HEAVY METAL CONTAMINATION IN THE SURFACE SEDIMENTS OF XUWEI-LIEZIKOU OFFSHORE AREA, NORTHERN JIANGSU PROVINCE, CHINA

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Abstract. A total of 30 samples were collected from surface sediments of Xuwei-Liezikou offshore area, northern Jiangsu Province, China, and the concentrations of 7 heavy metals including As, Hg, Cu, Pb, Zn, Cr and Cd and their spatial distributions were determined. Geo-accumulation index (I_{geo}), pollution load index (*PLI*) and potential ecological risk index were applied to evaluate the pollution status. The mean concentrations of Cd, Pb, As, Zn, Cu and Hg were 2.62, 1.96, 1.70, 1.42, 1.32 and 1.30 times of their respective background values, which indicated there were obvious accumulations of these heavy metals in surface sediments. It was observed that the high heavy metal concentrations were in the western and northern regions of the study area except for Cu, mainly located in estuary and port regions. The sediments in the entire study area were moderately polluted, and the main pollution factors were Cd and Pb. The study area suffered from a level between low and moderate ecological risks, and Cd was at the considerable ecological risk level, Hg was a moderate ecological risk, while other metals had low ecological risk level.
Keywords: *heavy metal concentration, spatial distribution, contamination assessment, ecological risk, northern Jiangsu Province*

Introduction

The heavy metal pollution in marine environment has received much attention, becoming a global environmental issue, because of their toxicity, wide sources, persistence, ecological risk, and the non-biodegradable nature of the contamination (Irabien and Velasco, 1999; Burger and Gochfeld, 2003; Hu et al., 2011; Waheed et al., 2013; Bastami et al., 2015; Harikrishnan et al., 2017). As we all know, sediments contain and accumulate a large number of heavy metal elements (Gao et al., 2015; Fang et al., 2016; Zhang et al., 2017). The sediments are not only a ‘sink’ of heavy metals but also a ‘source’ (Matthiessen and Law, 2002; Hill et al., 2013; Machado et al., 2016; Chen et al., 2017). On the one hand, heavy metal elements enter the water through various ways, these elements enter the water where they are subsequently adsorbed by suspended substances and settle on the sea floor. On the other hand, when some physical and chemical properties of the water change, the heavy metal elements in sediments would be released and thereafter cause pollution to the water. Therefore, the

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analysis of heavy metals in sediments is necessary to our understanding and protection of the marine environment.

Xuwei-Liezikou offshore area is located in the southern part of Lianyungang city in the northern Jiangsu Province of China and is an important part of Lianyungang Port. Because of its superior geographical position, excellent port resources and rich fishery resources, the study area has become a major gathering place for mariculture, port development and coastal industry. The development of ports and a large number of land-based pollutants entering the sea are bound to exert great pressure on the marine environment (Nethaji et al., 2017; Jahan and Strezov, 2018). The evaluations of heavy metal in sediments form Lianyungang offshore area have been investigated (Zhang et al., 2013; Li and Li, 2016; Zhang et al., 2016). However, previous studies mainly focused on the study of heavy metals in columnar sediments form the northern Lianyungang offshore area (e.g. Haizhou bay), and few reports have evaluated heavy metal contents and pollution in surface sediments form the southern Lianyungang offshore area. Therefore, this study evaluates the concentration and pollution level of heavy metals (As, Hg, Cu, Pb, Zn, Cd and Cr) in surface sediments of Xuwei-Liezikou offshore area in northern Jiangsu Province, which is a supplement to the study on heavy metals of Jiangsu Province and provides reference data for controlling heavy metal pollution in the marine environment.

Materials and methods

Study area

Xuwei-Liezikou offshore area is located in the south wing of Lianyungang Port in Jiangsu Province of China, bordered by the Yellow Sea in the east, the Yangtze River Delta Economic Belt in the south, and the Bohai Economic Circle in the north. Its estuaries include the Xishu River estuary on the west side of the Dongxi Island, the Shaoxiang River estuary and Xiaowa Port on the nearshore of the Xuwei Port, and the Liezikou estuary and Guanhe River estuary in the southwest. The coastwise areas of the study sea area belong to a coastal plain. The coast stretching from the Xishu River estuary to Shaoxiang River estuary is a bedrock coast with a coastline of 40.25 km. The coast stretching from the Shaoxiang River estuary to the Liezikou estuary is an erosive muddy coast with a coastline of 32.06 km. The coast stretching from the Liezikou estuary to the Guanhe River estuary is an erosive silty muddy coast with a coastline of 39.08 km.

There are also two sea-discharging projects in the study area, including the Lingang Sewage Treatment Plant treating the sewage from the Harbor Industrial Park in the Guanyun County and the Lianyungang Zhongxin Sewage Treatment Plant treating the sewage from Lianyungang Chemical Industrial Park. The sewage source involves industries about electricity, metallurgy, chemical, shipbuilding, paper making, pesticides, and pharmaceuticals.

Sample collection and processing

In the tide period of October 2014, a survey of the marine environment was carried out in Xuwei-Liezikou offshore area, northern Jiangsu Province, China. A total of 30 surface sediment survey stations were deployed. The coordinates and details of the sampling location points are listed in *Table 1* and shown in *Fig. 1*. Sample 1, Sample 2,

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and Sample 4 are located on the northeast side of Dongxi Island. Sample 3 is on the north side of the west embankment. Sample 8, Sample 11 and Sample 12 are on the northeast side of the Guanhe River estuary, and Sample 13 is on the Guanhe River estuary. Others survey samples are concentrated in the inner areas of the Xuwei Port. The survey investigated items including arsenic (As), mercury (Hg), copper (Cu), lead (Pb), zinc (Zn), chromium (Cr) and cadmium (Cd).

Table 1. *Coordinates of sampling locations*

Sample	Coordinates	Sample	Coordinates	Sample	Coordinates
1	35°04'16.70"N119°40'07.14"E	11	34°42'36.87"N120°13'39.87"E	21	34°33'19.85"N119°39'41.19"E
2	34°57'18.28"N119°33'21.48"E	12	34°37'15.93"N120°08'55.70"E	22	34°31'40.03"N119°39'44.72"E
3	34°46'50.34"N119°22'56.67"E	13	34°27'29.01"N119°59'18.82"E	23	34°32'19.82"N119°42'18.20"E
4	34°59'15.86"N119°47'26.26"E	14	34°44'46.27"N119°37'12.70"E	24	34°40'40.11"N119°42'23.17"E
5	34°42'42.91"N119°41'34.92"E	15	34°41'24.37"N119°34'09.43"E	25	34°36'43.98"N119°33'57.63"E
6	34°38'17.17"N119°38'00.08"E	16	34°39'24.12"N119°36'33.05"E	26	34°37'57.96"N119°34'30.48"E
7	34°36'13.98"N119°35'43.84"E	17	34°43'02.51"N119°38'29.32"E	27	34°39'26.66"N119°34'45.00"E
8	34°51'06.62"N120°01'06.66"E	18	34°35'34.23"N119°36'44.66"E	28	34°37'41.43"N119°35'58.95"E
9	34°37'48.48"N119°48'43.39"E	19	34°39'57.74"N119°44'50.55"E	29	34°37'15.01"N119°37'15.46"E
10	34°34'40.69"N119°44'59.25"E	20	34°37'13.56"N119°41'07.21"E	30	34°38'51.00"N119°31'32.21"E

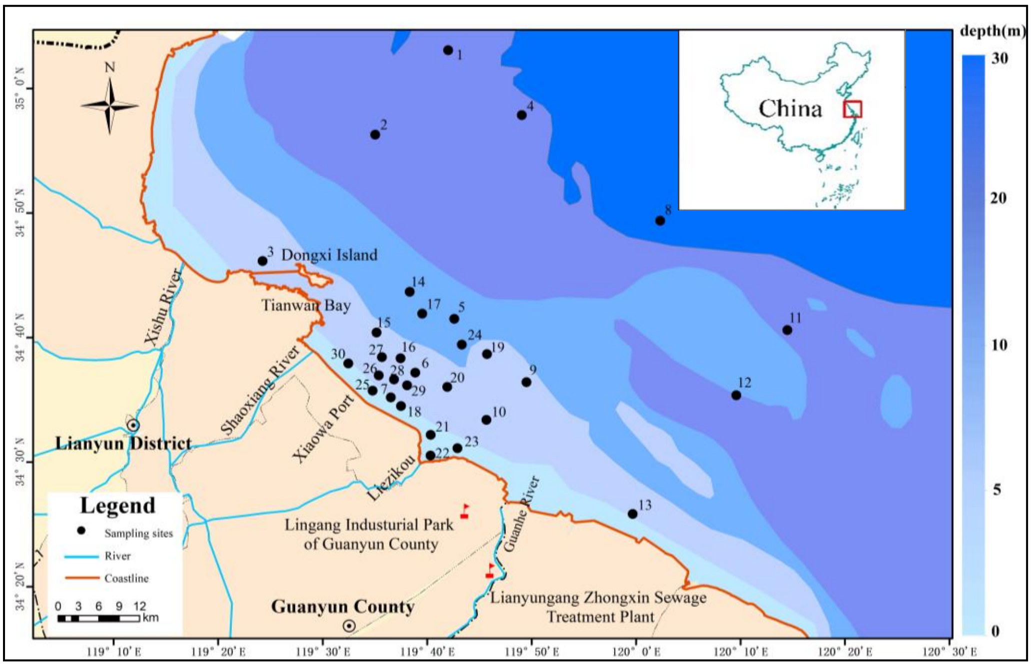

Figure 1. *Locations of surface sediment sampling sites in Xuwei-Liezikou offshore area*

The collection of sediment samples was carried out on October 10th, 2014. The methods used for the sample collection on site, the pretreatment and the preservation were in strict accordance with the *Marine Monitoring Regulations of China* (GB17378.4-2007) (AQSIQ, 2007). Samples that could not be analyzed on site were stored in a dark place after steps concerning subpackage, pre-treatments, freeze or sealing with the added fixing agent, and wrapping with plastic bags. Samples that need to be investigated were transported to the laboratory by the responsible person after the field sampling. Sediment samples were analyzed and tested at Nantong Marine

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Environmental Monitoring Center. The concentrations of Cu, Zn, Pb, Cd and Cr were determined by atomic absorption spectrometer (Varian AA240FS), and for As and Hg were measured by atomic fluorescence spectrometry (Beijing Jitian Instrument Co. AFS-930).

Evaluation method

Statistical evaluation

The standard deviation (SD) and coefficient of variation (CV) were calculated for sediment samples in Xuwei-Liezikou offshore area. The inverse distance weight method was used to carry out spatial interpolation of heavy metals, and ArcGIS10.2 spatial analysis module was used to draw the spatial distribution figures of heavy metal contents.

Geo-accumulation index (I_{geo})

Geo-accumulation index (I_{geo}), originally defined by Müller (1969), has been widely used to assess heavy metal pollution in the environment (Wang et al., 2015; Malvandi, 2017; Nethaji et al., 2017; Naifar et al., 2018). The formula used for the calculation of I_{geo} is as follows:

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n} \quad \text{(Eq.1)}$$

where C_n and B_n are the actual measured content of the heavy metal and the natural background value of the heavy metal, respectively. In this study, the background values of heavy metals in coastal soil in Jiangsu Province were used for B_n (Chen et al., 1985). Its degree of pollution of Müller (1981) is shown in *Table 2*.

Pollution load index (PLI)

Pollution load index (*PLI*) is an evaluation method proposed by Tomlinson and others in the study of heavy metal pollution level classification (Tomlinson et al., 1980; Badr et al., 2009), and it is convenient to apply. The index is composed of various heavy metal components in the study area. It can reflect the contribution of various heavy metals to pollution and the changing trend of heavy metals in space. The equation is shown as follows:

$$C_f^i = C_n^i / C_0^i \quad \text{(Eq.2)}$$

$$PLI = \sqrt[n]{C_f^1 \times C_f^2 \times C_f^3 \times \cdots \times C_f^n} \quad \text{(Eq.3)}$$

where $C^i{}_f$ is the pollution coefficient of the heavy metal i; $C_n{}^i$ is the measured concentration value of heavy metal i; $C_0{}^i$ is the background value for heavy metal i. In this study, the natural background values of heavy metals in coastal soil in Jiangsu Province are adopted for $C_0{}^i$ (Chen et al., 1985); n is the number of heavy metals; PLI is

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the pollution load index at a certain sample site. The pollution load index is generally divided into 4 grades (Zhu et al., 2013; Maanan et al., 2015), as shown in *Table 2*.

Potential ecological risk index

In 1980, Swedish scholar Lars Hakanson proposed a potential ecological risk index method for evaluating heavy metal pollution and ecological risk based on sedimentology principles (Hakanson, 1980). This evaluation method comprehensively considers the toxicity of heavy metals, the difference of background values of heavy metals, the sensitivity of heavy metal pollution under the effect of evaluation areas, and the general rule concerning the migration and transformation of heavy metals in sediments, the calculation equations can be express as follows:

$$C_f^i = C_n^i / C_0^i \quad \text{(Eq.4)}$$

$$C_{RI} = \sum_i^n C_f^i \quad \text{(Eq.5)}$$

$$E_r^i = T_r^i \times C_f^i \quad \text{(Eq.6)}$$

$$E_{RI} = \sum_{i=1}^m E_r^i \quad \text{(Eq.7)}$$

where the meanings of C^i_f, C_n^i and C_0^i are the same as in *Eq.2*; *n* is the number of heavy metals; C_{RI} is the comprehensive contamination coefficient; E_r^i is the potential ecological risk index for heavy metal *i*; T_r^i is the heavy metal toxicity response coefficient that reflects the toxicity level of heavy metals and the sensitivity of organisms to heavy metal pollution, the toxicity response coefficient for As, Hg, Cu, Pb, Zn, Cd and Cr are 10, 40, 5, 5, 1, 30 and 2, respectively (Hakanson, 1980); E_{RI} is the comprehensive potential ecological risk index of the heavy metals in the study area. The relationship among the evaluation index of heavy metal pollution, its degree of pollution and the degree of potential ecological risk of Hakanson (1980) are shown in *Table 2*.

Results and discussion

Concentration of heavy metals in Xuwei-Liezikou offshore area

The contents of heavy metals in the surface sediments of Xuwei-Liezikou offshore area are showed in *Table 3*. The concentrations (mg/kg) of As, Hg, Cu, Pb, Zn, Cd and Cr were in the ranges of 4.67~17.90, 0.011~0.062, 10.00~32.30, 14.40~33.50, 40.00~84.70, 0.049~0.211 and 30.10~74.70, with the averages of 12.54, 0.03, 19.84, 22.31, 66.80, 0.11 and 42.67, respectively. The mean concentrations for these metals were ranked as follows: Zn＞Cr＞Pb＞Cu＞As＞Cd＞Hg. All the heavy metals contents were lower than Class I sediment category according to the Chinese Marine Sediment Quality standard criteria (GB 18668-2002) issued by the Administration of Quality Supervision, Inspection and Quarantine (AQSIQ, 2002), indicating that the sediment environment in the study area was generally good.

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Table 2. *Standard for geo-accumulation index, potential ecological risk index and potential ecological risk index of heavy metals*

I_{geo}	Pollution level	*PLI*	Pollution level	C^i_f	Single-factor pollution level	C_{RI}	Comprehensive pollution level	E_r^i	Single-factor ecological risk level	E_{RI}	Comprehensive potential ecological risk level
≤0	Unpolluted	<1	unpolluted	<1	Low	<8	Low	<40	Low	<150	Low
0～1	Unpolluted to moderate	1～2	moderate	1～3	Moderate	8～16	Moderate	40～80	Moderate	150～300	Moderate
1～2	Moderate	2～3	strong	3～6	High	16～32	Heavy	80～160	Considerable	300～600	Considerable
2～3	Moderate to strong	≥3	extreme	≥6	Severe	≥32	Severe	160～320	High	≥600	Severe
3～4	Strong							≥320	Severe		
4～5	Strong to extreme										
>5	Extreme										

Table 3. *Descriptive statistic of heavy metal concentrations in surface sediments in Xuwei-Liezikou offshore Area. Comparison of heavy metal concentrations of surface sediments in the study area and other representative areas in China (unit: mg/kg)*

		As	Hg	Cu	Pb	Zn	Cd	Cr	References
Study Area	Range	4.67~17.90	0.011~0.062	10.00~32.30	14.40~33.50	40.00~84.70	0.049~0.211	30.10~74.70	This study
	Mean	12.54	0.03	19.84	22.31	66.80	0.11	42.67	
	SD	3.523	0.013	5.200	4.994	11.342	0.042	10.357	
	CV (%)	28.10	41.89	36.21	22.39	16.98	36.54	24.27	
South Jiangsu Province		na	na	19.1	19.7	62.6	0.12	72.8	Qiu et al., 2018
Laizhou Bay		7.1	0.04	10.99	13.37	50.63	0.19	32.69	Zhang and Gao, 2015
Rizhao offshore area		17.54	0.02	15.92	29.23	42.84	0.08	43.25	Song et al., 2017
Guangdong coastal region		20.83	0.13	43.83	44.29	139.93	0.38	86.97	Zhao et al., 2016
CMSQ- I		20	0.2	35	60	150	0.5	80	AQSIQ, 2002
Background value		7.38	0.023	15.02	11.40	47.15	0.042	60.11	Chen et al., 1985

CMSQ- I is Class I sediment category of the Chinese Marine Sediment Quality standard criteria (GB 18668-2002) issued by the Administration of Quality Supervision, Inspection and Quarantine (AQSIQ, 2002)

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Compared to the background values of heavy metals in coastal soil in Jiangsu Province (Chen et al., 1985), the mean concentrations of Cd, Pb, As, Zn, Cu and Hg were higher than the background values in the Jiangsu province except for Cr, which were 2.62, 1.96, 1.70, 1.42, 1.32 and 1.30 times of their respective background values, indicating there were obvious accumulations of these heavy metals in surface sediments. The standard deviation (SD) and coefficient of variation (CV) indicated moderate variability for As, Pb, Zn, Cr (15％＜CV＜36％) and high variability for Hg, Cu, Cd (CV＞36％) according to Phil-Eze (2010). These coefficients of variation of the heavy metals were higher, and the heavy metal concentrations varied over a wide range, which suggested an imbalance in the spatial distribution.

We compared the heavy metal concentrations in the study area with those other representative areas in China are also listed in *Table 3*. The mean concentrations of all heavy metals in study area were lower than those found in sediments of Guangdong coast. The mean Cu and Zn concentrations in study area were higher than those in South Jiangsu Province, Laizhou Bay and Rizhao offshore area. The mean concentrations of Cd and Cr in study area were lower than those in South Jiangsu Province. The mean As, Pb and Cr concentration was higher in study area than in Laizhou Bay, but lower than in Rizhao offshore area. The mean Cd and Hg concentration was higher in study area than in Rizhao offshore area, but lower than in Laizhou Bay.

Spatial distribution of the heavy metal concentrations

The spatial distributions of heavy metals in surface sediments of Xuwei-Liezikou offshore area are presented in *Fig. 2*.

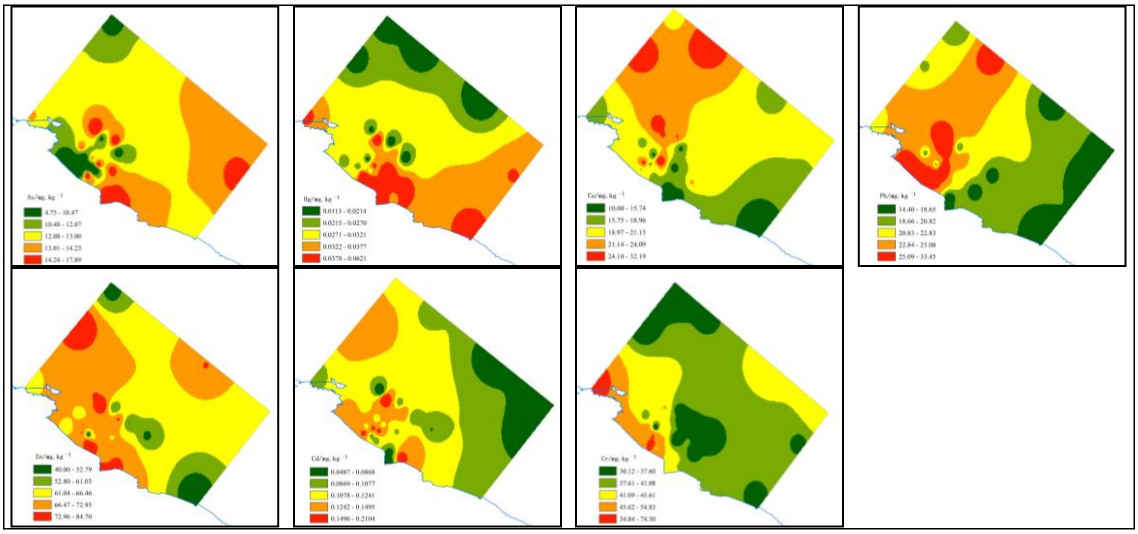

Figure 2. *Spatial distribution of heavy metals in Xuwei-Liezikou offshore Area*

The spatial distributions of Zn, Hg, Cd and As were similar, these elements had high concentration values in the western region of the study area, which was consistent with the major rivers inlets. The high concentration values of Pb were in the northern of the study area mainly located in the Xuwei Port. Cu tended to be higher in the northwest and lower in the southeast. In general, the heavy metal high-values areas, the western and northern region of the study area, were mainly located at the river estuaries and

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Xuwei Port. The result showed that land-based pollutants and ship pollutants had an important influence on heavy metal pollution in the study area.

Assessment of heavy metal contamination

Geo-accumulation indices of the heavy metals

The geo-accumulation indices (I_{geo}) of the heavy metals in Xuwei-Liezikou offshore area are shown in *Table 4*. The I_{geo} values of As, Hg, Cu, Pb, Zn, Cd and Cr were in the ranges of -1.25~0.69, -1.61~0.85, -1.17~0.52, -0.25~0.97, -0.82~0.26, -0.37~1.74 and -1.58~-0.27, with the averages of 0.11, -0.26, -0.23, 0.35, -0.11, 0.76 and -1.12, respectively. The mean I_{geo} values were ranked as follows: Cd>Pb>As>Zn>Cu>Hg>Cr. According to Müller (1981), the mean I_{geo} values in the study area ranged form -2 to 1, showing unpolluted and unpolluted to moderate polluted. The result indicated that the study area has not been obviously polluted as a whole. However, the I_{geo} values of Cd ranged from -0.37 to 1.74, and 10% of the sampling sites were unpolluted, 33% were unpolluted to moderately polluted, 57% were moderately polluted. The sampling sites that were moderately polluted for Cd were mainly distributed in the western region of the study area (*Fig. 3a*), indicating that the land-based pollutants had an important impact on the sediment environment in the study area. Meanwhile, it should be noted that the I_{geo} values form 87% of the sampling sites for Pb ranged form 0 to 1, indicating unpolluted to moderately polluted, the high I_{geo} values were located in the Xuwei port (*Fig. 3b*). Overall, the surface sediments were a low degree of pollution throughout the study area, and Cd and Pb were the main pollution factors.

Table 4. *Geo-accumulation indices (I_{geo}) and contamination degree of surface sediments*

I_{geo}	As	Hg	Cu	Pb	Zn	Cd	Cr
Min	-1.25	-1.61	-1.17	-0.25	-0.82	-0.37	-1.58
Max	0.69	0.85	0.52	0.97	0.26	1.74	-0.27
Mean	0.11	-0.26	-0.23	0.35	-0.11	0.76	-1.12
Compared with I_{geo} (% of sample in each class)							
$I_{geo}≤0$	30%	57%	77%	13%	63%	10%	100%
$0<I_{geo}≤1$	70%	43%	23%	87%	37%	33%	0%
$1<I_{geo}≤2$	0%	0%	0%	0%	0%	57%	0%

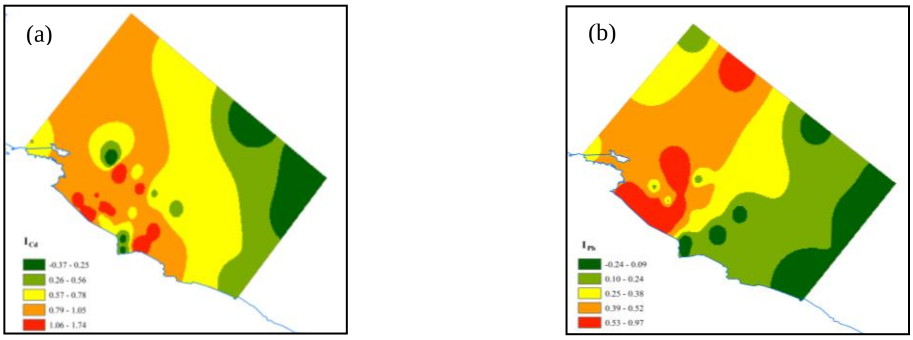

Figure 3. *Spatial distribution of the geo-accumulation indices for Cd and Pb*

Pollution load indices of the heavy metals

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The pollution load indices (*PLI*) of the heavy metals for surface sediments of Xuwei-Liezikou offshore area are presented in *Table 5*. The *PLI* values in the study area ranged from 1.15 to 1.91, with the averages of 1.44, the Xuwei-Liezikou offshore area was considered to be moderately polluted. 100% of all sample sites showed moderately polluted, indicating that the study area was affected by human activities. The high *PLI* values were in the western and northern region of the study area (*Fig. 4a*). The result was similar to the distribution characteristics of main pollution elements.

Table 5. *The pollution load indices of the heavy metals in the study area*

Sample	*PLI*	Sample	*PLI*	Sample	*PLI*
1	1.18	12	1.35	23	1.61
2	1.51	13	1.15	24	1.41
3	1.55	14	1.40	25	1.52
4	1.36	15	1.43	26	1.49
5	1.28	16	1.27	27	1.48
6	1.84	17	1.91	28	1.44
7	1.89	18	1.63	29	1.40
8	1.15	19	1.18	30	1.41
9	1.28	20	1.45	Min	1.15
10	1.54	21	1.30	Max	1.91
11	1.31	22	1.51	Mean	1.44

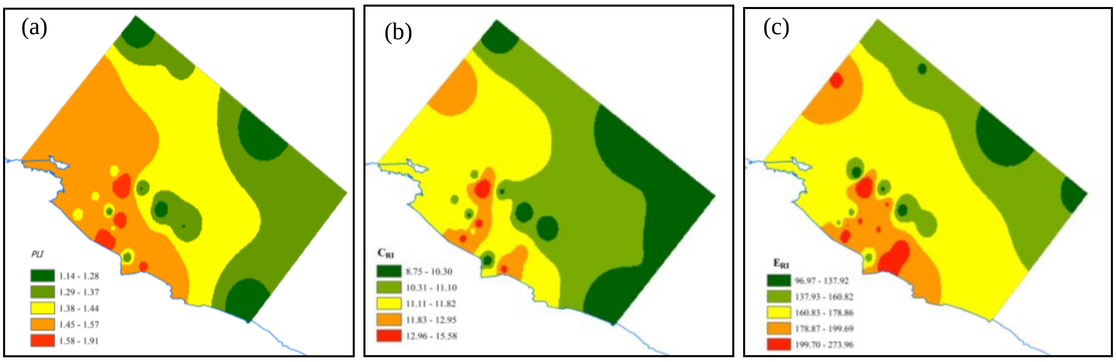

Figure 4. *Spatial distribution of PLI,*C_{RI} *and* E_{RI} *of heavy metals*

Potential ecological risk index in Xuwei-Liezikou offshore area

The contamination factor (C^i_f) values for the heavy metals in Xuwei-Liezikou offshore area are showed in *Table 6*. The mean C^i_f values of As, Hg, Cu, Pb, Zn, Cd and Cr were 1.70, 1.30, 1.32, 1.96, 1.42, 2.62 and 0.71, ranked as follows: Cd>Pb>As>Zn>Cu>Hg>Cr. 67% of the sampling sites for Cd were moderate pollution, while 33% (mainly located in the nearshore region) showed high pollution. 100% of the sampling sites for Pb were moderate pollution, and the high C^i_f values for Pb located in Xuwei Port. The C^i_f values of others elements showed low to moderate pollution. The C_{RI} values of the study area ranged from 8.75 to 15.6, with the mean of 11.21, indicating a moderate pollution. The high C_{RI} value distributed in the western and northern regions of the study area, mainly located in the estuary and port regions (*Fig. 4b*).

The potential ecological risk indices for the heavy metals in Xuwei-Liezikou offshore area are showed in *Table 7* and *Fig. 4c*. The mean E_r^i values for As, Hg, Cu, Pb, Zn, Cd and Cr were 17.03, 55.42, 6.60, 9.78, 1.42, 81.78 and 1.42, ranked as

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follows: Cd＞Hg＞As＞Pb＞Cu＞Cr=Zn. The mean E_r^i values for Cd showed a considerable ecological risk, Hg was a moderate ecological risk, the others elements were a low ecological risk. The E_{RI} values ranged from 96.97 to 274.62, with an average value of 173.46, which were a low to middle ecological risk (*Table 2*). The high E_{RI} values distributed in the western region of the study area (*Fig. 4c*), mainly located in the estuary regions, which was similar to the Cd distribution characteristics (*Fig. 2*). These results showed that the risks were mainly from Cd.

Table 6. *Contamination factor of the heavy metals in surface sediments*

	C^i_f							C_{RI}
	As	**Hg**	**Cu**	**Pb**	**Zn**	**Cd**	**Cr**	
Min	0.63	0.49	0.67	1.26	0.85	1.16	0.50	8.75
Max	2.43	2.71	2.15	2.94	1.80	5.02	1.24	15.60
Mean	1.70	1.30	1.32	1.96	1.42	2.62	0.71	11.21
Compared with C^i_f / C_{RI} (% of sample in each class)								
C^i_f≤1 (C_{RI}≤8)	10%	33%	23%	0%	3%	0%	93%	0%
1＜C^i_f≤3 (8＜C_{RI}≤16)	90%	67%	77%	100%	97%	67%	7%	100%
3＜C^i_f≤6	0%	0%	0%	0%	0%	33%	0%	0%

Table 7. *Potential ecological risk indices of the heavy metals in surface sediments*

	E_r^i							E_{RI}
	As	**Hg**	**Cu**	**Pb**	**Zn**	**Cd**	**Cr**	
Min	6.33	19.65	3.33	6.32	0.85	34.71	1.00	96.97
Max	24.26	108.35	10.75	14.69	1.80	150.71	2.49	274.62
Mean	17.03	55.42	6.60	9.78	1.42	81.78	1.42	173.46

Conclusion

The mean concentrations (mg/kg) of As, Hg, Cu, Pb, Zn, Cd and Cr were 12.54, 0.03, 19.84, 22.31, 66.80, 0.11and 42.67 in surface sediments of Xuwei-Liezikou offshore area, respectively. The averages of Cd, Pb, As, Zn, Cu and Hg were higher than the background values in the Jiangsu province except for Cr, which were 2.62, 1.96, 1.70, 1.42, 1.32 and 1.30 times of their respective background values, indicating there were obvious accumulations of these heavy metals of the study area. The spatial distributions of heavy metals showed that Zn, Hg, Cd and As had high concentration values in the western region of the study area, which was consistent with the rivers inlets, and the high concentration values of Pb were in the northern of the study area mainly located in the Xuwei Port. The results of contamination assessment showed the study area was moderately polluted, and the main pollution areas were in the western and northern region. The pollution mainly came form Cd and Pb. For the main pollution factors, further studies on their sources and impacts can be conducted to provide data for environmental protection. The study area suffered from a level between low and moderate risks, and Cd was an important factor causing ecological risks. The estuary areas where were prone to ecological risk should be paid attention to.

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