The influence of Cd Content Transported by Different Sources on Different Surface and Bottom Layers

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**Abstract:** According to the investigation data of Jiaozhou Bay in 1992, the vertical distribution, horizontal distribution and seasonal variation of Cd in the surface and bottom waters from the center of the bay to the south of the mouth of Jiaozhou Bay are studied, and the seasonal distribution, range of distribution and horizontal distribution trend are determined. The results show that in May, August and October, in the waters from southern mouth to the center of the bay, the Cd content of surface and bottom waters ranged from 0.12-1.19μg/L, in line with the national water quality standards for Class I and Class II seawater, which indicates that water quality was slightly polluted by the Cd content or was not polluted. The surface levels of Cd vary seasonally from low to high: spring, summer, and fall, the same was true for Cd seasonal variation in bottom waters. In the surface and bottom waters of Jiaozhou Bay from the south of the bay mouth to the center of the bay, in May, August and October, when the Cd content in surface waters was relatively low, and the corresponding bottom layer was relatively low; when the Cd in surface waters was relatively high, the corresponding bottom layer was relatively high; this shows that the loss of Cd content both from the surface and the bottom was relatively high. In May, August and October, in the waters from the southeast of the bay to the center of the bay, the horizontal distribution of Cd in the surface and the bottom waters have an opposite trend. From May to October, the seasonal variation of Cd content in surface waters in the southeast of the bay was mainly affected by the Cd content transported by main sea currents, while the bottom waters are mainly affected by river-transported Cd content. From May to October, in the central waters of Jiaozhou Bay, the seasonal changes of surface and bottom Cd content are not consistent with that of Cd content transported by main sea currents. On the temporal scale, in the waters of Jiaozhou Bay from the south of the bay to the center of the bay, in May, August and October, the Cd content in the surface and bottom waters varies within the same range, maintaining the consistency. On the spatial scale, in the waters from the southeast of the bay to the center of the bay, in May, August and October, according to the comparison between the Cd content transported by main sea currents and that transported by rivers, it can be proved that the horizontal distribution of Cd content in the surface waters was opposite to that of in the bottom waters.

**1. Introduction**

Human transport large amounts of cadmium (Cd) to the land, ocean and atmosphere, and finally reach the surface of the ocean water. From the perspective of vertical effect, under the action of gravity and currents, the Cd content is constantly sinking to the bottom of the sea. In the vertically moving water...
body, under the action of ocean currents, the Cd content is continuously transported to various waters [1-10]. Therefore, according to investigation data of the Cd in Jiaozhou Bay in 1992, the vertical and horizontal distribution and seasonal variation of Cd in the surface and bottom waters of Jiaozhou Bay from the bay mouth south to the bay center are researched, and variation range and horizontal distribution trend of surface and bottom Cd content are determined, the process seasonal change, horizontal migration and vertical settlement are demonstrated. This study provides scientific basis for the research on the consistency of vertical settlement and horizontal migration decline of Cd in surface and bottom waters.

2. Investigated Waters & Materials and Methods

2.1 Natural Environment of Jiaozhou Bay. Jiaozhou Bay (120°04′-120°23′E, 35°58′-36°18′N) is a semi-closed bay with the boundary between Tuan Island and Xuejial Island, connecting the Yellow Sea with the total area and average water depth of 446km², 7m, respectively. There are inflow rivers, such as Dagu River and Yang River, Haibo River, Licun River and Loushan River in Qingdao city have greater runoff and sediment concentration. Moreover, all the rivers has obvious seasonal changes in hydrological characteristics of rivers [11, 12].

2.2 Materials and Methods. The investigation data on Cd in Jiaozhou Bay waters in May, August and October 1992 adopted by this research are contributed by the North Sea Monitoring Center of the State Oceanic Administration. At Sites 55 and 60 water samples were got in Jiaozhou Bay waters in May, sites 53, 54, 55 and 60 were set in August; sites 52, 55 and 60 were set in October. (Figure 1) Three samples were taken according to depth for sample investigation in May, August, and October 1992, (surface and bottom waters were taken when >10m, and only surface waters were taken when <10m). The investigation of Cd in Jiaozhou Bay waters was carried out in line with the national standard method which has been added in the National Specification for Marine Monitoring (1991) [13].

3. Results

3.1 Surface and Bottom Waters. In May, in the waters of Jiaozhou Bay from the southeast of the bay to the center of the bay, the Cd content of the surface layer was 0.23-0.44μg/L, and the corresponding bottom layer was 0.09-0.72μg/L. This shows that the Cd content of both surface and bottom layers in this area was less than 1.00μg/L, which was in line with the national first-class sea water quality standard, so that water quality was not polluted by Cd content.
In August, in the waters from the center of Jiaozhou Bay to the west of the mouth, the Cd content of the surface layer was 0.12-0.75μg/L, and the corresponding bottom layer was 0.08-1.08μg/L. This shows that the Cd content of surface layer in this area was less than 1.00μg/L, which was in line with the national first-class seawater quality standard, and water quality was not polluted by Cd content. The Cd content of the bottom layer was greater than 1.00μg/L, which meets the national second-class seawater quality standards, and the water quality was slightly polluted by the Cd content.

In October, in the waters of Jiaozhou Bay from the south of the bay mouth to the southeast of the bay, the Cd content of the surface layer was 0.39-0.89μg/L, and the corresponding bottom layer was 0.30-1.19μg/L. This shows that the surface Cd content was less than 1.00μg/L, which meets the national first-class seawater quality standard, and the water quality was not polluted by any Cd content. The Cd content of the bottom layer was greater than 1.00μg/L, which meets the national second-class seawater quality standards, and the water quality was slightly polluted by the Cd content.

Therefore, in May, August and October, in the surface and the bottom waters from the south of the bay mouth to the center of Jiaozhou Bay, the Cd content ranged from 0.12 to 1.19μg/L, in line with the national water quality standards of Class I and Class II seawater, which indicates that the water quality was slightly polluted or not polluted.

3.2 Seasonal Distribution of Surface Waters. In the surface waters from the south of the bay mouth to the center of the bay, in May, the Cd content in the water ranged from 0.23 to 0.44μg/L; in August, 0.12 to 0.75μg/L; in October, 0.39-0.89μg/L. This shows that the Cd content in the surface water ranges from 0.12 to 0.89μg/L from May to October. The months in which the surface Cd content varied from low to high are May, August, and October. Therefore, the corresponding seasonal variation was spring, summer, and fall.

3.3 Seasonal Distribution of Bottom Waters. In the bottom waters from the south of the bay mouth to the center of the bay, in May, the Cd content in the water ranged from 0.09 to 0.72μg/L; in August, 0.08 to 1.08μg/L; in October, 0.30 to 1.19μg/L. This shows that the Cd content in the bottom water ranges from 0.08 to 1.19μg/L from May to October. The months in which the surface Cd content varied from low to high are May, August, and October. Therefore, the seasonal changes from low to high Cd content in the bottom waters are obtained as follows: spring, summer and fall.

3.4 Variation Range of the Surface and Bottom Waters. In the surface and bottom waters of Jiaozhou Bay from the south of the bay to the center of the bay, in May, when the surface content was relatively low in the range of 0.23-0.44μg/L, its corresponding bottom content was also low in the range of 0.09-0.72μg/L. In August, when the surface content was 0.12-0.75μg/L, the corresponding bottom content was 0.08-1.08μg/L. In October, when the surface layer content of Cd was high at 0.39-0.89μg/L, the corresponding bottom layer was 0.30-1.19μg/L. Moreover, the variation range of the surface Cd content was 0.12-0.89μg/L less than the bottom layer’s 0.08-1.19μg/L, and the amount of variation was basically the same. Therefore, when the content of the surface layer was relatively low, the corresponding bottom layer was relatively low; when the content was relatively high, the corresponding bottom layer was relatively high; This shows that in May, August and October, the loss of Cd content from the surface to the bottom was relatively high.

3.5 Horizontal Distribution Trend of Bottom and Surface Waters. The waters from the southeast of the bay to the center of Jiaozhou Bay are studied.

In May, from site 60 in the southeast waters of the bay to site 55 in the central waters of the bay, the Cd content in the surface waters rose along the gradient, from 0.23μg/L to 0.44μg/L while in the bottom layer decreased along the gradient, from 0.72μg/L to 0.09μg/L. This shows that the horizontal distribution trends of the surface and bottom waters are opposite.

In August, also from site 60 to site 55, the Cd content decreased along the gradient in the surface layer, from 0.75μg/L to 0.12μg/L, while rose in the bottom layer from 0.14μg/L to 1.08μg/L. This
shows that the horizontal distribution trends of the surface and bottom layers are opposite. This indicates that the horizontal distribution trend was the same as described above.

In October, it was measured at the same sites. In the surface waters, the Cd content rose along the gradient from 0.51μg/L to 0.89μg/L. In the bottom waters, the Cd content decreased from 1.19μg/L to 0.37μg/L. The conclusion is the same as above.

In a word, in May, August and October, in the southeast of the bay to the center of the bay, the horizontal distribution of Cd in the surface layer and the bottom layer had an opposite trend.

4.Discussion

4.1Sedimentation Process. Cd has undergone the effect of the vertical water body [14-16], and the Cd content has changed greatly after passing through the water body. Cd ions have strong hydrophilicity, and is easy to combine with phytoplankton and plankton in seawater. In summer, marine organisms multiply and their numbers increase rapidly [8]. Due to the reproductive activities of plankton, colloids are formed on the surface of suspended particles. At this time, the adsorption force is the strongest, adsorbing a large amount of Cd ions and bringing them to the surface. Under the action of gravity and water flow, Cd continuously sinks to the bottom of the ocean [1-12]. Therefore, continuous subsidence of Cd from the surface water to the bottom shows the sedimentation process.

4.2Seasonal Variation Process of Cd Content in Southeastern Waters of the Bay. In May, the Cd content in the surface waters of the southeast of Jiaozhou Bay gradually increased from a relatively low level of 0.23μg/L. By August, the Cd content reached the highest level of 0.75μg/L, followed by a gradual decline. By October, the Cd content reached a high level of 0.51μg/L. Therefore, the seasonal variation of Cd content in the surface layer from low to high is: spring, fall, and summer (as shown in Table 1).

The main sea currents pass through the waters of the southeast of the bay. The estuary waters of the Haibo River are relatively close to the waters of the southeast of the bay. Therefore, the surface and bottom water bodies in the southeast of the Haibo River Bay are subject to the Cd content transported by the main sea currents and the Haibo River.

In spring, the Cd content in the surface waters of the southeast of Jiaozhou Bay was 0.59μg/L, a relatively low level of Cd transported by main sea currents. So, the Cd content in spring was relatively low. In summer, main sea currents transported 1.11μg/L of Cd content, reaching the highest level. In fall, the Cd content transported by the main sea currents was low 0.39μg/L. Therefore, the Cd content drops a lot from summer to fall. However, the Cd content in fall was still relatively high. In summer, the surface water in the southeast of the bay was affected by the Cd content transported by the ocean currents. From above, the seasonal variation in the surface water of the southeast of the bay from low to high Cd content was: spring, fall, and summer.

In the surface waters in the southeast waters of Jiaozhou Bay, Cd ions are adsorbed on the surface of suspended particulate substance. Under the action of gravity and water flow, the Cd content continuously sinks to the bottom of the ocean. According to the theory of vertical effect, horizontal effect and water bodies [14-16], the Cd content rapidly and continuously sinks to the bottom of the sea, obtaining a cumulative effect and a dilution effect.

As a result, in May, Cd content in the bottom of the southeast waters of Jiaozhou Bay decreased from a high level of 0.72μg/L to the lowest level of 0.14μg/L by August, then gradually increased to the highest level of 1.19μg/L by October. It shows the seasonal variation of the Cd content in the bottom waters from low to high: summer, spring, and fall (as shown in Table 1).

| Locations                          | Seasonal variation of Cd content |
|-----------------------------------|----------------------------------|
| Cd content transported by main sea currents | fall | spring | summer |
In spring, high level of Cd content transported by rivers was 1.07μg/L. So, in spring Cd content in the bottom waters of the southeast of the bay hit the highest record 0.72μg/L. In summer, rivers transported 0.11μg/L of Cd content, making the least Cd of 0.14μg/L in the bottom waters. In fall, the Cd content transported by rivers was 0.66μg/L, a relatively high level. Therefore, the Cd content reached the highest level of 1.19μg/L in the bottom waters under the accumulation effect. To conclude, under the influence of the Cd content transported by the Haibo River, the seasonal variation in the Cd content of the bottom water body in the southeast of the bay from low to high was: summer, spring, and fall.

4.3 Seasonal Variation of Cd Content in the Central Waters of the Bay.

In May, the Cd content in the surface water of the center of Jiaozhou Bay gradually decreased from the low level of 0.44μg/L and reached the lowest value of 0.12μg/L by August. Then Cd content rose to a high level of 0.89μg/L by October. Therefore, the seasonal variation of Cd in the surface layer from low to high was: summer, spring, and fall.

Jiaozhou Bay is a shallow bay. The main sea currents enter Jiaozhou Bay with matter content, and surround a circle of inshore waters in the bay. In May, August and October, the main sea currents did not pass through the waters in the center of the bay.

The Cd content transported by the main sea currents was 0.59μg/L in May, 1.11μg/L in August, and 0.39μg/L in October. The seasonal variation of Cd content transported by main sea currents from low to high was: fall, spring, and summer. However, no Cd content was transported to the surface water of the center of Jiaozhou Bay in the same period.

In May, in the bottom water of the center of Jiaozhou Bay, Cd content rose from the lowest level of 0.09μg/L and reached a high level of 1.08μg/L by August. Then it began to gradually decrease and reached a low level of 0.37μg/L by October. Therefore, the seasonal variation of Cd content in the bottom layer from low to high was: spring, fall, and summer.

Therefore, from May to October, in the central water of Jiaozhou Bay, the seasonal variation of Cd content in the surface waters from low to high was: summer, spring, fall, while in the bottom waters was: spring, fall, and summer. The seasonal variation of Cd content transported by main sea currents from low to high was: fall, spring, and summer. This shows that in the central waters of Jiaozhou Bay, the seasonal variation of the bottom Cd content was different from the seasonal variation of the surface Cd content and the seasonal variation of the Cd content transported by main sea currents (as shown in Table 2).

According to the theory of vertical effect, horizontal effect and water bodies [12-14], the Cd content rapidly and continuously sinks to the bottom of the sea, and the Cd content of the surface layer reaches the bottom of the sea, influenced by cumulative effect and a dilution effect. However, the seasonal variation of bottom Cd content in the water of the center of the Bay was not affected by that of surface Cd content and of Cd content transported by main sea currents, presenting a different result. In this regard, further discussion and research are needed on the seasonal variation of the bottom Cd content.

Table 2 Seasonal variation of Cd content in different locations in the central waters of the bay from low to high

| Locations                        | Seasonal variation of Cd content |
|----------------------------------|----------------------------------|
| Cd content transported by main sea currents | fall | spring | summer |
| Cd content in surface waters     | summer | spring | fall |
| Cd content in bottom waters      | spring | fall | summer |
4.4 Sedimentation in the Temporal Dimension. On the temporal scale, in May, August and October, the variation range of Cd content in the surface and bottom waters from the southern part of Jiaozhou Bay mouth to the center of the bay was basically the same. When Cd content in surface waters was relatively low, and the corresponding bottom layer was relatively low, and vice versa. This shows that in May, August and October, the loss of Cd content from the surface to the bottom was relatively high. Moreover, the Cd content rapidly and continuously sinks to the bottom of the sea, resulting in a consistent variation in the surface and bottom layers. The variation range of Cd in the surface layer was smaller than that of in the bottom layer, which demonstrates the theory of vertical effect, horizontal effect and water bodies proposed by the author [10-12], which strengthens the cumulative effect and dilution effect of vertical water bodies.

According to the theory of vertical effect, horizontal effect and water bodies proposed by the author [10-12], the surface and bottom variation of Cd content reveals the cumulative effect and dilution effect of vertical water body. In May, the high content of Cd in the surface layer reached the bottom of the sea, forming a cumulative effect, and the low content of Cd in the surface layer reached the bottom of the sea, forming a dilution effect; The same was true in August and October. Therefore, at the same time, the Cd content in surface layer ranged from 0.12 to 0.89μg/L, which was less than in bottom layer’s 0.08 to 1.19μg/L. Therefore, it is believed that high Cd content existing in surface waters was less than that in bottom waters, because the Cd content in surface waters was always settling and accumulated in the bottom waters. In contrast, the low Cd content existing in surface waters was greater than that of in bottom waters, because Cd content in the surface layer was diluted in the bottom layer during the sedimentation process. It is further explained that when the Cd content of the water body is high, it will rapidly sink and accumulate on the sea floor. When the Cd content of the water body is low, it is further diluted by the water body.

4.5 Sedimentation in the Spatial Dimension. On the spatial scale, the Cd content from the southeast of the bay to the center of the bay transported by main sea currents was 0.59μg/L in May, 1.11μg/L in August, and 0.39μg/L in October. In the surface water of the center of Jiaozhou Bay, from May to October, the Cd content was transported by no source.

In May and October, the sedimentation of Cd content in the southeast waters of Jiaozhou Bay was higher than that in the central waters of the bay. In August, the situation was the opposite. In May and October, the Cd content transported by rivers was high, and by main sea currents was low, resulting in a relatively high Cd content in the bottom waters in the southeast of the bay, and relatively low in the surface waters. In August, the situation was the opposite. Therefore, in May, August and October, the horizontal distribution of Cd content in the surface layer from the southeast of the bay to the center of the bay was opposite to that of the bottom layer.

5. Conclusion
In May, August and October, from southern part of the bay mouth to the center of the bay, the Cd content of the surface and bottom waters ranged from 0.12-1.19μg/L, in line with the national water quality standards for Class I and Class II seawater, which indicates that water quality was slightly polluted by the Cd content or was not polluted.

The months in which the surface Cd content varied from low to high are May, August, and October. Therefore, the corresponding seasonal variation was spring, summer, and fall. The seasonal variation of Cd content in the bottom layer from low to high was: spring, fall, and summer.

In the surface and bottom waters of Jiaozhou Bay from the south of the bay to the center of the bay, in May, August and October, when the Cd content in surface waters was relatively low, and the corresponding bottom layer was relatively low; when the Cd in surface waters was relatively high, the corresponding bottom layer was relatively high; This shows that the loss of Cd content both from the surface and the bottom was relatively high.

In May, August and October, in the southeast of the bay to the center of the bay, the horizontal distribution of Cd in the surface layer and the bottom layer had an opposite trend.
From May to October, in the waters southeast of the bay, the seasonal variation of Cd content in the surface waters from low to high was: spring, fall, summer, while in the bottom waters was: summer, spring, and fall. The seasonal variation of Cd content transported by main sea currents from low to high was: fall, spring, and summer; and the seasonal variation of Cd content transported by rivers from low to high was: summer, fall, and spring. Therefore, the seasonal variation of Cd content in surface water in the southeast of the bay was mainly affected by the Cd content transported by main sea currents, and the bottom water was mainly affected by the Cd content transported by rivers.

From May to October, in the central water of Jiaozhou Bay, the seasonal variation of Cd content in the surface waters from low to high was: summer, spring, fall, while in the bottom waters was: spring, fall, and summer. The seasonal variation of Cd content transported by main sea currents from low to high was: fall, spring, and summer. This shows that in the central waters of Jiaozhou Bay, the seasonal variation of the bottom Cd content is different from the seasonal variation of the surface Cd content and the seasonal variation of the Cd content transported by main sea currents.

On the temporal scale, in May, August and October, the variation range of Cd content in the surface and bottom waters from the southern part of the bay mouth to the center of the bay was basically the same. This shows that the Cd content rapidly and continuously sinks to the bottom of the sea, resulting in a consistent variation in the surface and bottom layers.

On the spatial scale, in May and October, the sedimentation of Cd content in the southeast waters of Jiaozhou Bay was higher than that in the central waters of the bay. In August, the situation was the opposite. According to the comparison between the Cd content transported by main sea currents and the Cd content transported by rivers, the results are as follows: in May, August and October, the horizontal distribution of Cd content in the surface layer from the southeast of the bay to the center of the bay was opposite to that of the bottom layer.

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