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Primary Health Risk Analysis of Metals in Surface Water of Taihu Lake, China

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Abstract The status and health risks of eight metals, Pb, Cd, Cr, Cu, Zn, Fe, Ni and Mn, in surface water from Taihu Lake (Jiangsu Province, China) were evaluated. The results showed that the maximum hazard quotients (HQ) value through ingestion pathway and dermal adsorption pathway was 2.74E−01 (Ni) and 2.57E−02 (Cd), respectively. However, the individual hazard quotient and total hazard index of eight metals through ingestion and dermal adsorption pathway was all lower than 1, indicating that the pollution situation in the surface water of Taihu Lake concerning these metals has no or low adverse health effects.

Keywords Health risk · Metals · Taihu Lake · Surface water

Taihu Lake is a shallow eutrophic lake situated in the south of the Yangtze Delta, China. As the third largest freshwater lake in China, Taihu Lake is an important source of drinking water for the residents nearby (such as Shanghai, Suzhou, Wuxi, and Huzhou) and also the main freshwater fisheries (Wang et al. 2004). During the last five decades, industry and agriculture in Taihu basin has been developed rapidly, and the multiplicity of human activities have been increasing the anthropogenic inputs to the lake, resulting in the deterioration of water quality in many parts of the lake. The increasing effluent of electronic industry, metal-processing industry has aggravated the water contamination. The research of metals in aquatic systems has become one of the important issues in environmental sciences (Marcotrigiano and Storelli 2003). Ingestion of significant amounts of metals-containing drinking water may result in adverse health effects varying from shortness of breath to several types of cancers (Cantor 1997; Costa and Klein 2006; Dogan et al. 2005). Although some metals such as Fe, Cu, Mn and Zn are essential for organisms, toxic effects are observed when concentrations increase to specific concentrations (Kavcar et al. 2009). Therefore, measurement of metal concentration is useful to evaluate the metal burden. Previous studies have found that the concentrations of metals in Taihu Lake have been in heavy or medium-contamination levels, however, these studies did not assess the potential adverse health effects of metals (Qu et al. 2001). With the vigorously developing of governmental policy on pollution control and wastewater reduction, it is necessary to reassess the status of metals and their health risks.

The aim of this study is to determine the levels of eight metals (Pb, Cd, Cr, Cu, Zn, Fe, Ni and Mn) in surface water from Taihu Lake, and to assess their health risk by the human health risk assessment models basing on monitoring data. It provides useful reference for water system management of metals in Taihu Lake.

Materials and Methods

Surface water sampling was carried out in the Taihu Lake in June and December, 2009. A total of 28 locations throughout the Taihu Lake were collected. A global positioning system (GPS) was used to locate the sampling sites. The studied area spreads between 30°57′18″ and 31°31′14″ in north latitude and 120°00′36″ and 120°27′42″ in east

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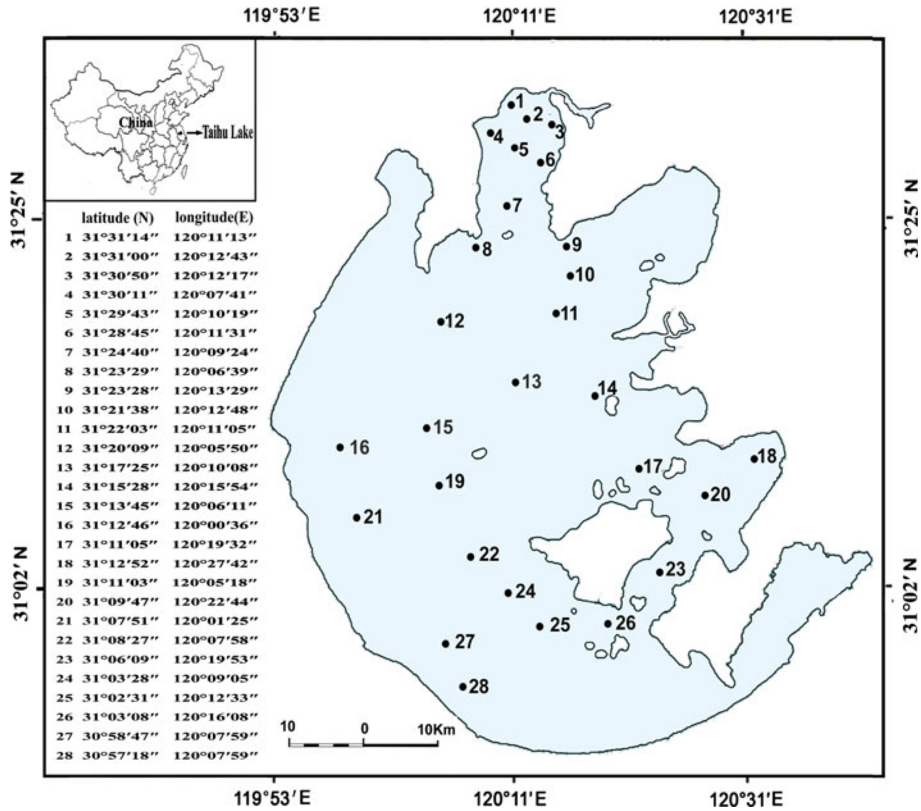

Fig. 1 Location of sampling sites in this study

longitude. Details of sampling sites were showed in the Fig. 1. The parameters of water samples, including sampling depth, pH, temperature, dissolved oxygen (DO) and turbidity were shown in the Table 1.

For all the analyses, cleaning and sampling procedures, Milli Q water and high-purity solvents were used. All glassware and polyethylene bottles used were prepared by soaking overnight with the dilute nitric acid solution and then rinsing once with tap water and three times with MilliQ water. After being dried in an oven at 60°C, the polyethylene bottles were tightly capped. All samples were transported to the laboratory in cooled containers. After acidification with HNO_3, the samples were treated with 0.45 μm filter membrane and kept in polyethylene bottles at −20°C for analysis. Blanks and replicates were collected for over 10% of the samples.

Water samples were digested and analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES, Perkin-Elmer, Optima 5300DV, USA) and Atomic fluorescence Spectrophotometer (AFS, AF-610A, China) according to the method of State Environmental Protection Administration of China (2002). For analytical quality control, reagent blanks and sample replicates were randomly inserted in the analysis process to assess contamination and precision. Recovery studies of metal determination were conducted to demonstrate the efficiency of the methods. The recovery rates were ranged in 87%–105%.

Health risk assessment models recommended by US Environmental Protection Agency (USEPA) were used to quantify the potential risk indexes of metals according to the monitoring data. The expose doses through ingestion and dermal adsorption pathway were calculated using the Eqs. 1 and 2, respectively (USEPA 1989, 2004; Wu et al. 2010).

$$D_{ingestion} = C \times \frac{IR \times EF \times ED}{BW \times AT} \quad (1)$$

$$D_{dermal} = C \times \frac{SA \times Kp \times ET \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

where $D_{ingestion}$ (μg/(kg day)), exposure dose through ingestion of water; D_{dermal} (μg/(kg day)), exposure dose

Table 1 Basic parameters of samples

Sampling date	Depth (m)	pH	Temperature (°C)	DO (mg/L)	Turbidity (FTU)
June 2009	1.10–2.55	7.45–8.57	21.43–26.63	5.97–8.45	20.21–193.29
December 2009	1.53–2.50	6.48–8.15	4.60–5.76	9.33–11.22	7.57–392.02

through dermal absorption; C (μg/L): concentration of metals determined in surface water; IR (L/day), ingestion rate, 1.4 L/day; EF (day/year): exposure frequency, 365 day/year for ingestion pathway, 350 day/year for dermal absorption pathway; ED (year): exposure duration, 70 year; BW (kg): average body weight, 57 kg; AT (day): averaging time, ED × 365 days; SA (cm^2): exposed skin area, 18,000 cm^2; K_p (cm/h): dermal permeability coefficient; ET (h/day): exposure time during bathing and shower, 0.25 h/day; CF: unit conversion factor, L/1,000 cm. These parameter values were obtained from the reference values of USEPA or statistical data of local residences.

The health risk of the metals could be divided into two types, i.e., non-carcinogenic risk and carcinogenic risk. Since the toxicity value of carcinogenic risk for the analyzed metals was not available, only non-carcinogenic risk was calculated in this study. Hazard quotient (HQ) was calculated by Eq. 3 to estimate non-carcinogenic risk (USEPA 1989).

$$HQ = D/RfD \tag{3}$$

In this equation, D is the exposure dose obtained from the Eqs. 1 and 2. RfD (μg/(kg day)) is the reference dose of the contaminant for non-carcinogenic risk. Ingestion reference doses (RfD_i) of metals were obtained from the USEPA (2010), while dermal absorption reference doses (RfD_d) were calculated by Eq. 4.

$$RfD_d = RfD_i \times ABS_g \tag{4}$$

where ABS_g is gastrointestinal absorption factor of metals, which applied the recommended values from USEPA (2004).

Non-carcinogenic HQs though ingestion and dermal adsorption pathway for each metal were summed and expressed as hazard index (HI) by the Eq. 5 to indicate its overall non-carcinogenic risk (USEPA 1989).

$$HI = HQ_{ingestion} + HQ_{dermal} \tag{5}$$

Results and Discussion

The summary statistics of analytical results including minimum, maximum, mean, standard deviation, median and permissible limit for metals were presented in Table 2. As shown in the table, the concentration of total metals ranged from 73.0 μg/L (site 24) to 1,713.15 μg/L (site 18) with a mean value of 704.08 μg L^{-1}. In terms of individual metal composition, the concentration of Fe was the highest, followed by Mn, Ni and Zn. The maximum values of Fe, Pb and Ni were above the permissible limit. However, the total concentration ranges of metals found in surface water of Taihu Lake were similar to or lower than the levels in other water bodies of China (Li et al. 2010; Muller et al. 2008).

According to the above monitoring data of eight metals, their health risks were calculated by USEPA risk assessment models. The HQ values of eight metals through ingestion pathway and dermal absorption pathway were listed in Tables 3 and 4, respectively. In general, when HQ value of pollutant is greater than 1, the pollutant might pose potential adverse health effects and needs for further analysis.

As shown in Table 3, the maximum HQ value of Ni (2.74E−01) through ingestion pathway is highest, followed by Pb (1.95E−01) and Cd (9.77E−02). Cu posed the lowest health risk (6.17E−03). The HQ values for each metal are all lower than 1. For dermal adsorption pathway (Table 4), the maximum HQ values for tested metals ranged from 5.41E−05 (Cu) to 2.57E−02 (Cd), which was

Table 2 The status of metals in the surface water of Taihu Lake and their permissible limit(μg/L)

Elements	Water standard			Limit of detection	Min	Mean	SD	Median	Max
	China[a]	USA[b]	WHO[c]						
Cd	5	5	3	1	ND	1.06	0.23	1.00	2.00
Cr	50	100	50	4	ND	1.91	1.00	2.00	4.35
Cu	1,000	1,300	2,000	4	ND	5.08	1.69	5.00	10.1
Fe	300			10	51	629	405	470	1,589
Mn	100		500	1	26.3	48.3	17.4	43.4	88.3
Ni			20	5	ND	18.38	46.06	4.15	224.0
Pb	10	15	10	30	ND	6.72	2.38	6.85	11.2
Zn	1,000			5	ND	18.07	17.47	13.65	95.95
Total					73.0	704.1	422.7	591.1	1,713.1

[a] MHPRC (2006) standards for drinking water quality, Ministry of Health of China

[b] USEPA (2006) National primary drinking water regulations

[c] WHO (2006) Guidelines for Drinking Water Quality, third edition

Table 3 Health risk of metals by ingestion pathway

Elements	RfD_i (μg/(kg·day))	Minimum	Mean	Median	Maximum
Cd	0.5	4.15E−02	5.20E−02	4.89E−02	9.77E−02
Cr	3	ND	1.55E−02	1.63E−02	3.54E−02
Cu	40	9.77E−04	3.11E−03	3.05E−03	6.17E−03
Fe	700	1.78E−03	2.20E−02	1.64E−02	5.55E−02
Mn	24	2.68E−02	4.91E−02	4.42E−02	8.99E−02
Ni	20	ND	2.25E−02	5.07E−03	2.74E−01
Pb	1.4	ND	1.17E−01	1.20E−01	1.95E−01
Zn	300	1.63E−04	1.47E−03	1.11E−03	7.81E−03
Total		7.12E−02	2.83E−01	2.25E−02	7.61E−01

ND Not detected

Table 4 Health risk of metals by dermal adsorption pathway

Elements	RfD_d (μg/(kg·day))	Minimum	Mean	Median	Maximum
Cd	0.005	1.09E−02	1.37E−02	1.29E−02	2.57E−02
Cr	0.015	ND	8.18E−03	8.57E−03	1.86E−02
Cu	12	8.57E−06	2.72E−05	2.68E−05	5.41E−05
Fe	105	6.24E−05	7.71E−04	5.76E−04	1.95E−03
Mn	0.96	1.76E−03	3.23E−03	2.90E−03	5.91E−03
Ni	5.4	ND	4.60E−05	1.04E−05	5.60E−04
Pb	0.42	ND	1.03E−03	1.05E−03	1.71E−03
Zn	60	1.31E−06	1.18E−05	8.92E−06	6.27E−05
Total		1.27E−02	2.70E−02	2.60E−01	5.45E−02

ND Not detected

also lower than 1. Considering the HI of each metal through both pathways, their HIs were lower than 1. These results indicated that all the tested metals have no or low adverse health effects for local residents. But as an early warning, the effect of Ni and Cd should attract more and long-term attention, and the investigations of them in the sediments and edible aquatic organism should be developed.

The total HQ (tHQ) of eight metals could be obtained from the summation of individual HQs. The calculated maximum tHQ for ingestion and dermal adsorption pathway were 7.61E−01 and 5.45E−02, respectively. The results indicated that the ingestion pathway posed higher health effect than the dermal adsorption pathway. The total maximum HIs of both pathways are lower than 1, indicating that the metals in the Taihu Lake surface water pose low hazard to local residents.

However, it must be noted that there are many uncertainties during risk assessment. Firstly, only water samples in June and December of 2009 were collected, which were limited. In order to better reflect and characterize the status of these metals, periodic determination of metal contents in the water is needed. Secondly, only eight metals in this study were determined, other metals that are toxic to the human, may increase the potential health risk of Taihu Lake. Further, the concentration of the metals in aquatic system is a kinetic transformation condition. It was closely related with the whole environmental condition and ecosystem of the lake such as water temperature, sediments, and aquatic livings. The sediments and aquatic livings could strongly accumulate the heavy metals and affect the human health through releasing them to drinking water in specific conditions or direct eating obtained. The present assessment was only focused on the surface water, which could underestimate the risk values of the studied metals.

In conclusion, health risk assessment models were applied to evaluate the potential health risks of eight metals in surface water of Taihu Lake. The results showed that the eight metals posed no or low health risk for local residents. Although there are some uncertainties existed in this study, the results could provide some information for the advanced water system management of metals in Taihu Lake.

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