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Distribution, sources and contamination assessment of heavy metals in surface sediments of the South Yellow Sea and northern part of the East China Sea

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ABSTRACT

Surface sediment samples collected from the South Yellow Sea and northern part of the East China Sea during spring and autumn, respectively, were analyzed for grain size, aluminum, and heavy metals (Cr, Ni, Cu, Zn, and Pb) to evaluate heavy metal levels and the contamination status. The results showed that all of the heavy metal concentrations met the standard criteria of the Chinese National Standard Criteria for Marine Sediment Quality. Both the EFs and a multivariate analysis (PCA) indicated that Cr, Ni, Cu, and Zn were mainly from natural contributions, while Pb was influenced by anthropogenic inputs, especially during autumn. The geoaccumulation index of Pb near the mouth of the Yangtze River suggested that the pollution degree in autumn was heavier than that in spring, which might be caused by the greater river discharge in summer and more heavy metal adsorption with finer grain sizes.

Over the past century, because of rapid industrialization, heavy metals have been discharged into coastal and estuarine environments through river discharges and anthropogenic inputs (Meybeck and Helmer, 1989; Cobelo-García and Prego, 2003; Prego and Cobelo-García, 2003; Hu et al., 2015). Due to the toxicity, persistence and bioaccumulation in the environment (Rainbow, 1995, 2007; Rainbow and Luoma, 2011; Wang et al., 2013), heavy metal contamination has attracted much more attention and become a global problem in recent years. Sediments in coastal and estuarine ecosystems, as a reservoir or sink for heavy metals, can act as a source of heavy metals for aquatic organisms when environmental conditions change (Chapman et al., 1998; Sundelin and Eriksson, 2001). The contaminated sediments may have toxic effects on benthic fauna and other aquatic organisms (Roberts, 2012; Hill et al., 2013). Thus, sediments in marine environments can play a great role in the deposition and transmission of heavy metals.

Estuarine and coastal areas, a region of active land-sea interactions, are sensitive to impacts from natural processes and anthropogenic activities (Li et al., 2007). Heavy metal contamination in marine sediments from these areas has occurred over the last several decades (Rubio et al., 2000; Selvaraj et al., 2004; Li et al., 2013). In this study, the study area includes the coasts of Jiangsu Province, Shanghai City and northern Zhejiang Province (Fig. 1), a coastal region that has seen rapid urbanization, industrialization and economic development during the past decades in China. However, with the rapid economic development, increasing environmental pressure of pollutants on marine ecosystems has occurred (Ma et al., 2001; Wu et al., 2001; Fang et al., 2009; Xu et al., 2016). For instance, several green algal blooms have occurred in this region since 2007 (Bao et al., 2015). As an important fishing ground and mariculture area, the region provides a large amount of nutrition and economic benefits to people in the study area. Heavy metals can be bio-accumulated by marine organisms and biomagnified through the food chain, resulting in elevated levels in seafood (Rainbow and Luoma, 2011), such as fishes, which ultimately does harm to human health. Most of the studies on heavy metal distributions, sources and contamination are less focused on the western South Yellow Sea (SYS) (Li et al., 2013; Jiang et al., 2014; Xu et al., 2014, 2016), where it is closely related to abundant human activities. In addition, there are few studies focused on seasonal changes in spring and autumn. Therefore, it is important to investigate heavy metal distributions and the degree of pollution in this area, in order to determine the environmental health risks and implement conservation of the marine environment. The main objectives of this study are to (1) investigate the current heavy metal (Cr, Ni, Cu, Zn, and Pb) distributions in the surface sediments; (2) distinguish the possible sources of the heavy metals using enrichment factors (EFs) and multivariate analysis;

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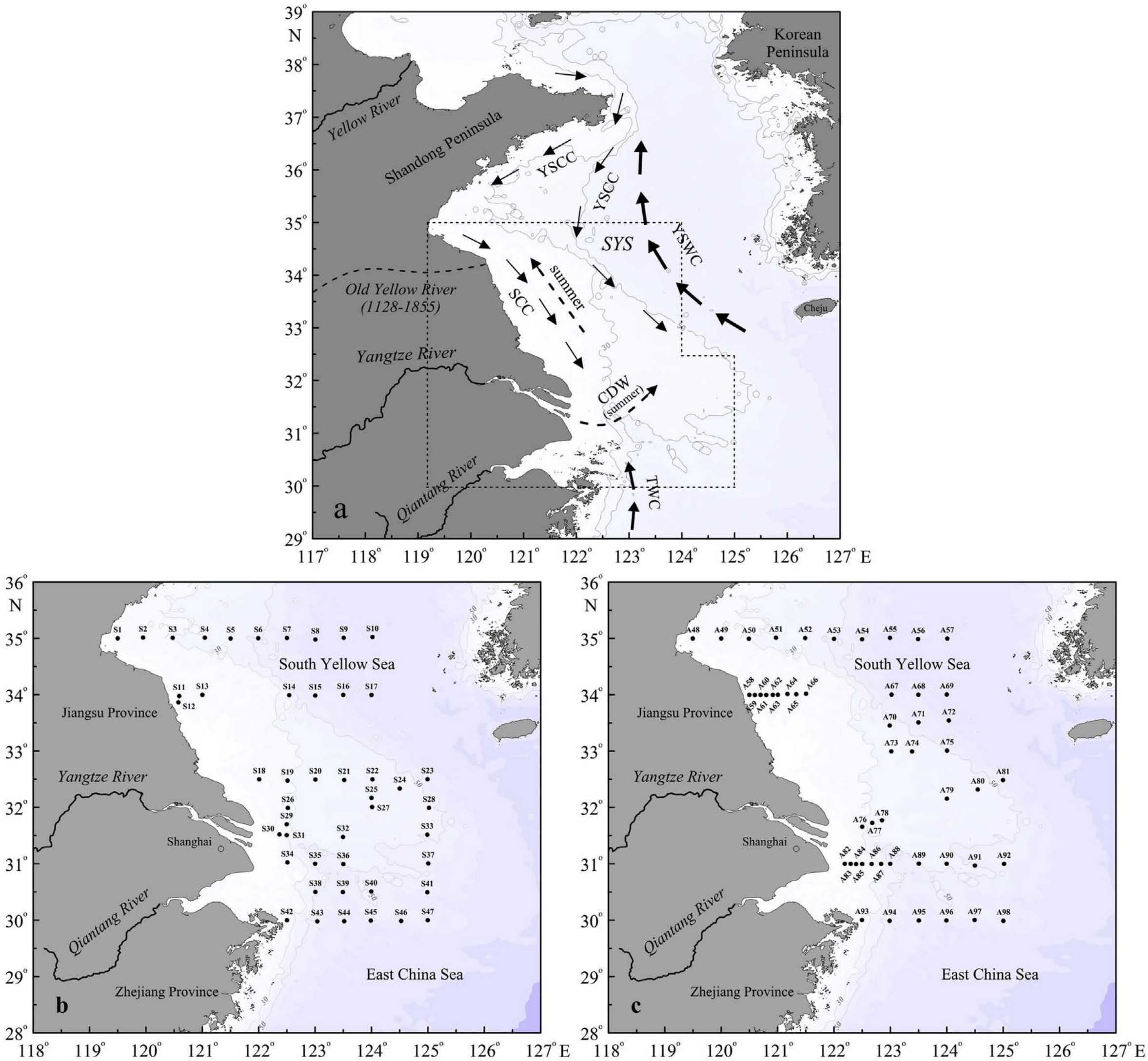

Fig. 1. Circulation system of the South Yellow Sea (a) and sampling stations during spring (b) and autumn (c) in 2009 (SYS, South Yellow Sea; YSCC, Yellow Sea Coastal Current; YSWC, Yellow Sea Warm Current; SCC, Subei Coastal Current; CDW, Changjiang Diluted Water; TWC, Taiwan Warm Current).

Table 1
Certified and measured concentrations of Al (%) and heavy metal concentrations (μg/g) of the standard reference materials (GBW07333, GBW07334).

Elements	GBW07333		GBW07334	
	Measured values	Certified values	Measured values	Certified values
Al	8.97	9.22 ± 0.23	5.91	5.83 ± 0.06
Cr	102.8	107 ± 4	61.5	60.0 ± 3.2
Ni	44.9	46.1 ± 1.1	41.7	39.2 ± 2.6
Cu	29.9	29.1 ± 1.1	20.1	20.7 ± 1.4
Zn	119.3	114 ± 6	93.6	90.4 ± 4.3
Pb	28.3	29.0 ± 1.6	17.1	16.8 ± 2.1

and (3) assess heavy metal contamination with the geoaccumulation index (I_{geo}).

The Yellow Sea, as a typical semi-enclosed epicontinental sea, receives huge discharges, mainly from the Yellow River (Huanghe) and Yangtze River (Changjiang), which account for approximately 10% of the world river sediment load (Milliman and Meade, 1983). The modern Yellow River and Yangtze River annually discharge approximately 1.1×10^9 and 5.0×10^8 tons of suspended sediments into the sea, respectively (Milliman and Meade, 1983). Over the past 7000 years, approximately 30% of the Yellow River-derived sediment has been transported into the Yellow Sea (Yang and Liu, 2007). In comparison, approximately 70% of the Yangtze River-derived sediment has been deposited in the deltaic system (Liu et al., 2006). The circulation system in the Yellow Sea is mainly composed of the Yellow Sea Warm Current (YSWC) and the Yellow Sea Coastal Current (YSCC) (Fig. 1a). The YSCC flows southward and southwestward along the east of the Shandong Peninsula, and the southward branch turns southeastward near 33–32°N. The Changjiang Diluted Water (CDW) usually flows northeastward in summer (Su and Yuan, 2005). Some studies found that a portion of the Yangtze River plume spread northward into the SYS in summer or autumn (Yuan et al., 2008; Wu et al., 2014; Lu et al., 2015). The grain sizes of the suspended sediments discharged from the Yangtze River and in the southwestern SYS are very fine, with mean grain sizes of 5.5–11 μm (Li et al., 2003) and 14–23 μm (Song et al., 2006), respectively. Because of the high specific surface area and humic substance content, heavy metals are prone to being bound in the fine-grained fractions (< 63 μm) of the sediments (Horowitz and Elrick, 1987; Moore et al., 1989). Therefore, heavy metals can be introduced in this way to the estuarine and coastal environment in the study area.

Forty-seven and fifty-one surface sediment samples were collected in the SYS and northern East China Sea in late spring and early summer