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Original Research

Pollution and Potential Ecological Risk Assessment of Heavy Metals in a Lake

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Abstract

This research was undertaken in order to determine and analyze various heavy metals present in sediments taken from Lake Donghu. Six heavy metals: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Relative enrichment factors and potential ecological risk indexes were used to study the pollution status of heavy metals in sediments and assess their potential ecological risk to the environment. Sediment enrichment factors of heavy metals were found in the following order Cr > As > Cd > Zn > Cu > Pb. Potential ecological risk indices for heavy metals were: Cd > As > Cr > Cu > Pb > Zn. The calculated potential ecological risk indices showed that the lake was polluted by heavy metals. Cd had moderate potential ecological risk to the ecological environment and was the main contributor to potential toxicity response indices for various heavy metals in Lake Donghu. Analysis of variance (ANOVA) was used to establish the significance of variations in heavy metals. The mean seasonal concentrations of metals showed that there were significant differences among seasons and sampling sites ($P<0.05$). The cause of pollution in Lake Donghu could be associated with industrial and human activities. We proposed strategies that can be applied in order to prevent accumulation of heavy metals in the lake.

Keywords: heavy metals, sediments, Lake Donghu, potential ecological risk index, sediment enrichment factor method

Introduction

Studies on heavy metals in sediments are vital in order to understand their impact on water ecosystems. Heavy metals are important environmental pollutants threatening the health of human populations and natural ecosystems [1-3]. Sediments, as one of the basic components of our environment, provide foodstuffs for living organisms. Sediments also serve as a sink and reservoir for a variety of environmental contaminants [4, 5] and sediments usually provide a record of catchments input into aquatic ecosystems [6]. Heavy metals are usually present at low concentrations in aquatic environments, but deposits of anthropogenic origin have raised their concentrations, causing environmental problems in lakes. There has been an increasing interest in finding out the concentration of metals present in marine sediments [7-16]. Many studies have found that heavy metals such as cadmium (Cd), chromium (Cr), and copper (Cu) occur naturally in water, soil, and biota, and are important and necessary micronutrients for living organisms, but toxic to certain concentrations. Their concentrations depend on local geology as well as anthropogenic activities [17-21]. Elevated levels of these heavy metals in the environment may arise from natural or anthropogenic routes [22, 23],

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including consumption of food from contaminated environments [23-28].

Lakes provide so much in the way of recreation, including fishing, boating, and swimming. They also provide important wildlife habitat for aquatic animals, hence the importance for the clarification of the information on concentration of heavy metals and their potential ecological risk. A variety of methods have been developed for the assessment of heavy-metals risk, including:

1. sediments enrichment factor
2. index of geological accumulation
3. pollution load index
4. potential ecological risk index
5. Nemerow synthetical pollution index
6. integrated pollution index
7. secondary phase enrichment factor [29, 30].

The method of potential ecological risk index is the only method that considers both concentrations and toxic response factors of heavy metals, and has been commonly employed due to the following advantages:

(i) R_i-value will increase when sediment contamination increases

(ii) a lake polluted by numerous substances will have a higher R_i-value than an area contaminated by only a few substances

(iii) various elements have different toxicological effects, among which some are highly toxic and others slightly toxic [31].

Ecological risk management provides policy makers and resource managers as well as the public with systematic methods that can inform decision making. A number of studies have applied this method [32-34].

The aim of this study is to assess the water quality of Lake Donghu (also known as East Lake) in terms of heavy metals by determining their concentrations from the samples taken from different locations in the lake. The relative enrichment factors and the potential ecological risk index were used to study the pollution status of heavy metals in sediments and assess their potential ecological risk. The concentrations of different heavy metals in sediment samples as well as their seasonal variations were analyzed systematically. The results provide a comprehensive sediment contamination status of heavy metals and the potential origin of contamination in the lake, giving insight into decision-making for water source security.

Materials and Methods

Description of the Study Area

Fig. 1 shows the details of sampling sites. Lake Donghu (30º33ºN, 114º23ºE) is 20.5 m above sea level, has a surface area of 32 km^2, its catchment area is 97 km^2, the mean depth is 2.2 m, and the maximum is 4.8 m. It is a shallow freshwater lake located in Wuhan city, the capital of Hubei Province, China. It is a natural dammed lake located on the right bank of the Yangtze River, which flows through Wuhan and is five kilometers away from the river [35]. From 1960 to the 1970s, Lake Donghu was separated from the Yangtze River by dams. The lake itself is composed of several bays separated by artificial dikes.

Donghu is exposed to domestic waste and industrial effluents. The drainage volume has been beyond the self purification capacity. A great number of atmospheric particles arising from the industrial processes such as the high combustion of coal-based power generation, iron and steel manufacture, and non-ferrous metal smelting fall into the

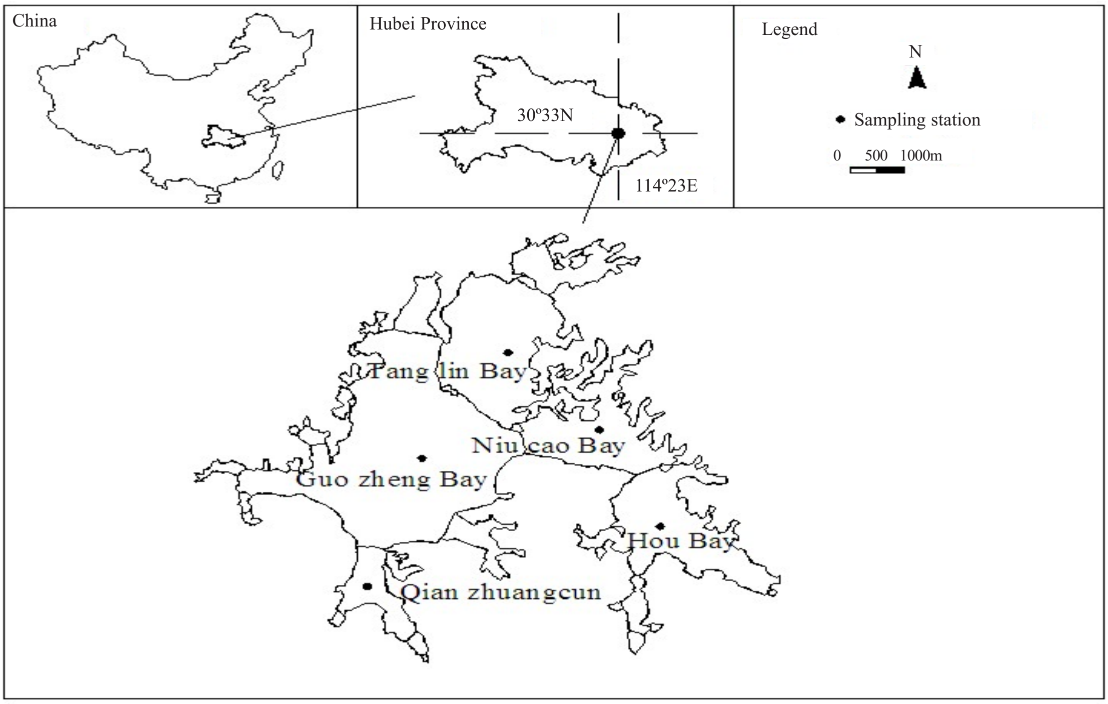

Fig. 1. Map showing sampling locations in Lake Donghu.

lake. Eroded sediments, debris, and other pollutants washed from watersheds also are deposited into the lake by inflowing streams. The increasing density of fish as well as the inflow of waste water from the city and industrial factories has caused a rapid change in the lake's biota [36]. The lake has experienced significant changes in the past, and become more polluted due to such human activities as the discharge of residential wastewater and the construction of roadway dikes. For a long time, it has become a model system for freshwater ecosystem studies.

The lake is divided into five different bays. The lake area, especially the northwestern coast, is a park and recreational area for the citizens of Wuhan, with museums, a botanical garden, observation towers, restaurants, beautiful groves of exotic swamp cypress, swimming sites, and sightseeing boats. It also is intensively utilized for fish production. There are many industries, hospitals, and factories, including a big steel plant located near the lake. There are many sewage inlets, and through these outlets domestic and industrial effluents enter the lake.

Collection and Treatment of the Samples

Sediment samples were collected monthly from April, 2008 to Mach 2009 and were taken from 5 different bays of the lake, namely: Tanglin, Guozheng, Niucao Hou, and Qianzhuancun. They were put in glass bottles (1000 cm^3) that had been cleaned with 5% HCl (v/v) and 5% HNO_3 (v/v), and transported to the laboratory for analysis. Sampling locations were selected based on the size and the shape of the lake. Due care was taken to prevent cross contamination during sample collection. Each sample was given a unique identifier to reflect the sample origin and sampling date .Samples were preserved in a refrigerator at -20ºC within 24 hours after collection till analysis. All these samples were air dried at room temperature and sieved through a 2-mm nylon sieve to remove coarse debris. Powdered samples were digested with an $HClO_4/HNO_3/HF$ mixture in Teflon tubes for total heavy metals analysis [37]. The solution of the digested sample was analyzed by inductively coupled plasma atomic absorption spectrometry (ICP/AES). Quality assurance and control were assessed using duplicates, method blanks, and standard reference materials.

Ecological Risk Assessment

Accumulating Status of Heavy Metals

Accumulating coefficients of heavy metals in sediments taken from the five different locations were computed and applied to indicate the accumulating status of heavy metal in the sediments from each sampling location. The computing equation for accumulating coefficient C_f^i is as follows:

$$C_f^i = C_m^i / C_n^i \quad (1)$$

...where, C_m^i is the value of heavy-metal concentration in the sediment samples, and C_n^i is the pre-industrial background values in sediments, mg/kg.

Pre-industrial reference levels (Pb 70.00 mg/kg, Cd 1.00 mg/kg, As 15.00 mg/kg, Cu 50.00 mg/kg, Zn 175.00 mg/kg, and Cr 90 mg/kg) were applied for the calculations of C_f^i, since they have been most frequently employed in this field of study [38]. The pre-industrial reference levels, which had been determined from about 50 lakes from Europe and America and were tested on 15 Swedish lakes, represent the "upper limit" of heavy metals in normal sediment particulates before global industrialization [39]. Therefore, the accumulating coefficient calculated in this study indicates the actual pollution status and presents some information about pollution-loading of heavy metals in sediments caused by local industrialization processes.

Heavy-Metal Potential Ecological Risk

The potential ecological risk index method developed by Häkanson was applied in this study. According to this method, the potential ecological risk coefficient E_r^i of a single element and the potential ecological risk index R_i of multi-element can be computed via the following equations:

$$E_r^i = T_f^i \times C_f^i \quad (2)$$

$$R_i = \sum_{i=1}^{n} E_r^i \quad (3)$$

In these equations: C_f^i is the accumulating coefficient of element *i* and T_f^i is the toxic-response factor of element *i* (which reflects its toxicity levels and the sensitivity of bio-organism to it). The toxic-response factors for common heavy metals Pb, Cd, As, Cu, Cr, and Zn were 5, 30, 10, 5, 2, and 1, respectively.

Results and Discussion

Ecological Risk Assessment of Heavy Metals

According to the calculated accumulating coefficients (Table 2), Cadmium was the main heavy metal polluting the lake and its E_r^i mean value was 68.5. The potential ecolog-

Table 1. Criteria for degrees of ecological risk caused by heavy metals in sediments [40].

R_i or E_r^i	Ecological pollution degree
$E_r^i < 40$ or $R_i < 150$	Low ecological risk for the water body
$40 \leq E_r^i < 80$ or $150 \leq R_i < 300$	Moderate ecological risk for the water body
$80 \leq E_r^i < 600$ or $300 \leq R_i < 600$	Considerable ecological risk for the water body
$160 \leq E_r^i < 320$ or $600 \leq R_i$	Very high ecological risk for the water body

Table 2. C_f^i of heavy-metal in sediments from Lake Donghu.

Sampling stations	As	Cd	Pb	Zn	Cu	Cr
Qian Zhuang cun	2.94	2.07	0.24	1.31	0.80	3.87
Guozheng Bay	4.06	2.38	0.22	1.01	0.73	4.19
Tangli Bay	3.63	2.22	0.23	0.95	0.67	4.24
Niucao Bay	3.51	2.20	0.20	0.78	0.68	4.32
Hou Bay	3.82	2.55	0.30	0.86	0.71	3.87
Mean	3.59	2.28	0.24	0.98	0.72	4.10

Table 3. E_r^i and R_i of heavy-metal in sediments from Lake Donghu.

Sampling stations	E_r^i						R_i
	As	Cd	Pb	Zn	Cu	Cr	
Qian Zhuang cun	29.4	62.1	1.2	1.3	8.0	7.7	109.8
Guozheng Bay	40.6	71.4	1.1	1.0	7.3	8.4	129.8
Tangli Bay	36.3	66.6	1.2	1.0	6.7	8.5	120.2
Niucao Bay	35.1	66.0	1.0	0.8	6.8	8.6	118.3
Hou Bay	38.2	76.5	1.5	0.9	7.1	7.7	131.9
Mean	35.9	68.5	1.2	1.0	7.2	8.2	122.0

Table 4. The mean monthly concentrations in Lake Donghu.

Seasons	As	Cd	Cr	Cu	Pb	Zn
Spring	46.41	2.24	20.14	194.92	58.71	368.45
Summer	50.68	2.16	19.86	158.52	27.69	391.21
Autumn	54.2	2.32	13.83	229.25	39.87	352.88
Winter	56.84	2.17	14.67	184.77	38.84	375.36

ical risk indices were found in the following order Cd > As > Cr > Cu > Pb > Zn (Table 3). The mean of heavy metals studied were: Cr > As > Cd > Zn > Cu > Pb (Table 3). The mean accumulating coefficients of Cr, As, Cd, Zn, Cu, and Pb were found to be 3.59, 2.28, 0.24, 0.98, 0.72, and 4.10, respectively. All the values of R_i in the sediments were less than 150: Qian Zhuang cun 109.8, Guozheng Bay 129.8, Tangli Bay 120.2, Niucao Bay 118.3, and Hou Bay 131.9, indicating a low ecological risk of heavy metal to the lake. The E_r^i-value of cadmium in all sampling locations and arsenic in Guozheng Bay were greater than 40 but less than 80, which reflects a moderate ecological risk for the water body posed by these metals.

In a nutshell, the heavy metals under investigation in sediments reflected a low ecological risk to the water body with the exception of cadmium which posed a moderate ecological risk to the whole lake and arsenic, which posed a moderate ecological risk to Guozheng Bay.

Seasonal Variation of Heavy Metals in Donghu

The seasonal variations in the concentrations of heavy metals in Lake Donghu during the period of study are shown in Table 4. Seasonal concentration was expressed as the mean monthly concentrations (Fig. 2) of the season. According to the weather pattern in Wuhan City, spring is from March to May, summer from June to August, autumn from September to November, and winter from December to February. The results show that in Lake Donghu, the concentrations of heavy metals vary from season to season ($p<0.05$). As, Cd, and Cu were present at high concentrations levels in winter, Cr and Pb attained their highest concentration in spring, and Zn in summer. It has been found that the low Pb concentrations indicate the minor importance of anthropogenic input, and on the other hand elevated Pb concentrations in surface waters indicate the anthropogenic inputs to water body, it can be confirmed that the main source of lead in Donghu in spring is associated with anthropogenic activities.

The seasonal variations of investigated heavy metals in Lake Donghu are associated with inflow changes, as environmental conditions change, various phases of elements in particulate matter are altered and might be released in solution. The winter season in 2008 was a period of heavy rainfall, leading to high fluvial inputs. The flows into the lake carrying metals from industrial wastes have been responsible for the increased concentration of the majority of metals in the winter season.

Heavy Metals Distributions

The concentrations of trace elements in the five different sampling locations in Lake Donghu are presented in Fig. 3. One-way analysis of variance (ANOVA) showed that the difference in metal concentrations among sampling sites is significant ($P<0.05$). The concentrations of heavy metals in Lake Donghu were found in the following order: Zn > Cu > AS > Pb > Cr > Cd. The maximum mean values of As, Cd, and Cr were detected at higher concentrations in sediment samples taken from Hou Bay, with mean monthly concentrations of 57.32, 2.55, and 21 mg/kg, respectively. Cu and Pb attained their maximum concentrations in Quanzhuang cun 229.22 and 40.22 mg/kg (close to the industrialized area). It can be confirmed that the augmentations of these metals in location is due to the large steel industry located near this sampling location. Zn reached its highest point in a sediment sample taken from Niucao Bay:

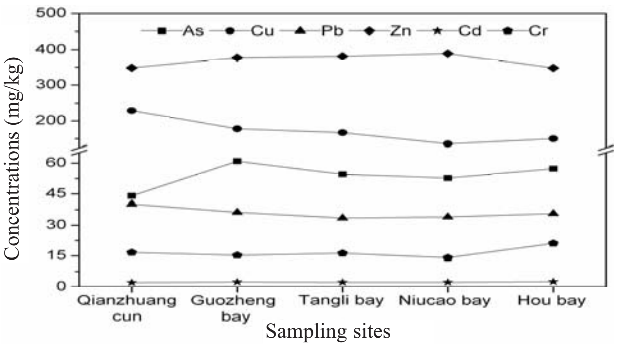

Fig. 2. Heavy metals distribution in Lake Donghu.

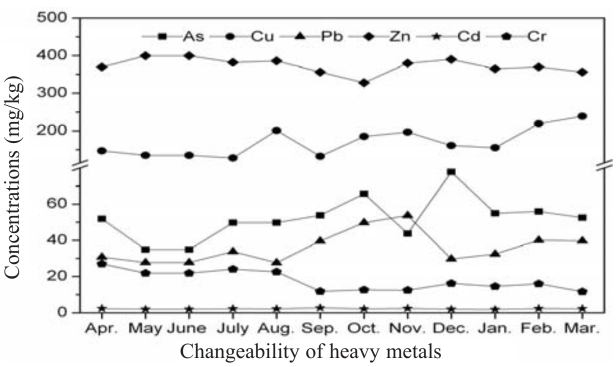

Fig. 3. Monthly changeability of heavy metals in Lake Donghu.

389.11 mg/kg. According to the investigation, Hou Bay and Quanzhuang cun showed high anthropogenic activities.

The high levels of Cd and Pb in water can be attributed to the geological environment surrounding the lake, fishing activities, and sewage discharge [41]. According to the research made, Hou Bay ranked the first in accumulating the trace metal, Qianzhuang cun ranked the second, Tanglin Bay the third, Niucao Bay the forth, and Guonzheng Bay was the least polluted. High metal concentrations can be attributed to the augmentation of industrial waste, and other human activities such as agriculture and fishing. Their difference in heavy metal concentrations are attributed to the different loading in different locations.

Conclusion

The heavy metals under investigation in sediments reflected a low ecological risk to Lake Donghu, with an exception for cadmium, which posed a moderate ecological risk to the whole lake, and arsenic, which posed a moderate ecological risk to Guozheng Bay. The results of sediment samples taken from five locations showed that the lake has been slightly contaminated by heavy metals and its pollution can be attributed to human activities near and in the lake, as well as industrial pollution inputs. These observations suggest that the Pollution Board of Wuhan City should ensure that sewage disposal facility by residential complexes are efficient, adequate, and being satisfactorily operated. Potential reduction of industrial pollution input can be accomplished by meeting the wastewater discharge criteria. Elimination of potential future sources of pollution will help maintain good water quality in Lake Donghu.

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