Dynamic Migration Process of Cd to the Bay Center

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Abstract: Based on the horizontal and vertical matter content changing models proposed by the author himself, this article calculates the horizontal loss amount, vertical disputed amount and vertical sediment amount, and determines the block diagram of horizontal and vertical Cd content changing model, applying the investigation matters about the Cd content of Jiaozhou Bay in May, August, and October, 1992. The calculation results show that the variation range of absolutely horizontal loss amount of Cd content in the bottom layer is 0.63-0.82μg/L and the variation range of relatively horizontal loss amount is 68.90-87.50% in May and October. In August, the absolutely horizontal increase amount and relatively horizontal increase amount of Cd content in the bottom layer are 0.94μg/L and 87.03%, respectively. The Cd content in the surface and bottom layer of southeast waters in August all have the absolutely vertical disputed amount 0.61μg/L and relatively vertical disputed amount 81.33%. The Cd content in the surface and bottom layer of southeast waters in May and October have the absolutely vertical sediment amount within 0.49-0.68μg/L and relatively vertical sediment amount within 57.14-68.05%. In the center of the bay, the Cd content in the surface and bottom layer in August have the absolutely vertical sediment amount 0.96μg/L and relatively vertical sediment amount 88.88%. In May and October, the absolutely vertical disputed amount and relatively vertical disputed amount of Cd content in the surface and bottom layer of bay center are 0.35-0.52μg/L and 58.42-79.54%, respectively.

1. Introduction
The offshore currents enter Jiaozhou Bay with low content of cadmium (Cd). After entering the bay, the currents circle the nearshore waters in the bay, and then leave the inner waters. When the ocean currents enter the bay, rivers, offshore ocean currents and surface runoff transport a large amount of Cd content to Jiaozhou Bay [1-6]. Therefore, applying the horizontal matter content changing model and vertical matter content changing model proposed by the author, based on the survey data of the Cd content of Jiaozhou Bay in May, August and October 1992.

2. Survey waters and methods
2.1 The natural environment of Jiaozhou Bay. The location of Jiaozhou Bay is in the southern part of Shandong Peninsula, between 120°04'-120°23'E and 35°58'-36°18'N. There are more than a dozen rivers entering the sea in Jiaozhou Bay, among which the Dagu River, Yang River and the Haibo River, Licun River and Loushan River in Qingdao City with larger runoff and sand content [7, 8].

2.2 Methods. The survey data of Cd content in Jiaozhou Bay in May, August and October 1992 used in this study are contributed to the North Sea Monitoring Center of the State Oceanic Administration.
In May, August and October, two stations were set up in the waters of Jiaozhou Bay to get water samples: stations 55 and 60 (Figure 1). Sampling was conducted three times in May, August and October 1992, respectively. Water samples were taken according to the water depth (surface and bottom layers were taken when the depth >10m, and only the surface layer was taken when the depth <10m) for investigation and sampling. The survey of Cd content in Jiaozhou Bay water body was carried out according to the national standard method, which was recorded in the national “Marine Monitoring Code” (1991) [9].

Fig. 1 Investigation sites in Jiaozhou Bay

3. Results and Discussions

3.1 Ocean currents passing through southeast waters of Jiaozhou Bay. The offshore currents enter the Jiaozhou Bay with high content of Cd, and pass the bay mouth to the inner of the bay. In addition, the ocean currents circle the nearshore waters in the bay, then leave the inner of Jiaozhou Bay and reach the western waters of the bay mouth (Figure 2).

Fig. 2 The flow trajectory of offshore ocean currents carrying high-content of Cd in Jiaozhou Bay (μg/L)

In May, August and October, in the surface layer of southeast waters of Jiaozhou Bay, where the station is 60, offshore currents pass through the mouth waters of Jiaozhou Bay from outside waters to the inner waters, and then reach the southeast waters of Jiaozhou Bay. The offshore currents affect the southeast surface waters of Jiaozhou Bay.
In May, August and October, the offshore currents around the nearshore waters in the bay have not affected the surface water in the center of Jiaozhou Bay.

In May, August and October, ocean currents carry matter content and reach the surface layer of southeast waters. Then, in the southeast waters of the bay, the matter content has been deposited from surface layer to the bottom. Then, under the action of gravity and tidal currents, the Cd content that continues to sink to the seabed gradually migrates to the central bottom of the bay along the nearshore seabed (Figure 3). As the bottom layer of the center of the bay continues to accumulate, the matter content rises to the surface layer of the center of the bay.

![Fig. 3 The depth and topography of Jiaozhou Bay (m)](image)

Therefore, the matter content changing model proposed by the author can be used to calculate the vertical sediment amount in the two waters and the horizontal changing amount in the bottom layer between two waters.

3.2 *The definition of horizontal matter content variation.* In Jiaozhou Bay, ocean currents carry matter content, and with the movement of ocean currents, the matter content continues to decrease [10]. Then, through water exchange, according to the definitions and formulas proposed by the author, the horizontal loss amount, vertical disputed amount and vertical sediment amount of the substance content can be calculated. The horizontal loss amount of matter content is divided into absolutely horizontal loss amount and relatively horizontal loss amount. The vertical disputed amount and vertical sediment amount of matter content are divided into absolutely vertical disputed and sediment amounts and relatively vertical disputed and sediment amounts.

3.3 *The definition and formula of horizontal matter content variation.* In the surface layer from southeast waters to the center waters of Jiaozhou Bay, it is assumed that the matter (M) content in the southeast of the bay is A and the matter content in the central waters of the bay is B.

From the southeast waters to the central waters of the bay, the absolutely horizontal loss amount is D>0, and the relatively horizontal loss amount is E. When D<0, it means that absolutely horizontal loss amount is -D>0, from the central waters to the southeast waters of the bay.

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

Assuming that in the bottom waters of Jiaozhou Bay from southeast to the center, the matter
content in the southeast waters is a and the matter content in the center waters is b. From the southeast waters to the central waters of the bay, the absolutely horizontal loss amount is \(d\geq 0\), and the relatively horizontal loss amount is \(e\). When \(d < 0\), it means that from the central waters to the southeast waters of the bay, the absolutely horizontal loss amount is \(-d\geq 0\).

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

### 3.4 The definition and formula of vertical matter content variation

From the southeast waters to the central waters of Jiaozhou Bay, suppose that the matter content in the surface layer of southeast waters of the bay is A, and the matter content in the bottom layer is a. Assuming the location of the water area is n, from the surface waters to the bottom, the absolutely vertical disputed amount is \(V_{na}\geq 0\), and the relatively vertical disputed amount is \(V_{nr}\). When \(V_{na} < 0\), it means the absolutely vertical sediment amount of matter content is \(-V_{na}\geq 0\). When \(V_{na} < 0\), the relatively vertical sediment amount is \(V_{nr}\).

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

### 3.5 Horizontal loss amount in the surface and bottom waters

Assume that from station 60 in the southeast waters to the station 55 in the central waters simply means from A to B. The matter content is mainly Cd content. The horizontal change of Cd content reveals the horizontal loss amount of Cd content in the surface and bottom layers.

According to the trajectory of ocean currents, it is necessary to calculate the horizontal loss amount of Cd content in the bottom layer.

In May, August and October, in the bottom water of Jiaozhou Bay from the southeast to the center, the Cd content has changed a lot [10]. Through formula (2), the horizontal loss amount of Cd content in the bottom layer can be calculated (Table 1).

| From A to B | d   | e   | e    |
|------------|-----|-----|------|
| May        | 0.63| 0.8750| 87.50% |
| August     | -0.94| 0.8703| 87.03% |
| October    | 0.82| 0.6890| 68.90% |

### 3.6 Vertical disputed amount & vertical sediment amount

The matter content is mainly Cd content. The vertical change of Cd content reveals the vertical disputed amount and vertical sediment amount of Cd content in the surface and bottom layers.

In May, August and October, in the waters from southeast to the center of Jiaozhou Bay, the Cd content has undergone great changes from the surface to the bottom [10]. Through formula (3), the vertical disputed amount and vertical sediment amount of Cd content in the bottom layer can be calculated (Table 2).

| Time  | Water Area        | Vna   | Vnr   | Vnr  |
|-------|-------------------|-------|-------|------|
| May   | Southeast waters of the bay | -0.49 | 0.6805| 68.05% |
|       | Central waters of the bay | 0.35  | 0.7954| 79.54% |
| August| Southeast waters of the bay | 0.61  | 0.8133| 81.33% |
|       | Central waters of the bay | -0.96 | 0.8888| 88.88% |
| October| Southeast waters of the bay | -0.68 | 0.5714| 57.14% |
|       | Central waters of the bay | 0.52  | 0.5842| 58.42% |

### 3.7 Matter content variation

In May, the offshore ocean currents carry the Cd content around the coastal waters in the bay. After passing through the southeast waters of the bay, there is a large amount...
of Cd sedimentation. It does not affect the surface water in the center of Jiaozhou Bay, nor does it affect the bottom water in the same water area (Figure 4).

Fig. 4 The offshore currents in Jiaozhou Bay carrying high matter content

From May to August, the offshore ocean currents continue to carry the Cd content to the coastal waters surrounding the bay, and do not affect the surface waters in the center of Jiaozhou Bay. However, in the bottom layer from the southeast of the bay to the bay center, with the horizontal migration of Cd content, it has a huge impact on the bottom water body in the center of Jiaozhou Bay (Figure 5).

Fig. 5 The subsidence with high matter content carried by the offshore ocean currents in Jiaozhou Bay

From August to October, the offshore ocean currents begin to drastically reduce the Cd content carried by them. Because the offshore ocean currents surround the coastal waters of Jiaozhou Bay, it does not affect the surface water in the center of Jiaozhou Bay. However, the surface water in the center of Jiaozhou Bay is affected by the bottom waters with a large amount of Cd content (Figure 6).
Fig. 6 The subsidence and rise with high matter content carried by the offshore ocean currents in Jiaozhou Bay

The offshore ocean currents surround a circle of nearshore waters in the bay, and select a certain water area in the circle of nearshore waters as the representative. Then, the southeast waters of the bay are selected as the representative here, which reveals the Cd content of the nearshore waters has migrated to the central waters of the bay. According to the matter vertical water effect principle, matter horizontal water effect principle and water body effect principle proposed by the author himself [10], quantitatively study the horizontal and vertical migration process of Cd content in the waters from southeast to the central waters applying the horizontal and vertical matter content changing models.

4. Conclusion

According to the horizontal matter content changing model and the vertical matter content changing model proposed by the author, this paper calculates the horizontal loss amount, vertical disputed amount and vertical sediment amount of Cd content in the surface and bottom layers, and determines the block diagram of horizontal and vertical Cd content changing model.

In the waters from southeast of the bay to the center, the absolutely horizontal loss amount of Cd content in the bottom layer varies from 0.63 to 0.82μg/L in May and October, and the relatively horizontal loss amount varies from 68.90% to 87.50%. In August, the absolutely horizontal increase amount of Cd content in the bottom layer is 0.94μg/L, and the relatively horizontal increase amount of Cd content in the bottom layer is 87.03%.

In the southeast waters of the bay, the absolutely vertical disputed amount of Cd content in the surface and bottom layers is 0.61μg/L in August, and the relatively vertical disputed amount is 81.33%. In May and October, the Cd content in the surface and bottom layers has an absolutely vertical sediment amount of 0.49-0.68μg/L, and relatively vertical sediment amount within 57.14-68.05%.

In the central waters of the bay, the absolutely vertical sediment amount of Cd content in the surface and bottom layers is 0.96μg/L, and its relatively vertical sediment amount is 88.88%. In May and October, the absolutely vertical disputed amount of Cd content in the surface and bottom layers is within 0.35-0.52μg/L, and its relatively vertical disputed amount ranges within 58.42-79.54%.

The calculation results of the horizontal loss amount and horizontal increase amount of the Cd content in the bottom layer show that whether the horizontal loss amount or the horizontal increase amount of the Cd content, migrating from the bottom waters in the southeast of the bay to the seabed and then to the bay center, is very high, reaching 68.90-87.50%, which indicating that the horizontal migration of Cd content in the bottom layer is rapid and large.
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