

# The influence of the Pb Content of Source Transport on its Distribution in the Bottom Layer

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**Abstract:** Based on the survey data of Jiaozhou Bay in 1992, the vertical distribution and seasonal variation of Pb in the surface and bottom waters from the bay center to the south of the bay mouth were studied, and the seasonal distribution, range and horizontal distribution trend of Pb content in the surface and bottom waters were determined. The results show that in May, August and October, Pb content in the waters from the south of the bay mouth to the center of the bay, and in the whole water body from the surface to the bottom, ranged from 4.20 to 24.39  $\mu\text{g/L}$ , which met the national sea water quality standard of class II, class III and class IV. In other words, water quality was mildly, moderately and severely polluted by Pb. In the surface and bottom water, the Pb content was from low to high in May, October and August; In addition, the seasonal change of Pb content in the water body from low to high was as follows: spring, autumn and summer. In May, August and October, when the content of Pb in the surface layer was high, the corresponding bottom layer was high. And when the content of Pb in the surface layer was relatively high, and the corresponding bottom layer was relatively high. It shows that in May, August and October, the loss of Pb content from the surface layer to the bottom layer was relatively large. Further, in the waters from the southeast to the center, in May and August, the horizontal distribution trend of Pb in the surface layer was opposite to that in the bottom layer. But in October, the horizontal distribution trend of Pb in the surface layer was consistent with that in the bottom layer. What's more, from May to October, the seasonal variation of Pb content in the bottom layer of the water body in the southeastern Jiaozhou Bay was mainly decided by that of Pb content transported by the open ocean current. In the water body in the center of Jiaozhou Bay, the seasonal change of Pb content in the bottom layer was different from that in the surface layer and from that in the ocean current. In terms of time scale, in the waters from the southern bay mouth to the center of the bay, in May, August and October, the Pb content in the surface and the bottom layer changed in the same range, maintaining the consistency. Furthermore, in terms of spatial scale, in May and August, according to the high content and increasing trend of Pb transported by the open sea current, the horizontal distribution trend of Pb in the surface layer was opposite to that in the bottom layer. Nonetheless, in October, the Pb content transported by the open sea current was relatively low and showed a trend of decrease. And the horizontal distribution of Pb in the surface layer was consistent with that in the bottom layer.

## 1 Introduction

A large amount of Pb carried by humans to the land, ocean and atmosphere reached the surface of the ocean water body through the transportation of ships and wharfs, surface runoff and rivers, and then was continuously transported to all waters through the ocean current. In this process, a large amount of Pb content was deposited to the seabed [1-6]. Therefore, this article, with the aid of Jiaozhou bay lead (Pb) survey data in 1992, studies the vertical distribution and seasonal variation of Pb in the surface and bottom waters from southern bay mouth to center of the bay, ascertains the season distribution, range and horizontal distribution trend of Pb content in the surface and bottom layer, shows the process of the Pb content's seasonal change and vertical

settlement of Jiaozhou bay waters.

## 2 Survey Waters, Materials and Methods

### 2.1 Natural Environment of Jiaozhou Bay

Jiaozhou bay is in the south of the Shandong Peninsula. Its geographical location is  $120^{\circ} 04' - 120^{\circ} 23' \text{ E}$ ,  $35^{\circ} 58' - 36^{\circ} 18' \text{ N}$ . It is bounded by Tuan Island and Xuejia Island and connected with the Yellow Sea, with an area of about  $446 \text{ km}^2$  and an average water depth of about 7 m. It is a typical semi-closed bay. There are more than ten rivers flowing into the sea, among which Dagu River, Yang River, and Haibo River as well as Licun River and Loushan River whose hydrological characteristics have obvious seasonal changes [7, 8].

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## 2.2 Materials and Methods

The Pb survey data of the Jiaozhou bay's water body in May, August and October in 1992 used in this study were given by the North Sea Monitoring Center of the State Oceanic Administration. In May, water samples were collected from two sites: sites 55 and 60; In August, water samples were taken from sites 53, 54, 55 and 60; and in October, water samples were collected from sites 52, 55 and 60 (Figure 1). Sampling was carried out according to the depth of water (When the depth > 10 m, the surface and bottom layers were both taken; Only the surface layer when the depth <10 m) to conduct the investigation. The Pb survey of Jiaozhou bay's water body was carried out according to the national standard methods included in the National Code for Marine Monitoring (1991) [9].

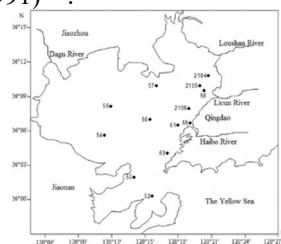


Figure. 1. Investigation sites in Jiaozhou Bay

## 3 Results

### 3.1 Surface and Bottom Water Bodies

In May, in the waters of Jiaozhou bay from the southeast to the center, Pb content in the surface layer was 5.54 - 7.37  $\mu\text{g/L}$ , while that in the bottom layer was 4.20 - 10.43  $\mu\text{g/L}$ . It indicates that Pb content in the surface layer and bottom layer of the whole water body was greater than 1.00  $\mu\text{g/L}$ , but less than 50.00  $\mu\text{g/L}$ , which was up to the national sea water quality standard of class II, class III and class IV. It means that the water quality was mildly, moderately and heavily polluted by Pb content.

Besides, in August, in the waters of Jiaozhou bay from the center to the southwest, Pb content in the surface layer was 5.53 - 15.90  $\mu\text{g/L}$ , while that in the bottom layer was 7.85 - 24.39  $\mu\text{g/L}$ . It manifests that in the whole water body, Pb content in the surface layer and bottom layer was more than 5.00  $\mu\text{g/L}$ , but less than 50.00  $\mu\text{g/L}$ , which conformed to the national sea water quality standard of class III and class IV. In other words, the water quality was heavily affected by Pb content pollution.

Moreover, in October, in the waters from the south of the bay mouth to the southeast of Jiaozhou bay, Pb content in the surface layer of Jiaozhou bay was 9.67 - 13.25  $\mu\text{g/L}$ , while that in the corresponding bottom layer was 7.49 - 15.38  $\mu\text{g/L}$ . It demonstrates that in the whole water body, Pb content in the surface layer and the bottom layer was greater than 5.00  $\mu\text{g/L}$ , but less than 50.00  $\mu\text{g/L}$ , which met the national sea water quality standard of class III and class IV. So, there was heavy Pb pollution in the water.

So, in May, August and October, Pb content in the whole water body from the southern part of the bay mouth to the center and from the surface layer to the bottom layer ranged from 4.20 to 24.39  $\mu\text{g/L}$ , which matched the national sea water quality standard of category II, III and IV. It means that the water quality was mildly, moderately and severely polluted by Pb.

### 3.2 Seasonal Distribution of Pb Content in Surface Layer

In the surface water body of Jiaozhou bay from the south of the bay mouth to the center of the bay, in May, Pb content ranged from 5.54 to 7.37  $\mu\text{g/L}$ ; In August, 5.53 - 15.90  $\mu\text{g/L}$ ; In October, 9.67 - 13.25  $\mu\text{g/L}$ . It shows that Pb content in surface water in May, August and October varied from 5.53 to 15.90  $\mu\text{g/L}$ . The Pb content in surface water was from low to high in May, October and August. Therefore, the seasonal change of Pb content in surface water body from low to high was as follows: spring, autumn and summer.

### 3.3 Seasonal Distribution of Pb Content in Bottom Layer

Besides, in the bottom water body of Jiaozhou bay from the south of the bay mouth to the center of the bay, in May, the Pb content varied from 4.20 to 10.43  $\mu\text{g/L}$ . In August, 7.85 - 24.39  $\mu\text{g/L}$ ; In October, 7.49 - 15.38  $\mu\text{g/L}$ . It indicates that in May, August and October, Pb content in the bottom water body ranged from 4.20 to 24.39  $\mu\text{g/L}$ . The Pb content in the bottom water was from low to high in May, October and August. So, the seasonal variation of Pb content in bottom water from low to high was as follows: spring, autumn and summer.

### 3.4 Range of Pb Content in Surface Layer and Bottom Layer

In the surface and bottom waters of Jiaozhou bay from the south of the bay entrance to the center of the bay, in May, when the Pb content in the surface layer 5.54 - 7.37  $\mu\text{g/L}$  was low, the corresponding Pb content in the bottom layer 4.20 - 10.43  $\mu\text{g/L}$  was low. In August, when the Pb content in the surface layer 5.53 - 15.90  $\mu\text{g/L}$  was high, the Pb content in the bottom layer 7.85 - 24.39  $\mu\text{g/L}$  was high. Similarly, in October, when the Pb content in the surface layer 9.67 - 13.25  $\mu\text{g/L}$  was higher, the Pb content in the bottom layer 7.49 - 15.38  $\mu\text{g/L}$  was higher. Moreover, the range of Pb content in the surface layer 5.53 - 15.90  $\mu\text{g/L}$  was smaller than that in the bottom layer 4.20 - 24.39  $\mu\text{g/L}$ , but the change was basically the same. Therefore, the content of Pb in the surface layer was relatively low while that in the bottom layer was relatively low. When the content of Pb in the surface layer was high, that in the corresponding bottom layer was high. The content of Pb in the surface layer was relatively high while that in the bottom layer was relatively high. It manifests that in May, August and October, the loss of Pb content from surface layer to bottom layer was relatively large.

### 3.5 The Horizontal Distribution Trend of Pb Content in Surface Layer and Bottom Layer

From site 60 in the southeastern waters of Jiaozhou bay to site 55 in the central waters:

In May, Pb content in the surface layer increased along the gradient from 5.54 µg/L to 7.37 µg/L. In the bottom layer, Pb content decreased along the gradient from 10.43 µg/L to 4.20 µg/L. It demonstrates that the horizontal distribution trend of the surface layer and the bottom layer was opposite.

Besides, in August, Pb content in the surface layer decreased along the gradient from 11.30 µg/L to 5.53 µg/L. In the bottom layer, Pb content increased along the gradient from 18.88 µg/L to 24.39 µg/L. It indicates that the horizontal distribution trend of the surface and the bottom layer was opposite.

In addition, in October, Pb content in the surface layer increased along the gradient from 9.67 µg/L to 10.45 µg/L. In the bottom layer, Pb content increased along the gradient from 7.49 µg/L to 11.63 µg/L. It shows that the horizontal distribution trend of the surface layer and the bottom layer was consistent.

## 4 Discussion

### 4.1 Subsidence Process

When Pb passes through the water body, it goes through the effect of vertical water body [10-12], which makes the Pb content change greatly. Pb ions have strong hydrophilicity and are easy to combine with floating plants and animals and particles in sea water. In summer, Marine life multiplies and increases rapidly [8]. In addition, due to the reproduction of plankton, the suspended particles form colloids on their surface. At this time, their adsorption force is the strongest, which absorbs a large number of Pb ions and brings them into the surface water. Due to the action of gravity and water flow, Pb continuously sinks to the sea floor [1-6]. Thus, the deposition and migration process of Pb from surface water to seabed is presented.

### 4.2 Seasonal Variation of Pb Content in Southeastern Bay

In the surface water of southeastern Jiaozhou bay, in May, Pb content started to rise from the lower value of 5.54 µg/L. Afterwards, in August, Pb content reached a maximum value of 11.30 µg/L, and then began to decline. After that, in October, Pb content reached a higher value of 9.67 µg/L. As a result, the seasonal variation of Pb content in the surface layer from low to high was as follows: spring, autumn and summer.

In the surface water body in the southeast of Jiaozhou bay, in spring, Pb content was from the conveyance by the open sea current. The Pb content of conveyance was relatively high 20.79 µg/L, but the Pb content of the water body was relatively low. So, the Pb content in spring was relatively low. In summer, Pb content was from the transport by the open ocean current. The Pb

content of transport reached the highest 37.53 µg/L, and the Pb content of the water body was relatively high. Consequently, the Pb content in summer was the highest. In autumn, Pb content came from the transportation of the open seas current. The Pb content of transportation reached a high level 13.25 µg/L, and the Pb content of the water body was also relatively high. Therefore, the Pb content in autumn was relatively high. The seasonal change of Pb content from low to high in ocean current transport was as follows: autumn, spring and summer. It indicates that in the surface water of the southeastern waters of Jiaozhou bay, Pb ions are adsorbed on the surface of suspended particles. And under the action of gravity and water flow, Pb rapidly and continuously sinks to the sea floor according to the effect theory of vertical water body, horizontal water body and water body [10-12]. The Pb content reaching the seabed was affected by the accumulation effect and dilution effect, and was showed in the bottom water body of the southeastern waters of Jiaozhou bay: In May, Pb content started to rise from the high value of 10.43 µg/L. After that, in August, Pb content reached the highest value of 18.88 µg/L and then began to decline. Afterwards, in October, Pb content reached a high value of 7.49 µg/L. So, the seasonal variation of Pb content in the bottom layer from low to high was as follows: autumn, spring and summer (Table 1).

**Table 1.** Seasonal variation of Pb content from low to high in different locations in the southeastern waters of the bay

Position of Pb content	Seasonal variation of Pb content from low to high		
	autumn	spring	summer
Pb content transported by open ocean current	autumn	spring	summer
Pb content in the surface layer	spring	autumn	summer
Pb content in the bottom layer	autumn	spring	summer

Thus, the seasonal variation of Pb content in the bottom layer was mainly decided by that of Pb content transported by the ocean current.

### 4.3 Seasonal Variation of Pb Content in the center of Jiaozhou Bay

In the surface water in the center of Jiaozhou bay, Pb content started to decrease from the low value of 7.37 µg/L in May. And in August, Pb content reached the minimum value of 5.53 µg/L and then began to rise. In October, Pb content reached a higher value of 10.45 µg/L. Therefore, the seasonal change of Pb content in the surface layer from low to high was as follows: summer, spring and autumn.

In the surface water body in the southeast of Jiaozhou bay, in spring, Pb content was from the conveyance of the open sea current 20.79 µg/L. The Pb content of conveyance was relatively high, but the Pb content of the water body was relatively low. So the Pb content in spring was relatively low. After that, in summer, Pb content was from the transport of open ocean current 37.53 µg/L and reached the highest level. The Pb content of the water body was relatively high as well. Therefore,

the Pb content in summer was the highest. Afterwards, in autumn, Pb content came from the transportation of open water current 13.25 µg/L, too. Pb content of transportation was higher as well as that in the water body. Thus, Pb content in autumn was relatively high. The seasonal variation of Pb content from low to high in ocean current transport was as follows: autumn, spring and summer.

In the bottom water body in the central waters of Jiaozhou bay, Pb content started to increase from the low value of 4.20 µg/L in May. In August, Pb content reached a high value of 24.39 µg/L and then gradually decreased; In October, Pb content reached a high value of 11.63 µg/L. As a result, the seasonal change of Pb content in the bottom layer from low to high was as follows: spring, autumn and summer.

To sum up, in the central waters of Jiaozhou bay, the seasonal variation of Pb content in the bottom layer was different from that in the surface layer and that transported by the open ocean current (Table 2).

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

Position of Pb content	Seasonal variation of Pb content from low to high		
	autumn	spring	summer
Pb content transported by open ocean current	autumn	spring	summer
Pb content in the surface layer	summer	spring	autumn
Pb content in the bottom layer	spring	autumn	summer

According to the effect theory of vertical water body, horizontal water body and water body [12-14], the Pb content in the surface layer rapidly and continuously sinks to the seabed, and was impacted by the accumulation effect and dilution effect. However, the seasonal variation of Pb content in the surface and bottom layer in the waters in the center of the bay reveals the different results that the seasonal variation of Pb content in the bottom layer was not affected by the seasonal variation of Pb content in the surface layer or that of Pb content transported by the open ocean current in the center of Jiaozhou bay. Therefore, the seasonal change of Pb content in the bottom layer was affected by the change of Pb content, which needs further discussion and research. Thus, it is necessary to further explore and study what affects the seasonal variation of Pb content in the bottom layer.

#### 4.4 Seasonal Variation Mechanism

The waters in the southeast of Jiaozhou bay are very close to the waters in the baymouth. So the Pb content transported by the open sea current directly affects the waters in the southeast through the waters in the bay mouth. From May to October, in surface waters in the southeastern Jiaozhou bay, the Pb content of surface layer was from low to high in spring, autumn and summer; the Pb content of the bottom layer from low to high was as follows: autumn, spring, summer; the seasonal variation of Pb content was from low to high in ocean current transport in autumn, spring and summer. It

is disclosed that the Pb content transported by the ocean current has little influence on the surface water in the southeastern part of the bay, but has much influence on the corresponding bottom water. Furthermore, the deposition of the Pb content carried by the open sea current was relatively high in the waters in the southeastern bay. Therefore, the seasonal variation of Pb content in the bottom layer was determined by that of Pb content transported by the open ocean current. At this time, under the interference of the Pb content transported by the open sea current, the change of Pb content in the surface layer in the southeastern part of the bay has little influence on the change of Pb content in the bottom water. Thus, the Pb content carried from the source can affect the Pb content in the bottom water more than that in the surface water.

In the water body in the center of Jiaozhou bay, from May to October, there was no input source for Pb content in the surface layer. Hence, the Pb content of the bottom water was not affected by any input source. Meanwhile, the seasonal variation of Pb content in the surface layer from low to high was as follows: summer, spring and autumn; The seasonal variation of Pb content in the bottom layer was from low to high in spring, autumn and summer. It shows that the seasonal variation of Pb content in the bottom layer was completely different from that in the surface layer. However, according to the effect theory of vertical water body, horizontal water body and water body [12-14], the seasonal variation of Pb content in the bottom layer should be consistent with that in the surface layer. It indicates that the seasonal change of Pb content in the bottom layer must be influenced by other input sources. Therefore, it is necessary to further look into other input sources that affect the seasonal variation of Pb content in the bottom layer.

#### 4.5 Settlement on the Temporal Scale

On the temporal scale, in the waters from the south of the bay mouth to the center of Jiaozhou bay, in May, August and October, the Pb content in the surface layer and the bottom layer changed in the same range. The content of Pb in the surface layer was relatively low while that in the bottom layer was relatively low; when Pb content in the surface was high, that in the corresponding bottom was high; the content of Pb in the surface layer was relatively high while that in the bottom layer was relatively high. It shows that in May, August and October, the loss of Pb content from surface layer to bottom layer was relatively large. In addition, Pb content rapidly and continuously sinks to the sea bottom, resulting in the consistency of Pb content changes in the surface and bottom layers. The variation range of Pb content in the surface layer was smaller than that in the bottom layer, which indicates the effect theory of vertical water body, horizontal water body and water body proposed by the authors [10-12].

According to the vertical water effect principle, horizontal water effect principle and water effect principle proposed by the authors [10-12], the changes of Pb content in the surface and bottom layer reveal the

cumulative effect and dilution effect of vertical water. In May, the high content of Pb in the surface reached the seafloor and was affected by the dilution effect, while the low content of Pb in the surface reached the seafloor and was impacted by the accumulation effect. After that, in August, the high content of Pb in the surface layer reached the seabed and got the cumulative effect. Similarly, in October, the higher content of Pb in the surface layer reached the seabed and got the cumulative effect. Therefore, the Pb content in the surface layer 5.53 - 15.90  $\mu\text{g/L}$  was less than that in the bottom layer 4.20 - 24.392  $\mu\text{g/L}$ . Both the high content and the low content Pb in the surface layer are lower than that in the bottom layer. So it is believed that the Pb content in the surface layer was always settling and accumulating in the bottom layer.

#### 4.6 Settlement on the Spatial Scale

In terms of spatial scale, from the southeast to the center in Jiaozhou bay, Pb content was 20.79  $\mu\text{g/L}$  from the outer sea current in May, 37.53  $\mu\text{g/L}$  from the outer sea current in August, and 13.25  $\mu\text{g/L}$  from the outer sea current in October. However, in the surface water body of Jiaozhou bay center, from May to October, Pb content was not any source.

In May, the deposition of Pb content in the southeastern waters of bay was higher than that in the central waters of the bay. The opposite was true in August and October.

In May and August, the Pb content transported by the offshore current was relatively high. Moreover, from May to August, the Pb content carried by the offshore current increased. Therefore, in May and August, the horizontal distribution trend of Pb in the surface layer was opposite to that in the bottom layer in the water body from the southeast to the center of Jiaozhou bay.

Nevertheless, in October, the Pb content moved by the offshore current was relatively low. Besides, from May to August, the Pb content transported by the offshore current decreased. Consequently, in October, the horizontal distribution trend of Pb in the surface layer was consistent with that of the bottom layer in the water body from the southeast to the center of Jiaozhou bay.

### 5 Conclusion

In May, August and October, Pb content in the surface and bottom layer of the whole water body, in the waters from the south of the bay mouth to the center of Jiaozhou bay, ranged from 4.20 to 24.39  $\mu\text{g/L}$ , which met the national sea water quality standard of class II, class III and class IV - the water quality was mildly, moderately and severely polluted by Pb.

In the water body of Jiaozhou bay from the south of the bay mouth to the center of the bay, the Pb content in the surface layer was from low to high in May, October and August, and the seasonal changes were as follows: spring, autumn and summer. The content and the seasonal changes of Pb in the bottom layer were the same. In other words, the content of Pb in the surface

layer was relatively low while that in the bottom layer was relatively low. When the Pb content in the surface layer was high, that in the bottom layer was high. The content of Pb in the surface layer was relatively high while that in the bottom layer was relatively high. It shows that in May, August and October, the loss of Pb content from surface layer to bottom layer was relatively large.

In May and August, in the water body from the southeast to the center of Jiaozhou bay, the horizontal distribution trend of Pb in the surface layer was reverse to that in the bottom layer. Nonetheless in October, the horizontal distribution trend of Pb in the surface layer was in accordance with that of the bottom layer in the water body.

From May to October, in the water body in the southeast of Jiaozhou bay, the Pb content of surface layer was from low to high in spring, autumn and summer; that of the bottom layer was from low to high in autumn, spring, summer, and that carried by open ocean current was from low to high in autumn, spring and summer. So the seasonal variation of Pb content in the bottom layer was mainly determined by that of Pb content transported by the ocean current.

From May to October, in the water in the center of Jiaozhou bay, the Pb content of surface layer changed from low to high in summer, spring and autumn; that of the bottom layer changed from low to high in spring, autumn and summer, that of sea current delivery from low to high was in autumn, spring and summer. It shows that in the central waters of Jiaozhou bay, the seasonal variation of Pb content in the bottom layer is different from that in the surface layer and that in the ocean current.

On the temporal scale, in the waters from the south of the bay mouth to the center of Jiaozhou bay, in May, August and October, the Pb content in the surface layer and the bottom layer changed in the same range. The rapid and continuous deposition of Pb content to the seabed was demonstrated. As a result, the changes of Pb content in the surface layer and the bottom layer were consistent.

On the spatial scale, in May, the deposition of Pb content in the waters in the southeast of Jiaozhou bay was higher than that in the waters in the center of the bay. But in August and October, the deposition of Pb content in the southeastern waters of Jiaozhou bay was lower than that in the central waters of the bay. In the water body of Jiaozhou bay from the southeast to the center, in May and August, according to the high content and increasing trend of Pb transported by the ocean current, the horizontal distribution trend of Pb in the surface layer was opposite to that in the bottom layer. However, in October, because the Pb content delivered by the ocean current was relatively low and decreased, the horizontal distribution of Pb in the surface layer was consistent with that in the bottom layer.

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