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Baseline

Environmental background values of trace elements in sediments from the Jiaozhou Bay catchment, Qingdao, China

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A B S T R A C T

Selected trace elements (As, Cr, Zn, Cu, Cd, Co, Pb and Ni) in 76 surface sediment samples collected from the rivers and the intertidal zone of Jiaozhou Bay (JZB) were evaluated to assess their environmental background values in the JZB catchment. Overall, the sediment quality in the area meets the China Marine Sediment Quality criteria. The background values (ranges) of the elements As, Cr, Zn, Cu, Cd, Co, Pb and Ni were, respectively, 8.28 (4.10–12.46), 67.96 (38.40–97.52), 56.80 (16.42–196.51), 19.13 (5.71–64.06), 0.10 (0.02–0.42), 6.51 (2.08–20.40), 17.97 (12.26–55.84) and 20.69 (10.43–30.95) mg/kg. The background values of most of the trace elements were lower than those in Chinese soil, the upper continental crust, global shales and global pre-industrial sediments. The results may assist in defining future coastal and river management measures specifically targeted at monitoring trace element contamination in the JZB catchment.

Trace elements (e.g., As, Cr, Zn, Cu, Cd, Co, Pb and Ni) are major pollutants in coastal environments. Trace elements reach the aquatic environment by various pathways and can endanger aquatic life and destroy ecosystems; they can also affect human health through their enrichment and transport in the food chain (Varol, 2011; da Silva et al., 2015; Keshavarzi et al., 2015; Morina et al., 2015; Chen et al., 2016; Jamshidi and Bastami, 2016; Schintu et al., 2016). Several geochemical normalization approaches exist to assess trace element contamination in sediments and its ecological risks; these include the enrichment factor (EF), contamination factor (CF), pollution load index (PLI) and geoaccumulation index (I_{geo}) (Müller, 1979; Hu et al., 2013; Chen et al., 2016; Hanif et al., 2016; Jamshidi and Bastami, 2016; Schintu et al., 2016; Xu et al., 2016). The process of calculating these parameters requires the determination of environmental background values.

The environmental background value is the normal concentration of an element in an unpolluted natural state, which strongly varies by region. Therefore, study and identification of environmental background values is critical to the assessment of trace element contamination (Fukue et al., 2006; de Paula Filho et al., 2015; Hanif et al., 2016). Most previous researchers have used the average concentration of elements in the upper continental crust (UCC) (Taylor and McLennan, 1995; Hu et al., 2013), shale (Turekian and Wedepohl, 1961), preindustrial sediments (Cobelogarcía and Prego, 2003; Liu et al., 2010) or other large-scale reference systems to determine environmental background values (Gao et al., 1998; Xu et al., 2017). However, the geochemical characteristics of elements in a given location have generally been overlooked, which has caused large deviations in the assessment results.

Jiaozhou Bay (JZB), which is located on the southern coast of the Shandong Peninsula, China, is a typical semi-enclosed shallow bay with an area of 340 km^2 (Gao et al., 2014). More than 10 small seasonal rivers with varying water and sediment loads discharge into the bay (Fig. 1). The JZB is essential to the development of the city of Qingdao and is known as the "Mother Bay of Qingdao". Since China's reform and opening, Qingdao has experienced rapid economic development and accelerated urbanization, resulting in increased pollutant discharge to the JZB catchment. In previous assessments of trace element contamination in the JZB, researchers have used trace elements in Chinese soil (Li et al., 2011) and preindustrial sediments in the JZB (Liu et al., 2010; Xu et al., 2016) as background values. These methodologies have

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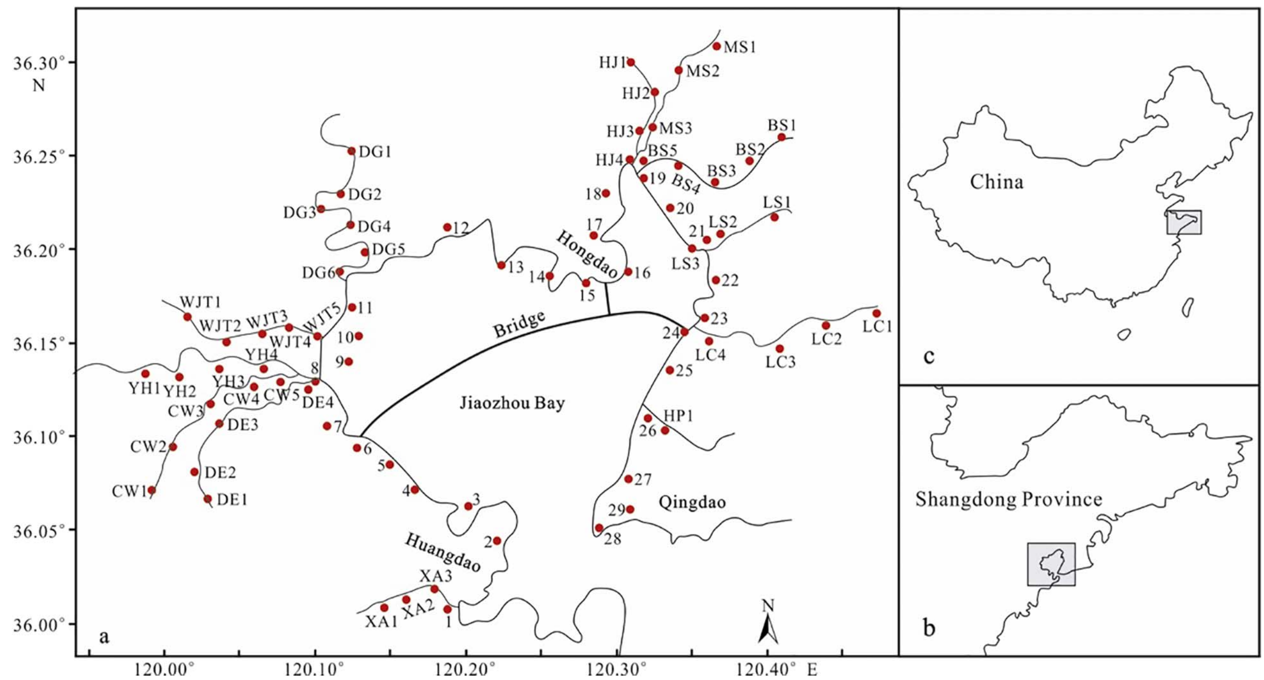

Fig. 1. Sampling sites for riverine and intertidal surface sediments in the JZB (a), Shandong Province (b), China (c).

led to very different results. Therefore, it remains important to determine the environmental background values of trace elements in the JZB catchment.

In 2015, 76 surface sediment samples were collected from the rivers and intertidal zone of the JZB. These samples were distributed evenly across the study area (Fig. 1). Contaminated areas seriously impacted by human activities were avoided during sampling. Large calcareous pieces of debris were removed, as were rock and plant fragments. The sediment types were identified using Folk's classification scheme (Folk et al., 1970). Seven samples were classified as Sand, six samples were classified as Silty sand, fifty-three samples were classified as Sandy silt, and the remaining ten samples were classified as Silt (Xu et al., 2016, 2017).

Concentrations of trace elements (As, Cr, Zn, Cu, Cd, Co, Pb and Ni) were determined using a Perkin Elmer ELAN 9000 inductively coupled plasma mass spectrometer (ICP-MS). Pretreatment and analytical methods are described by Xu et al. (2016, 2017). The instrument's analytical accuracy was assessed by analyzing United States Geological Survey (USGS) and Chinese certified reference materials (BCR-2, BHVO-2, GBW07315, and GBW07316). Overall, the measured values of the reference materials were within the range of certified values, indicating satisfactory recoveries (Xu et al., 2016, 2017).

The main methods for determining the environmental background values of trace elements in sediments are listed as follows: (1) using the concentration of trace elements in the fine fraction of sediments (< 63 μm) (de Paula Filho et al., 2015); (2) using the elemental concentration of sediments in the relatively stable section of deep core samples (Cobelogarcía and Prego, 2003); and (3) using the raw trace element data from surface sediments by eliminating the values corresponding to contamination and calculating the statistical mean and standard deviation (Chen et al., 2001).

In this study, we calculated environmental background values as follows: the Grubbs test was applied to the raw data to remove outliers; a normality test was performed on the raw data and the logarithmically transformed data; and statistics including the mean and standard deviation were calculated for the elemental concentrations. For elements with normally distributed concentrations in sediments, the environmental background value was obtained from the arithmetic average (X), and its range was defined as X ± S (where S is the arithmetic standard deviation). For elements with logarithmically distributed concentrations, the environmental background value was obtained from the geometric mean (X′), and its range was defined as X′ multiplied/divided by $(S')^2$ (where S′ is the geometric standard deviation). If an element's concentration showed a skewed distribution, then the data interval corresponding to 5–95% was defined as the range of environmental background values, and the median was defined as the background value (Chen et al., 2001).

The averages and ranges of the trace element concentrations are listed in Table 1. When compared to the China Marine Sediment Quality criteria (MSQ, CSBTS, 2002, Table 1), the overall sediment quality in the area generally met the criteria (Xu et al., 2016, 2017). Fig. 2 shows that the distribution of various trace elements differed throughout the study area. The coefficients of variation for Cd, Pb, Cu, and Zn were, respectively, 156.83%, 123.62%, 95.99%, and 84.74% (Table 1), which

Table 1
Trace element concentrations (mg/kg) in sediments from the JZB catchment and the China Marine Sediment Quality criteria.

	As	Cr	Zn	Cu	Cd	Co	Pb	Ni
Maximum	20.57	185.53	347.08	178.73	2.36	18.46	325.36	50.03
Minimum	0.96	7.14	8.18	4.46	0.01	1.10	8.21	2.04
Mean	8.28	69.51	80.91	29.40	0.26	7.56	33.51	20.69
Coefficient of variation (%)	50.49	46.48	84.74	95.99	156.83	54.30	123.62	49.62
MSQ-1	≤ 20	≤ 80	≤ 150	≤ 35	≤ 0.5	NA	≤ 60	NA
MSQ-2	≤ 65	≤ 150	≤ 350	≤ 100	≤ 1.5	NA	≤ 130	NA

NA: not available.