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Baseline

Assessment of heavy metal contamination in surface sediments from the nearshore zone, southern Jiangsu Province, China

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ABSTRACT

We determined the heavy metal concentrations and evaluated the pollution status of 213 surface sediment samples collected from the nearshore zone of southern Jiangsu Province, China. The distributions of lead (Pb) and zinc (Zn) were similar, and their concentrations were highest in tidal creeks dominated by fine-grained sediments, such as the Dawanhong and Wangcanghong creeks and the outer part of Lanshayang Creek. The spatial distributions of chromium (Cr) and cadmium (Cd) were similar, with high concentrations south of Yangkou Port and Haozhi Port. Copper (Cu) concentrations were high off the coast of Rudong. The sediments were not polluted by Cu, but were weakly polluted by Cd, Cr, Pb, and Zn. The results of principal component analysis indicated that Pb and Zn were mainly from natural sources, Cd and Cr were from anthropogenic sources, and Cu was from a mixture of natural and anthropogenic sources.

The pollution of marine environments as a result of rapid economic development and increased human activities has attracted attention worldwide. There is particular concern about pollution from heavy metals, because of their toxicity, persistence, and bioaccumulation (Bryan and Langston, 1992; Dassenakis et al., 1997; Yang et al., 2015). Marine sediments can be regarded as heavy metal receptacles in the marine environment, because most of the heavy metals in seawater finally accumulate in sediments via absorption and sedimentation of suspended material. At the same time, the sediments represent an internal source of pollution as the heavy metals can be released back into the sea when environmental conditions change (Diagomanolin et al., 2004; Fang et al., 2009; Gao and Li, 2012). Compared with seawater and marine species, marine sediments are sensitive indicators of heavy metal concentrations and are easy to collect, and therefore are often used to assess the quality of the marine environment (Hill et al., 2013; Rubio et al., 2000; Tam and Wong, 2000). While previous studies in China have examined the distribution of heavy metal contamination in the northern part of Jiangsu Province (Lv et al., 2013; Xu et al., 2014; Zheng et al., 2017), the Changjiang Estuary (Chen et al., 2016; Zhang et al., 2009), and the South Yellow Sea (Yuan et al., 2012), heavy metal contamination in the nearshore zone of southern Jiangsu Province has received little attention. The aim of this study is therefore to assess the distribution of heavy metal contamination in surface sediments in the nearshore zone of southern Jiangsu. We hope that this study will provide the scientific basis for the protection of the ecological environment and sustainable use of coastal areas.

There are several current systems in the Yellow Sea and nearby regions (Fig. 1). The Yellow Sea Warm Current enters the Yellow Sea from the southwestern side of Cheju Island and then gradually turns northward and runs along the western side of the Yellow Sea Deep Trough. When it reaches the North Yellow Sea, it turns west and may extend as far as the Bohai Sea in winter, where its salinity drops below 32. The Yellow Sea and North Jiangsu Coastal Currents flow mainly southwards along the western coast of the Yellow Sea during summer and winter, and local convergent–divergent tidal currents occur over tidal sand ridges off the coast of Jiangsu (Li et al., 2001).

We collected 213 surface sediment samples in the nearshore zone of southern Jiangsu Province in 2012, 2015, and 2016 using a grab sampler (Fig. 1). We kept the top 5 cm of the sediments and divided each sample into two parts: one for element analysis and the other for grain size analysis. After digestion with 10% hydrogen peroxide to remove organic matter and dispersal with sodium hexametaphosphate, the grain sizes were determined with a Mastersizer-2000 laser particle size analyzer (Malvern, UK). The grain size properties were calculated using the formula of Folk and Ward (1957).

The subsamples were oven-dried at a constant temperature ($< 60\,^{\circ}C$) and ground to $< 63\,\mu m$ before element analysis. Then, ~ 0.05 g of each powered sample was completely digested in a closed

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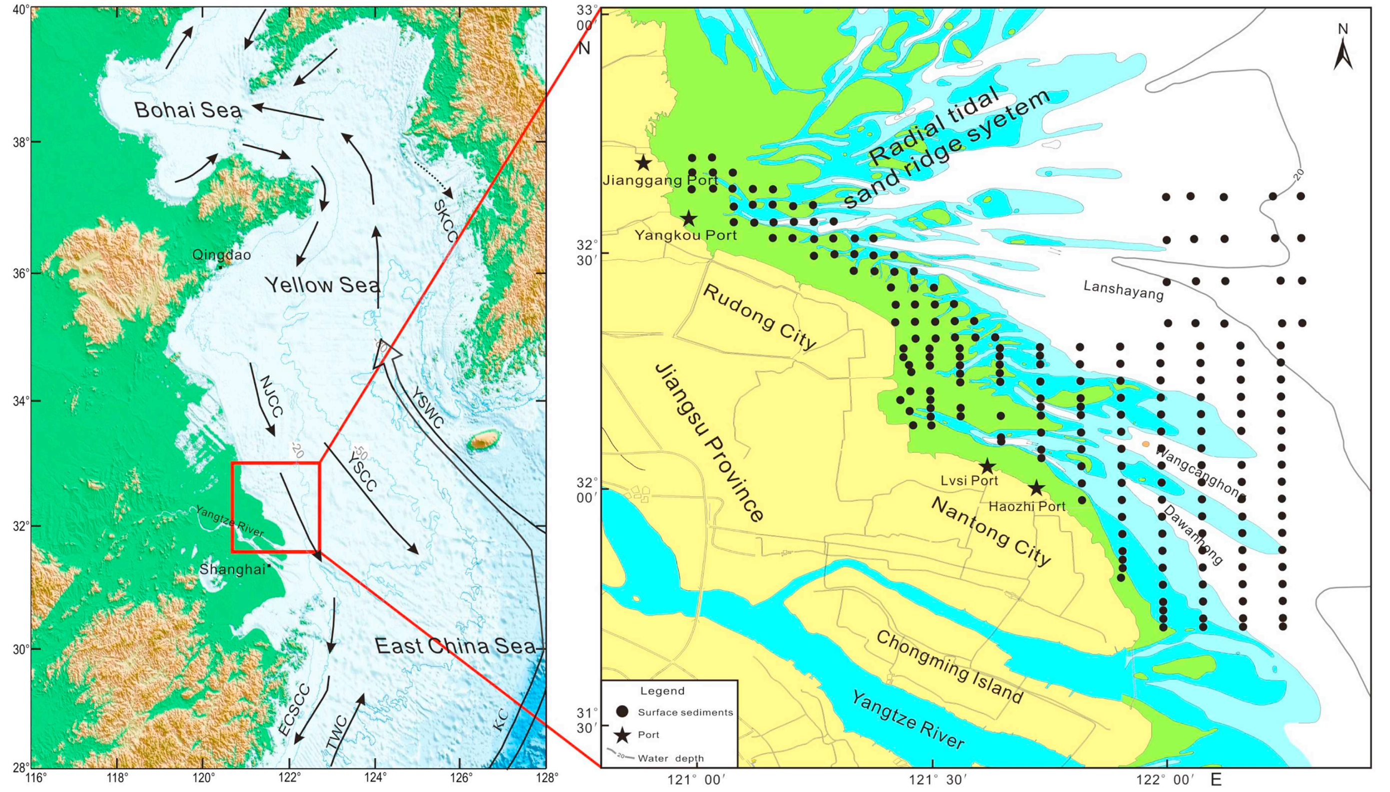

Fig. 1. Bathymetry, regional circulation pattern (during winter), and locations of surface sediment sampling sites in the near-shore area of Southern Jiangsu (KC, Kuroshio Current; YSWC, Yellow Sea Warm Current; TWC, Taiwan Warm Current; YSCC, Yellow Sea Coastal Current; SKCC, South Korean Coastal Current; NJCC, North Jiangsu Coastal Current; ECSCC, East China Sea Coastal Current).

Teflon digestion vessel with 4 ml nitric acid (HNO_3) and 3 ml hydrofluoric acid at 195 °C for 48 h. The digestion vessel was then opened and the samples were evaporated on a heating plate until semi-dry. Once cool, the digested samples were made up to a final volume of 40 ml with a solution of 2% HNO_3. Concentrations of three major elements, aluminum (Al), iron (Fe), and manganese (Mn), were determined by X-ray fluorescence spectrometry (XRF, Axios PW4400). Concentrations of five heavy metals, copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), and chromium (Cr), were determined by inductively coupled plasma–mass spectrometry (ICP–MS; Thermo X series). We checked the quality of the analysis by using parallel samples and the national sediment standard GBW07309 (GSD-9), which were analyzed every 10 unknown samples. The relative error of the parallel samples was < 5% and the standard material recovery was between 90% and 100%.

The mean grain size (Mz) ranged from 1.1Φ to 7.3Φ (mean of 4.1Φ), which indicates that the sediments consisted mainly of silt and sandy silt. The Cu, Pb, Zn, Cd, and Cr concentrations ranged from 7.0 to 46.0, 3.7 to 33.6, 12.9 to 117.2, 0.02 to 0.49, and 34.8 to 236.7 mg/kg, respectively (means of 19.1, 19.7, 62.6, 0.12, and 72.8 mg/kg, respectively; Table 1).

We compared the heavy metal concentrations in the study area with those in other areas (Table 1). There were no data for Cr in northern Jiangsu Province or the South Yellow Sea, or for Cd in Liaodong Bay. Apart from Cr, the concentrations of which were lower in Liaodong Bay than in the study area (Hu et al., 2013), the mean concentrations of Cu, Pb, Zn, Cd, and Cr were lower in the study area than in other areas nearby (Gao and Chen, 2012; Xu et al., 2014; Yuan et al., 2012; Zhang et al., 2009), which indicates that heavy metal contamination was relatively low in this area.

Apart from Cd, the average heavy metal concentrations in surface sediments in the coastal areas of Jiangsu were higher in recent years than in 2008 (Zhang, 2013), and the mean Cu, Pb, Zn, and Cr concentrations were 16.0%, 11.6%, 50.3%, and 105.5% higher than those in 2008, respectively. The heavy metal pollution has increased overall in recent years. The increase in pollution may be attributed to rapid social and economic development, intensification of human activities,

Table 1
Comparison of the heavy metal concentrations in surface sediments in the nearshore area of southern Jiangsu and other representative areas (unit: mg/kg).

Locations	Cu	Pb	Zn	Cd	Cr	Reference
Study area	7.0–46.0	3.7–33.6	12.9–117.2	0.02–0.49	34.8–236.7	This study
	19.1	19.7	62.6	0.12	72.8	
Jiangsu coastal areas	16.47	17.02	41.65	0.22	35.43	Zhang (2013)
Changjiang Estuary	30.7	27.3	94.3	0.26	78.9	Zhang et al. (2009)
north Jiangsu Province	35.0	25.7	88.6	0.19	na	Xu et al. (2014)
South Yellow Sea	16.9	17.8	93.7	0.3	na	Yuan et al. (2012)
Coastal Bohai Bay	38.5	34.7	131.1	0.22	101.4	Gao and Chen (2012)
Liaodong Bay	19.4	31.8	71.7	na	46.4	Hu et al. (2013)
MSQ-1	35	60	150	0.5	80	AQSIQ (2002)

MSQ-1 is the Chinese Marine Sediment Quality standard criteria (GB 18668-2002) issued by the Administration of Quality Supervision, Inspection and Quarantine (AQSIQ).

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