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Spatial-temporal distribution and risk assessment of mercury in different fractions in surface sediments from the Yangtze River estuary

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ABSTRACT

The temporal and spatial distributions of mercury in different fractions and its potential ecological risk were investigated in sediments from the Yangtze River estuary (YRE) by analyzing data collected from the study area. The results showed that mercury in the organic and residual fractions had dominant proportions, from 15.2% to 48.52% and from 45.96% to 81.59%, respectively. The fractions were more susceptible to seasonal changes than other fractions. Higher proportions of mercury in organic fraction were found in wet seasons; the opposite was true for mercury in residual fraction. With respect to the spatial distribution, the concentration mercury in exchangeable, carbonate and Fe-Mn oxide fractions showed a decreasing trend from the inner estuary to the outer estuary, but no obvious trends were found in the distributions of mercury in the organic and residual fractions. The risk assessment code (RAC) was used to evaluate the potential ecological risk in the study area based on the proportions of exchangeable and carbonate fractions. The average RAC values during the four periods were 6.00%, 2.20%, 2.83%, and 0.61%. Although these values show that the risk in the study area is generally low, the distribution of RAC values indicates that the inner estuary has a medium risk, with a value up to 10%.

Estuaries, which are partially enclosed coastal areas, are the confluence of rivers and the open sea. They are influenced by both the terrestrial environment and the maritime environment, such as tides, waves and drainage from the rivers (Chaalali et al., 2013). Large populations tend to reside on the banks of estuaries because of their advantageous geographical position and high productivity (Costanza et al., 2016). As a result, the estuary area can experience rapid social and economic development. However, these areas also suffer from several environmental and ecological problems, especially water contamination (Coco 2008; Mathivanan and Rajaram, 2014; Islam et al., 2015). Sediments are crucial components of the water environment and act as pollutant sinks, so investigating contamination in sediments is very important (Abdolahpur et al., 2013).

Heavy metals have high toxicity and are the primary environmental pollutants in the water column and sediments in estuaries (Alves et al., 2014). Natural processes and anthropogenic activities are the main sources of heavy metals (Yang et al., 2013). Heavy metals are characterized by biotoxicity, bioaccumulation ability and environmental stability, which have negative effects on the environment and human health (Choi et al., 2012). In estuary ecosystems, heavy metals migrate between the water column and the sediments through several complex mechanisms, such as changes in the redox conditions resulting from seasonal variations and the resuspension of sediments caused by water turbulence (Wang et al., 2012). When resuspension occurs, heavy metals become desorbed from the sediments into the water column, causing secondary contamination (Lenzi, 2010; Gillan et al., 2012). Therefore, attention must be paid to heavy metals in sediments.

Assessment of heavy-metal contamination is one method used to evaluate the ecological risks from heavy metals. Several methods have been used for such evaluations, including the single-factor index (Li et al., 2016), the sediment enrichment factor (Santolin et al., 2015) and the index of geo-accumulation (I_{geo}) (Banerjee et al., 2017). Assessments that are based on only one heavy metal are insufficient because of the complexity of environmental contamination; thus, comprehensive assessments are required. The Nemerow index (Angulo, 1996), the pollution load index (Wang et al., 2011) and the potential ecological risk index (RI) (Duodu et al., 2017) have been used by many researchers to evaluate the combined influence of heavy metals. Among the various assessment methodologies, concentrations have been frequently used to assess the contamination level of heavy metals (Kadhum et al., 2015; Liu et al., 2016; Xu et al., 2017).

Heavy metals exhibit different fractions under different circumstances (Prartono et al., 2016). The bioavailability and mobility of heavy metals depend on the chemical fractions, which can be

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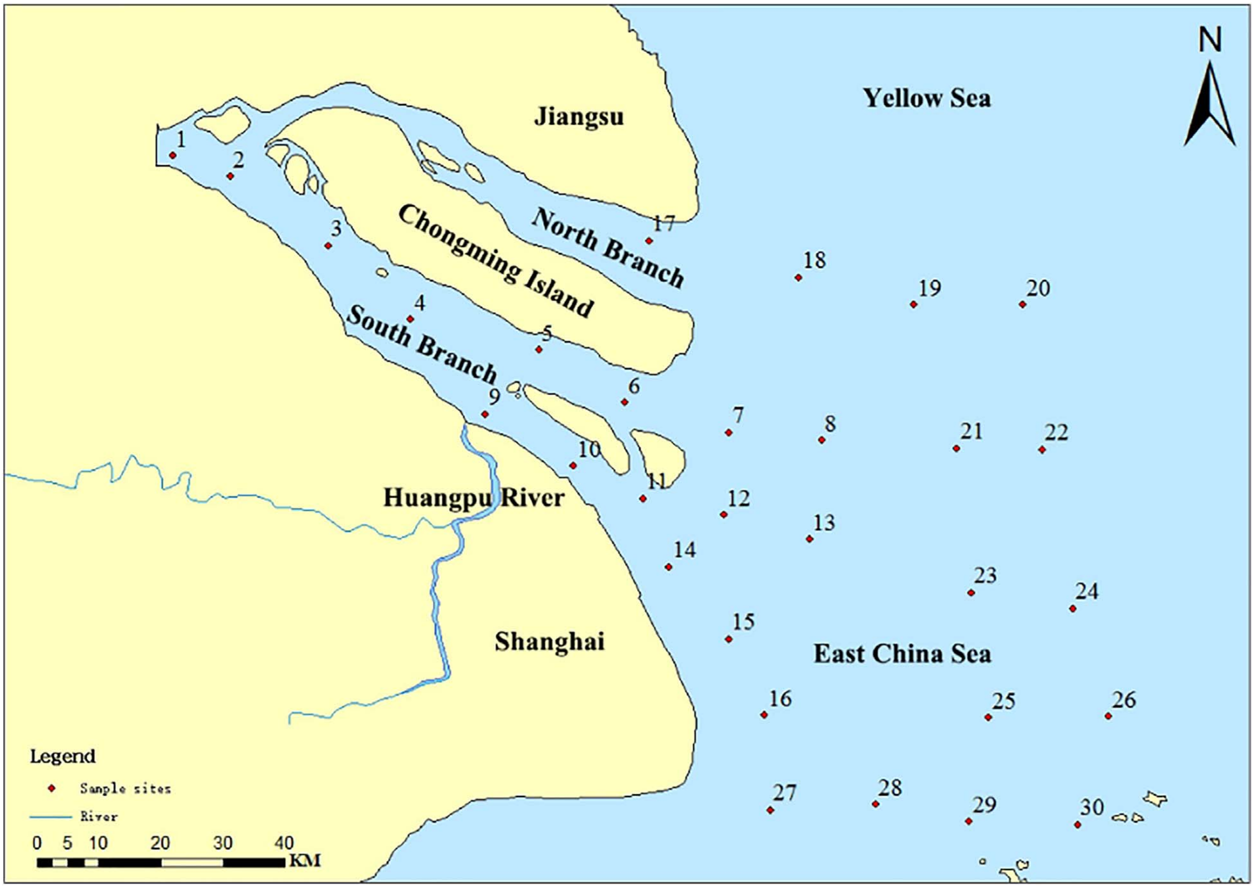

Fig. 1. Location of the Yangtze River Estuary and 30 sampling sites.

Table 1
Risk assessment code categories.

Risk categories	The percentages of exchangeable and carbonate fractions (%)
No risk	< 1
Low risk	1–10
Medium risk	11–30
High risk	31–50
Very high risk	> 50

Table 2
Proportions of mercury in different fractions at four periods.

Fractions of mercury	Proportion of fractions (%)			
	2010–8	2010–11	2011–2	2011–5
Exchangeable	2.22	0.90	2.21	0.39
Carbonate	2.58	1.06	2.25	0.23
Fe-Mn oxides	1.85	0.93	1.92	0.61
Organic	47.39	15.52	36.02	48.52
Residual	45.96	81.59	57.60	50.25

categorized into exchangeable, carbonate, Fe-Mn oxide, organic and residual fractions (Tessier et al., 1979; Wang et al., 2016). Of these five categories, the exchangeable and carbonate fractions are the most labile, contributing to their high bioavailability and mobility (Zhang et al., 2017). The risk assessment code (RAC) has been widely used to assess the potential ecological risk based on the chemical fractions of heavy metals because of the varying bioavailability and mobility of different fractions (Velimirović et al., 2011; Bastami et al., 2017; Marrugo-Negrete et al., 2017).

In this research, mercury in different fractions in the Yangtze River estuary (YRE) was selected as the study object. The main goals of this study were to (1) identify the temporal changes in mercury in five fractions, (2) determine the spatial distribution of mercury in different fractions, and (3) calculate the potential ecological risk level based on the RAC method to support the management of mercury contamination in the YRE.

The YRE, which is located along the eastern coast of China, is the outlet of the Yangtze River Basin (Fig. 1). It is divided by the Chongming Island into two branches. The YRE has becomes a major economic center because of its convenient geographic location. This estuary has produced great economic benefits but has also experienced serious environmental pollution problems, especially water pollution from heavy metals (Cao et al., 2015).

Surface sediment was collected at 30 sampling sites in the study area in August 2010, November 2010, February 2011 and May 2011. At each site, three independent samples were collected and composed into a mixed sample. Polytetrafluoroethylene (PTFE) bags were used to cryopreserve the samples and transfer the samples to the laboratory. A 0.284-mm membrane sieve was used to obtain a homogeneous powder from the samples, which were preprocessed through the removal of coarse fragments and a drying treatment and then stored at 4 °C. The Tessier sequential extraction procedure was used to analyze the mercury content in the exchangeable, carbonate, Fe-Mn oxide, organic and residual fractions (Tessier et al., 1979).

Duplicates, method blanks and standard reference materials were used to execute the quality assurance and quality control. Standard reference materials were used to examine the accuracy of the determination method. Errors were controlled within allowed scope. More details can be found in Liu et al. (2016).

Kriging methods have been widely used to execute the spatial interpolation due to its more precise estimates and minor estimation