

Spatial-Temporal Migration of Cd in Marine Bay

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Abstract. This paper quantified the spatial-temporal migration processes of Cadmium (Cd) in Jiaozhou Bay in 1989. Results showed that the horizontal losses of Cd in surface and waters in April 1989 were 37.50% and 16.66%, respectively. The vertical dilution of Cd in the bay center in July 1989 was relatively high i.e. 50.00%. Cd contents in both the surface and bottom waters were decreasing in a certain degree during the horizontal and vertical migration processes. No matter whether it is from the bay center to the bay mouth, or from the bay mouth to the bay centers, Cd contents were decreasing in a certain degree. In case of the rate of loss of Cd in the surface water was relatively high, and the rate of loss of Cd in the bottom water would also be relatively high and vice versa. In April 1989, Cd in the surface waters could be transported to the bottom of sea rapidly and continuously, and the vertical loss of Cd could be as high as 1/3 during the vertical migration process. Furthermore, in July 1989, the vertical loss of Cd was as high as 50.00%, where the vertical losses in Jiaozhou Bay were increasing from 1/3 in April to 1/2 in July. The vertical losses in Jiaozhou Bay were increasing along with an increase in the content of Cd in the surface waters.

1. Introduction

Cd is widely used in the industries [1-2]. In the past several decades, the industries in many countries and regions are increasing rapidly [3-8]. As a result, a large amount of Cd-containing wastes are generated and discharged to the environment [9-10]. However, the treatment of wastes in many countries and regions is always lagging, resulting in pollution of Cd in many marine bays [11-15]. Hence, understanding the spatial-temporal migration processes of Cd in marine bay is essential to the environmental protection and remediation [16-20].

Jiaozhou Bay is a semi-closed bay located in Shandong Province, China [21-25]. This bay had been polluted by various pollutants since 1980s due to the rapid development of industries [26-32]. Using the investigation on Cd in surface and bottom waters in 1989 in Jiaozhou Bay, this study examined the horizontal and vertical distributions, and quantified the spatial-temporal migration processes. This investigation provides a basis for research on the vertical sedimentation and horizontal migration of Cd in marine bay.



2. Materials and methods

2.1. Study area and data collection. Jiaozhou Bay is located in the south of Shandong Province, eastern China (35°55'-36°18' N, 120°04'-120°23' E). The total area and average water depth are 446 km² and 7 m, respectively. The bay mouth is very narrow (3 km), and is connected to the Yellow Sea in the south. There are a dozen of rivers including Dagu River, Haibo River, Licun River, Loushan River, etc. all of which are seasonal rivers [33-34].

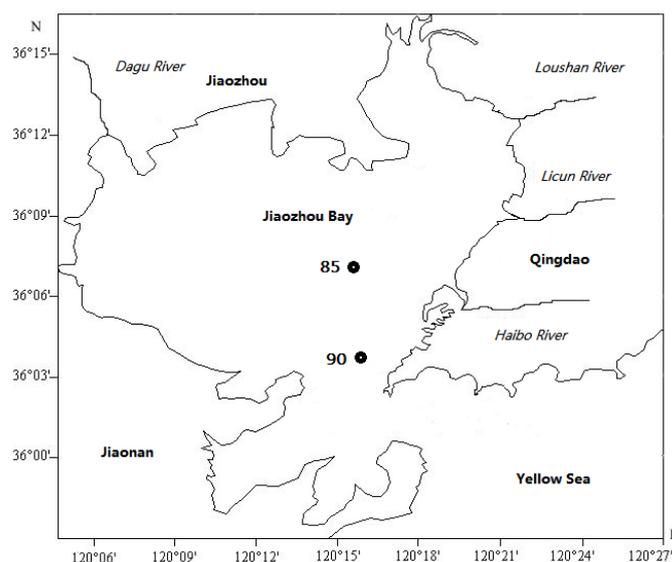


Fig. 1 Geographic location and monitoring sites in Jiaozhou Bay

The investigation on Cd in Jiaozhou Bay was carried out by North China Sea Environmental Monitoring Center. In April and July 1989, Cd contents in the surface and bottom waters were measured in Site 85 and Site 90 in the bay center and in the bay mouth, respectively (Fig. 1). Cd in the waters was sampled and monitored following the National Specification for Marine Monitoring [35].

2.2. Modelling for horizontal migration processes of Cd: Considering that the Cd contents in the surface and bottom waters in the bay center are A and a , and in the bay mouth are B and b , respectively. In surface waters, and from the bay center to the bay mouth, the migration could be calculated as follows:

$$D=A-B, \quad E=(100 \times |A-B| / \max(A, B))\% \quad (1)$$

where, D is the horizontal absolute loss amount in the surface waters, and E is the horizontal relative loss amount.

In bottom waters, and from the bay center to the bay mouth, the migration could be calculated as follows:

$$d=a-b, \quad e=(100 \times |a-b| / \max(a, b))\% \quad (2)$$

where, d is the horizontal absolute loss amount in the bottom waters from the bay center to the bay mouth, and e is the horizontal relative loss amount.

2.3. Modelling for vertical migration processes of Cd: Considering that the Cd contents in the surface and bottom waters in Site n in the bay center are A and a , respectively. From the surface waters to

bottom waters, the migration could be calculated as follows:

$$V_{na}=A-a, \quad V_{nr}=(100 \times |A-a| / \max(A, a))\% \quad (3)$$

where, V_{na} is the horizontal absolute dilution amount from the surface waters to bottom waters, V_{nr} is the horizontal relative dilution amount. While from the bottom waters to surface waters, V_{na} refers to the horizontal absolute accumulation amount, and V_{nr} refers to the horizontal relative accumulation amount.

3. Results

3.1. Horizontal changes of Cd: The horizontal migration process of Cd in the surface waters was calculated according to the contents of Cd in Site 85 and Site 90. The horizontal losses of Cd in the surface and bottom waters were calculated by Eq. (1) and Eq. (2), respectively. It could be seen from Table 1 that the horizontal absolute loss amounts of Cd were -0.030 - $0.010 \mu\text{g L}^{-1}$, and the horizontal relative loss amounts were 37.50%-16.66%.

Table 1 Horizontal changes in the content of Cd in the surface and bottom waters in Jiaozhou Bay during 1989

Month	Surface waters		Bottom waters	
	$D/\mu\text{g L}^{-1}$	$E/\%$	$d/\mu\text{g L}^{-1}$	$e/\%$
April	-0.030	37.50	0.010	16.66

3.2. Vertical loss of Cd: The vertical migration processes of Cd were calculated by Eq. (3) and the results are listed in Table 2. It could be seen from Table 2 that the vertical absolute dilution amounts of Cd were 0.002 - $0.037 \mu\text{g L}^{-1}$, and the horizontal relative dilution amounts were 2.85%-41.66%. The vertical absolute accumulation amounts of Cd were $0.007 \mu\text{g L}^{-1}$, and the vertical relative accumulation amounts were 58.33%.

Table 2 Vertical changes in the content of Cd in waters in Jiaozhou Bay during 1989

Time	Location	$V_{na}/\mu\text{g L}^{-1}$	$V_{nr}/\%$
April	Bay center	-0.01	16.66
	Bay mouth	0.03	37.50
July	Bay center	0.06	50.00

4. Discussion

4.1. Horizontal and vertical changes of Cd: In the internal waters of Jiaozhou Bay, Cd was mainly sourced from river runoff, and Cd contents were decreasing from the high value region to peripheral zones by means of marine current and tide. In April 1989, along with the flow direction of marine current from the bay mouth to the bay center, the horizontal losses of Cd in surface and waters were 37.50% and 16.66%, respectively (Fig. 2). Hence, the vertical accumulation of Cd in the bay center was relatively low, 16.66%, while the vertical dilution of Cd in the bay mouth was relatively high, 37.50% (Fig. 2). In July 1989, the vertical dilution of Cd in the bay center was relatively high as 50.00%. In general, Cd contents in both the surface and bottom waters were decreasing in a certain degree during the horizontal and vertical migration processes.

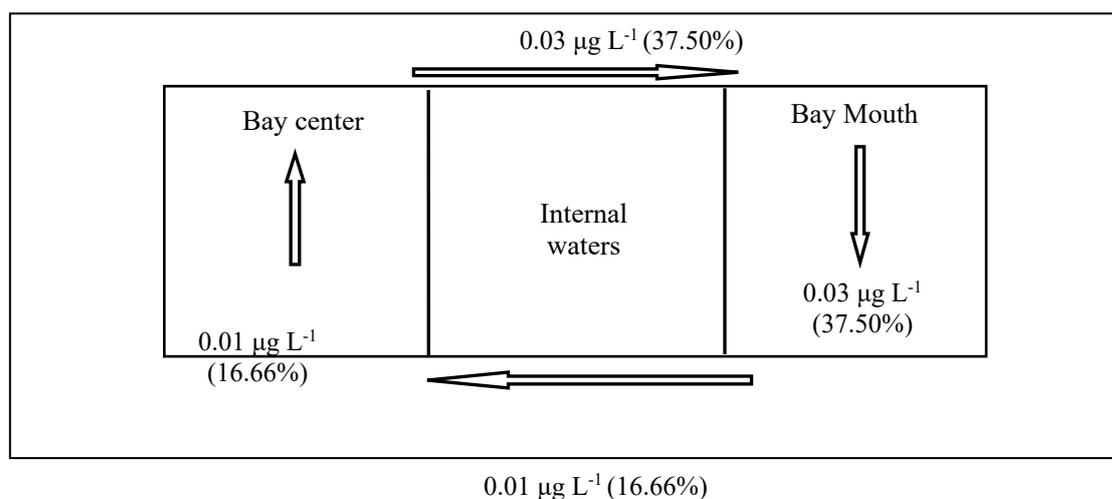


Fig. 2 Block diagram model for horizontal-vertical changes in the content of Cd in Jiaozhou Bay in April 1989

4.2. Horizontal loss of Cd: In April 1989, from the bay mouth to the bay center, the horizontal loss of Cd in the surface waters was relatively high i.e. 37.50%. Meanwhile, from the bay center to the bay mouth, the horizontal loss of Cr\Cd in the surface waters was also relatively high as 16.66%. In general, irrespective of whether it is from the bay center to the bay mouth, or from the bay mouth to the bay centers, Cd contents were decreasing in a certain degree. In case of the rate of loss of Cd in the surface water was relatively high, the rate of loss of Cd in the bottom water would also be relatively high, and vice versa.

4.3. Vertical loss of Cd: Cd contents were also changing significantly during the vertical migration process. In April 1989, Cd contents in the surface and bottom waters were relatively low as $0.05\text{-}0.08 \mu\text{g L}^{-1}$ and $0.05\text{-}0.06 \mu\text{g L}^{-1}$, respectively. In general, the Cd contents in both the surface and bottom waters in April 1989 were relatively low, yet the vertical losses of Cd in April were 16.66%-37.50%. This indicated that Cd in the surface waters could be transported to sea bottom rapidly and continuously, and the vertical loss of Cd could be as high as 1/3 during the vertical migration process. Furthermore, in July 1989, the vertical loss of Cd could be as high as, 50.00%. This indicated that along with time in year 1989 from April to July, the Cd contents in the surface waters were increasing, and the vertical migration processes were changing from vertical accumulation to vertical dilution. The vertical losses of Cd in Jiaozhou Bay were increasing along with an increase in the content of Cd in the surface waters from 1/3 in April to 1/2 in July.

5. Conclusions

In April 1989, the horizontal losses of Cd in the surface and bottom waters were 37.50% and 16.66%, respectively. In July 1989, the vertical dilution of Cd in the bay center was relatively high as, 50.00%. Cd contents in both the surface and bottom waters were decreasing in a certain degree during the horizontal and vertical migration processes. No matter from the bay center to the bay mouth, or from the bay mouth to the bay center, Cd contents were decreasing in a certain degree. In case of the rate of loss of Cd in the surface water was relatively high, the rate of loss of Cd in the bottom water would also be relatively high, and vice versa. Along with time in year 1989 from April to July, Cd contents in the surface waters were increasing, and the vertical migration processes were changing from vertical accumulation to vertical dilution. The vertical losses in Jiaozhou Bay were increasing along with an increase in the content of Cd in the surface waters from 1/3 in April to 1/2 in July.

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