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Distribution characteristics and sources of trace metals in sediment cores from a trans-boundary watercourse: An example from the Shima River, Pearl River Delta

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ABSTRACT

Metal pollution in sediments from the Shima River, a typical transboundary watercourse in the Pearl River Delta area, was investigated. Sediment cores were collected at eight sites from the upper to the lower reaches crossing Shenzhen, Dongguan and Huizhou cities. Sediment physicochemical properties and the total concentrations of trace metals (V, Cr, Co, Ni, Cu, Zn, As, Cd and Pb) were determined. The results showed that riverine sediment was significantly polluted by Cr (content range: 13.8–469 mg kg^{-1}), Ni (14.1–257 mg kg^{-1}), Cu (10.8–630 mg kg^{-1}), Zn (50.2–1700 mg kg^{-1}) and Cd (0.172–2.26 mg kg^{-1}). The geoaccumulation indices (I_{geo}) of trace metals decreased in the order Cd > Zn > Ni > Cu > Co > Cr > Pb > As > V. The pollution load indices and potential ecological risk indices (RI) at the sampling sites were similar, with more severe pollution and greater risk presenting in the upper and middle reaches (S1–S6) compared with the lower reaches (S7 and S8). Cd contributed significantly (77.2–87.6%) to the RI. Source identification based on multivariate statistical techniques, including principal component analysis (PCA), correlation analysis (CA) and hierarchical cluster analysis (HACA), was performed to differentiate the origins of trace metals. PCA and CA yielded similar results, indicating that As and V originated from natural sources (e.g., parent materials) and that the other metals were related to anthropogenic activities. HACA based on the I_{geo} showed that Cd was associated mainly with fertilizers, and the origins of Cr, Ni, Cu and Zn were probably industrial effluents, whereas Co and Pb were related to traffic activities. HACA of sediment cores suggested that Dongguan and Shenzhen cities contribute large quantities of metals to the riverine sediment, whereas few metals were discharged from Huizhou City.

1. Introduction

Riverine sediment is one of the primary components of river ecosystems. It is of importance for aquatic organisms (Pejman et al., 2015), as it provides a vital habitat for benthic organisms. However, with expanding urbanization, rapid industrialization and intense human activities, numerous toxic metals have been transported into river water and have accumulated in sediment, leading to severe deterioration of sediment quality (Christophoridis et al., 2009; Huang et al., 2012). Generally, sediment is considered not only as a sink for trace metals as a result of the rapid deposition of metals after adsorption onto suspended particles or fine organic matter, but also as a source because of the re-suspension of deposited particles in the aquatic environment (Hou et al., 2013). Sediment pollution by toxic metals has attracted considerable concern due to its potential risks to aquatic ecosystems. Trace metals such as Cu, Pb, Zn, Cd, Cr and Ni, which have distinctive physicochemical properties such as stability, bioaccumulation, non-degradation, persistence and toxicity in environmental media (Gao et al., 2015a; Li et al., 2013), can lead to adverse impacts ranging from relatively minor disturbances to major disruption to aquatic organisms due to bioaccumulation and biomagnification (Esen et al., 2010). These contaminants may then enter the human food chain and cause health problems (Varol and Şen, 2012).

Trace metals in sediment originate mainly from rock weathering and anthropogenic sources (Zhou et al., 2007). In past

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decades, massive amounts of metals have entered the river system from point sources, such as mining and smelting activities, domestic wastewater and industrial effluents, and non-point sources, such as indiscriminate application of fertilizers and pesticides in agricultural fields (Christophoridis et al., 2009; Fu et al., 2014; Gao et al., 2015a; Liu et al., 2013), as well as atmospheric deposition (Bai et al., 2011). These contaminants have been deposited mostly in sediments. The hydrological regime, hydrochemical properties and grain size of suspended particles and organic matter have been found to be key factors affecting the sedimentation rate and distribution characteristics of metals in sediment during transport in a river (Dai et al., 2007; Liu et al., 2010). The spatial distribution characteristics of metals in sediment may indirectly reflect the locations of pollution sources. In addition, the use of multivariate statistical techniques (e.g., principal component analysis [PCA], correlation analysis [PC] and hierarchical cluster analysis [HACA]) to analyze heavy-metal concentration datasets has been shown to be powerful for the identification of pollution sources (Singh et al., 2004; Han et al., 2006; Zhou et al., 2007).

Generally, trace metals have been found to be major pollutants in highly urbanized areas. In China, rapid development in the Pearl River Estuary (PRE) and the Yangtze and Yellow river regions has resulted in heavy metal pollution of riverine sediments in these areas (Ip et al., 2007; Ma et al., 2015; Zhang et al., 2009). More severe trace-metal sediment pollution has been reported in small-scale urbanized watersheds compared with large basins (Fu et al., 2014; Huang et al., 2012; Wang et al., 2015a) as a consequence of weak dilution effects resulting from lower runoff quantities and greater pollution loading. Thus, more attention should be paid to the aquatic environments of small watersheds in urban areas.

Dongguan City, located on the eastern side of the Pearl River Delta (PRD), South China, has undergone rapid urbanization and industrialization since Chinese reform and opening in 1978. More than 4000 factories in the leather, chemical, automobile, equipment, electronics manufacturing and metal processing industries have been established, turning Donguang City into an important industrial base in the PRD area. Subsequently, direct discharge of industrial effluents and domestic wastewater into the environment and the application of agricultural chemicals have resulted in elevated heavy metal concentrations in urban soils and surface water bodies (Gao et al., 2015a; Wu et al., 2015). However, to our knowledge, little information on riverine sediment quality in Dongguan City is available. Hence, the aims of the present study were (1) to investigate the spatial and vertical distribution characteristics of trace metals (V, Cr, Co, Ni, Cu, Zn, As, Cd and Pb), (2) to investigate the accumulation of trace metals and potential ecological risks caused by pollution, and (3) to identify metal sources in detail. The results obtained in this study may provide a scientific basis for local ecological compensation, implementation of pollution remediation strategies and securing the safety of the water supply in the PRD area.

2. Materials and methods

2.1. Study area

The Shima River, with a length of 88 km and a catchment area of 1249 km^2, is located on the eastern side of the PRE, South China. It has a southern subtropical monsoon climate, with mean annual precipitation of 1954 mm and a mean temperature of 22.9 °C.

The Shima River is a typical transboundary catchment distributed across Dongguan, Huizhou and Shenzhen cities, with catchment areas of 682.3, 400.7 and 140.7 km^2, respectively (Gao et al., 2015c). It is the largest tributary of the Dongjiang River in Dongguan City and it originates from the Guanlan River in Baoan District, Shenzhen City (Fig. 1). The river flows from south to north and discharges through an outlet located at Qiaotou Town into the Dongjiang River, which is an important water resource area in the PRD, providing approximately 80% of Hong Kong's potable water through river extraction at the Taiyuan pumping station. Consequently, the Shima River catchment is of strategic importance in the protection of a safe water supply due to the short distance between the inlet of the water supply pumping station and the drainage outlet from the Shima River. The Yantian River, originating from Yantian Reservoir, and Xiegang Creek, originating from The Tonghu Lake Wetland in Huizhou City, are two main tributaries that merge with the Shima River at the towns of

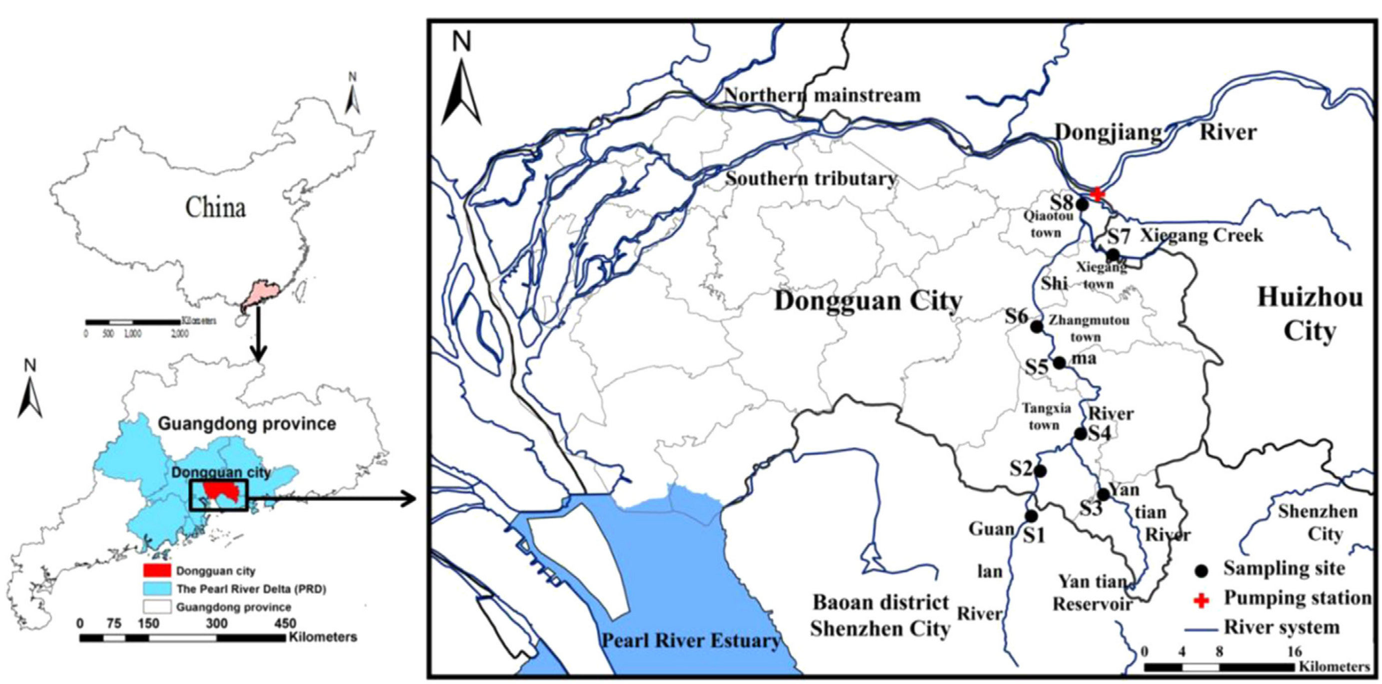

Fig. 1. Map of the study area and locations of sampling sites.