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Assessment of heavy metal contamination in urban river sediments in the Jiaozhou Bay catchment, Qingdao, China

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ABSTRACT

Selected heavy metals (Cu, Pb, Zn, Cr, Cd, and As) in 47 river sediment samples collected in the Jiaozhou Bay (JZB) catchment were evaluated to assess their spatial distributions and the potential ecological risks. The heavy metal concentrations in the sediments ranged from 4.5–178.7 mg kg^{-1} for Cu, 8.2–65.8 mg kg^{-1} for Pb, 8.2–325.7 mg kg^{-1} for Zn, 12.2–185.5 mg kg^{-1} for Cr, 0.013–1.486 mg kg^{-1} for Cd, and 1.2–20.6 mg kg^{-1} for As. The results showed that the overall sediment quality in the area generally met the China Marine Sediment Quality criteria. Based on the effect-range classification (the threshold effect level (TEL)/probable effect level (PEL) Sediment Quality Guidelines, Cu, Cr, and As were likely to have adverse biological impacts on local aquatic ecosystems. The geoaccumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI) values suggested that elevated levels of Cd, As, and Pb contamination occurred in the eastern JZB catchment (i.e., Hongjiang River, Moshui River, Baisha River, Loushan River, Licun River, and Haipo River). This study presents the current state of the sediment quality in the JZB catchment. The results may assist in the definition of future coastal and river management measures specifically targeted at monitoring heavy metal contamination.

1. Introduction

Heavy metals in aquatic sediments originate from both natural sources (mainly erosion and rock weathering) and anthropogenic activities (e.g., industrial discharge, mining, agriculture, transportation, damming, sewage disposal, and wastewater runoff) (Çevik et al., 2009; Feng et al., 2011; Hernández-Crespo and Martín, 2015; Keshavarzi et al., 2015; Sun et al., 2015; Xu et al., 2016a). Heavy metals are recognized as a group of pollutants with high ecological significance because they are not removed from water via self-purification (Ghrefat and Yusuf, 2006). They can accumulate in suspended particulates and sediments, be released back into aquatic systems under favorable conditions, enter the food web, and cause health problems (Ghrefat and Yusuf, 2006; Varol, 2011; da Silva et al., 2015; Keshavarzi et al., 2015; Morina et al., 2015).

Over 50% of the global population lives in urban centers. Therefore, understanding the processes that affect urban systems is a global issue (Taylor and Owens, 2009). Expanding urbanization and industrialization has resulted in enormous increases in the volumes of heavy metals being discharged into urban rivers. Therefore, people living in and around urban centers are often exposed to unhealthy environments (Taylor and Owens, 2009; Lin et al., 2012; Sibanda et al., 2015; Xu et al., 2016a). Heavy metal contamination in urban river sediments has become the most serious problem in urban environments, and it has attracted increased attention from researchers (Gaur et al., 2005; Lin et al., 2012; Keshavarzi et al., 2015; Kadhum et al., 2016). Studying the distributions of heavy metals in urban river sediments can aid in assessing anthropogenic contamination in rivers and provide evidence of the anthropogenic impacts on ecosystems.

Qingdao is a coastal city situated at the southern tip of the Shandong Province in northern China with an area of 11,282 km^2 and a population of 9.0 million. Jiaozhou Bay (JZB) is a typical semi-enclosed coastal embayment located within the territory of Qingdao, and it connects to the Yellow Sea through a 3 km-wide channel (Fig. 1). Due to rapid economic and social developments in this region, JZB is influenced by human activities, leading to increased industrial, agricultural, and aquacultural inputs. Previous studies have indicated that heavy metal levels have increased in JZB in recent years (State Oceanic Administration (SOA) of China, 2004; Dai et al., 2007; Wang et al., 2007; Xu et al., 2016a). However, data were only available in the river outlet, intertidal, and/

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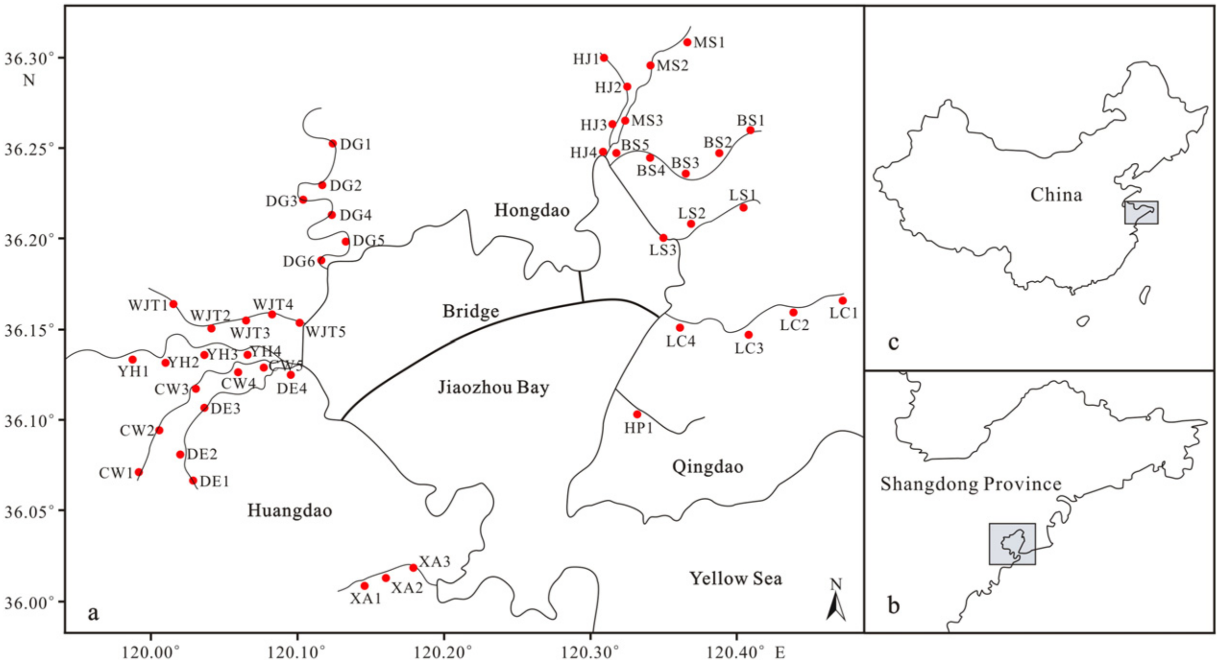

Fig. 1. Locations of the study area and river sampling sites in the Jiaozhou Bay catchment, Qingdao (a), Shandong Province (b), China (c). XA-Xin'an River; DE-Daoer River; CW-Caowen River; YH-Yanghe River; WJT-Wangjiatan River; DG-Dagu River; HJ-Hongjiang River; MS-Moshui River; BS-Baisha River; LS-Loushan River; LC-Licun River; HP-Haipo River.

or deep water areas (Dai et al., 2007; Wang et al., 2007; Deng et al., 2010; Ye et al., 2011; Xu et al., 2016a). Thus, studies of the urban rivers around the bay are lacking, limiting our understanding of the potentially adverse environmental impacts associated with heavy metal pollution in the area.

In recent decades, various indices have been developed to assess heavy metal contamination in sediments and the associated ecological risk. Geochemical normalization approaches such as the geoaccumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI) methods have been commonly used for this purpose (Müller, 1979, 1981; Feng et al., 2011; Hu et al., 2013; Zhao et al., 2015). This study addresses existing research gaps and provides valuable information regarding the spatial distributions of selected heavy metals in the urban rivers around the JZB catchment. The goals of this paper are to (1) determine the concentrations of heavy metals (Cu, Pb, Zn, Cr, Cd, and As) in the surface sediments of twelve rivers around the JZB catchment, (2) assess the potential ecological risks of these metals using the Sediment Quality Guidelines (SQGs), and (3) assess the heavy metal contamination using the I_{geo}, EF, CF, and PLI methods.

2. Materials and methods

2.1. Study area and sampling

Qingdao is located in the warm temperate monsoon climate zone. The annual mean temperature is 12.7 °C, and the annual average rain precipitation is 662.1 mm (Chen and Wang, 2012). From 1949 to 2013, the population of Qingdao City increased from 4.0×10^6 to 9.0×10^6 (Qingdao Municipal Statistics Bureau, 2014). The wastewater discharge in urban districts was 84.6×10^6 t yr^{-1} in 1980 (Shen, 2001), and it increased to 472×10^6 t yr^{-1} in 2013 (Qingdao Municipal Statistics Bureau, 2014). The Jiaozhou Bay Bridge (Fig. 1), which stretches 42 km and is the longest sea bridge in the world, was opened in July 2011.

More than 10 small seasonal rivers with varying water and sediment loads discharge into the bay, notably, the Xin'an (XA), Daoer (DE), Caowen (CW), Yanghe (YH), Wangjiatan (WJT), Dagu (DG), Hongjiang (HJ), Moshui (MS), Baisha (BS), Loushan (LS), Licun (LC), and Haipo (HP) Rivers (Fig. 1; Table 1). However, most of these rivers have become channels for industrial and domestic waste discharge due to increased

Table 1
Lengths, drainage areas, water discharges, and sediment loads in small rivers of the Jiaozhou Bay catchment, Qingdao.

Rivers	Area	Length (km)	Drainage area (km^2)	Water discharge (10^4 m^3 a^{-1})	Sediment load (10^4 t a^{-1})	References
Xin'an River	Western Jiaozhou Bay	12	20.96	ND	ND	Qingdao Daily (2012)
Daoer River		25	82.9	413	0.431	Zhao (2007); Sheng et al. (2014)
Caowen River		25.35	128.75	1089	1.136	Zhao (2007); Sheng et al. (2014)
Yanghe River		49	303	2106	2.215	Zhao (2007); Sheng et al. (2014)
Wangjiatan River		12.7	37.3	315	0.329	Zhao (2007); Sheng et al. (2014)
Dagu River		179.9	6131.3	50,366	36.590	Zhao (2007); Sheng et al. (2014)
Hongjiang River	Eastern Jiaozhou Bay	25.5	56	558	1.027	Zhao (2007); Sheng et al. (2014)
Moshui River		42.3	317.2	3734	6.867	Zhao (2007); Sheng et al. (2014)
Baisha River		33	215	3133	1.280	Zhao (2007); Sheng et al. (2014)
Loushan River		5.1	26.5	721	1.057	Zhao (2007); Sheng et al. (2014)
Licun River		22.5	131.5	3576	5.245	Zhao (2007); Sheng et al. (2014)
Haipo River		7	14	381	0.559	Zhao (2007); Sheng et al. (2014)

ND: no data.