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Concentrations, diffusive fluxes and toxicity of heavy metals in pore water of the Fuyang River, Haihe Basin

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ABSTRACT

While the concentrations of heavy metals in pore water provide important information about their bioavailability, to date few studies have focused on this topic. In this study, pore water in river sediments collected from nine sampling sites (S1–S9) was examined to determine the concentrations, fluxes, and toxicity of heavy metals in the Fuyang River. The results showed that the average concentrations of Cr, Ni, Cu, As, Zn, and Pb in pore water were 17.06, 15.97, 20.93, 19.08, 43.72, and 0.56 $\mu g\ L^{-1}$, respectively; these concentrations varied as the pore water depth increased. The diffusive fluxes of Cr, Ni, Cu, As, Zn, and Pb were in the following range: (−0.37) to 3.17, (−1.37) to 2.63, (−4.61) to 3.44, 0.17–6.02, (−180.26) to 7.51, and (−0.92) to (−0.29) $\mu g\ (m^2\ day)^{-1}$, respectively. There was a potential risk of toxicity from Cu to aquatic organisms, as indicated by a value of the Interstitial Water Criteria Toxic Units that exceeded 1.0. Values of the Nemeraw Index were 2.06, 0.48, 0.11, 0.20, 1.11, 1.03, 0.99, 0.88, and 0.89 from S1 to S9, respectively. Only S1 was moderately polluted by heavy metals in pore water.

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1. Introduction

Pollution of the natural aquatic environment by heavy metals is a problem worldwide, because of their toxicity, persistence, and abiotic degradation in the environment, and bioaccumulation in food webs (Covelli et al., 1999; Al-Najjar et al., 2011; Li et al., 2015). Originating from natural sources and anthropogenic activities, such as industrial effluents, mining and refining, agricultural drainage, domestic discharges, and atmospheric deposition, heavy metals pose serious threats to the environment and human health (Bo et al., 2015; Palma et al., 2015). Heavy metals transported into the aquatic system are mainly incorporated into bottom sediments through adsorption, flocculation, and precipitation in the water column (Botte et al., 2007; Cheng et al., 2015), and they may be toxic to aquatic organisms when threshold concentrations are reached. However, metals that settle out of the water column are more likely to be re-suspended and re-dissolved into pore water, from where sediment-associated heavy metals can be released into the overlying water by diffusive fluxes (de Mora et al., 2004; Yu et al., 2012). Diffusive fluxes not only result in a concentration gradient at the sediment–water interface, but also deteriorate the quality of the water and potentially cause secondary contamination to the water environment (Covelli et al., 1999; Li et al., 2015). During this process, pore water, either alone or in combination with sediment ingestion, plays the role of an intermediary in the process of pollutions exchange between sediment and overlying water. Some researchers considered that only free metal ions in interstitial water could directly produce biological effects (He et al., 1998; Blasco et al., 2000; Kalnejais et al., 2015). In addition, pore water toxicity associated with heavy metals has been widely conducted in the world, and the Interstitial Water Criteria Toxicity Units (IWCTU) was always chosen to detect the toxicity of the single or multiple metals in pore water (Fairey et al., 1998; Liu et al., 1999; Lourino-Cabana et al., 2011).

The Haihe Basin is located in the political, economic, and cultural center of China. Heavy industrial development and rapid urbanization have caused significant heavy metal pollution in rivers in this region, especially in the Fuyang River, which is part of the Ziya River System (Tang et al., 2013). Along its entire channel, treated and untreated industrial and agricultural wastewater and domestic sewage have been discharged into the Fuyang River for several decades (Tang et al., 2014). Further, heavy metals and the other contaminants that entered rivers, finally ended up in riverine sediments. The sediments of the Fuyang River were known to be seriously polluted by trace metals, and studies have already

Abbreviations: IWCTU, Interstitial Water Criteria Toxic Units; NI, Nemeraw Index

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reported the enrichment of, and the ecological risk from heavy metals in these sediments (Tang et al., 2013, 2014). These pollutants may be a source of stress for aquatic communities (Oliveira et al., 2014). To date, however, few studies have examined heavy metal fluxes from sediments, and the concentrations and toxicity of heavy metals in pore water in this region. This information is needed to gain an understanding of the source of the heavy metals in the river water and the risk of toxicity to the environment and aquatic organisms.

Because of the risk of transformations from sediment-associated heavy metals to the more available dissolved heavy metal fractions, contamination, diffusive fluxes, and the toxicity of chromium (Cr), nickel (Ni), copper (Cu), arsenic (As), zinc (Zn), and lead (Pb) were examined in the Fuyang River, part of the Haihe Basin. The aims of this study were: (1) to investigate heavy metal concentrations in interstitial water and the diffusive fluxes of heavy metals at the sediment–water surface, and (2) to analyze the toxicity of trace elements in the pore water with using the Interstitial Water Criteria Toxic Units (IWCTU) and Nemeraw Index (NI).

2. Materials and methods

2.1. Study area

The Fuyang River, located in North China, belongs to the Haihe Basin. It is located between 36°37′–38°20′N and 114°41′–116°06′E (Fig. 1). The catchment of the Fuyang River covers an area of 2747 km^2, and it has a northern temperate continental monsoon climate with an average temperature of 13.4 °C. The mean annual precipitation is 550 mm. It has various tributaries, including the Niuwei River, Xiao River, Wangyang Ditch, and Shaocun Canal. Also, the river flows through four major cities of Hebei Province, namely Handan, Xingtai, Shijiazhuang, and Hengshui. The Fuyang River has therefore been subject to industrial and agricultural

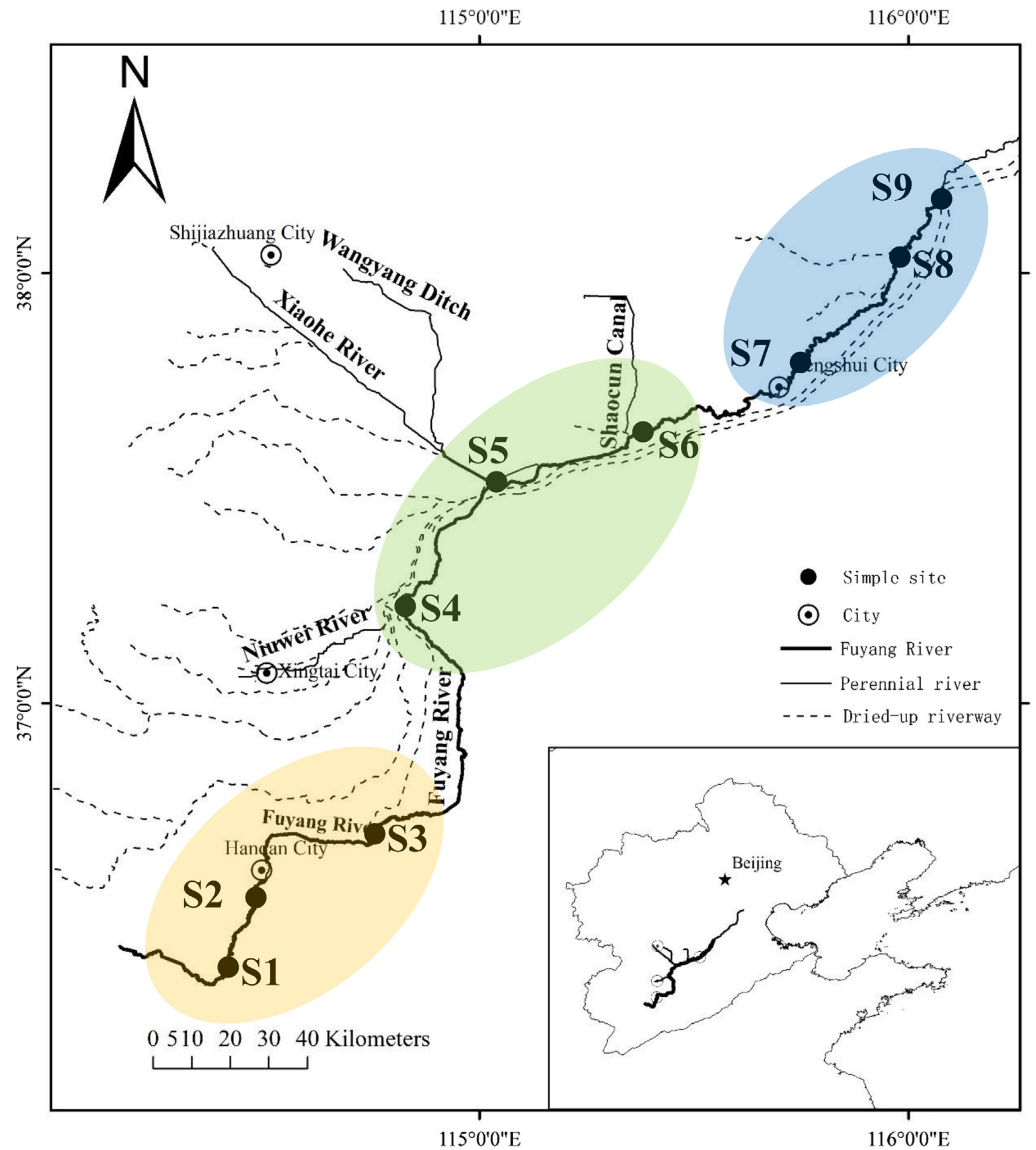

Fig. 1. Map showing sampling stations along the Fuyang River.

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