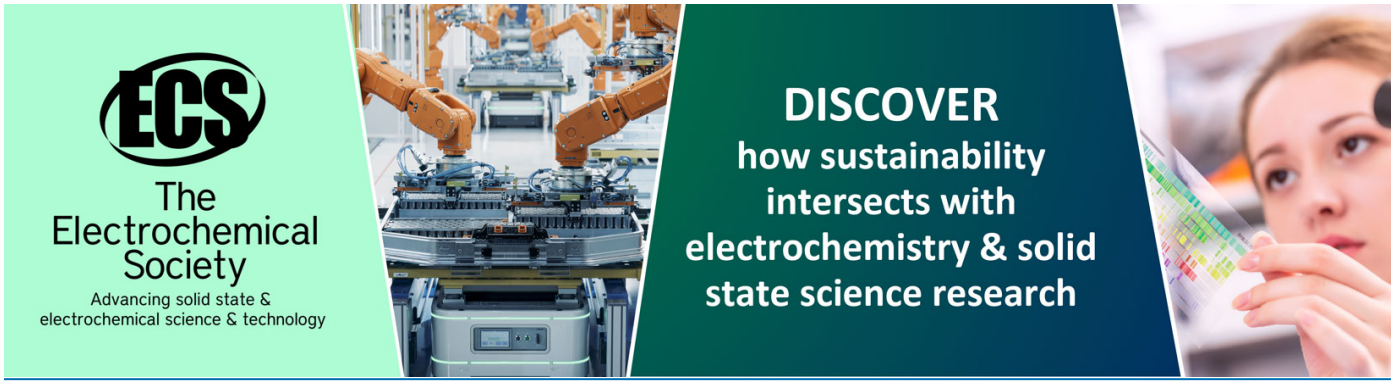
Vertical Transfer of Cd Content Between Two Parallel Currents in Opposite Motion



Vertical Transfer of Cd Content Between Two Parallel Currents in Opposite Motion

Dongfang Yang[1, 2, *], Qing Li[1], Longlei Zhang[1], Qi Wang[1], and Haixia Li[1]

[1]Accountancy Shool, Xijing University, Xi'an 710123, China

[2]North China Sea Environmental Monitoring Center, SOA, Qingdao 266033, China

[*] dfyang@shou.edu.cn

Abstract: Based on the investigation data about Cd in Jiaozhou Bay in August, 1992, we calculated the horizontal increase amount and vertical diluted amount of Cd content in surface and bottom layers from the southwest waters of the bay to the west waters of the bay mouth, and set up the model block diagram of horizontal and vertical changes of Cd content. The results present that in August, the absolutely increase amount of Cd content in surface and bottom layers was 0.16-0.34μg/L, and the relatively increase amount of Cd content in surface and bottom layers was 51.51-66.66%. In the waters of southwest bay and west bay mouth, Cd content in surface and bottom layers had absolutely vertical diluted amount of 0.24-0.42μg/L, and its relatively vertical diluted amount was 63.63-75.00%. In the horizontal migration process of Cd content in the surface and bottom layers, the horizontal increase amount of Cd content in the surface and bottom layers reached a relatively high level from the southwest of bay to the west of bay mouth. It reveals that in the bay waters, in the parallel and opposite movement of the two currents, the current entering into the bay carried a high value of Cd content, and the Cd content migrated from the water with high content to the water with low content through the diffusion and migration of Cd content. Moreover, the migration direction of Cd content was perpendicular to the parallel movement direction of the two currents. In this way, the low-value Cd content in the outward current was increased, and at the same time, the vertical diffusion, migration and settlement of the high-value Cd content led to the increase of the Cd content in bottom layer in the outward current. In the process of vertical sediment of Cd content in the surface and bottom layers, the current had a low value of Cd content in the bay waters, and the vertical diluted amount of Cd content in the surface and bottom layers reached a high level; in the bay mouth waters, the current had high Cd content, but the vertical diluted amount of Cd content in the surface and bottom layers was also very high. In conclusion, the vertical diluted amount of Cd content in the surface and bottom layers kept a high value regardless of whether the current left the bay or whether the current carried high or low Cd content.

1.Introduction

The main sea current entered Jiaozhou Bay with high content of Cd from outside the bay through the bay mouth, which causes the changes of Cd content in the surface and bottom layers of seawater in Jiaozhou Bay. When the current leaves the bay, the Cd content migrates horizontally and vertically, passing through the water body from the surface, undergoing horizontal migration, and sinking to the seabed [1-6]. Therefore, by the application of the horizontal and vertical matter content change models

and the survey data on Cd content in Jiaozhou Bay in August, 1992, the horizontal migration process and vertical sediment process of Cd content when the current left Jiaozhou Bay are demonstrated, which enlarges study platform for the vertical sediment and horizontal migration of Cd content in surface and bottom waters.

2. Waters, Dataset and Methods

2.1 Natural Environment of Jiaozhou Bay. In the south of Shandong Peninsula, Jiaozhou Bay location between Tuan island and Xuejia island is 120 ° 04 ′ - 120 ° 23 ′ E, 35 ° 58 ′ - 36 ° 18 ′ N. Facing the Yellow Sea, covering an area of about 446km^2, Jiaozhou Bay is a typical semi closed Bay with an average water depth of about 7m. Flowing into Jiaozhou Bay, many rivers such as Dagu River, Yang River and Haibo River, Licun River and Loushan River are the ones with large runoff and sediment concentration. Further, The hydrological characteristics of these rivers can alter in different seasons [7, 8].

2.2 Dataset and Methods. The survey data on Cd in Jiaozhou Bay in August, 1992 are used in this study. Further, the dataset is originated from North China Sea Environmental Monitoring Center, SOA. In August, we got water samples at two sites in Jiaozhou Bay: site 54 and site 53 (Figure 1). By the water depth, samples of the surface and bottom layers were taken if > 10m; sample only of the surface layer was taken if < 10m). On the basis of the national standard method included in the National Specification for Marine Monitoring (1991) [9], the Cd in Jiaozhou Bay was investigated.

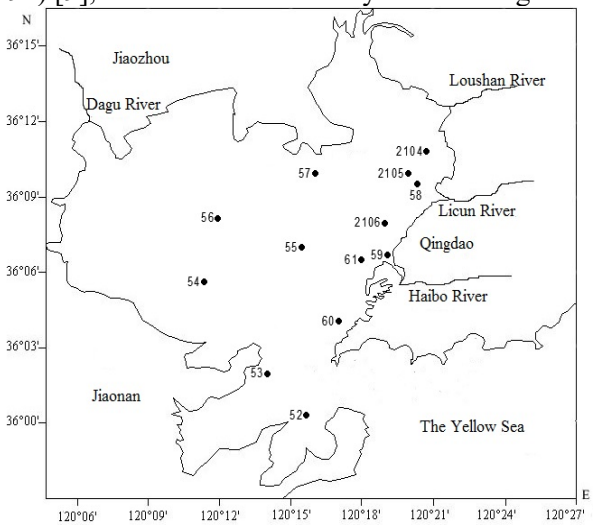


Figure 1 Survey sites in Jiaozhou Bay

3. Results

3.1 Waters from Southwest Bay to West Bay Mouth. The main sea current entered Jiaozhou Bay with high content of Cd from outside the bay through the bay mouth. In addition, the current circled the nearshore waters in the bay, and then left the bay and reached the western waters of the bay mouth.

In August, in the southwest waters of Jiaozhou Bay, the site is 54. And in the western waters of bay mouth, the site is 53. The main sea current in the surface waters went into the bay waters through the southern waters of bay mouth and then surrounded the nearshore waters in the bay, reaching site 54 with Cd content of 0.32μg/L. After that it reached site 53 with Cd content of 0.66μg/L. Similarly, the main sea current bay, in the bottom waters, went into the bay waters through the southern waters of bay mouth. The current first encircled the nearshore waters in the bay and got site 54, with a maximum Cd content of 0.08μg/L, and then reached site 53, with a Cd content of 0.24μg/L.

3.2 The Definitions of Horizontal Matter Content Changes. In Jiaozhou Bay, the current carriesmatter content. If there is no source to provide matter content for the current, the matter content will decrease continuously with the movement of the current [10-11]. By applying the definitions and formulae, the horizontal loss amount, we calculated vertical diluted amount and vertical sediment amount of matter content. We would divide the horizontal loss amount of matter content into absolutely horizontal loss amount and relatively horizontal loss amount. At the same time, we would divide the vertical diluted and sediment amounts of matter content into absolutely vertical diluted and sediment amounts and relatively vertical diluted and sediment amounts.

3.3 Formulae for Horizontal Matter Content Changes. In the surface waters of Jiaozhou Bay from southwest bay to west bay mouth, it is considered that the matter (M) content is A in southwest bay and B in west bay mouth.

We would assume that the absolutely horizontal loss amount of matter content is regarded as $D>0$ and the relatively horizontal loss amount is regarded as E from southwest bay waters to west bay waters. If $D<0$, it means that the absolutely horizontal loss amount of matter content from the western waters of the bay mouth to the southwestern waters of the bay is regarded as $-D>0$,or the absolutely horizontal increase amount of matter content from southeast bay waters to west bay waters is regarded as $-D>0$.

$$D=A-B, \qquad E=|A-B|/\max(A,B) \qquad (1)$$

In the bottom waters of Jiaozhou Bay from southwest bay to west bay mouth, in the same way, it is assumed that the matter content is a in southwest bay and b in west bay mouth.

The absolutely horizontal loss amount of matter content is regarded as $d>0$ and the relatively horizontal loss amount is regarded as e from southwest bay waters to west bay mouth waters. If $d<0$, it means that the absolutely horizontal loss amount of matter content from the western waters of the bay mouth to the southwestern waters of the bay is regarded as $-d>0$, or the absolutely horizontal increase amount of matter content from southeast bay waters to west bay mouth waters is regarded as $-d>0$.

$$d=a-b, \qquad e=|a-b|/\max(a, b) \qquad (2)$$

3.4 The Formula of Vertical Matter Content Changes. In the waters of Jiaozhou Bay from the southwest of bay to the west of bay mouth, it is assumed that the matter content in the surface waters of southwest bay is regarded as A, that in the bottom waters is regarded as a, and the investigation site is regarded as n. What's more, the absolutely vertical diluted amount of matter content is $V_{na}>0$ and the relatively vertical diluted amount of matter content is regarded as V_{nr}. If $V_{na}<0$, the absolutely vertical sediment amount of matter content is $-V_{na}>0$, and the relatively vertical sediment amount of matter content is regarded as V_{nr}.

$$V_{na}=A-a, \qquad V_{nr}=|A-a|/\max(A, a) \qquad (3)$$

3.5 Horizontal Loss Amount of Cd Content in the Surface and Bottom Layers. It is determined that from site 54 to site 53 is simply from A to B, and Cd content is the main part of matter content. The horizontal loss amount of Cd content in surface and bottom layers is revealed through the horizontal changes of Cd content.

In August, in the surface water of Jiaozhou Bay from southwest bay to west bay mouth, when the ocean current left the bay, the Cd content in surface layer in the water changed largely [10], and by applying formula (1), calculated is the horizontal increase amount of Cd content in surface layer (Table 1).

Table 1 horizontal increase amount of Cd content in surface layer

From A to B	D	E	E
August	-0.34	0.5151	51.51%

Table 2 horizontal increase amount of Cd content in bottom layer

From A to B	d	e	e
August	-0.16	0.6666	66.66%

At the same time, in the bottom water of Jiaozhou Bay from southwest bay to west bay mouth, when the ocean current left the bay, the Cd content in bottom layer also changed a lot [10], and by applying formula (2), calculated is the horizontal increase amount of the Cd content in bottom layer (Table 2).

3.6 Vertical Diluted Amount and Vertical Sediment Amount. Cd content is the main part of matter content. Through the vertical changes of Cd content, the vertical diluted amount and vertical sediment amount of Cd content in the surface layer and bottom layer are revealed.

In August, in Jiaozhou Bay, from the southwest of the bay to the west of the bay mouth, the Cd content in the surface and bottom layers changed much [10-11]. By using formula (3), calculated are the vertical diluted amount and vertical sediment amount of Cd content in bottom layer (Table 3).

Table 3 Vertical diluted amount and vertical sediment amount of Cd content in surface and bottom layers

Time	Waters	V_{na}	V_{nr}	V_{nr}
August	Southwest waters of bay	0.24	0.7500	75.00%
	Western waters of bay mouth	0.42	0.6363	63.63%

4. Discussion

*4.1 Changes in Matter Content of Current Track in the Bay.*In Jiaozhou Bay waters in August, the Cd content 1.11μg/L was from the transportation of the main sea current. The main sea current went into Jiaozhou Bay with high content of Cd and surrounded a circle of nearshore waters in the bay (Figure 2). The current first passed site 54 and reached site 53. The horizontal and vertical migration processes of Cd content in the waters from the southwest of bay to the west of bay mouth are quantitatively studied through the horizontal and vertical change models of matter content proposed by the authors.

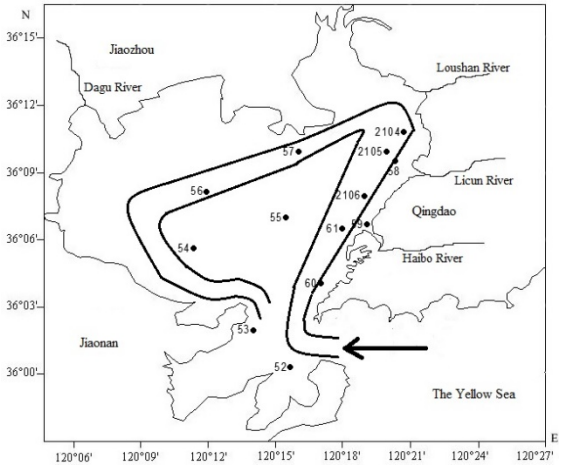


Figure 2 The flow path of the main sea current with high matter content in Jiaozhou Bay (μg/L)

4.2 Vertical Changes of Cd Content. On the spatial scale, in August from southwest of bay to west of bay mouth, the Cd content 1.11μg/L was from the transportation of main sea current. Under the action of tides and currents in the bay, the Cd content in Jiaozhou Bay was decreasing along the gradient. When the current surrounded the nearshore waters of the bay and reached the southwest waters of the bay, the Cd content carried by the current has been reduced to 0.32μg/L. At the same time, the Cd content in the bottom water also decreased greatly to 0.08μg/L. At last, when the current reached the western waters

of the bay mouth, that is, when the current left the bay, the Cd content in the surface water rose sharply, and that carried by the current increased to 0.66μg/L. At the same time, the Cd content in the bottom water also increased greatly 0.24μg/L. With the extension of the migration path of Cd content, the Cd content in surface and bottom water had a large amount of sediment. However, from the southwest of the bay to the west of the bay mouth, the Cd content in the surface and bottom waters increased greatly. It indicates that there must have been a source which provided Cd content for the current in the migration process of Cd content from the southwest of the bay to the west of the bay mouth. The Cd content in the surface and bottom water in the bay had a large amount of sediment in the movement of current. Then, only in the bay mouth water area, the Cd content in the surface and bottom water bodies increased greatly. It shows that in the bay mouth waters, the current flowing out of the bay met the current flowing in the bay, and the two currents moved parallel to each other in opposite directions (Figure 3). In this way, the inward current with high Cd content would affect the outward current with low Cd content and increase the Cd content in that current (Figure 3). Therefore, in the bay mouth waters, a large amount of Cd content was obtained in the outward current, which led to a substantial increase in Cd content in the surface and bottom water bodies. In addition, from the southwest waters of the bay to the west waters of the bay mouth, the horizontal increase amount of Cd content in surface layer reached a high value of 51.51%, and at the same time, the horizontal increase amount of Cd content in bottom layer reached a higher value of 66.66% (Figure 4).

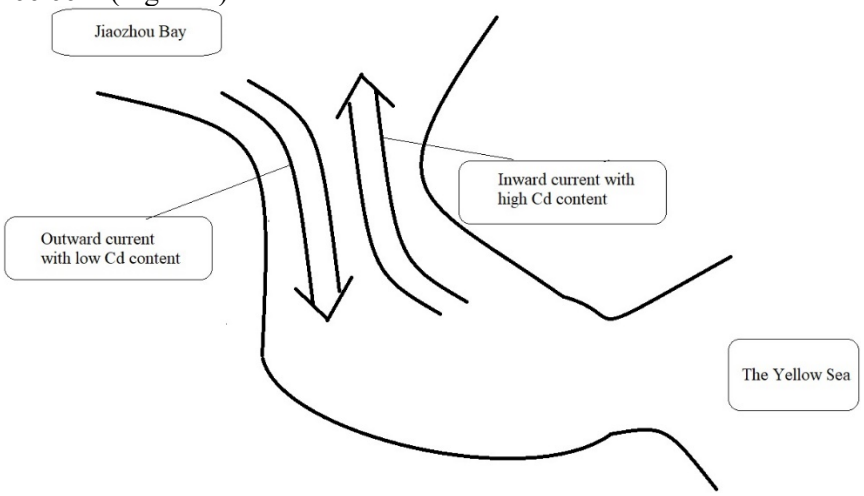


Figure 3 Two currents moving in parallel and opposite directions in bay mouth waters in Jiaozhou Bay

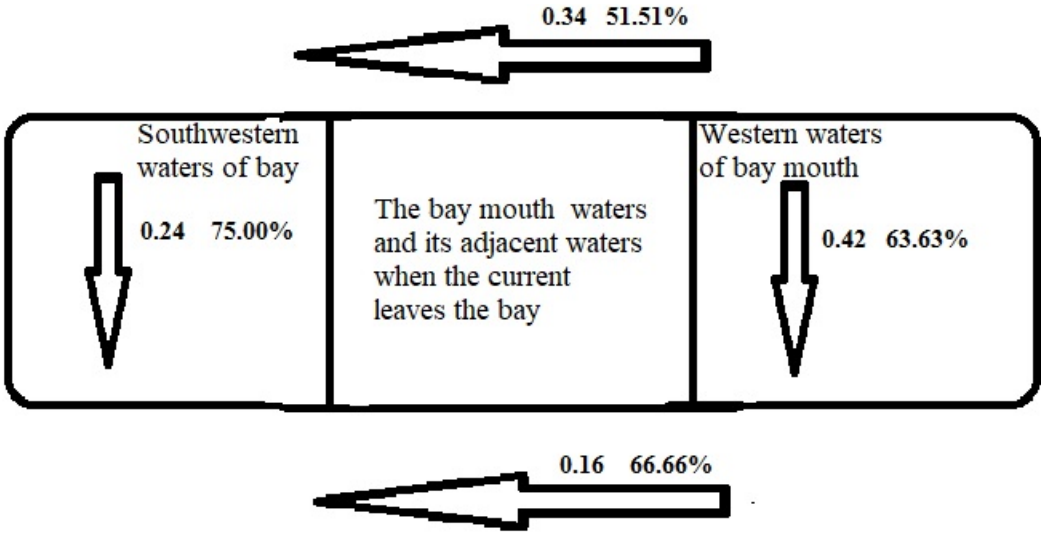


Figure 4 Model block diagram of horizontal and vertical changes of Cd content in August

In August, the vertical diluted amount of Cd content in surface and bottom layers reached a high value of 75.00% in southwest bay waters and 63.63% in west bay mouth waters (Figure 4). Therefore, the vertical diluted amount of Cd content in surface and bottom layers reached a high value of 75.00% before the current left the bay, and reached a high value of 63.63% after the current left the bay. Thus, before and after the current left the bay, the vertical diluted amount of Cd content in the surface layer and bottom layer kept a high value.

4.3 Horizontal Loss Amount. In August, the horizontal increase amount of Cd content in surface layer reached 51.51% from the southwest of bay to the west of bay mouth (Table 1),which indicates that in the bay mouth waters, in the parallel and opposite movements of the two currents, the inward current carried a high value of Cd content. Through the diffusion and migration of high Cd content, the Cd content migrated from the high-content water body to the low-content water body, which increased the Cd content in the outward current. Moreover, the migration direction of Cd content is perpendicular to the parallel movement direction of two ocean currents (Figure 5).

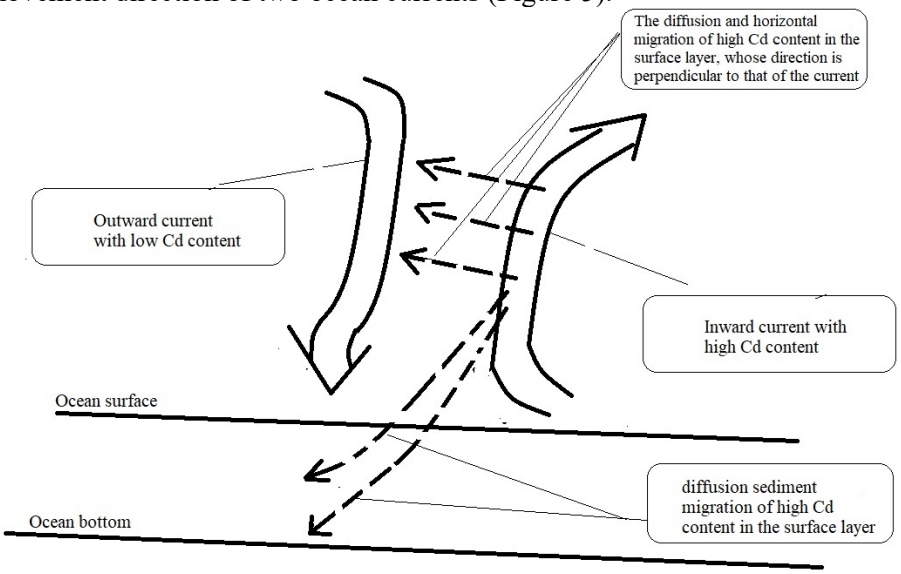


Figure 5 Diffusion and horizontal migration and diffusion sediment migration of Cd content between two currents

In August, from the southwest waters of the bay to the west waters of the bay mouth, the horizontal increase amount of Cd content in the bottom layer reached 66.66% (Table 2). It shows that the inward current with high Cd content and the outward current with low Cd content had parallel and opposite movements, and they also had mutual contact and friction. In the movement of these two currents, the high Cd content carried by the inward current would vertically affect the low Cd content carried by the outward current, which would provide high Cd content for the outward current. In this way, not only the low-value Cd content of the outward current was increased, but also the Cd content in bottom layer of the outward current was increased by vertical diffusion, migration and sediment of the high-value Cd content.

Accordingly, in the process of horizontal migration of Cd content in the surface and bottom layers, two currents moved in parallel and opposite directions. high Cd content carried by one current would vertically migrate to another parallel and opposite current, which increased the Cd content carried by this current and further increased the Cd content in bottom layer of this current.

4.4 Vertical Loss Amount. The main sea current transported the high Cd content 1.11μg/L in August in Jiaozhou Bay. By the effect of tides and currents in the bay, the Cd content was decreasing along the gradient. As the current surrounded the nearshore waters of the bay and arrived to the southwest waters

of the bay first, the Cd content carried by the current has been reduced to 0.32μg/L. In the southwest waters of the bay, the vertical diluted amount of Cd content in the surface and bottom layers got a high value of 75.00%. Then, the main sea current left the waters in the bay and arrived to the waters in the west of the bay mouth where it was affected by the high Cd content carried by the inward current. Therefore, the Cd content carried by the outward current has increased to 0.66μg/L in the western waters of the bay mouth. At the same time, the vertical diluted amount of Cd content in surface layer and bottom layer got a high value of 63.63%.

In conclusion, the vertical sediment process of Cd content in surface and bottom layers shows that the current had low Cd content in the bay waters, and the vertical diluted amount of Cd content in surface and bottom layers were very high. In the bay mouth waters of the bay, the current had a high Cd content, and the vertical diluted amount of Cd content in the surface and bottom layers reached a high level. Therefore, the vertical diluted amount of Cd content in the surface layer and bottom layer kept a high value regardless of whether the current left the bay or whether the current carried high or low Cd content.

5. Conclusion

By applying the horizontal and vertical matter content change models designed by the authors, we would calculate the horizontal increase amount and vertical diluted amount of Cd content in the surface and bottom layers, and set up the model block diagram of the horizontal and vertical change of Cd content.

In August, the absolutely increase amount of Cd content in surface layer and bottom layer was 0.16-0.34μg/L, and the relatively increase amount of Cd content in surface layer and bottom layer was 51.51-66.66%. In the waters of southwest bay and west bay mouth, the absolutely vertical diluted amount of Cd in surface and bottom layer is 0.24-0.42μg/L, and the relatively vertical diluted amount is 63.63-75.00%.

In the waters of Jiaozhou Bay from the southwest of the bay to the west of the bay mouth, when the current left the bay, the Cd content in the surface water rose sharply, and that carried by the current increased to 0.66μg/L. At the same time, the Cd content in the bottom water also increased greatly to 0.24μg/L.

In the bay mouth water area, the outward current met the inward current, and the two currents moved parallel to each other in opposite directions. In this way, the inward current with high Cd content would affect the outward current with low Cd content and increase the Cd content in that current. As a result, in the bay mouth waters, a large amount of Cd content was obtained in the outward current, which led to a substantial increase in Cd content in the surface and bottom water bodies. Therefore, from the southwest waters of the bay to the west waters of the bay mouth, the horizontal increase amount of Cd content in surface layer got a high value of 51.51%, while the horizontal increase amount of Cd content in bottom layer got a higher value of 66.66%.

The vertical diluted amount of Cd content in surface and bottom layers arrived to a high value of 75.00% before the current left the bay, and arrived to a high value of 63.63% after the current left the bay. Thus, before and after the current left the bay, the vertical diluted amount of Cd content in the surface layer and bottom layer kept a high value.

References

[1] Dongfang Yang, Haixia Li, Ye Li, Qi Wang, Longlei Zhang. Yang's Clearing Up Features in Marine Bay [J]. Earth and Environment Science, 2018, 439(032021): 1-5.

[2] Dongfang Yang, Sixi Zhu, Hongmin Suo, Yang Xiuqin, Ming Wang. Source Strength Ratio and Source input Ratio of Cd in Marine Bay [J]. Earth and Environment Science, 2018, 439(042033): 1-5.

[3] Dongfang Yang, Sixi Zhu, Chunhua Su, Yunjie Wu, Xiaodan Wang. Settlement processes and features of Cd in Jiaozhou Bay [J]. Earth and Environment Science, 2018, 199(022018): 1-5.

[4] Dongfang Yang, Haixia Li, Ye Li, Qi Wang, Longlei Zhang. Spatio-temporal status and vertical migration features of the settlement processes of Cd in Jiaozhou Bay [J]. Earth and Environment

Science, 2018, 199(022019): 1-5
[5] Dongfang Yang, Dongmei Jing, Sivakumar Manickam, Longlei Zhang, Haixia Li. Spatial-temporal migration of Cd in marine bay [J]. Earth and Environment Science, 2018, 199(022063): 1-5
[6] Dongfang Yang, Ma Weimin, Zhikang Wang, Xiuzhen Tao, Sixi Zhu. Seasonal-temporal changes of Cd in bottom waters in Jiaozhou Bay [J]. Advances in Engineering Research, 2018, 78: 126-129.
[7] Yang Dongfang, Gao Zhenhui, Wang Pei-gang, Sun Pei-yan Liu Shuang. Silicon limitation on primary production and its destiny in Jiaozhou Bay, China Ⅴ Silicon deficit process[J]. Chin. J. Oceanol. Limnol. 2005, 23(2): 169-175.
[8] Yang Dongfang, Gao Zhenhui, Sun Peiyan, Zhao Sheng, Zhang Youchi. Silicon limitation on primary production and its destiny in Jiaozhou Bay, China Ⅵ The ecological variation process of the phytoplankton [J]. Chin. J. Oceanol. Limnol. 2006, 24(2): 186-203.
[9] State Oceanic Administration. The Specification for Marine Monitoring [Z]. Beijing: China Ocean Press, 1991.
[10] Dongfang Yang, Danfeng Yang, Fengyou Wang, Sixi Zhu, Xiuqin Yang. Definition and formula of substance content change in marine bay and the application [J]. Advances in Engineering Research, 2017, 118: 847-853.
[11] Dongfang Yang, Danfeng Yang, Fengyou Wang, Sixi Zhu, Ming Wang. Environmental dynamic value of substance in marine bay[J]. World Scientific Research Journal, 2016, 2(3): 191-196.