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Heavy metals in surface sediments of the Jialu River, China: Their relations to environmental factors

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HIGHLIGHTS

- Zhengzhou City had major effect on the pollution of the Jialu River.
- TN, OP, TP and COD_{Mn} in water drove heavy metals to deposit in sediments.
- B-IBI was sensitive to the adverse effect of heavy metals in sediments.

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ABSTRACT

This work investigated heavy metal pollution in surface sediments of the Jialu River, China. Sediment samples were collected at 19 sites along the river in connection with field surveys and the total concentrations were determined using atomic fluorescence spectrometer and inductively coupled plasma optical emission spectrometer. Sediment samples with higher metal concentrations were collected from the upper reach of the river, while sediments in the middle and lower reaches had relatively lower metal concentrations. Multivariate techniques including Pearson correlation, hierarchical cluster and principal components analysis were used to evaluate the metal sources. The ecological risk associated with the heavy metals in sediments was rated as moderate based on the assessments using methods of consensus-based Sediment Quality Guidelines, Potential Ecological Risk Index and Geo-accumulation Index. The relations between heavy metals and various environmental factors (i.e., chemical properties of sediments, water quality indices and aquatic organism indices) were also studied. Nitrate nitrogen, total nitrogen, and total polycyclic aromatic hydrocarbons concentrations in sediments showed a co-release behavior with heavy metals. Ammonia nitrogen, total nitrogen, orthophosphate, total phosphate and permanganate index in water were found to be related to metal sedimentation. Heavy metals in sediments posed a potential impact on the benthos community.

1. Introduction

The pollution of aquatic systems by heavy metals has been known as one of the most challenging pollution issues due to the toxicity, abundance, persistence, and subsequent bio-accumulation of heavy metals [1]. When discharged into rivers, heavy metals can be strongly accumulated in sediments and biomagnified along the aquatic food chains [2]. Because of the non-degradability of heavy metals, toxic effects are often observed at points far away from the sources [3]. An analysis of the distribution of heavy metals in sediments could be used to investigate anthropogenic impacts on aquatic ecosystems and assess the risks posed by human waste discharges [2].

The level of heavy metals in sediments is not an isolated factor, but interacts with surrounding environmental factors. Investigation on the relations between heavy metals and various environmental factors is beneficial to comprehensively evaluate the impacts of heavy metals on the ecosystem and grasp the pollution characteristics of local environment. Although analyses

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of heavy metals in sediments have been carried out extensively, unfortunately, few researches have focused on the interaction of heavy metals with the environment.

The Jialu River is an important tributary of the Huaihe River, and has been severely polluted by a variety of contaminant sources such as industrial and domestic wastewater [4], trade wastes, and untreated or lightly treated sewage wastes [5]. In recent years, the pollution in the Jialu River Basin has attracted increasing attention and many researches have been carried out [4–8]. To our knowledge, there has been no study reported on the pollution of heavy metals in the Jialu River Basin. To address this critical knowledge gap, the present study aimed not only to investigate the state of the metal pollution in surface sediments in the Jialu River but also to evaluate their relations to various environmental factors including chemical properties of sediments, water quality indices, aquatic organism indices, anthropogenic activities and hydrological conditions. Specifically, the objectives of this research were to: (i) determine the concentration level and distribution patterns of various heavy metals in the surface sediments of the Jialu River, (ii) assess the associated ecological risks of the heavy metals, (iii) uncover the impact of the metal pollution on the ecological systems, and (iii) identify the key environmental factors affecting the heavy metals pollution.

2. Materials and methods

2.1. Study area

The Jialu River is 256 km long and its basin covers an area of 5896 km^2. It originates from Xinmi County, Henan Province, while flows via Zhengzhou City, Zhongmu County, Weishi County, Xihua County, and then merges down into the Shaying River near Zhoukou City. The average discharge of the Jialu River (measured by a gauge station in Zhongmu during 2007) was 15.11 m^3/s. Zhengzhou is the main city in this basin with a strong impact on the ecological environment of the Jialu River. As one of the six most important industrial cities in Central China, Zhengzhou City has a long history for textile and metallurgy industries. It is also a major transportation hub at the Central China.

A complete sequence of strata is developed in the Jialu River Basin (belong to the Huaihe River Basin), i.e., Archean, Neoproterozoic, Cambrian, Ordovician, Carboniferous, Permian, Tertiary and Quaternary [9]. Gneiss is primarily distributed in the mountainous areas of this basin, and unconsolidated sediments of Tertiary and Quaternary are distributed over the plains [10].

Due to the rapid economic growth and urbanization, the Jialu River has been severely polluted by a variety of contaminant sources and several reports indicated the pollutant levels in this area. The annual effluents of the Jialu River contained 726 kg of nonylphenol (NP) and 30.2 kg of octylphenol (OP) [5]. The total concentration of 16 priority polycyclic aromatic hydrocarbons (PAHs) in sediments of the Jialu River ranged from 466.0 to 2605.6 ng/g dry weight (d.w.) with a mean concentration of 1363.2 ng/g [7]. The total concentrations of nitrosamines and secondary amines in groundwater of the Jialu River Basin were 0–101.1 ng/L and 0.36–4.38 μg/L, respectively [4].

2.2. Field sampling

The sampling and field surveys took place during September 2009. Fig. 1 shows the sampling locations. The sampling procedures for surface sediments (0–10 cm depth), water and aquatic organisms were reported in a prior work [7]. The sediment samples were stored in a −80 °C freezer until the metal analysis in 2012.

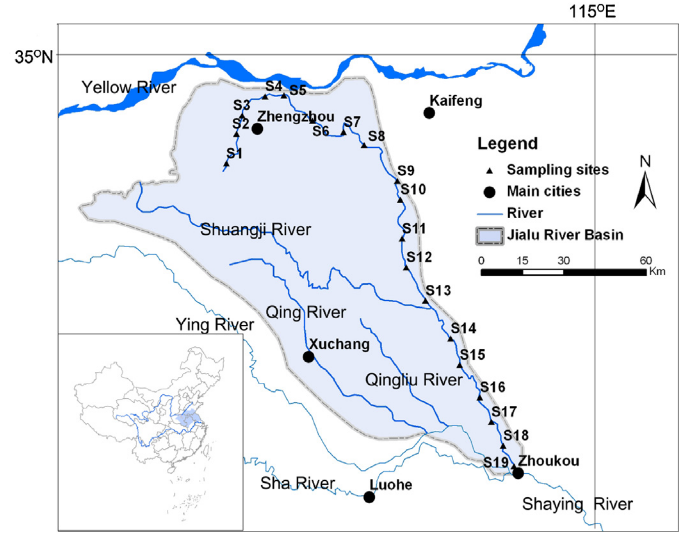

Fig. 1. Sampling location in the Jialu River, China.

2.3. Heavy metal analysis

As, Cd and Hg were measured using atomic fluorescence spectrometer (AFS) (Rayleigh, Beijing, China), where the sediment samples were digested with aqua regia. For As measurement, the digestion solution was reduced by thiourea–HCl mixture before measurement. Cr, Cu, Ni, Pb, Zn and other elements (Al, Ba, Ca, Co, Fe, K, Mg, Mn, Na, Sr, Ti and V) were analyzed using inductively coupled plasma optical emission spectrometer (ICP-OES) (PerkinElmer, Wellesley, MA, USA). In these cases, the sediment samples were digested with HCl–HNO_3–HF–$HClO_4$ mixture. The details of the analytical methods have been provided elsewhere [11].

All analytical data were subject to strict quality control. The instruments were calibrated daily using calibration standards. Precision and accuracy were verified using standard reference materials from the National Research Center for Geoanalysis of China [sediment, GBW07304 (GSD-4)]. Accepted recoveries ranged from 90% to 108%. Differences in heavy metal concentrations between this study and certified values were <10%. Blank samples for digestion and analysis methods were evaluated in duplicate with each set of samples. The relative deviation of the duplicate samples was <5% in all batch treatments.

2.4. Risk assessment

The ecological risks of heavy metals in sediments were assessed using three different methods including consensus-based Sediment Quality Guidelines (SQGs) [12], Potential Ecological Risk Index (PERI) [13] and Geo-accumulation Index (GAI) [14]. The details about the assessment methods are provided in Supporting Information (SI1, Risk assessment method).

2.5. Environmental factors

The chemical properties of sediments as ammonia nitrogen (NH_4–N), nitrate nitrogen (NO_3–N), total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC) were determined according to the standard methods for soil analysis [15]. Total PAHs concentrations (ΣPAHs) in the sediments were previously reported [7].

The water transparency was assessed in the field. Other water quality indices, including NH_4–N, NO_3–N, TN, orthophosphate (OP), TP, and permanganate index (COD_{Mn}) were determined in the laboratory following the standard analytical methods [16].