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Original Articles

Spatial distribution, fractionation, toxicity and risk assessment of surface sediments from the Baiyangdian Lake in northern China

Chao Zhang[a,b], Baoqing Shan[a,b,*], Yu Zhao[a], Zhixin Song[a,b], Wenzhong Tang[a,b,*]

[a] State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[b] University of Chinese Academy of Science, Beijing 100049, China

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ABSTRACT

The pollution of Baiyangdian Lake (BYDL) has been of concern since the Xiongan New Area was established. To conduct ecological restoration of BYDL, the heavy metals (HMs) levels in sediments were assessed. Specifically, Surface sediments (0–10 cm) samples in BYDL were analyzed for Cd, Cr, Cu, Ni, Pb and Zn in October 2016 to evaluate the risk posed by trace metals, as well as their bioavailability and toxicity. The results demonstrated that HMs showed high pollution and risk levels in most sample sites as a result of Cd and Pb. Metals speciation analysis demonstrated that Cd, Cu, Pb and Zn were dominated by non-residual fractions that originated from anthropogenic sources and presented higher bioavailability. The risk assessment code indicated that Cd poses a medium level biological risk in BYDL, which reached 10.25% and 29.38%. The bioavailable metals index showed a strong correlation with acute toxicity (R^2 = 0.704), indicating bioavailable metals are an important reason for sediment acute toxicity. Canonical correspondence analysis demonstrated that HMs have a coercive effect on the distribution of benthic invertebrates. Overall, the results indicate that HMs pollution should be considered during the development of strategies for ecological restoration in BYDL.

1. Introduction

Baiyangdian Lake plays a key role in the Xiongan New Area in China. Routine monitoring data have revealed serious pollution in BYDL, including ammonia nitrogen, total nitrogen and chemical oxygen demand. Before the ecological restoration of Baiyangdian, a detailed study should be conducted to assess the risk of contamination. Previous studies have shown that phosphorus and ammonia nitrogen in sediments showed pollution and posed a potential risk to the ecosystem (Dong et al., 2011; Zhao et al., 2011). However, few researchers have conducted comprehensive and detailed investigations of HMs pollution in BYDL. In the 1970s, upstream industrial wastewater was imported into BYDL, causing two-thirds of the region to be contaminated. As a result, a large amount of pollution has accumulated in the sediments, including HMs. Heavy metals that are released and migrate in sediment could cause a potential threat to aquatic biota and human health (Yi et al., 2011; Zhuang et al., 2016). Accordingly, it is necessary to assess the bioavailability, risks and toxicity of HMs in surface sediments for BYDL.

Bioavailable HMs have recently received increased attention owning to their potential to bioaccumulate and be biomagnified up the food chain (Pejman et al., 2015; Xu et al., 2017). The European Community Bureau of Reference (BCR) method is commonly used to analyze HMs chemical fractions (Nemati et al., 2011; Zhang et al., 2017), including acid-soluble metals (F1), reducible metals bound to Fe and Mn (F2), oxidizable metals bound to organic matter and sulfides (F3), and residual metals bound to silicate minerals (F4). According to the BCR procedure, F1, F2, and F3 show a decreasing tendency for bioavailability, while the residual fraction is not bioavailable (Rodríguez et al., 2009; Zhang et al., 2016a).

The risk assessment code (RAC) and bioavailable metals index (BMI) was used to evaluate the bioavailability and potential toxicity of HMs based on the F1 fraction (Rosado et al., 2016; Zhao et al., 2012). The RAC provides a better interpretation of the relationship between the trace metals bioavailable fraction and the environmental risk posed by HMs (Yang et al., 2014). Toxic units (TU) are widely used to evaluate the comprehensive toxicity of HMs (de Castro-Català et al., 2016). Bioassays and toxicity tests can reveal the biological responses to different contamination strengths associated with various HMs (Jarque et al., 2016). Biotoxicity tests can directly test sediment toxicity, rather than provide an empirical inference based on the contamination content. For example, luminescent bacteria are widely used to quickly and

* Corresponding authors at: State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China.
E-mail addresses: bqshan@rcees.ac.cn (B. Shan), wztang@rcees.ac.cn (W. Tang).

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accurately analyze soil, sediment, and water acute toxicity (Rosado et al., 2016; Zhang et al., 2015).

Here, some representative sites in the study region were selected to conduct a systematic bioavailability, risk and toxicity assessment of HMs in BYDL. The specific goals of this study were to: (1) assess the potential ecological risk of trace metals; (2) investigate the bioavailability using BCR sequential extraction; (3) analyze a possible relationship between the observed toxicity and bioavailability of metals; and (4) evaluate the effects of heavy metals on the distribution of benthic invertebrates in BYDL.

2. Materials and methods

2.1. Study area

The Xiongan New Area will become a new residential area, where the contaminants of BYDL may affect human beings health. Baiyangdian Lake (38°43′–39°02′ N, 115°38′–116°07′ E), which is located in northern China and has a total area of 366 square kilometers. The major land or cover types in Baiyangdian include water, arable land, construction land, forests, grasslands, and urban areas. Baiyangdian belongs to the eastern monsoon region warm temperate semiarid region, and the average annual rainfall is only 552.7 mm. The BYDL contains eight upstream rivers, which are Baigou River, Ping River, Bao River, Fu River, Tang River, Zhulong River, Xiaoyi River, and Cao River. Among them, Fu River, Baigou River, Xiaoyi River and Tang River have received wastewater from wastewater treatment plants, battery manufacturing and printing and dyeing industries, which could enter the BYDL through these rivers. The other rivers have been dry off for a few years, and have little effect on the BYDL. Battery manufacturing waste water from Baoding city containing lead and cadmium had been discharged into Tang River for a long time. Printing and dyeing industries waste water, which contained chromium and copper, has been input into Xiaoyi River. Wastewater treatment plants from Baoding city would result that cadmium, lead and chromium entranced into Fu River and Baigou River. Non-point source inputs from fluvial transport were important ways for BYDL pollution in this area.

2.2. Sample collection and analysis

Surface sediments (0–10 cm) were collected from 25 stations in BYDL to investigate the heavy metals pollution with three parallel samples on October of 2016 (Fig. 1). All sediments were collected employing a Peterson grab sampler, then stored on ice until transported to the laboratory. Each sample was subsequently freeze-dried, ground, homogenized, passed through a 100-mesh sieve, and stored in polypropylene bags. The dried samples were sealed and stored at −20 °C until analysis, which was conducted within 4 weeks.

The metals concentrations and fractions in the surface sediments were analyzed. For total content analysis, a HF: $HClO_4$ (V:V = 5:1) mixture was added into sediment samples, then digested using a microwave digester (MARS Xpress; CEM, Matthews, NC, USA). Total P in sediment was measured by treating at 500 °C (2h), followed by 1 mol L^{-1} HCl extraction (16 h) (Aspila et al., 1976) .Total phosphorus (TP) was determined using a continuous flow analyzer (Bran and Luebbe Autoanalyer, SPX, Charlotte, NC, USA). The conditions for microwave digestion of sediment samples is shown in Table S1 of the supporting information (SI). The organic matter (OM) content was analyzed based on residual titration of $K_2Cr_2O_7$ as shown in previous literature (Bao, 2000). Percent total sulfur (TS), total nitrogen (TN) and total carbon (TC) of sediment were measured using elemental analyzer (vario EL III, Elenemtar, Germany) based on previous method. Each sample (20–30 mg) was individually flushed with carrier gas to remove atmospheric nitrogen, and the catalytic combustion was carried out at a permanent temperature of up to 1200 °C (Islam et al., 2015).

A modified three-stage BCR sequential extraction procedure was used to determine the metals chemical fractions (Arain et al., 2008) and the experience was performed using the previous literature (Zhang et al., 2017). Duplicate samples, standard reference samples (GBW07436, National Institute of Metrology, Beijing, China), and blanks were analyzed for quality assurance and quality control. The recoveries of the chemical fractions and total heavy metals contents ranged from 90% to 108% and 93% to 109%, respectively, and the relative standard deviation was less than 5% (Table S2). The heavy metals concentrations were determined using an Optima 2000DV inductively coupled plasma optical emission spectrometer (detection limits of 0.003–0.050 mg/L, Perkin Elmer, Waltham, MA, USA), and an Agilent 7500a inductively coupled plasma mass spectrometer (detection limits of 0.025–0.200 μg/L, Agilent Technologies, Santa Clara, CA, USA).

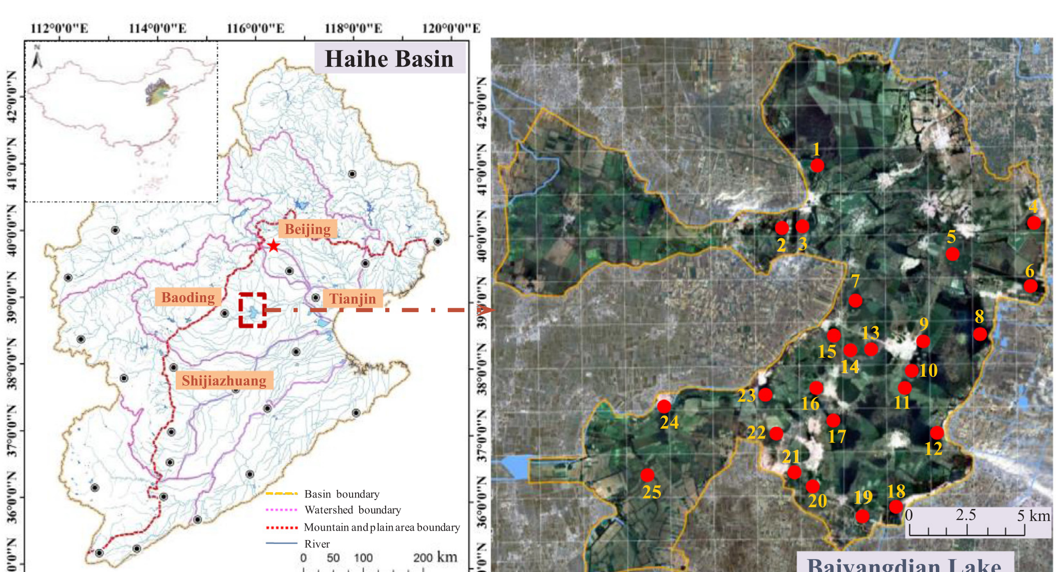

Fig. 1. Location of BYDL in the Haihe Basin of China and sampling sites in the study area.