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Distribution and transport of heavy metals in estuarine–inner shelf regions of the East China Sea

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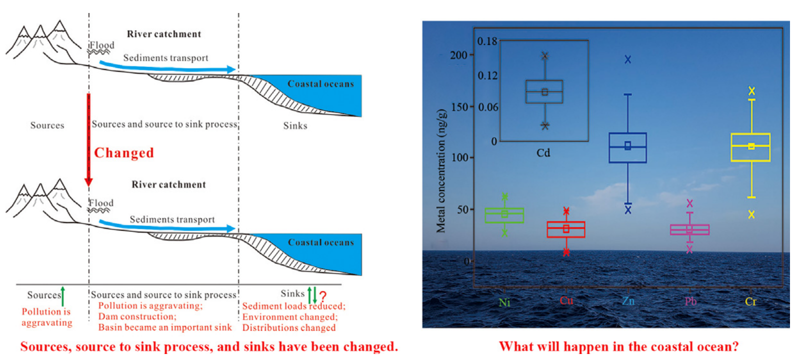
HIGHLIGHTS

- Distribution patterns of heavy metals in the East China Sea are depicted.
- Hydrodynamics and sediment properties are the main factors affecting heavy metal distribution.
- Spatial patterns have drastically changed in the context of intensive human activities.

GRAPHICAL ABSTRACT



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ABSTRACT

This study analyzes the distribution and transportation of heavy metals in surface sediments by determining the concentrations of 6 heavy metals (Cr, Zn, Ni, Pb, Cu, and Cd) based on 164 surface sediments collected from the East China Sea (ECS). The results indicated that concentrations of heavy metals were higher in the south than the north with a clear boundary near 30° N. The distributions of the six heavy metals could be divided into four groups that corresponded well with different sediment components, suggesting that hydrodynamic sorting processes play an important role in the selective transportation of sedimentary heavy metals. In addition, the spatial distributions of heavy metals were more consistent with fine-grained sediments having a grain size lower than 32 μm. Heavy metal concentrations were slightly higher than found in previous studies conducted from 2002 to 2010. In addition, their spatial patterns have changed drastically compared to data from 2006, suggesting that intensive inland human activities have had a profound impact on heavy metal transportation and distribution in the estuarine & inner-shelf regions of the ECS.

1. Introduction

Heavy metal pollution has been identified as one of the most concerning worldwide environmental crises in past decades. Seven of these (As, Cd, Cu, Pb, Ni, Se, and Zn) are regulated by the United States' Environmental Protection Agency due to their toxicity,

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abundance, and persistence (Ha et al., 2014). Although these heavy metals originate from both natural processes and anthropogenic activities (Chen et al., 2014; Huang et al., 2015), levels of anthropogenic heavy metals in the environment have increased dramatically since the Industrial Revolution (Chen et al., 2014; Guo and Yang, 2016). Once released, they are present throughout the environment including in air, water, soil, and sediment (Huang et al., 2018; Chowdhury et al., 2016; Birch, 2016; Wu et al., 2016), but most are eventually deposited into marine sediments via riverine runoff or atmospheric precipitation (Pan and Wang, 2012; Yin et al., 2016; Wu et al., 2018). Therefore, marine sediments are considered an important sink of heavy metals, especially in coastal ocean, due to rapid urbanization and industrialization (Xia et al., 2011; Yin et al., 2016; Ip et al., 2004; Chen et al., 2014).

Estuaries and their adjacent inner shelf regions are an important component of coastal oceans, receiving large amounts of terrestrial materials discharged via riverine input (such as heavy metals) (Yin et al., 2016). However, such transportation has been changed substantially by intensive human activity in river catchments including land-use changes, fertilizer use, dam construction, and water withdrawal. For example, dam construction intercepts large amounts of terrestrial material, resulting in sediment starvation in coastal oceans and erosion of river deltas including those of the Ebro, Nile, Mississippi, Mekong, and Colorado (Stanley, 1996; Blum and Roberts, 2009; Syvitski et al., 2005; Anthony et al., 2015). In some cases, the sedimentary environment in the estuarine-inner shelf regions had changed, resulting in coarser surface sediments (Luo et al., 2012; Yang et al., 2018). Such changes have also influenced the distribution and composition of heavy metals in riverine-estuary-shelf systems because their transportation is increasingly dominated by fine-grained sediments. Therefore, more attention should be paid to the environment in estuarine, coastal, and shelf areas associated with large rivers in response to upstream changes.

The East China Sea (ECS) is a typical river-dominated marginal sea primarily influenced by the Changjiang River, the longest river (6370 km) in Asia with an annual sediment discharge of 4.78×10^8 t (Milliman and Farnsworth, 2013). A large subaqueous delta has developed near the Changjiang River Estuary (Liu et al., 2007) and a massive muddy sedimentary system has formed on the inner shelf of the ECS (Fig. 1b) (Gao and Collins, 2014). At the same time, intensive industrialization and urbanization in the catchment have resulted in large amounts of terrestrial pollutants (including heavy metals) being discharged into the Changjiang River and eventually into the ECS.

However, the transport of terrestrial materials from river catchments to estuaries and shelves has changed substantially due to human activities such as those noted above (Syvitski et al., 2005; Gao et al., 2015; Yang et al., 2018). For example, the impoundment of the Three Gorges reservoir has resulted in a rapid decrease in the downstream discharge of sediments (Yang et al., 2011; Gao et al., 2015; Wang et al., 2017) and associated materials (Li et al., 2014), including large amounts of heavy metals absorbed by fine-grained sediments. The rapid decrease in sediment size and discharge has significantly changed the sedimentary environment and dynamics in the estuarine-inner shelf regions of the ECS inducing channel erosion in the middle and lower reaches, altering the sediment composition substantially (Yang et al., 2011; Gao et al., 2015, 2017). These variations have inevitably changed the distribution and transportation of heavy metals in the Changjiang River Estuary and the inner shelf of the ECS.

Previous studies have demonstrated that the composition, origin, and dispersal paths of terrestrial material in the ECS changed after

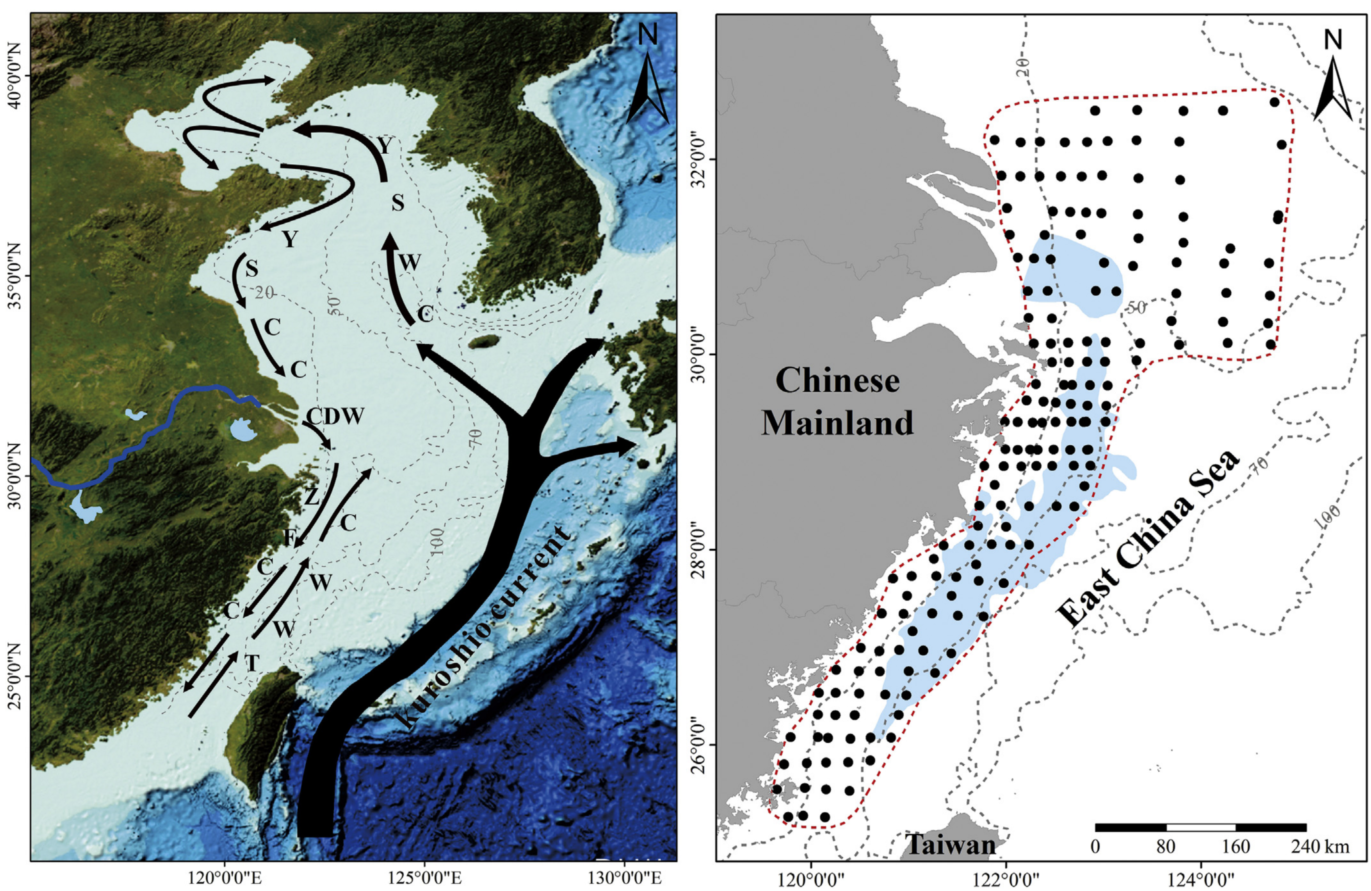

Fig. 1. Study area within the East China Sea showing (a) major oceanic currents including the Changjiang-diluted water (CDW), Zhejiang-Fujian coastal current (ZFCC), Taiwan warm current (TWWC), Yellow Sea coastal current (YSCC), Yellow Sea warm current (YSWC), and Kuroshio current; and (b) sampling sites along the Changjiang River Estuary and inner shelf regions. The red dotted line represents the delineations of the Changjiang Subaqueous Delta (CSD) and the Zhejiang-Fujian Coastal Mud Deposits (ZFCMD) by Su and Huh (2002). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)