The Content Distribution and Pollution Assessment of Heavy Metals in the Surface Sediments of Dalian Bay

Qinbang Sun*, Fan Gao, Yang Wang, Depeng Li and Zhaolin Chen
National Marine Environmental Monitoring Center, Dalian 116023, China

Keywords: Sediment; Heavy metal; Pollution assessment; Principal Component Analysis; Dalian Bay

Abstract: The distribution of 6 heavy metals sediments samples collected in the coastal waters of Dalian Bay in May 2015, was studied. The results showed that the content range of Cu, Pb, Zn, Cd, Hg and As in the surface sediments samples were 9.10~84.90, 9.80~65.90, 29.70~259.00, 0.12~1.30, 0.021~0.350, 4.18~44.50 mg·kg^{-1}, and the average values were respectively 34.62, 30.47, 106.50, 0.36, 0.12 and 11.10 mg·kg-1. Moreover, the content values of Cd and Hg were lower than the background values of the national coastal zone. The quality of marine sediments samples was evaluated by the single-factor pollution index method in this study. The evaluating results showed that the average content of Cu, Pb, Zn, Cd, Hg and As was consistent with the marine sediment quality I standard, and the pollution level of the 6 heavy metals was Cu > Zn > Cd > Hg > As＞Pb. With the Hakanson potential ecological risk index method, the survey data were analyzed. The analysis results showed that the potential ecological risk index level of Dalian Bay was medium, and the potential ecological risk indexes of surface sediments heavy metals were almost similar. The correlation analysis of heavy metals survey data in the surface sediment showed that there was a positive correlation between Cu, Pb, Zn, Cd and As in the surface sediments of the sea area and the correlation coefficient was large, indicating that they had a certain homology. The TOC content was positively correlated to the Cu, Zn and Cd content, and the petroleum was correlated to Cu, Pb, Zn, and Cd content. This indicated that the distribution of heavy metals was effected by TOC and petroleum. The main source of heavy metal pollution in marine sediments was further studied by the principal component analysis, and the contribution rate of the first 2 principal components was 86.87%. Combined with the correlation analysis results, the principal component analysis results showed that the main source of heavy metal Cu, Pb, Zn and Cd in Dalian Bay was the industrial pollution. This paper reveals the distribution characteristics of heavy metals in the sediments of Dalian Bay, and provides scientific basis for the marine ecological civilization constructionand the comprehensive control of marine environment.

1 INTRODUCTION

Dalian Bay is a semi-closed natural bay at the southern end of Liaodong peninsula, along the coast of which there are rich port resources and many chemical plants and sewage outlets (Li et al., 2016). In recent years, the large-scale marine reclamation land activities and the development of port industries have brought great pressure to the marine environment of the sea area. The heavy metal content in marine surface sediments is an important basic data to measure the quality of the marine environment. Heavy metal pollution has become an important content of marine environmental pollution assessment (Zhang et al., 2012; Alam et al., 2018; Krika and Krika, 2017; Mallick et al., 2016; Gurumoorthi et al., 2016; Islam et al., 2016; Vaezi et al., 2016; Chen et al., 2015)At present, numerous studies have focused on pollution of Dalian Bay. For example, Wang Shaofang et al reported the last 100 years evolution of heavy metal pollution in the Dalian bay (Wang et al., 2002). Wang Jiahua reported the pollutions and source directive significance of heavy metals in the sediments of Dalian bay (Wang et al., 2002). Zhang Yufeng reported the spatial-temporal distribution, structural features and ecological responses of nutrients in Dalian Bay (Zhang et al., 2015). Ma Xindong reported the main pollution factors and sources contribution of water quality in Dalian Bay (Ma et al.,2016). Liu Chuantao observed the occurrence and bioavailability of mercury in the surface sediments of the Dalian Bay (Liu et al.,

Sun, Q., Gao, F., Wang, Y., Li, D. and Chen, Z.
The Content Distribution and Pollution Assessment of Heavy Metals in the Surface Sediments of Dalian Bay.
DOI: 10.5220/0008189403110318
In *The Second International Conference on Materials Chemistry and Environmental Protection (MEEP 2018)*, pages 311-318
ISBN: 978-989-758-360-5

2017). However, there are few reports on the pollution assessment of heavy metals in the surface sediments of Dalian Bay in recent years. In this paper, the contents and pollution characteristics of heavy metals (Cu, Pb, Zn, Cd, Hg and As) in the surface sediments were studied through the heavy metals survey data of the Dalian Bay in May 2015. The pollution status and sources of heavy metals in the marine sediments of Dalian Bay were assessed with Hakanson potential ecological risk index method and the principal component analysis method, which would provide a scientific basis for the ecological civilization construction of Dalian Bay and the comprehensive control of heavy metals pollution in the marine environment of Dalian Bay.

2 MATERIALS AND METHOD

2.1 The Overview of Research Area

The Dalian Bay lies on the southern tip of Liaodong peninsula, whose three sides are surrounded by land, and only whose southeast is connected with the Yellow Sea. The coastline is a typical bedrock harbor type coast. At the mouth of the Bay, Sanshan Island like a barrier protects the whole bay. And there are 3 inner bay from the southwest to the northeast at the top of the Bays, namely, which are Choushuitao, Tianshuitao and Hongtuduizi bays (Chen and Wang, 2016) The total area of the bay is about 174 km^2, and the coastline is tortuous, which is a typical bedrock harbour coast. The seabed geomorphology type is single and belongs to flat shoal. The tide of the sea area is a regular half day. The tidal current belongs to the irregular half day tidal current. The velocity of residual current in the bay is relatively small, and is affected by the monsoon and has obvious seasonal variation. The sources of sediment in this bay are mainly the waste residues abandoned by coastal plants and mining enterprises and the weathered erosion debris along the coast. There are no big rivers around the bay, and there are only some intermittent streams. The silts carried by sewage, waste discharge and flood in the flood season, are the main source of marine sediments in the bay (Bao, 1991).

2.2 The Collection and Analysis of Samples

In May 2015, 14 sediment survey stations (Figure 1) were set up in the Dalian Bay Area (Figure 1) to sample surface sediments. The survey parameters mainly included Cu, Pb, Zn, Cd, Hg, As, TOC and petroleum. The sediment samples were collected using the 0.025m^3 grab dredge, and the samples were filled in the clean polyethylene bags with a bamboo knife for the subsequent analysis of heavy metals parameters. The samples were filled with the aluminum lunch boxes for the analysis of TOC and petroleum parameters. The heavy metal samples were dried in the oven at 105 ℃ (the mercury, organic carbon, and oil samples were dried at 45℃). The samples were grinded in an agate bowl, and were screened over 80-mesh nylon sieves (oil and organic matter were screened over metal sieves) for the analysis. The content of Cu, Pb, Zn and Cd in each sampling station was determined by the atomic absorption spectrophotometry. The content of Hg and As were determined by the atomic fluorescence spectrometry. The content of TOC was determined with the potassium dichromate redox capacity method, and the content of petroleum was determined by the ultraviolet spectrophotometry.

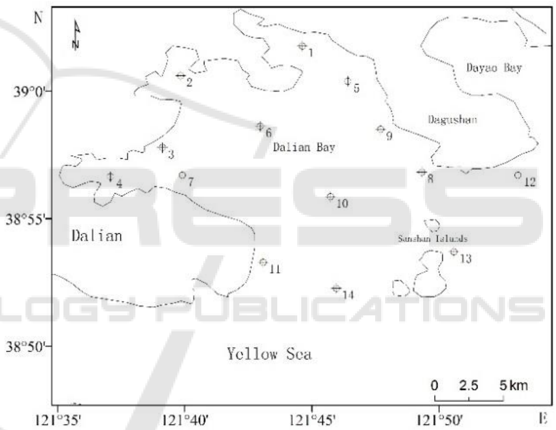

Figure 1: The distribution of sampling stations.

2.3 The Assessment Method

2.3.1 Single-factor Pollution Index Method

The single-factor pollution index method is the simplest method of evaluating the environmental quality index. There is no dimension, and each pollution factor is evaluated separately, and the results of the standard-reaching rate/exceeding standard rate, exceeding standard multiplier, statistical multiplier and statistical representative value are obtained by the statistical analysis (Luo et al., 2016).

The mathematical calculation expression of the single-factor pollution index is:

$$I_i = C_i / S_i \quad (1)$$

In the expression, I_i is the pollution index of factor i, and C_i is the measuring content of factor i, and S_i is the assessment standard value of factor i.

2.3.2 Subtitle Potential Ecological Risk Index Method

The potential ecological risk index method was first put forward by Swedish scholar Hakanson (Hakanson, 1980), which could comprehensively reflect the potential impact of heavy metals in the sediments on the ecological environment (Ding et al., 2005; Zhou et al., 2015) The Hakanson potential ecological risk indexes and classification are shown in Table 1.

The mathematical expressions of potential ecological risk assessment on the heavy metals of sediments, which were put forward by Hakanson, were:

$$C_f^i = C_d^i / C_R^i \quad (2)$$

$$E_r^i = T_r^i \cdot C_f^i \quad (3)$$

$$RI = \sum T_r^i \cdot C_d^i / C_b^i \quad (4)$$

In the expressions, C_f^i is the pollution coefficient of heavy metal element i, and E_r^i is the potential ecological risk index of heavy metal element i, and T_r^i is toxicity coefficient, and C_d^i is the measuring value of heavy metal content (mg·kg^{-1}),and C_b^i is the reference value of assessment(mg·kg^{-1}),and RI is the comprehensive potential ecological risk index of heavy metal.

Table 1: Hakanson potential ecological risk indexes and classification.

The Potential ecological risk factor (E_r^i)	Ecological risk pollution degree	The Potential ecological risk index (RI)	Total potential ecological risk degree
E_r^i <40	Slight	RI<150	Slight
40< E_r^i ≤80	Medium	150<RI ≤300	Medium
80< E_r^i ≤160	Strong	300<RI ≤600	Strong
160< E_r^i ≤320	Very strong	RI≥600	Very strong
E_r^i ≥320	Fortissimo	—	—

2.3.3 Principal Component Analysis Method

The Principal Component Analysis (PCA) is a statistical analysis method of mastering the main contradiction. It can reflect the most of the original information of multiple variables by simplifying the data (that is, using less comprehensive indicators instead of a large number of indicators that have a certain correlation). Many studies have proved that the principal component analysis method can be used to analyze the source of the elements and the main affecting factors on the enrichment of the elements in the sediments. Therefore, PCA is a helpful tool to analyze and evaluate the source of pollutants in the sediments by more and more researchers (Li et al., 2006; Kzrysztof and Danuta , 2003).

3 RESULTS AND DISCUSSION

3.1 The Change Characteristics of Heavy metals Elements Content

The average content values of heavy metals Cu, Pb, Zn, Cd, Hg and As in the sediments in May 2015 were 34.62, 30.47, 106.50, 0.36, 0.12 and 11.10 mg·kg^{-1}, respectively. The results (Table 2) showed that the average contents of Cd and Hg in the surface sediments of the Dalian Bay sea area were lower than the background values of heavy metals in the national coastal zone (Compiling Group of Environmental Quality Investigation Report of the National Coastal Zone Office,1989), while the average contents of other investigating factors were higher than the reference background values.

Table 2: The contents of heavy metals in the surface sediments (mg·kg^{-1}).

Heavy metal	Content range	Average value	The background value
Cu	9.1~84.9	34.62	30
Pb	9.8~65.9	30.47	25
Zn	29.7~259	106.50	80
Cd	0.12~1.3	0.36	0.5
Hg	0.021~0.35	0.12	0.2
As	4.18~44.5	11.10	10

Compared with the reference background value, the distribution of the stations whose had high content of Cu, Pb, Zn and As were the same, and the stations were mainly located in the offshore area of the Bay top; The average value of Cu is 1.15 times of the background value, and the highest value appeared at station No. 4 (84.90 mg·kg^{-1}); The average value of Pb was 1.22 times of the background value, and the highest value appeared at station No. 7 (65.90 mg·kg^{-1}); The average value of Zn was 1.33 times of the background value, and the highest value appeared at station No. 4 (259.00 mg·kg^{-1});The average value of As was 1.11 times of the background value, and the highest value appeared at station No. 7 (44.50 mg·kg^{-1}). For the station No. 4 (1.30 mg·kg^{-1}) and No. 7 (0.96 mg·kg^{-1}), Cd content was higher than the reference background value, while for all the other stations, Cd content was lower than the reference background value. For the station No. 1, No. 12 and No. 13, Hg content was higher than the reference background value in the North Sea Area of the bay mouth. The content of Hg in the three stations was 0.35 mg·kg^{-1}, which was 1.75 times of the reference background value. Compared with the background values of heavy metals in the national coastal zone, the pollution level of heavy metals in the sediments of Dalian Bay was relatively light, and the main pollution factors were Cu, Pb and Zn, and the exceeding standard rate was 50%.

3.2 The Pollution Risk Assessment of Heavy Metals in the Surface Sdiments

3.2.1 The Single-factor Pollution Index of Heavy Metals in the Surface Sediments

In this study, heavy metals in the surface sediments of Dalian Bay were evaluated with a single-factor pollution index method by making comparison with I standard of marine sediment quality. According to Eq.1, the calculation results of the single-factor pollution indexes of heavy metals were shown in Table 3.

Table 3: The single-factor pollution index evaluation in surface sediments.

Heavy metals	Single factor	The standard value of marine sediment quality /mg.kg^{-1}		
Cu	0.99	I	II	III
Pb	0.51	≤35.0	≤100.0	≤200.0
Zn	0.71	≤60.0	≤130.0	≤250.0
Cd	0.71	≤150.0	≤350.0	≤600.0
Hg	0.59	≤0.50	≤1.50	≤5.00
As	0.55	≤0.20	≤0.50	≤1.00

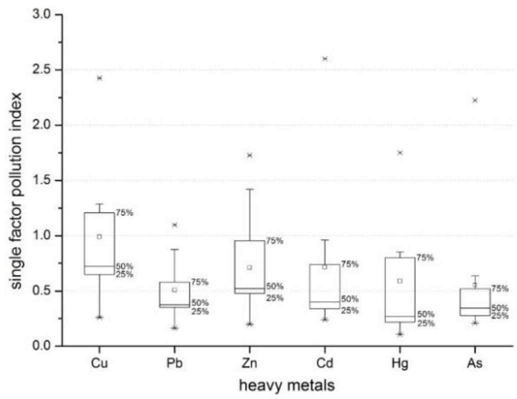

Figure 2: The boxplot of single factor pollution index evaluation.

According to Table 3, the average values of the single-factor pollution indexes of Cu, Pb, Zn, Cd, Hg and As were less than 1. The evaluation value of each heavy metal element met the I standard of marine sediment quality. The pollution level of 6 heavy metals was: Cu > Zn > Cd > Hg > As > Pb.

According to Figure 2, all the evaluation factors had abnormal values in the individual station. In general, each evaluation factor in the survey stations could meet the I standard of marine sediment quality. The sediments of Dalian Bay had not been significantly polluted by the heavy metals, which was consistent with the evaluation of heavy metal pollution in the surface sediments of the Dalian Bay conducted by Wang (Wang, 2012). Compared with the I standard values of marine sediment quality, the pollution level of heavy metals in the sediments of Dalian Bay was relatively light, and the main pollution factor was Cu, and the exceeding standard rate was close to 50%.

3.2.2 The Potential Ecological Risk Index of Heavy Metals in the Surface Sediments

In order to ensure that the selected background value was close to the actual value of the sea area, the background value of heavy metals in the national coastal zone was used as the reference value in the study, and the toxic response parameters of heavy metal elements were shown in Table 4. According to Eq. (2) - (4), the heavy metal potential ecological risk index ($\mathrm{E_r^i}$) and the comprehensive potential ecological risk index (RI) were calculated in Table 5.

According to Table 5, the average content of Cu, Pb, Zn, Cd, Hg and As were less than 40, and the ecological risk of each single pollutant (E_r^i) lay at the low level. The order of the potential ecological risk index of the average content of 6 heavy metals was Hg > Cd > As > Pb > Cu >Zn. The comprehensive ecological risk index (RI, 69.28) was less than 150, and the potential ecological risk grade of heavy metals in the sea area was "relatively low".

Table 4: The background reference values and toxicity coefficients of heavy metals in the sediments.

Factor	Cu	Pb	Zn	Cd	Hg	As
C_b^i(mg/kg)	30	25	80	0.5	0.2	10
T_r^i	5	5	1	30	40	10

Table 5: The potential ecological risk index of heavy metals in the sediments.

Statistical value	The Potential ecological risk factor (E_r^i)						The Potential ecological risk index (RI)
	Cu	Pb	Zn	Cd	Hg	As	
Minimum value	1.52	1.96	0.37	7.20	4.20	4.18	33.40
Maximum value	14.15	13.18	3.24	78.00	70.00	44.50	156.84
Average value	5.77	6.09	1.33	21.39	23.60	11.10	69.28

According to Figure 3, the spatial distribution of potential ecological risk index in the Dalian Bay area showed a SW (Southwest)-NE (Northeast) direction (a low NE value and a high SW value). The relatively high ecological risk index appeared in the south west side of the bay of Dalian, and the low ecological risk index in the bay area was lower, while the ecological risk index of the sea area near Sanshan Island showed a certain increase. Overall, the potential ecological risk index of heavy metals in the surface sediments of this area was basically the same.

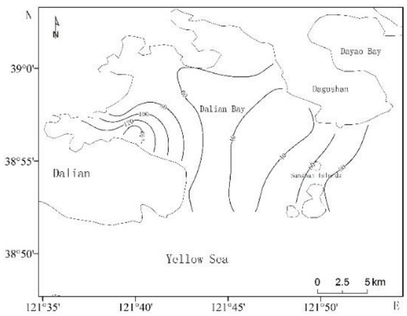

Figure 3: The spatial distribution of potential ecological risk index of heavy metals.

3.2.3 The Correlation Analysis of Heavy Metals

The homology of heavy metals in the sediments could be determined by the correlation analysis of heavy metals. The change of TOC content and composition was one of the important factors to determine the distribution of heavy metals in the surface sediments (Borg and Jonsson, 1996) The Pearson correlation analysis of heavy metal contents in 6 surface sediments with the content of TOC and petroleum was carried out in this study. The results were shown in Table 6.

Table 6: The correlation coefficients among heavy metals and TOC in the sediments.

Category	C_{Cu}	C_{Pb}	C_{Zn}	C_{Cd}	C_{Hg}	C_{As}	C_{TOC}	C_{Oil}
C_{Cu}	1							
C_{Pb}	0.913**	1						
C_{Zn}	0.992**	0.899**	1					
C_{Cd}	0.959**	0.830**	0.951**	1				
C_{Hg}	-0.460	-0.451	-0.508	-0.312	1			
C_{As}	0.863**	0.817**	0.811**	0.838**	-0.168	1		
C_{TOC}	0.631*	0.487	0.682**	0.542*	-0.505	0.346	1	
C_{Oil}	0.752**	0.533*	0.804**	0.747**	-0.515	0.399	0.779**	

Note: * Correlation is significant at the 0.05 level (2-tailed);** Correlation is significant at the 0.01 level (2-tailed).

According to Table 6, there was a positive correlation between Cu, Pb, Zn, Cd and As, and the correlation coefficient was large, which indicated that they had some homology. There was a strong correlation between TOC and Cu, Cd and Zn, which indicated that the heavy metals of the sea water in the study area could be chelated through the surface adsorption of TOC, and the generated metal organic complexes were removed from the water and adsorbed in the particles of the surface sediments (Qiu et al., 2005; Reuter and Perdue, 1977). There was a strong correlation between petroleum and Cu, Pb, Zn and Cd, indicating that petroleum might be the main source of Cu, Pb, Zn and Cd, and petroleum had a certain influence on the distribution of Cu, Pb, Zn and Cd.

3.2.4 The Source Analysis of Heavy Metals Based on PCA Method

According to the analysis of section 3.2.3, there was a strong correlation between the heavy metal elements in the surface sediments of Dalian Bay. Through the principal component analysis (shown in Table 7), 86.87% of the total information of 6 pollutants , TOC and petroleum in the surface sediments of Dalian bay could be reflected by 2 principal components (eigenvalues: 5.77+1.18=6.95 variables), that is, the first 2 principal components had been able to reflect most of the data.

Table 7: The main calculated results of principal component analysis (PCA).

Component	First principal component	Second principal component
Total	5.77	1.18
% of Variance	72.12	14.75
Cumulative %	72.12	86.87
Cu	0.988	0.134
Pb	0.894	0.232
Zn	0.996	0.042
Cd	0.939	0.225
Hg	-0.540	0.614
As	0.805	0.522
TOC	0.720	-0.500
Oil	0.814	-0.396

The contribution rate of the first principal component was 72.12%, which showed that the factor variable had high positive load on the content of Cu, Pb, Zn, Cd and As, and the load of the first principal component on TOC was 0.720, and the high load on TOC showed the importance of the organic matter as the metal ion binding, and from Table 6 and 7, 3 heavy metals (Cu, Zn, Cd) and TOC had a significant positive correlation. It could be concluded that the release of metal ions accompanied by the degradation of organic matter is one of the sources of heavy metals in the sediments. Therefore, the first principal component mainly characterized the contribution of organic matter to the source of heavy metals in the sediments; The first principal component on the petroleum was 0.814, and from Table 6 and 7, Pb, Zn and Cd had a significant positive correlation with petroleum, and the oil had a high load in the principal component analysis, which indicated that oil was one of the important sources of heavy metal Cu, Pb, Zn and Cd elements. Therefore, the first principal component mainly characterized the contribution of organic matter and oil to the source of heavy metals in the sediments, which was consistent with the conclusion of the correlation analysis of the heavy metals in the section 3.2.3. Through consulting literature and field investigation, it was found that the sedimentary environment of Dalian Bay was affected by the pollution of the surrounding chemical plant and the petroleum pollutants in the sediments of the coastal waters. Therefore, the contribution of heavy metals such as Cu, Pb and Zn to the first principal component could reflect the actual significance of the first principal component, that is, the effect of the industrial pollutant discharge on the marine sediments. According to the correlation analysis of pollutants in the section 3.2.3, we could found that there was a strong correlation between Cu, Pb, Zn, Cd and As. It was known that the first principal component mainly dominated the source of heavy metals in the sediments. The load of second principal components on Hg and As contents could be seen from Table 7, of which Hg is the highest (0.614). As Hg and As elements were less correlated with TOC and petroleum, it was deduced that Hg and As were less likely to exist as the binding compounds of organic and petroleum in the sediments. Therefore, the industrial pollutant discharge in the area had little influence on the distribution of the Hg and As content.

4 CONCLUSIONS

Through the study of the distribution characteristics of Cu, Pb, Zn, Cd, Hg and As in the surface sediments of Dalian Bay in May 2015, the obtained main results were as follows:

(1) The average content of Cd and Hg in the surface sediments of Dalian Bay was lower than the reference background value. The average contents of other investigation factors were higher than the reference background values. Compared with the reference background values, the spatial distribution of stations containing the highest content of Cu, Pb, Zn and As was the same, and the stations were mainly located in the offshore area of Bay top. Compared with the background values of heavy metals in the national coastal zone, the pollution level of heavy metals in the sediments of Dalian Bay was relatively light. The main pollution factors were Cu, Pb and Zn, and the exceeding standard rate is 50%.

(2) The evaluated results of marine sediment quality with the single-factor pollution index method showed that the average content of Cu, Pb, Zn, Cd, Hg and As could meet the I standard of marine sediment quality. The potential ecological risk index of Dalian Bay was "relatively low", and the order of the potential ecological risk indexes of the average content of 6 heavy metal elements was: Hg > Cd > As > Pb > Cu > Zn. The spatial distribution feature showed a SW-NE direction (a low NE value and a high SW value). In general, the potential ecological risk index of heavy metals in the surface sediments of Dalian Bay had little difference as a whole.

(3) The correlation analysis of heavy metals in surface sediments showed that there was a positive correlation between Cu, Pb, Zn, Cd and As in the surface sediments, and the correlation coefficient was larger, indicating that they had a certain homology. There was a positive correlation between TOC and 3 heavy metals (Cu, Zn and Cd), while there was a correlation between petroleum and 4 heavy metals (Cu, Pb, Zn and Cd). TOC and petroleum had a certain influence on the distribution of heavy metals. The main sources of heavy metal pollution in the marine sediments were further studied with the principal component analysis method, and the contribution rate of the first 2 principal components was 86.87%. According to the correlation analysis, the main source of Cu, Pb, Zn and Cd was the industrial pollutant discharge.

REFERENCES

Alam, A. R., Hossain, A. B. M., Hoque, S., & Chowdhury, D. A., 2018. Heavy Metals in Wetland Soil of Greater Dhaka District, Bangladesh. Pollution, 4(1), 129-141.

Bao, Y. E., 1991. Annals of China Gulf[M], China Ocean Press. Beijing, 1st edition.

Borg, H., Jonsson, P., 1996. Large-scale metal distribution in Baltic Sea sediments.Marine Pollution Bulletin, 32: 8-21.

Chen, J., Wang, Y. X., 2016. Effects of the coastline changes on the hydrodynamic condition in the Dalian Bay. Marine Science Bulletin. 35(3): 351-359.

Chen, M., Cai, Q. Y., Xun, H. et al., 2015. Research Progress of Risk Assessment of Heavy Metals Pollution in Water Body Sediments. Ecology and Environmental Sciences. 24(6): 1069-1074.

Compiling Group of Environmental Quality Investigation Report of the National Coastal Zone Office,1989. The Report on the Comprehensive Survey of Coastal and Marine Resources in China- Environmental Quality Investigation Report, China Ocean Press. Beijing.

Ding, X. G., Ye, S. Y., Gao, Z. J., 2005. Methods of Heavy Metal Pollution Evaluation for Offshore Sediments. Marine Geology Letters, 21(8): 31-36.

Gurumoorthi, K., & Venkatachalapathy, R., 2016. Spatial and seasonal trend of trace metals and ecological risk assessment along Kanyakumari coastal sediments, southern India. Pollution, 2(3): 269-287.

Hakanson, L. 1980. An ecological risk index for aquatic pollution control: a sediment ological approach. Water Research, 14(8): 975-1001.

Islam, S. M., Bhuiyan, M. A. H., Rume, T., & Mohinuzzaman, M., 2016. Assessing heavy metal contamination in the bottom sediments of Shitalakhya River, Bangladesh; using pollution evaluation indices and geo-spatial analysis. Pollution, 2(3): 299-312.

Krika, A., & Krika, F., 2017. Evaluation of the status of heavy metal pollution in surface water and sediments of the Nil River (North Eastern Algeria). Pollution, 3(2): 301-310.

Kzrysztof, L., Danuta, W., 2003. Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik Reservoir.Chemosphere, 51: 723-733.

Li, Q., Yan, Q. L., Li, H. B. et al., 2016. Distribution of viriobenthos in surface sediment in Dalian and Dayao Bay.Marine Environmental Science. 35(2): 184-189

Li, Y., Yu, Z. M., Song, X. X., 2006. Application of Principal Component Analysis(PCA)for the Estimation of Source of Heavy Metal Contamination in Marine Sediments. Environmental Sciences. 27(1): 137-141.

Liu, C. T., Wang, L. J., Zhang, Y. F. et al., 2017. Speciation and bioavailability of mercury in surface sediments of Dalian Bay. Journal of Dalian Ocean University.32(5):603-610.

Luo, F., Wu, G. R.,Wnag, C. et al., 2016. Application of Nemerow pollution index method and Single-factorevaluation method in water quality evaluation. Envoronement and Sustainable Development.5:87-89.

Ma, X. D., Lin, Z. S., Wang, L. J. et al., 2016. Analysis of major pollution factors in sea water and contribution of pollution sources in Dalian Bay .Marine Environmental Science. 35(3):417-421.

Mallick, D., Islam, M., Talukder, A., Mondal, S., Al-Imran, M., & Biswas, S., 2016. Seasonal variability in water chemistry and sediment characteristics of intertidal zone at Karnafully estuary, Bangladesh. Pollution, 2(4), 411-423.

Qiu, Y. W., Zhu, L. S., Li, M. Q., 2005. Distribution characteristics of heavy metals and grain size of sediments from Hailing Bay,China.Marine Science Bulletin, 17(1):69-76.

Reuter, J. H., Perdue, E. M., 1977. Importance of heavy metal-organic matter interactions in nature waters. Geochimica et Cosmochimica Acta , 41:325-334.

Vaezi, A. R., Karbassi, A. R., Habibzadeh, S. K., Heidari, M., & ValikhaniSamani, A. R., 2016. Heavy metal contamination and risk assessment in the riverine sediment. Indian Journal of Geo-Marine Sciences, 45 (8), 1017-1023.

Wang, J. H., 2012. Research on Heavy Metal Pollution and source of material analysis in sediment of Dalian Bay.Liaoning: Dalian Maritime University.

Wang, S. F., Wei, M. R., Lin, J. X., 2002. The Evolution of Heavy Metal Pollution During Last Hundred Years in the Dalian Bay. Earth Science Frontiers. 9(3): 209-215.

Zhang, X. R., Zhang, Y.,Ye, Q. et al., 2012. Environment quality of Liaodong bay and pollution evolution of heavy metals. Marine Geology & Quaternary Geology. 32(2): 21-29.

Zhang, Y. F., Tian, J., Yang, S. et al., 2015. Distribution and structure of nutrients in seawater and ecological responses in Dalian Bay. China Environmental Science.35(1):236-243.

Zhou, X. B., Mei, P. Y., Peng, L. L. et al., 2015. Contents and Potential Ecological Risk Assessment of Selected Heavy Metals in the Surface Sediments of Bohai Bay. Ecology and Environmental Sciences, 24(3): 452-456.