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Frontier Article

Contamination characteristics, ecological risk and source identification of trace metals in sediments of the Le'an River (China)

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ABSTRACT

Recognizing the pollution characteristics of trace metals in river sediments and targeting their potential sources are of key importance for proposing effective strategies to protect watershed ecosystem health. In this study, a comprehensive investigation was conducted to identify the contamination and risk characteristics of trace metals in sediments of Le'an River which is a main tributary of the largest freshwater lake in China, Poyang Lake. To attain this objective, several tools and models were considered. Geoaccumulation index and enrichment factor were used to understand the general pollution characteristic of trace metals in sediments. Discriminant analysis was applied to identify the spatial variability of sediment metals. Sediment quality guidelines and potential ecological risk index were employed for ecological risk evaluation. Multivariate curve resolution-alternating least square was proposed to extract potential pollution sources, as well as the application of Monte-Carlo simulation for uncertainty analysis of source identification. Results suggested that the sediments in Le'an River were considerably polluted by the investigated trace metals (Cd, Cr, As, Hg, Pb, Cu, Zn and Ni). Sediment concentrations of these metals showed significant spatial variations. The potential ecological risk lay in high level. Comparatively speaking, the metals of Cd, Cu and Hg were likely to result in more harmful effects. Mining activities and the application of fertilizers and agrochemicals were identified as the main anthropogenic sources. To protect the ecological system of Le'an River and Poyang Lake watershed, industrial mining and agricultural activities in this area should to be strictly regulated.

1. Introduction

Due to their toxicity, persistence, and non-biodegradable nature, trace metals containing mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), and chromium (Cr) in river sediments have attracted a great deal of worldwide attention (Singh et al., 2005; Yang et al., 2009). Metal residues in river sediments may accumulate in aquatic flora, fauna, and microorganisms, which may enter into the food chain and consequently result in human health problems (Olivares-Rieumont et al., 2005; Varol, 2011). On the other hand, river sediment can accumulate and integrate the temporal variability of heavy metals in river water originating from anthropogenic activities into spatial river sediment (Yuan et al., 2011). Therefore, river sediments not only act as the main sink for trace metals, but also are the potential secondary sources of pollutants in aquatic environment when the river conditions change (Singh et al., 2005). Due to the fact that sediments in lots of rivers in the world have been contaminated by trace metals in varying degree, people face an increasing threat with regards to water security (Viere et al., 2009). To prevent river pollution and improve the watershed ecosystem health, it is important to well understand the contamination characteristics of trace metals in sediments and target their potential sources (Casas et al., 2003; Sakan et al., 2009).

Locating in the northeastern of Jiangxi province, China, the Le'an River is a main tributary of Poyang Lake which is a crucial wetland area for swans, wild geese and white cranes to live through winter in the world. The river not only is the main source of drinking water for millions of inhabitants of that region, but also supplies water for industrial and agricultural activities in areas close to the river. Due to large uncontrolled metal inputs over the past several decades from the developing industrial and agricultural operations, particularly mineral extraction, the Le'an River and its estuary at Poyang Lake has been subjecting to serious environmental challenge of sediment contamination by heavy metals (UNESCO, 1996; He et al., 1997, 1998, 2001; Wen and Allen, 1999; Liu et al., 2013).

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As the largest freshwater lake in China, Poyang Lake has significant ecological, social, economic, and recreational value (Wei et al., 2014). Recently, the Chinese government has decided to restore the aquatic environment of Le'an River to protect the ecosystem of Poyang Lake catchment. Before measures are adopted, as mentioned above, it is necessary to identify the contamination characteristics and ecological risks of trace metals in river sediments. In particular, information on the significance and extent of pollutant contents in sediments from different sources is so important that appropriate actions can be effectively targeted to reduce pollutant inputs to river. However, few reports which focused on the study of source identification for trace metals in sediments of the Le'an River have been found.

In the present study, a detailed investigation was conducted to comprehensively understand the contamination and risk characteristics of sediment metals in Le'an River and to identify their potential pollution sources. Geochemical methods containing geoaccumulation index and enrichment factor were employed to analyse the pollution status of trace metals in sediments and to estimate the impact of anthropogenic activities. Discriminant analysis was applied to identify the spatial variability of sediment metals. Sediment quality guidelines and potential ecological risk index were applied for ecological risk evaluation. The multivariate curve resolution-alternating least square (MCR-ALS) was proposed to identify the potential pollution sources. In contrast to traditional multivariate analysis tools (i.e. primary component analysis and factor analysis), the solution obtained from the MCR-ALS method obey non-negativity constraint, which make their interpretation physically meaningful due to fewer negative values (Tauler et al., 2009; Wentzell et al., 2006). The systematical research presented here will provide a framework to help the study of pollution characteristic identification for trace metals in river sediments. Meanwhile, the results may serve to provide a scientific basis for best-management practices to protect the watershed ecosystem.

2. Materials and methods

2.1. Study area

The Le'an River (Fig. 1) lies between eastern longitudes 116.5° to 117.9° and northern latitudes 28.7° to 29.3°. It originates from the western foot of Huaiyu Mountain and runs 279 km from east to west crossing through Wuyuan, Dexing, Leping and Poyang counties, and finally flows into the Poyang Lake which is the largest freshwater lake in China. The Dawu River (~14 km) and Jishui River (~31 km) are its main tributaries. The former runs through the Dexing copper mine which is the largest open-cast mine in China and drains into the Le'an River. The latter is another metal-polluted tributary draining several mines for copper, zinc and lead. In geology, the stratum is full-fledged except Silurian, Devonian and Tertiary, and spread all over the study area (Teng et al., 2010). Paddy soil, yellow soil and red soil are the main soil types. The continental climate of the study area is a variety of subtropical monsoon type of climate with moderate temperature difference between summer and winter. The average annual temperature is 17 °C, and the annual mean rainfall is 1900 mm.

2.2. Sample collection

A total of 30 surface sediment samples were collected in May 2014. Fig. 1 shows the location of the sampling sites. Samples were collected from the upper stream (W1–W3), middle stream (D1–D12) and downstream (L1–L15) of the Le'an River. All sampling sites were located using a global positioning system. The samples were collected from the center of the river as far as possible avoiding the interference of organic matter. Approximately the top 2 cm of sediments were collected using a Van Veen grab. After sampling, the sediment samples were sealed in clean polyethylene bags, placed in a cooler at 4 °C, and transported to the laboratory immediately for further analysis.

2.3. Chemical analysis and quality control

Sediment samples were dried, and passed through a 100-mesh sieve to remove stones and plant fragments, and then powdered and stored in acid washed and deionized water rinsed glass bottles prior to analysis. For content determinations, about 0.1 g sediment subsamples were subjected to a digestion solution with concentrated nitric acid and concentrated hydrochloric acid. After digestion using an electric digestion instrument, the sample solutions were filtered, and adjusted to a suitable volume with double deionized water. The contents for trace metals were determined with inductively coupled plasma atomic emission spectrometry and inductively coupled plasma mass spectrometer. To ensure the quality of analysis, the laboratory quality assurance and control methods were implemented, including the use of standard operating procedures, analysis of reagent blanks, calibration with standards and analysis of replicates. The relative standard deviation indicating the precision of analytical procedures ranged from 5% to 10%. All analyses were carried out in duplicate, and the results were expressed as the mean.

A total of 15 elements were determined for each sediment sample. In this study, 8 general common trace metals (Cd, Cr, Pb, Hg, As, Cu, Zn, and Ni) were chosen as analysis variables to evaluate the contamination and risk characteristics of sediment metals

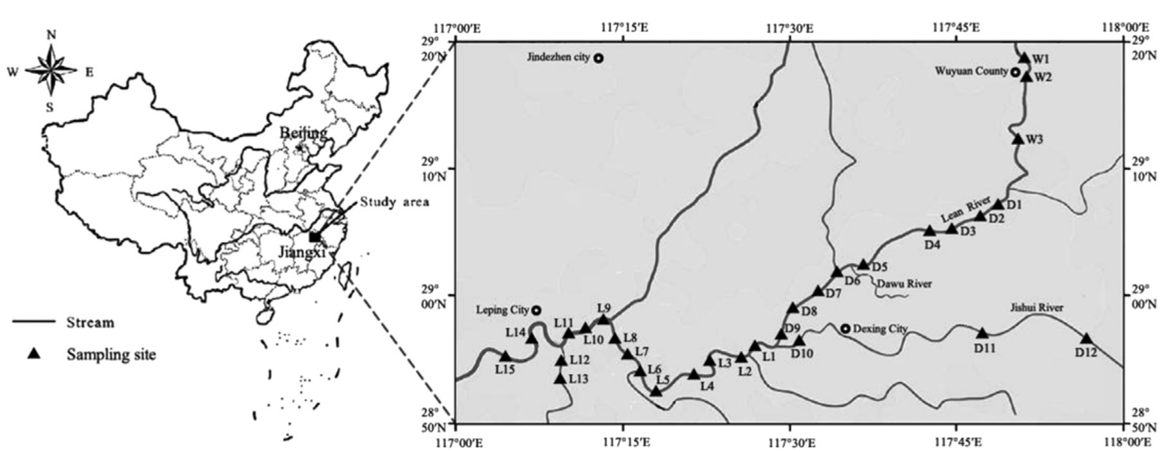

Fig. 1. Study area and sampling sites of trace metals in sediments of the Le'an River.