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Distribution, source and pollution level of heavy metals in river sediments from South China

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ABSTRACT

The sediment pollution caused by heavy metals has attracted a great deal of attention due to its persistence, bioaccumulation and toxicity. This research was the first to consider the whole of South China to obtain an overall profile of heavy metal spatial distribution, possible sources and pollution levels in river systems. For these data, 14 selected heavy metals were analysed in river sediments collected from sampling sites in Guangdong, Fujian, Guangxi and Hainan Provinces. The geoaccumulation index and enrichment factor revealed that river systems in South China were universally contaminated by Cd, As and Sn, which might be distributed by anthropogenic activities. Moreover, Guangdong Province, a relatively developed area in South China, was relatively polluted by certain heavy metals such as Ni, Cu, Zn and Mn. Multivariate statistical analyses such as Pearson's correlation matrix and a principal component analysis determined that several of the heavy metals might be derived from similar anthropogenic activities such as industrial effluents and domestic sewage discharge. In terms of heavy metal contamination in South China, necessary measures should be undertaken to protect rivers in South China.

1. Introduction

It is well known that rivers not only produce life but also multiply and generate human culture (Bhardwaj et al., 2017). Rivers perform a suite of ecological functions, such as water transport, aquaculture, habitat and shielding effects (Liao et al., 2016a). However, due to rapid industrialization, heavy metals have been discharged into rivers without effective purification (Zhang et al., 2017). Heavy metals have attracted much more attention on account of their inherent toxicity, vast sources, non-degradability, bioaccumulation and persistence in the aquatic environment (Gao et al., 2016; Paramasivam et al., 2015). Following the discharge of heavy metals into rivers, contamination can be distributed between different components of these aquatic systems, such as water, sediments and biota (Ali et al., 2016; Maanan et al., 2015). Consequently, only a small amount of the heavy metals remains in the water column, and the majority is deposited in the sediments (Malvandi, 2017). More specifically, heavy metals are bound to sediments through multiple mechanisms, including particle surface adsorption, ion exchange, co-precipitation and complexation with organic matter (Dong et al., 2014; Passos et al., 2010; Peng et al., 2009). River sediments serve as a reservoir or sink of heavy metals for aquatic organisms (Chapman et al., 1998; Sundelin and Eriksson, 2001). Additionally, several of the sediment-bound metals can be released into the water column through sediment resuspension, desorption reactions, reduction or oxidation reactions (Dong et al., 2012; Feng et al., 2007; Zhao et al., 2013), and this release may be more hazardous to animal and human life via the food chain. Thus, sediments in the aquatic environment can play a significant role in the deposition and transmission of heavy metals.

Heavy metals in sediments can originate from both natural sources (e.g., geological weathering, atmospheric precipitation and erosion from wind, waves, storms and bioturbation) and anthropogenic activities (e.g., industrial discharge, mining, transportation, and agricultural and urban activities) (Feng et al., 2011; Keshavarzi et al., 2015; Sun et al., 2015). Thus, sediment quality serves as a useful parameter for characterizing the influence of natural sources and anthropogenic activities; furthermore, sediment quality can provide evidence of anthropogenic effects on ecosystems and direct the policy and management of the surrounding areas (Wang et al., 2014; Xu et al., 2014).

In many countries, such as the Member States of the European Union and Japan, effective management and restoration technologies have been established to protect local ecological environments and

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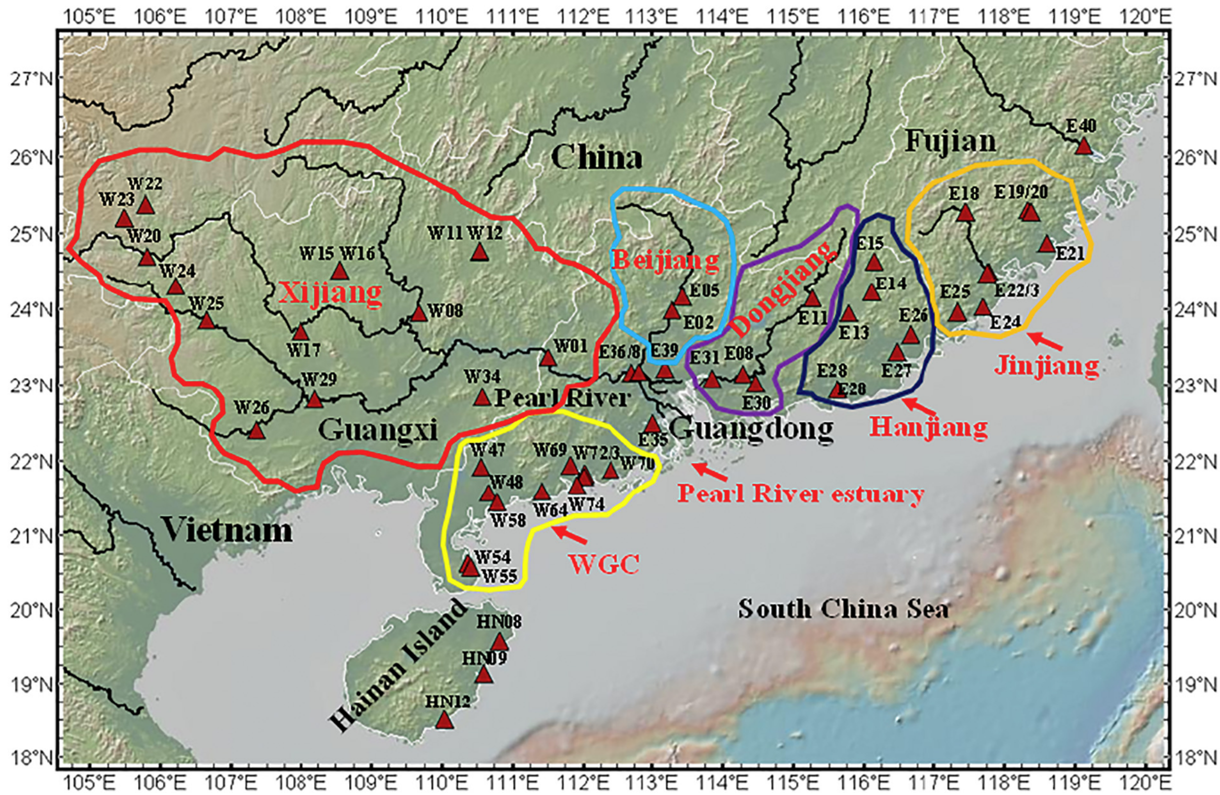

Fig. 1. Location of the study area and river sampling sites in Guangdong Province, Fujian Province and Guangxi Province, South China.

drinking water (Gu et al., 2012). Compared with other developing countries, China is currently suffering from great challenges with regard to heavy metal contamination due to rapid economic growth and intense industrialization (Wang et al., 2013; Wu et al., 2016). South China in particular, as one of the most rapidly developing regions in China, has undergone considerable environmental changes since the reform and opening-up policy of 1978, especially in local electronics industries that have generated a considerable amount of heavy metal contamination (Zhang et al., 2017). Thus, there is an urgent need to conduct research regarding heavy metal contamination in South China.

In this context, we selected several representative regions of South China as study areas, including Guangdong, Guangxi, Fujian and Hainan Provinces, which are shown in Fig. 1. Guangdong Province is a traditional industrial zone, while Guangxi, Fujian and Hainan Provinces are traditional agricultural regions. Studies on heavy metal pollution have demonstrated that rapid economic development will significantly affect the water quality of rivers (Wan et al., 2008; Zhou et al., 2007). Guangdong is the province with the most highly developed economy and the highest aquaculture production rate in China. The well-known Pearl River Delta (PRD), located in Guangdong Province (102°14′–115°53′E, 21°31′–26°49′N), is one of the most important regions for waterborne commerce (Yang et al., 2012). At present, numerous studies have focused primarily on the total content of heavy metals and pollution levels in the Pearl River, such as in the eight estuaries of the Pearl River (Ip et al., 2007; Wang et al., 2008; Yu et al., 2010), the Pearl River itself in the Guangzhou region (Li et al., 2009; Min et al., 2000) and so on; however, little information is available on the overall spatial distribution of heavy metal pollution in river systems over the entirety of Guangdong Province. Moreover, the rapid development of industries in Guangxi, Fujian and Hainan Provinces might also contribute to the degradation of the quality of their river systems, threatening the survival of aquatic life. Therefore, it is essential to determine the concentration of heavy metals and their potential hazardous risks in these river systems, on which little work has been completed. Additionally, to gain a more comprehensive understanding, a profile of these three provinces that shows an overall spatial distribution of heavy metals should be developed.

In summary, few studies have considered South China as a whole to obtain an overall heavy metal spatial distribution in the river systems. Therefore, this study aims to address the research gap to provide worthwhile information on the spatial distribution and possible sources and pollution levels of heavy metals. In recent decades, a considerable number of indexes have been developed to assess heavy metal pollution levels, spatial distribution and source apportionment, such as the geoaccumulation index (I_{geo}), enrichment factor (EF) and so on (Feng et al., 2011; Müller, 1979, 1981). The goals of this paper are as follows: (1) examine the spatial distribution of heavy metals in the rivers of South China; (2) assess heavy metal contamination using the I_{geo} and EF methods; and (3) identify the possible sources of these metals in river sediments from South China.

2. Sampling and methods

2.1. Study areas

The present study primarily examines the concentrations of heavy metals in South China, a region characterized by an uncoordinated economy; thus, we will discuss each area separately. The river study sites were distributed throughout South China and mainly comprised Guangdong, Guangxi, Fujian and Hainan Provinces (Fig. 1).

The river system in Guangdong Province generally comprises the Pearl River Basin, Hanjiang River Basin and coastal rivers of western and eastern Guangdong. As the second largest river in China, the Pearl River is a collection of all rivers and streams in the PRD, comprising three tributaries: the Dongjiang River, Beijiang River and Xijiang River. These three rivers comprise 89.6% of the total flow of the Pearl River. The Xijiang River is the main tributary that accounts for approximately 70.8% of the total annual flow. The Xijiang River flows throughout