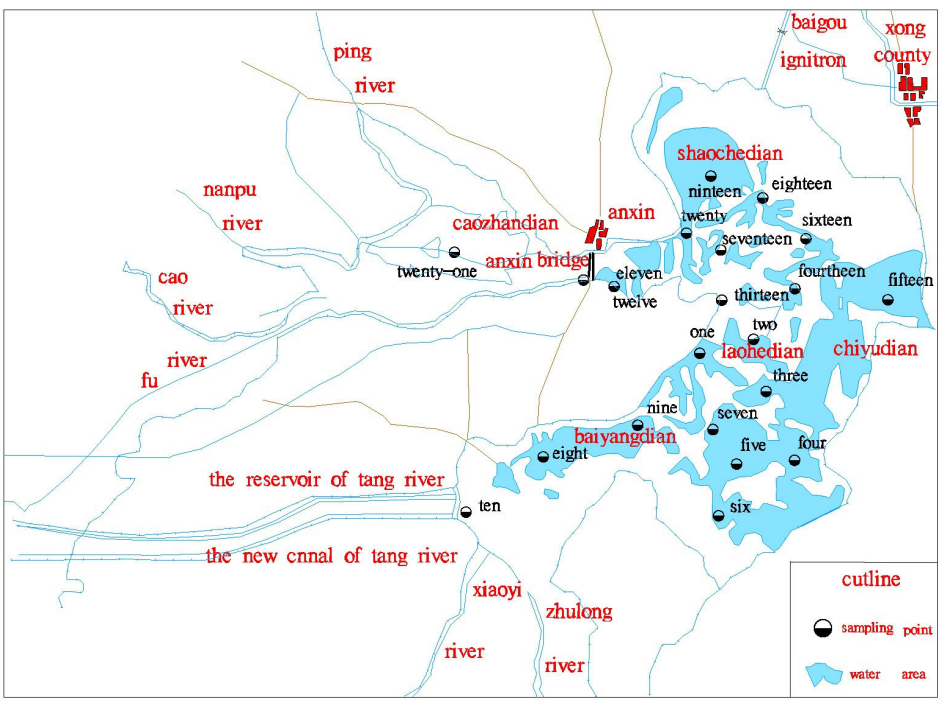

Fig. 1 Distribution of sampling locations in sediment of Baiyangdian Lake

(Note: one-Dadiantou, two-Laowangdian, three-Dongdian, four-Fanyudian, five-Qiantang, six-Liangzhuang, seven-Datianzhaung, eight-Guancheng, nine-Duancun, ten-Anxin bridge, eleven-Nanliuzhuang, thirteen-Zhainan,

fourteen-Guangdianzhangzhuang, fifteen-Zhaolinzhuang, sixteen-Liuzhuangzi, seventeen- Wangjiazhai, eighteen-Guolikou, nineteen-Shaochedian, twenty-Dazhangzhuang, twenty-one- Zaozhadian)

Total nitrogen (TN) is measured by mixed catalyst digestion-Kai's azotometer distillation-standard vitriol titration method; total phosphorus (TP) by $HClO_4$-H_2SO_4 digestion-molybdenum, antimony and scandium colorimetry; organic matter (OM) by potassium dichromate volumetric procedure-external heating method; Pb, Cd, Cu, and Zn by HCl-HNO_3-$HClO_4$ to digest, and atomic absorption spectrophotometry (Lu, 1999).

3 RESULS AND ANALYSIS

3.1 Comparison of contents of heavy metal of sediment in 19 Chinese lakes

The distribution and contents of heavy metal of sediment in 19 Chinese lakes listed in Fig. 1 and Table 1.

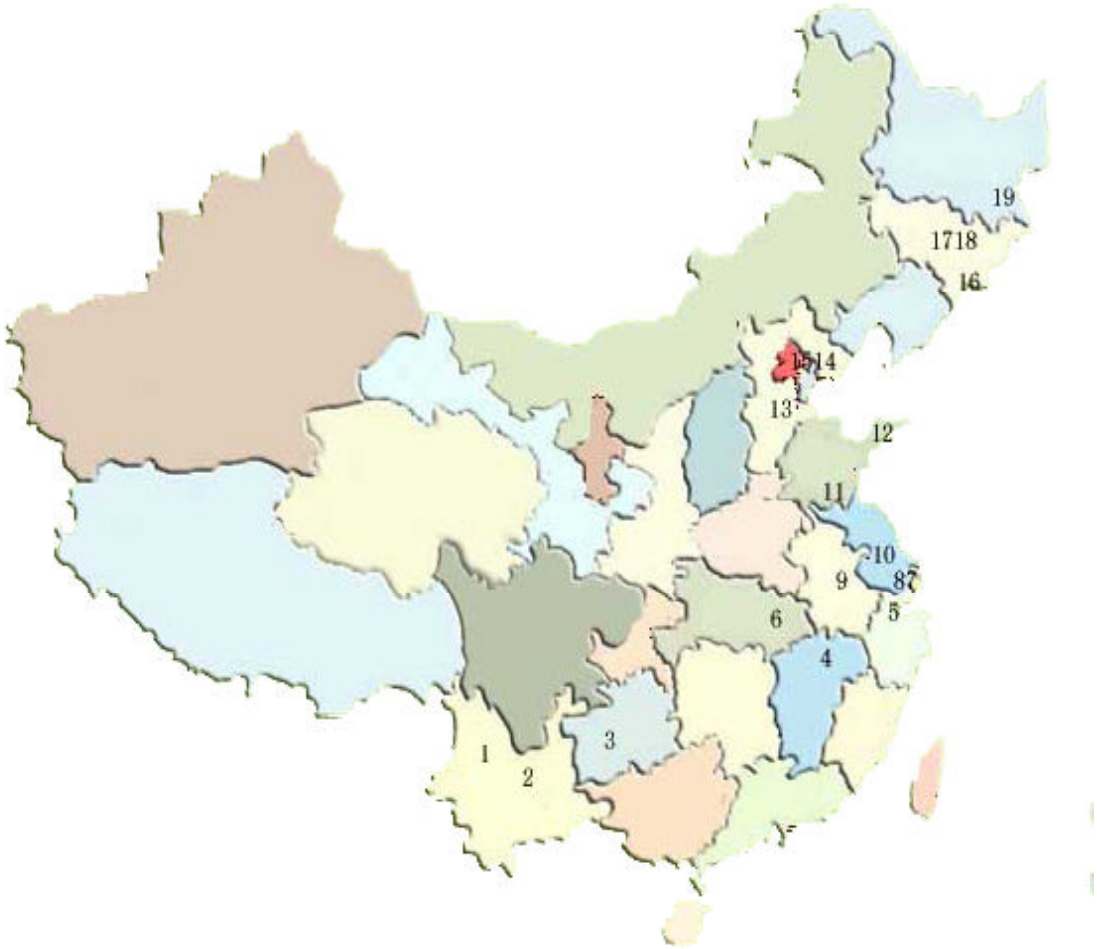

Fig. 1 Distribution of 19 Chinese Lakes

Note：

1 Erhai lake of Yunnan; 2 Dianchi lake of Yunnan; 3 Honfeng lake of Guizhou; 4 Boyang lake of Jiangxi; 5 West lake of Zhejiang; 6 East lake of Hubei; 7 Yangcheng lake of Jiangsu; 8 Taihu lake of Jiangsu; 9 Chaohu lake of anhui; 10 Xuanwu lake of Jiangsu; 11 Nansihu lake of Shandong; 12 Wanyue lake of Shandong; 13 Baiyang lake of Hebei; 14 Weiming lake of Beijing; 15 Kunming lake of Beijing; 16 Changbai lake of Jilin; 17 Nanhu lake of Jilin; 18 Songhua lake of Jilin; 19 Jingpo lake of Heilongjiang

Table 1 Contents of sediment heavy metal in 19 Chinese Lakes (mg/kg)

Lake	Cu	Zn	Cr	Pb	Cd	Hg	Ni	As
Erhai lake	111.0	127.0	130.0	60.0	0.59		80.0	
Dianchi lake	920.0	2208.0	55.0	647.0	164.85		466.0	
Honfeng lake	32.0	177.4		26.6	0.88	0.42		
Boyang lake	22.0	64.4	51.7	28.7	<0.5	0.03		
West lake	20.6	88.6	68.5		0.43	1.50		17.7
East lake	53.0	240.0		45.0	2.63			
Yangcheng lake	38.7	132.0	111.0	60.1	0.28		37.7	
Taihu lake	97.4	223.1	96.2	72.5	0.49	0.09	40.3	21.4
Chaohu lake			52.8	43.0	0.46	0.24		8.9
Xuanwu lake	56.6	592.3	73.8	36.9	0.27	1.77	52.1	11.0
Wanyue lake	13.1	17.3	36.1	6.7	0.15			
Nansihu lake	38.9	89.6	54.5	19.1		0.09	40.3	12.2
Baiyang lake	30.6	111.3		54.6	7.03			
Weiming lake	12.0	153.6	104.0	26.0				
Kunming lake			66.5	28.7	1.90	0.06		
Nanhu lake	27.7	239.6		15.8	0.59			
Changbai lake	29.3	196.0	35.7	50.0	2.00		20.0	
Songhua lake	137.3	224.1	85.6	34.3	0.82	2.10	101.2	
Jingpo lake	22.4	84.6	82.8	12.1	0.48	0.11	39.3	7.3

From Table 1, it can be seen that Dianchi lake is the most polluted lakes among 19 lakes except Cr. The contents of Cu, Zn, Pb, Cd and Ni are 920, 2208, 647, 164.8 and 466 mg/kg, respectively. The maximum contents of Cr is 130 mg/kg in Erhai lake of Yunnan province. The maximum contents of Hg is 2.10 mg/kg in Songhua lake of Jilin province. The maximum contents of As is 21.4 mg/kg in Taihu lake of Jiangsu province. The minimum contents of Cu, Zn, Cr, Pb, Cd, Hg, Ni and As are 12.0 in Weiming lake of Beijin, 17.3 Wanyue lake of Shangdong, 35.7 Changbai lake of Jilin, 6.7 Wanyue lake, 0.15 Wanyue lake, 0.03 Boyang lake of Jiangxi, 20.0 Changbai lake and 7.3 mg/kg Jingpo lake of Heilongjiang, respectively.

3.2 Analysis and comparison of heavy metal contents of sediment in Baiyangdian lake at different stage

Microelements of sediments are initially derived from weathering of parent rock, mans activity leads some elements to accumulate, and invokes environmental pollution. Research of the world's lacustrine deposits show that augments of heavy metal elements is a vital environmental pollution problem (Fjeld et al 1994; Islam, 2000). Table 2 displays cruising data of sediment at Baiyangdian. The results indicated that average contents of heavy metal Cu, Zn and Pb in sediment don't exceed the value of 3 environmental quality standards listed in the Table 2. While Cd in sediment at Baiyangdian is seriously polluted, whose content is 16.7 times of Taihu, maximum of Cd at Baiyangdian is 7.0 times of that of Taihu, and minimum content of Cd at Baiyangdian is 47.0 times of that of Taihu; and Cd at Baiyangdian is 11.7 times of soil environmental quality standards (second grade), also exceeding quality standards of marine sediment (2nd and 3rd kind).

Major sources of Cd are from wastewater, sludge and exhaust gas from smelting, plating, dye industry, besides, gasoline and tyre also contain Cd. Cadmium has great toxicity to human and warm-blooded animal, when human body intake cadmium, Cd albumen is formed in vivo, and reach at every pore through blood, and is laid aside selectively in organs such as kidney, liver etc. Cadmium has even greater toxicity to fishes and other aquatic

animals, and has an effect of accumulation in aquatic animal body (Cheng, 2002). Cd pollution of sediment at Baiyangdian should receive high regard.

Table 2 Contents of heavy metal in Baiyangdian lake and the related standard（mg/kg）

Item		*Cu*	*Zn*	*Cd*	*Pb*
Baiyangdian Lake	Range	12.13 ~ 64.14	59.53 ~ 236.38	5.17 ~ 10.43	33.38 ~ 85.70
（2004）	Average	30.66	112.33	7.03	54.61
Taihu Lake (2000)	Range	22.0 ~ 72.90	53.7 ~ 202.0	0.11 ~ 1.50	27.0 ~ 67.9
(Yuan, 2003)	Average	35.84	102.62	0.42	40.14
Soil Environment Standard（pH>7.5）		100	250	0.6	350
Pollutant Standard of Sludge		500	1000	20	1000
Ocean Sediment	Second kind	100	350	1.50	130
Standard	Third kind	200	600	5.00	250

From Fig. 3, content of Cu of sediment at Baiyangdian Lake area does not change much, the value in 2004 is only 0.87 mg/kg higher than that in 1980, and does not differ much with the soil background value of north China either (30.5 mg/kg on plain, 34.8 mg/kg in mountains). Content of Zn is raised impressively, but hasn't constituted a threat. Content of Pb is in a tendency of scaling up year by year. Pollution of Cd is exceptionally serious, having already become 77 times of that of 1980. After entering anaphase of the 1980s, the climate is continuously droughty, once assume basically a phase of waterless for 5 sequential years. Content of pollutants arrived at the minimum in 1994, a period when administration of Baiyangdian stepped into the right path, various rules and regulations were worked up successively, and seriously polluting minor enterprises were closed down one after another.

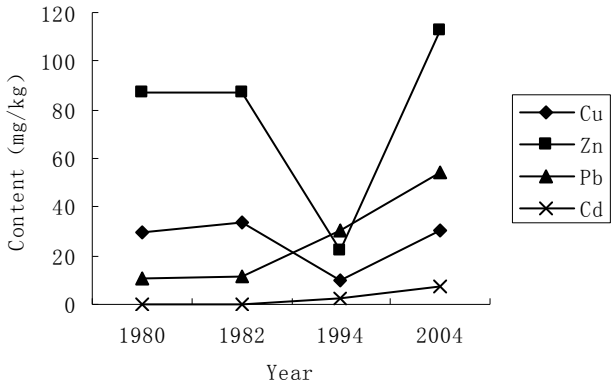

Fig. 3 The changes of sediment contents of heavy metal in Baiyangdian lake

3.3 Analysis on distribution features of heavy metal in sediment

In overview of analysis on many previous findings of sediment pollution in Baiyangdian Lake is caused by emission of wastewater from Fu River, sewage affiliation river of Baoding City and haphazard emission of

domestic sewage from the lake region. Special geographical surrounding leads to special environmental problems, at Baiyangdian cottages are surrounded by water, and water is contained in cottage, at densely populated Chunshui Village is almost secluded from the outside, abundant domestic garbage is freely piled up, sewage is freely emitted, bringing about a severe threat to water environment..

Pollution of sediment in Baiyangdian principally presents following features: upstream are more serious than downriver regions; surface layer of 0-10 ㎝ is serious than 10-20 ㎝, the more nearer from drainage mouth, the more serious pollution is. In Lake region where villages are densely located and population is big, water quality is bad, content of heavy metal is high, and enclosed fish farming, duck and crab cultivating fields will aggravate pollution. Seriously polluted spots are access of Fu River, original wastewater reservoir of Tang River, densely populated Chunshui Village and Wangjiazhai Village, and etc..

3.4 Potential ecological risk index assessment of heavy metal

By using method of the potential ecological risk index assessment, the heavy metal evaluation of polluted sediment has been conducted in Baiyangdian lake. The results showed that the contents of Cd and Pb were very high in sediment of Baiyangdian lake. There were extremely stronger ecological risk for Cd and slight-medium ecological risk for Pd (Table 3). The maximum location of ecological risk index (RI) is the Dadiantou among 21 location surveyed. The Shaochedian ranked second.

Table 3 Ei of heavy metal and RI of location with relatively high polluted degree of sediment in Baiyangdian lake (regard local background value as the contrast)

Location	No.	E_i				RI
		Cu	Zn	Pb	Cd	
Dadiantou	1	6.13	1.44	37.8	4226.9	4272
Shaochedian	19	4.62	1.45	33.1	3973.6	4012
Guancheng	8	6.84	1.71	31.9	3309.5	3350
Wangjiazhai	17	4.61	1.70	25.9	3301.6	3334
Nanliuzhuang	12	7.14	2.94	32.6	3225.8	3268

4 ANALYSIS ON CAUSE OF POLLUTION AND SOME SUGGESTION

4.1 Analysis of cause of pollution

As a typical shallow water lakes at the North, Baiyangdian both provide condition and foundation for peripheral urban economy development. There are analogous and different aspects on pollution cause and emphasis of treatment in existence. Due to heterogeneity of pollutants import, differentia among pollutants content at different areas are quite much. Pollution of Baiyangdian is created equally by immoderate discharge of wastewater. In virtue of survey of the cooperation group on Baiyangdian pollution scientific research, totally 197 plants vent sewage on the upstream regions. Based on survey of 137 factories, wastewater quantity per day is 336 thousand tons, paper manufacture, chemical industry, electric power, dye printing and petroleum industry are 5 trades which discharge most quantity thereinto, occupying 94.2% of overall amout. For the moment, 20 vital contaminative enterprises are located on the upstream of Baiyangdian. Main pollutants in industrial wastewater are COD, BOD, sulphide, volatile phenols, suspended matter, petroleum, zinc, lead, mercury, cadmium, chrome, arsenic, cyanide etc. In addition, domestic sewage is completely drained into the lake; otherwise, some small civilian plants with miserable equipment, mostly without sewage disposal system, sewage and industrial refuse are emitted optionally. Enclosed fish farming are everywhere in the lake, which will bring pollution to the lake.

4.2 Suggestion

Aiming at actuality of pollution in Baiyangdian and living actuality of the people in the lake region, scientific management of the lake region and drainage mouth on the upstream is keystone of the disposal. So far, 2 macro scale sewage treatment plants have been built up in Baoding City, treated industrial wastewater is drained into the lake by Fuhe River. On a near day, regulating engineering is carried out in Fu River, so it is no doubt that ecologic setting of Baiyangdian will be improved.

The department concerned must execute strict law enforcement, and reinforce management. Pollution treatment facility should keep normal running, and be strictly prohibited being left unused. Industrial wastewater and domestic sewage drained into the lake must be admitted into network for centralized processing and emission. Exercise strict control over seriously polluting minor enterprises and village-and-town enterprises without sewage treatment capability.

Pursue "clean production". Various byworks in the lake region such as enclosed fish farming, duck and crab breeding, as well as their density, must be effectively controlled. domestic garbage of local people is to be integrated processed. It is necessary to insist upon the local traditional modus operandi of using canal mud as fertilizer, instructively dredge mud for fertilizer on the premise of without causing soil pollution. Thus may both stabilize crop yield of reed as representative, also dredge up polluted sediment in the lake region.

Number of oil-using vessels and quality of oil must be controlled, to prevent oil pollution and so-induced oxygen deficit of water bodies.

Apart from strengthening control of major industrial pollution sources, improving the purification ability of non-point pollutants in the regional environment should be the main approach to control the pollution in this region. On the basis of analysis, investigation and simulative experiments, the control of sources and runoff techniques and measures pollution involving ecological fertilization, conservation of soil and water, sewage and solid waste treatment and establishment of ecological buffer zones and wetland ecological systems were put forward to control the pollution in the Baiyangdian Lake.

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