Calculation of Loss Amount from Southeast Bay to Southwest Bay

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Abstract: Applying investigation data about Pb in Jiaozhou Bay in August, 1992 and according to horizontal matter content change model and the vertical matter content change model proposed by the authors, the horizontal loss amount, vertical diluted amount and vertical sediment amount of Pb content in the surface and bottom layers from southeast bay to southwest bay are calculated. What’s more, the model diagram of vertical change and horizontal change of Pb content is designed. The calculation results show that in August in 1992, the absolutely loss amount of Pb content in the bottom layer was 11.03μg/L, and the relative loss amount of Pb content in the bottom layer was 58.42%. Meanwhile, the absolutely increase amount of Pb content in the surface layer was 4.60μg/L, and the relatively increase amount of Pb content in the surface layer was 28.93%. In the southeast bay, the relatively vertical sediment amount of Pb content in the surface and bottom layers was 40.14%, and the absolutely vertical sediment amount of Pb content in the surface and bottom layers was 7.58μg/L. Similarly, in the southwest bay, Pb content in the surface layer and bottom layer had an absolutely vertical diluted amount of 8.05μg/L with a relatively vertical diluted amount of 50.62%. In August, the main sea current carried Pb content through the surface nearshore waters around the bay where many sources of Pb content existed. The law of horizontal loss amount shows that: when Pb content migrated horizontally in the surface layer, Pb content did not lose but increased. However, when Pb content migrated horizontally in the bottom layer, a lot of Pb content was lost due to a long distance. Moreover, the law of the vertical loss amount revealed that Pb content was transported by the main sea current and was relatively high in its vertical migration process. As a result, the vertical sediment amount 40.14% of Pb content in surface and bottom layers was changed to the vertical diluted amount 50.62% of Pb content in the surface and bottom layers when the main sea current flowed from southeast bay waters to southwest bay waters.

1. Introduction

Human beings continuously discharge lead (Pb) content into the Marine environment, which leads to Pb pollution in open seas and offshore waters. After Pb content reaches the surface of seawater, with the migration of ocean currents, the Pb content in surface water migrates from one water surface to another. When it migrates vertically, it sinks to the seabed [1-6]. As a result, using the horizontal and vertical matter content change model proposed by the authors, combined with survey data, the horizontal migration process and vertical sediment process of Pb content in Jiaozhou Bay were demonstrated, and the pollution process and pollution degree of Pb content polluted by main sea current were explained, which provides a scientific basis for studying the vertical sediment and horizontal migration of Pb content in surface and bottom waters.
2. Waters, Materials and Methods

2.1 Natural Environment in Jiaozhou Bay. Jiaozhou Bay is located in the south of Shandong Peninsula, Shandong Province, China. It is bounded by the connecting line between Tuan Island and Xuejia Island and connected with the Yellow Sea. Jiaozhou Bay has a narrow mouth and wide interior, with a width of 15 nautical miles from east to west and a length of 18 nautical miles from south to north (at low tide), covering an area of about 446km². It is a typical semi-enclosed bay. The natural deep-water channel has a water depth of about 10-15m, without sediment deposition and generally without freezing in winter [7, 8].

2.2 Materials and Methods. The Pb survey data of Jiaozhou Bay in August 1992 used in this study are contributed by North China Sea Environmental Monitoring Center, SOA. In August, water samples were collected at two sites in Jiaozhou Bay: site 60 and site 54 (Figure 1). Sampling was conducted once in August 1992, and the water samples were got on the basis of the water depth (samples of the surface layer and bottom layer were got when depth was more than 10m; sample of only the surface layer was got when depth was less than 10m). According to the national standard method included in Specification for Marine Monitoring (1991) [9], the PHC in Jiaozhou Bay was investigated.

3. Results

3.1 Waters from Southeast Bay to Southwest Bay. The main sea current entered Jiaozhou Bay with high Pb content from outside the bay through the bay mouth. It flowed around the inshore waters of the bay.

In August, in the southeast waters of Jiaozhou Bay, the site is 60. In the southwest of Jiaozhou Bay, the site is 54. In the surface water, the main sea current entered Jiaozhou Bay through the southern waters of bay mouth and reached site 60, with a Pb content of 11.30μg/L. Then the main sea current surrounded the coastal waters of Jiaozhou Bay and reached site 54, with a Pb content of 15.90μg/L. In a similar way, in the bottom waters, the main sea current entered the bay through the southern waters of the bay mouth and reached site 60. The highest Pb content was 18.88μg/L, and then the main sea current circled around the offshore waters and arrived at site 54, with a Pb content of 7.85μg/L.

3.2 Definitions of Changes of Horizontal Matter Content. In Jiaozhou Bay, the current carried the matter content, and the matter content decreased with the current movement. Based on the definitions and formulas proposed by the authors, the horizontal loss amount, vertical diluted amount and vertical
sediment amount of matter content are calculated. The horizontal loss amount can be divided into absolutely horizontal loss amount and relatively horizontal loss amount. Vertical diluted and sediment amounts can be divided into absolutely vertical diluted and sediment amounts and relatively vertical diluted and sediment amounts.

3.3 Formulas of Vertical Matter Content Changes. In the surface water of Jiaozhou Bay from southeast to southwest, it is assumed that the matter (M) content in southeast waters is regarded as A and that in southwest waters is regarded as B. The absolutely horizontal loss amount of matter content is \( D > 0 \), and the relatively horizontal loss amount is \( E \). If \( D < 0 \), the absolutely horizontal loss amount of matter content from the southwest bay waters to the southeast bay waters is \(-D > 0\).

\[
D = A - B, \quad E = \frac{|A - B|}{\max(A, B)} \quad (1)
\]

Likewise, in the bottom waters of Jiaozhou Bay, the matter content in the southeast and that in the southwest are assumed to be a and b. The absolutely horizontal loss amount is \( d > 0 \), and the relatively horizontal loss amount is \( e \). If \( d < 0 \), it means that the absolutely horizontal loss amount is \(-d > 0\) from the southwest waters of the bay to the southeast waters of the bay.

\[
d = a - b, \quad e = \frac{|a - b|}{\max(a, b)} \quad (2)
\]

3.4 Formula of Vertical Matter Content Change. In the waters from southeast to southwest of Jiaozhou Bay, it is assumed that the matter content in the surface layer of southeast bay is regarded as A, the matter content in the bottom layer is regarded as a, and the water site is n. From the surface waters to the bottom waters, the absolutely vertical diluted amount of matter content appears \( V_{na} > 0 \), and the relatively vertical sediment amount of matter content is regarded as \(-V_{na} > 0\), and if \( V_{na} < 0 \), then the relatively vertical sediment amount of matter content is regarded as \( V_{nr} \).

\[
V_{na} = A - a, \quad V_{nr} = \frac{|A - a|}{\max(A, a)} \quad (3)
\]

3.5 Horizontal Loss Amount of Surface Layer and Bottom Layer. It is assumed that from site 60 in southeast bay waters to site 54 in southwest bay waters are abbreviated as from A to B, and the main matter content is Pb content. Through the horizontal changes of Pb content, the horizontal loss amounts of Pb content in surface layer and bottom layer are revealed.

In August, the surface water of Jiaozhou Bay went from A to B, and passed through the nearshore waters of the bay. The Pb content in the surface layer changed greatly, and the horizontal loss amount of Pb content in the surface layer is calculated by formula (1) (Table 1).

| From A to B | D   | E       | E        |
|------------|-----|---------|----------|
| August     | -4.60 | 0.2893 | 28.93%   |

Meanwhile, the bottom water in Jiaozhou Bay went from A to B, passing through the coastal waters of the bay, and there have also been great changes in the Pb content in the bottom layer. The horizontal loss amount of Pb content in the bottom layer was calculated by formula (2) (Table 2).

| From A to B | d   | e       | e        |
|------------|-----|---------|----------|
| August     | 11.03 | 0.5842 | 58.42%   |

3.6 Vertical Diluted and Sediment Amounts. Pb content was the main matter content. Through the vertical change of Pb content, the vertical diluted and sediment amounts of Pb content in the surface and bottom layers were revealed.

In August, in Jiaozhou Bay, from the southeast to the southwest of the bay, from the surface to the bottom, Pb content in the surface and bottom layers of the water body changed significantly. The vertical
diluted and sediment amounts of Pb content in the surface and bottom layers are calculated by formula (3) (Table 3).

| Time      | Water                     | Vna  | Vnr     | Vnr%  |
|-----------|----------------------------|------|---------|-------|
| August    | Waters of southeastern bay | -7.58| 0.4014  | 40.14%|
|           | Waters of southwestern bay | 8.05 | 0.5062  | 50.62%|

**4. Discussion**

**4.1 Changes of Matter Content in Current of Bay.** Jiaozhou Bay is a shallow bay, which is generally dustpan-shaped, inclines linearly in the bay mouth area and turns to tilt eastward. Its water depth is shallow in northwest and deep in southeast. The main sea current entered Jiaozhou Bay with high Pb content from outside Jiaozhou Bay through the bay mouth. The current followed along the coastal waters in the northeast of the bay to the bayhead waters in the northeast of the bay and reached the estuary waters of Loushan River. Then it turned west and crossed the coastal waters in the north of the bay. After that, it reached the westernmost waters in the northwest of the bay — the estuary waters of Dagu River, and then turned to the south, along the nearshore waters in the west of the bay, and reached the bay mouth waters (Figure 2). Therefore, the main sea current entered Jiaozhou Bay with high content of Pb, and surrounded a circle of nearshore waters in the bay.

![Figure 2 Current trajectory of high Pb content carried by the main sea current in Jiaozhou Bay (μg/L)](image-url)

In the process of matter content migration, matter content has changed. In Jiaozhou Bay waters, in August, Pb content transported by the main sea current was 37.53μg/L. The main sea current entered the bay waters and flowed through site 60 in the southeast of the bay and site 54 in the southwest of the bay. According to the principle of matter vertical water body effect, matter horizontal water body effect and water body effect proposed by the authors [11-13], the horizontal change of matter content reveals the loss effect of horizontal water body, while the change of matter content in the surface layer and bottom layer reveals the cumulative effect and dilution effect of vertical water body. Therefore, the horizontal and vertical migration processes of Pb content in the waters from southeast bay to southwest bay are quantitatively studied through the horizontal and vertical matter content change models put forward by the authors.

**4.2 Horizontal and Vertical Variations of Pb Content.** On the spatial scale, in the surface water of southeast Jiaozhou Bay, the Pb content transported by the main sea current in August was 37.53μg/L. In Jiaozhou Bay, under the action of tides and currents in the bay, Pb content showed a gradient downward...
trend. However, when the current flowed around the coastal waters of the bay from the southeast to the southwest, Pb content did not decrease but increased. This suggests that in the nearshore waters, there were a lot of sources providing Pb content for nearshore currents: Pb content 13.91μg/L from ships and terminals transport, Pb content 20.61μg/L of Haibo river, Pb content 26.21μg/L from Licun River transportation, Pb content 26.92μg/L from Loushan river transportation, and Pb content 26.81μg/L of Dagu River transportation.

In August, the horizontal increase amount of Pb content in the surface layer was high 28.93% from the southeast waters of the bay through the coastal waters of the bay to the southwest waters of the bay. But the horizontal loss amount of Pb content in the bottom layer reached a high 58.42% (Figure 3). The vertical sediment amount of Pb content was high 40.14% in the surface layer and bottom layer in southeast bay, while the vertical diluted amount of Pb content in the surface layer and bottom layer in southwest bay was high 50.62% (Figure 3).

So in August, the absolutely horizontal increase amount of Pb content in the surface layer was 4.60μg/L and the relatively horizontal increase amount was 28.93%. The absolutely horizontal loss amount of Pb content in the bottom layer was 11.03μg/L, and the relatively horizontal loss amount was 58.42%. Besides, in the southeast bay, the absolutely vertical sediment amount of Pb content was 7.58μg/L, and the relatively vertical sediment amount was 40.14%. The absolutely vertical diluted amount of Pb content in the surface and bottom layers was 8.05μg/L, and the relatively vertical diluted amount was 50.62%.

4.3 Horizontal Loss Amount. In August, the horizontal increase amount of Pb content in the surface layer from the southeast waters through the southeast coastal waters to the southwest waters was high 28.93% (Table 1). Thus, there were many sources of Pb content here. Whereupon the horizontal migration of Pb content in the surface layer not only made up for the loss of Pb content in the surface layer, but also led to an increase of that when the current reached the waters of southwest bay.

Meanwhile, from the coastal waters in the southeast of the bay to those in the southwest of the bay, the horizontal loss amount of Pb content in the bottom layer reached a relatively high level of 58.42% (Table 2). It indicates that a large amount of Pb content in the bottom layer has settled to the seabed here. In the process of horizontal migration of Pb content in the bottom layer, a great deal of loss of Pb content in the bottom layer was caused after a long journey.

Judging from these, in August, in the surface water, the main sea current carried Pb content through a circle of the nearshore waters in the bay where many sources of Pb content are provided. Thus, the horizontal migration process of Pb content in the surface layer not only made up for the loss of it, but also increased it. However, in the process of horizontal migration of Pb content in the bottom layer, due to the long distance, the loss of Pb content in the bottom layer was great.
4.4 Vertical Loss Amount. In August, Pb content transported by the main sea current in Jiaozhou Bay was 37.53μg/L. The main sea current first entered the surface waters of the southeast bay, then passed through the nearshore waters of the bay and reached the waters of the southwest bay. In the southeast sea area of the bay, the vertical sediment amount of Pb content in the surface layer and bottom layer was relatively high, accounting for 40.14%. In the southwest waters of the bay, the vertical diluted amount of Pb content in the surface and bottom layers reached 50.62%. It shows that the high Pb content transported by the main sea currents reached the southeast sea area of the bay first, and the high Pb content in the surface layer could rapidly and continuously settle to the seabed, with a high sediment amount 40.14%. Then, the main sea current crossed a circle of the nearshore waters of the bay and reached the waters southwest of the bay. There was no sediment on the seabed, but there was a relatively high diluted amount 50.62%, indicating that the high Pb content in the surface layer was still deposited in large quantities.

Put simply, in August, in the process of vertical migration, the Pb content transported by the main sea current was relatively high. From southeast waters to southwest waters, the vertical sediment amount of Pb content in the surface and bottom layers 40.14% was transformed to the vertical diluted amount of Pb content in the surface and bottom layers 50.62%.

5. Conclusion
According to the horizontal and vertical matter content change models proposed by the authors, the horizontal loss amount, vertical diluted amount and vertical sediment amount of Pb content in surface and bottom layers are calculated, and the model block diagram of horizontal and vertical changes of Pb content is determined.

In August, the absolutely increase amount of Pb content in the surface layer was 4.60μg/L, and the relatively increase amount of Pb content was 28.93%. The absolutely loss amount of Pb content in the bottom layer was 11.03μg/L, and the relatively loss amount of Pb content was 58.42%. Besides, in the southeast bay, the absolutely vertical sediment amount of Pb content was 7.58μg/L, and the relatively vertical sediment amount was 40.14%. The absolutely vertical diluted amount and the relatively vertical diluted amount of Pb content in both surface layer and bottom layer was 8.05μg/L and 50.62% respectively in the southwest bay.

In the meantime, in the surface water, the main sea current carried Pb content through the inshore waters within a circle, and there were many sources of Pb content here. Thus, in the process of horizontal migration of the Pb content in the surface layer, not only the loss of Pb content in the surface layer was compensated, but also the Pb content in the surface layer was increased. While in the process of horizontal migration of Pb content in the bottom layer, the loss of Pb content in the bottom layer was great due to the long distance.

At the same time, the vertical sediment amount of Pb content in the surface and bottom layers was high 40.14% in the waters of southeast Bay. In the southwest waters of the bay, the vertical diluted amount of Pb content in the surface and bottom waters was relatively high, which was 50.62%. It reveals that the high Pb content transported by the main sea current reached the southeast waters of the bay first, and the high content Pb in the surface layer could settle rapidly and continuously to the seabed, where a relatively high sediment amount of 40.14% was obtained. Then, the main sea current passed through a circle of the nearshore waters of the bay and reached the waters in the southwest of the bay. There was no deposition at the seabed, but there was a relatively high diluted amount of 50.62%, which indicates that the high Pb content in the surface layer was still settling in large quantities.

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