Horizontal Distribution Trend of Cadmium Content in Surface and Bottom Waters

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Abstract: According to investigation data of Jiaozhou Bay in 1991, this paper studied the vertical distribution and seasonal variation of Cd in surface and bottom waters from bay center to northern bay mouth, and determined its seasonal distribution, variation range and horizontal distribution trend. The results showed that in May and August, in the entire waters from bay center to northern bay mouth, from surface to bottom, the Cd content range was 0.06-0.58μg/L, which shows that the water was not polluted by Cd. From May to August, in bay center, the seasonal variation of Cd content at surface and bottom was an order of summer > spring. In May and August, in northern bay mouth, the seasonal variation of Cd content at surface was an order of spring > summer, and summer > spring at bottom. The seasonal variation of Cd content shows that the Cd content at surface was not controlled by season, but source transport. Besides, Cd content at bottom was not controlled by season, but cumulative effect and dilutive effect when Cd content at surface reached seafloor. In Jiaozhou Bay, in surface and bottom waters from bay center to northern bay mouth, the horizontal distribution trend of Cd contents at surface and bottom was presented. The horizontal distribution trend of Cd content at surface and bottom was opposite in May and consistent in August. The results disclosed the principle of horizontal distribution trend at surface and bottom. Cd content was transported from sources reached surface, then rapidly and constantly sedimentated to seafloor. When Cd content reached high before being cumulated in seafloor, the horizontal distribution trend of Cd content at surface and bottom was consistent. On the contrary, it was opposite. In bottom waters, the accumulation of Cd content and its gravity features determined the consistent horizontal distribution trend of matter content at surface and bottom.

1. Introduction
Cadmium (Cd) is widely applied in many industries, causing waste water and exhaust gas containing Cd in production and usage. Through river flow, Cd content reached the surface waters of sea and was transported vertically to seafloor [1-18]. Therefore, based on investigation data in 1991, this paper studied the vertical distribution and seasonal variation of Cd in surface and bottom waters from bay center to northern bay mouth, determined its seasonal distribution, variation range and horizontal distribution trend, and displayed the seasonal variation and vertical sedimentation of Cd content, to provide scientific evidence for the vertical sedimentation and horizontal transport of Cd in surface and bottom waters.
2. Investigation Waters, Materials and Methods

2.1 Natural environment of Jiaozhou Bay
Jiaozhou Bay, located in southern Shandong Peninsula, is a typical semi-closed bay. The geographical location is 120°04′-120°23′E, 35°58′-36°18′N. Bounded by the line connecting Tuandao Cape and Xuejiadao Island, it connects with Yellow Sea, covering an area of about 446km², with the average depth of about 7m. There are dozens of rivers reaching the ocean in Jiaozhou Bay, among of which, the rivers with a larger volume of runoff and sand content include Dagu River, Yang River, Haibo River in Qingdao, Licun River, Loushan River and so on. These rivers are seasonal streams, and hydrological characteristics vary seasonally [19, 20].

2.2 Materials and methods
The materials about Cd in Jiaozhou Bay waters in May and August of 1991 was provided by North China Sea Environment Monitoring Center, State Oceanic Administration. In May and August, two sites were established for sampling in Jiaozhou Bay: 55 and 60, shown in Figure 1. Samplings were performed for three times in May and August in 1990, respectively. According to the depth of water, sampling and survey were conducted (surface and bottom layers were sampled when the depth of water is more than 10m, but just surface layer when less than 10m). The survey on Cd of Jiaozhou Bay waters was in accordance with national standard method, which was included in The Specification for Marine Monitoring (1991) [21].

![Fig. 1 Investigation sites in Jiaozhou Bay](image)

3. Results

3.1 Surface and bottom waters
In Jiaozhou Bay, in waters of bay center to northern bay mouth, in May, the Cd content at surface was 0.06-0.58μg/L, and 0.06-0.08μg/L at corresponding bottom. In August, Cd content at surface was 0.15-0.40μg/L, and 0.16-0.38μg/L at corresponding bottom. It indicated that the entire waters from bay center to northern bay mouth, from surface to bottom, satisfied the Case I Sea Water Quality Standard (1.00μg/L), which showed that the water of surface and bottom was not polluted by Cd.

Hence, in May and August, in waters of bay center to northern bay mouth, the Cd content at surface and bottom was 0.06-0.58μg/L, satisfying Case I Sea Water Quality Standard (1.00μg/L), which showed that the water of surface and bottom was not polluted by Cd.
3.2 Seasonal distribution of surface waters
In Jiaozhou Bay, in surface waters from bay center to northern bay mouth, the Cd content at surface was 0.06-0.58μg/L in May and 0.15-0.40μg/L in August. It indicated that the variation range of Cd content at surface in May and August was 0.06-0.58μg/L. Cd content at surface was low in August and high in May, so the seasonal variation of Cd content at surface was an order of spring > summer.

3.3 Seasonal distribution of bottom waters
In Jiaozhou Bay, in bottom waters from bay center to northern bay mouth, the Cd content at bottom was 0.06-0.08μg/L in May and 0.16-0.38μg/L in August. It indicated that the variation range of Cd content at bottom in May and August was 0.06-0.38μg/L. Cd content at bottom was low in May and high in August, so the seasonal variation of Cd content at surface was an order of summer > spring.

3.4 Variation range of surface and bottom waters
In waters from bay center to northern bay mouth, when Cd content at surface reached high as 0.06-0.58μg/L in May, the content at corresponding bottom was low as 0.06-0.08μg/L. Whereas, when Cd content at surface reached high 0.15-0.40μg/L in August, the content at corresponding bottom was high as 0.16-0.38μg/L. In addition, the variation range of Cd content at surface was 0.09-0.18μg/L, less than 0.10-0.30μg/L at bottom. The variation was basically same. As a result, when Cd content at surface was high, the content at corresponding bottom was low or high.

3.5 Horizontal distribution trend at surface and bottom
The investigation area was waters from bay center to northern bay mouth. In May, from 55 site in bay center to 60 site in northern bay mouth, at surface, Cd content increased along with gradients from 0.06μg/L to 0.58μg/L. At bottom, Cd content decreased along with gradients from 0.08μg/L to 0.06μg/L. It showed that the horizontal distribution trend at surface and bottom was opposite. Hence, in May, in this area, horizontal distribution trend of Cd at surface and bottom was opposite.

In August, from 55 site in bay center to 60 site in northern bay mouth, at surface, Cd content decreased along with gradients from 0.40μg/L to 0.15μg/L. At bottom, Cd content decreased along with gradients from 0.38μg/L to 0.16μg/L. It showed that the horizontal distribution trend at surface and bottom was consistent. Hence, in August, in this area, horizontal distribution trend of Cd at surface and bottom was consistent.

4. Discussion
4.1 The process of sedimentation
With the effect of vertical waters [25-27], Cd content varied greatly through waters. The hydrophilia of Cd ion was strong, easily to be combined with zooplankton and phytoplankton, suspended particles in sea water. From spring to summer, then again to summer, marine organism began to bloom with a rapidly increasing quantity [23]. Besides, due to the blooming of plankton, the surface of suspended particles formed colloid with the strongest adsorption capacity to absorb a great number of Cd ion and bring to surface waters. Due to gravity and flow, Cd was sedimented constantly to seafloor [1-24]. Hence, the sedimentation of Cd from surface waters to seafloor presented the sedimentation and transport of Cd.

4.2 The seasonal variation of waters in bay center
In surface waters of bay center, in May, Cd content increased from lower value of 0.06μg/L to high value of 0.40μg/L in August, so the seasonal variation of Cd content at surface was an order of summer > spring.

In surface waters of bay center, in spring, there was no source, Cd content was low, so Cd content in spring was lower. In summer, Cd content came from atmospheric sedimentation, so Cd content in
summer was higher. It showed that in surface waters of bay center, because Cd was adsorbed to surfaces of many suspended particles, with the effect of gravity and flow, Cd was constantly sedimentated to seafloor. It was influenced by effect theory of vertical waters, horizontal waters and waters [12-14]. Cd content was rapidly and constantly sedimentated to seafloor, so it at surface is impacted by cumulative effect and dilutive effect when reaching seafloor, showing that the seasonal variation of Cd content at bottom was an order of summer > spring. Thus, in bottom waters of bay center, in May, Cd content increased from low value of 0.08μg/L to high value of 0.38μg/L in August, and the seasonal variation of Cd content at bottom was an order of summer > spring.

In short, from May to August, in waters of bay center, the seasonal variation of Cd content at surface and bottom was an order of summer > spring.

4.3 The seasonal variation of waters in northern bay mouth
In surface waters of northern bay mouth, in May, Cd content decreased from high value of 0.58μg/L to low value of 0.15μg/L in August, so the seasonal variation of Cd content at surface was an order of spring > summer.

In surface waters of northern bay mouth, in spring, Cd content was transported by ships and wharfs in northern bay mouth, so Cd content was higher in spring. In summer, there was no source, so Cd content in summer was lower. It indicated that in surface waters of northern bay mouth, because Cd was adsorbed to surfaces of many suspended particles, with the effect of gravity and flow, Cd was constantly sedimentated to seafloor. Cd was influenced by effect theory of vertical waters, horizontal waters and waters [12-14]. Cd content was rapidly and constantly sedimentated to seafloor, so Cd content at surface was impacted by cumulative effect and dilutive effect when Cd content at surface reached seafloor, showing that the seasonal variation of Cd content at bottom was an order of spring > summer. Thus, in bottom waters of northern bay mouth, in May, Cd content increased from low value of 0.06μg/L to high value of 0.16μg/L in August, and the seasonal variation of Cd content at bottom was an order of spring > summer.

In short, from May to August, in waters of northern bay mouth, the seasonal variation of Cd content at surface was an order of spring> summer, and spring > summer at bottom.

4.4 Seasonal variation mechanism
In surface waters of bay center, in spring, when there was no source, Cd content was lower; in summer, when there was source, Cd content was higher. In surface waters of northern bay mouth, in spring, when there was source, Cd content was higher; in summer, when there was no source, Cd content was lower. Hence, Cd content at surface was not controlled by season, but source transport.

In bottom waters of bay center, the seasonal variation of Cd content at bottom and surface was consistent, which showed the gravity feature of heavy metal Cd. Cd content was rapidly and constantly sedimentated to seafloor. Cd was influenced by effect theory of vertical waters, horizontal waters and waters [12-14]. Cd content at surface was influenced by dilutive effect when reaching seafloor. In bottom waters of northern bay mouth, the seasonal variation of Cd content at bottom and surface was opposite, which showed the gravity feature of heavy metal Cd. Cd content was rapidly and constantly sedimentated to seafloor. Cd was influenced by effect theory of vertical waters, horizontal waters and waters [12-14]. Cd content at surface was influenced by cumulative effect when reaching seafloor. Thus, Cd content at bottom was not controlled by season, but cumulative effect and dilutive effect when Cd content at surface reached seafloor.

4.5 The variation of sedimentation
In terms of variation, from bay center to northern bay mouth, in May and August, the variation range of Cd content at surface and bottom was basically same. When Cd content at surface was high, Cd content at corresponding bottom was low or high. It showed that Cd content was rapidly and constantly sedimentated to seafloor. In seafloor, the variation of Cd content from low value to high value through constant accumulation resulted in the consistent variation of Cd content at surface and
bottom along with the change of time. According to effect principle of vertical waters, horizontal waters and waters proposed by the author [10-12], Cd content was rapidly and constantly sedimentated to seafloor. In seafloor, the variation of Cd content from low value to high value disclosed the variation of Cd content from dilutive effect of vertical waters to cumulative effect.

4.6 Space sedimentation
In May, in northern bay mouth, Cd content was transported by ships and wharfs in northern bay mouth, and Cd content at surface was high, but low at bottom. It showed that Cd content at surface was sedimentated to seafloor, however, Cd content was not cumulated in seafloor yet. Whereas, in bay center, there was no source, so Cd content at surface and bottom was low. In this way, the horizontal distribution trend of Cd content at surface and bottom was opposite.

In August, in northern bay mouth, there was no source, so Cd content at surface and bottom was low. In bay center, Cd content came from atmospheric sedimentation. It was sedimentated to seafloor in a large number, so Cd content in seafloor reached high after constant accumulation. So the horizontal distribution trend of Cd content at surface and bottom was consistent.

Cd content was transported by sources reaches surface, then rapidly and constantly sedimentated to seafloor. When it reached high before being cumulated, the horizontal distribution trend of Cd content at surface and bottom was consistent. When it reached low before being cumulated, the horizontal distribution trend of Cd content at surface and bottom was opposite. In bottom waters, the accumulation of Cd content and its gravity feature determined the consistent horizontal distribution trend of matter content at surface and bottom.

5. Conclusion
In May and August, in the entire waters from bay center to northern bay mouth, from surface to bottom, Cd content range was 0.06-0.58μg/L, satisfying Case I Sea Water Quality Standard (1.00μg/L), which showed that the water at surface and bottom was not polluted by Cd.

From May to August, the seasonal variation of Cd content at surface and bottom was an order of summer > spring in bay center, spring > summer at surface and summer > spring at bottom in northern bay mouth. The seasonal variation of Cd content showed that Cd content at surface was not controlled by season, but source transport. Besides, Cd content at bottom was not controlled by season, but cumulative effect and dilutive effect when Cd content at surface reached seafloor.

In terms of variation, from bay center to northern bay mouth, in May and August, the variation range of Cd content at surface and bottom was basically same. In addition, Cd content was rapidly and constantly sedimentated to seafloor, resulting in the consistent variation of Cd content at surface and bottom along with the change of time. According to effect principle of vertical waters, horizontal waters and waters proposed by the author, Cd content was rapidly and constantly sedimentated to seafloor. In seafloor, the variation of Cd content from low value to high value disclosed the variation of Cd content from dilutive effect of vertical waters to cumulative effect.

In space sedimentation, in surface and bottom waters from bay center to northern bay mouth, the horizontal distribution trend of Cd content at surface and bottom was presented. In May, the horizontal distribution trend of Cd content at surface and bottom was opposite but consistent in August. Cd content transported by sources reached surface, then it was rapidly and constantly sedimentated to seafloor. When it reached high before being cumulated, the horizontal distribution trend of Cd content at surface and bottom was consistent, otherwise, it was opposite. In bottom waters, the accumulation of Cd content and its gravity feature determined the consistent horizontal distribution trend of matter content at surface and bottom.

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References
[1] Dongfang Yang, Zhenqing Miao, Marine Bay Ecology (I) [M]. Beijing, China Ocean Press, 2010, 1-320.
[2] Dongfang Yang, Zhenhui Gao, Marine Bay Ecology (II) [M]. Beijing, China Ocean Press, 2010, 1-330.
[3] Yang Dongfang, Chen Yu, Wang Hong, Yang Chunru, Guo Junhui. Environmental Background Composition and Transfer Process of Cadmium in Jiaozhou Bay [J]. Coastal Engineering, 2010, 29(4): 73-82.
[4] Dongfang Yang, Yu Chen, Yanxiang Chang, Chunxiu Liu, Yichen Wang. The Source and Distribution of Cadmium in Jiaozhou Bay [J]. Coastal Engineering, 2013, 32(3): 68-78.
[5] Dongfang Yang, Sixi Zhu, Fengyou Wang, Huazhong He and Yunjie Wu. The distribution and content of Cadmium in Jiaozhou Bay [J]. Applied Mechanics and Materials Vols. 644-650. 2014, 5325-5328.
[6] Dongfang Yang, Fengyou Wang, Youfu Wu, Huazhong He and Sixi Zhu. The structure of environmental background value of Cadmium in Jiaozhou Bay waters [J]. Applied Mechanics and Materials Vols. 644-650. 2014, 5333-5335.
[7] Dongfang Yang, Sixi Zhu, Fengyou Wang, Youfu Wu and Huazhong He. Study on the Cadmium in surface waters in Jiaozhou Bay [M]. 2014 IEEE workshop on advanced research and technology industry applications. Part D, 2014, 1012-1014.
[8] Dongfang Yang, Sixi Zhu, Xiuqin Yang, Xiaoli Zhao and Fengyou Wang. Pollution level and Sources of Cd in Jiaozhou Bay [J]. Materials Engineering and Information Technology Application. 2015, 558-561.
[9] Dongfang Yang, Sixi Zhu, Fengyou Wang, Xiuqin Yang and Xiaoli Zhao. Distribution and aggregation process of Cd in Jiaozhou Bay [J]. Advances in Computer Science Research. 2015, 2352: 194-197.
[10] Dongfang Yang, Shengtao Chen, Baolei Li, Xiao Geng and Zijun Xu. Research on the vertical distribution of Cadmium in Jiaozhou Bay waters [J]. Proceedings of the 2015 international symposium on computers and informatics. 2015, 2667-2674.
[11] Dongfang Yang, Fengyou Wang, Zhaohui Sun, Xiaoli Zhao, Sixi Zhu. Research on Vertical distribution and settling process of Cd in Jiaozhou bay [J]. Advances in Engineering Research. 2015, 40: 776-781.
[12] Dongfang Yang, Fengyou Wang, Xiuqin Yang, Ming Wang, Sixi Zhu. Cadmium background pollution in Jiaozhou Bay [J]. Advances in Engineering Research. 2016, 60: 1347-1350.
[13] Dongfang Yang, Danfeng Yang, Sixi Zhu, Fengyou Wang, Zhikang Wang. Spatial-temporal variations of Cd in Jiaozhou Bay [J]. Advances in Engineering Research. 2016, 60: 403-407.
[14] Dongfang Yang, Xiuqin Yang, Ming Wang, Sixi Zhu, Fengyou Wang. The slight impacts of marine current to Cd contents in bottom waters in Jiaozhou Bay [J]. Advances in Engineering Research. 2016, 60: 412-415.
[15] Dongfang Yang, Fengyou Wang, Sixi Zhu, Ming Wang, Xiuqin Yang. Homogeneity of Cd contents in Jiaozhou Bay waters [J]. Advances in Engineering Research. 2016, Vol.65: 298-302.
[16] Dongfang Yang, Xiancheng Qu, Yu Chen, Shubo Fang and Yinjiang Zhang. Sedimentation mechanism of Cd in Jiaozhou Bay waters [J]. Advances in Engineering Research. 2016, 80: 993-997.
[17] Dongfang Yang, Danfeng Yang, Sixi Zhu, Zhikang Wang, Ming Wang. Sedimentation process and vertical distribution of Cd in Jiaozhou Bay [J]. Advances in Engineering Research. 2016, 80: 998-1002.
[18] Dongfang Yang, Sixi Zhu, Zhikang Wang, Xiuqin Yang, Fengyou Wang. Spatial-temporal changes of Cd in Jiaozhou Bay [J]. Computer Life, 2016, 4(5): 446-450.
[19] Dongfang Yang, YuChen, Zhenhui Gao, et al. Silicon Limitation on primary production and its destiny in Jiaozhou Bay, China IV transect offshore the coast with estuaries [J]. Chinese Journal of Oceanology and Limnology. 2005, 23(1): 72-90.
[20] Dongfang Yang, FanWang, ZhenhuiGao et al. Ecological phenomena of phytoplankton in Jiaozhou Bay [J]. Marine Sciences, 2004, 28(6): 71-74.
[21] State Oceanic Administration. The Specification for Marine Monitoring (HY003.4-91) [M]. Beijing: China Ocean Press, 1991: 205-282.