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Spatial motion process of Cr in the bay mouth of Jiaozhou Bay

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Abstract. by the investigation of Chromium (Cr) dataset in waters around the bay mouth in Jiaozhou Bay in 1983, calculated were the absolute and relative horizontal loss, and vertical accumulation and dilution amounts, and identified the spatial motion processes. Results showed that the absolute and relative horizontal losses were 0.12-0.59 $\mu\text{g L}^{-1}$ and 7.69-93.93%, respectively. The absolute and relative vertical accumulation amounts were 0.14-0.86 $\mu\text{g L}^{-1}$ and 8.86-86.86%, while the absolute and relative vertical dilution amounts were 0.02-0.62 $\mu\text{g L}^{-1}$ and 2.17-80.00%, respectively. Cr was mainly sourced from river runoff and marine current, and was moving to the bay mouth from the inside of the bay mouth and the outside of the bay mouth, respectively. There were high sedimentation processes, and were forming high accumulation processes in bottom waters. Therefore, there were diffusion and sedimentation processes in waters in the inside of the bay mouth and the outside of the bay mouth. This spatial motion process, was named as Yang's Phenomenon.

1. Introduction

The industry and economy in China have been developing for many years, which induced the Cr pollutants in water, atmosphere and land to enlarge the pollution in the environment, leading to the serious Cr pollution issues in many countries and regions. Furthermore, human activities caused many marine bays to be polluted by Cr. So, cautiously studying the spatial motion processes of Cr in marine waters is helpful to pollution control. Jiaozhou Bay, a semi-closed bay was investigated, the dataset in waters around the bay mouth in Jiaozhou Bay in May, September and October 1983 determined the horizontal and vertical moving processes, revealed the moving laws, and examined scientific basis for the migration processes of Cr in marine bay.

2. Material and method

Study area and data collection. Jiaozhou Bay was in the south of Shandong Province, eastern China (35°55'-36°18' N, 120°04'-120°23' E), its total area is 446 km² (Fig. 1). The bay with narrow mouth (3 km) showed the rivers such as Dagu River, Haibo River, Licun River, and Loushan River etc.. Cr Dataset in Jiaozhou Bay from North China Sea Environmental Monitoring Center, by National Specification for Marine Monitoring [1], presented the investigations in May, September and October 1983. 3 sampling sites were regarded as waters inside the bay mouth (H36), in the middle of the bay mouth (H35), and the outside of the bay mouth (H82) (Fig. 1).



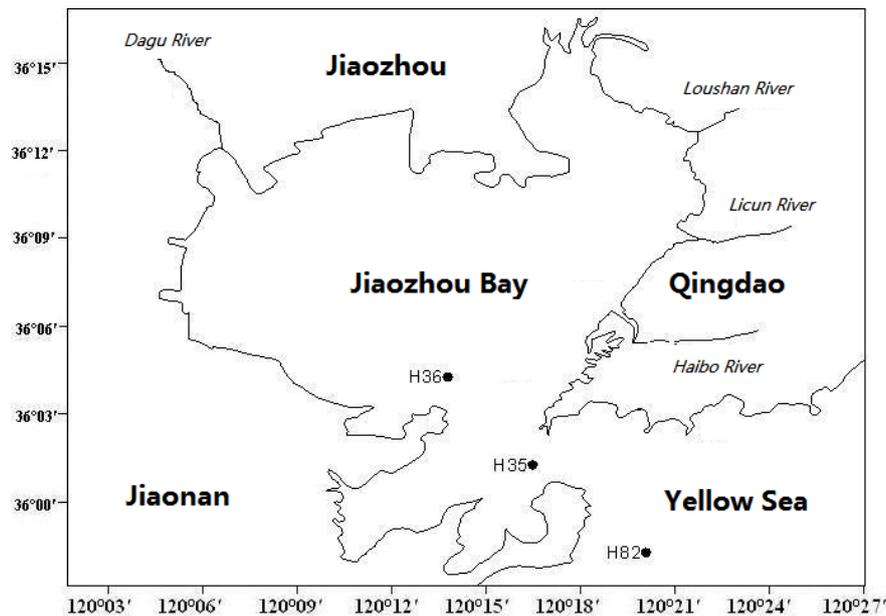


Fig. 1 Jiaozhou Bay with sampling sites

Modeling for horizontal loss. The contents of the substances in waters in marine bays were changing continuously water exchange between the open waters and the internal waters in the bay [10-13]. Supposed that substance contents in surface waters inside the bay mouth, in the middle of the bay mouth and the outside of the bay mouth were A , B and C , respectively

In surface waters, and from waters inside the bay mouth to waters in the middle of the bay mouth, the calculation formula horizontal loss is:

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

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

In surface waters, and from waters in the middle of the bay mouth to the outside of the bay mouth, the calculation formula horizontal loss is:

$$F=B-C, \quad G= | B-C | / \max(B,C) \quad (2)$$

where, F is the absolute horizontal loss amount in surface waters, G is the relative horizontal loss amount in surface waters.

In bottom waters, and from waters inside the bay mouth to waters in the middle of the bay mouth, the calculation formula horizontal loss is:

$$d=a-b, \quad e= | a-b | / \max(a,b) \quad (3)$$

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

In bottom waters, and from waters in the middle of the bay mouth to the outside of the bay mouth, the calculation formula horizontal loss is:

$$f=b-c, \quad g= | b-c | / \max(b,c) \quad (4)$$

where, f is the absolute horizontal loss amount in surface waters, g is the relative horizontal loss

amount in surface waters.

The horizontal changes of Cr in surface and bottom waters in Jiaozhou Bay were calculated according to Cr contents in Site H36, H35 and H82, respectively (Table 1 and Table 2).

Table 1 Horizontal loss amount of Cr in surface waters

Month	From H36 to H35		From H35 to H82	
	$D/\mu\text{g L}^{-1}$	$E/\%$	$F/\mu\text{g L}^{-1}$	$G/\%$
May	0.17	56.66%	-0.16	55.17%
September	0.22	23.91%	-0.20	22.22%
October	0.12	7.69%	1.00	69.44%

Table 2 Horizontal loss amount of Cr in bottom waters

Month	From H37 to H35		From H35 to H37	
	$d/\mu\text{g L}^{-1}$	$e/\%$	$f/\mu\text{g L}^{-1}$	$g/\%$
May	-0.93	93.93%	0.88	88.88%
September	-0.22	19.64%	0.66	58.92%
October	-0.68	43.03%	0.95	60.12%

Modeling for vertical loss. Supposed that substance contents in surface and bottom waters in a certain sampling site are A and a , respectively. From surface waters to bottom waters, the calculation formula for this migration process is:

$$V_{na}=A-a, \quad V_{nr}=(100 \times |A-a| / \max(A,a))\% \quad (5)$$

where, V_{na} is the absolute horizontal dilution amount from surface waters to bottom waters if $V_{na} > 0$, V_{nr} is the relative horizontal dilution amount. If $V_{na} < 0$, V_{na} refers to the absolute horizontal accumulation amount, and V_{nr} refers to the relative horizontal accumulation

The vertical changes of Cr in waters in Jiaozhou Bay were calculated according to Cr contents in Site H36, H35 and H82, respectively (Table 3).

Table 3 Vertical loss amount of Cr in Jiaozhou Bay

Month	Site	$V_{na}/\mu\text{g L}^{-1}$	$V_{nr}/\%$
May	H36	0.24	80.00%
	H35	-0.86	86.86%
	H82	0.18	62.06%
September	H36	0.02	2.17%
	H35	-0.42	37.50%
	H82	0.44	48.88%
October	H36	0.66	42.30%
	H35	-0.14	8.86%
	H82	-0.19	30.15%

3. Discussion

Horizontal and vertical changes of Cr. Cr in waters inside the bay mouth was mainly sourced from river runoff, while in waters outside the bay mouth was mainly sourced from marine current. In waters in the bay mouth, Cr contents were decreasing from high-value region to low-value region by means of tide and current. In May 1983, from H36 to H35 the horizontal loss of Cr in surface waters was 65.34%, while from H82 to H35 was 55.15% (Fig. 2). From H35 to H36 the horizontal loss of Cr in bottom waters was 93.93%, while from H35 to H82 was 88.88%, respectively (Fig. 2). The vertical accumulation of Cr in H35 was 86.86%, while the vertical dilutions of Cr in H36 and H82 were 80.00% and 62.06%, respectively. The horizontal and vertical changes of Cr in May 1983 were very

high.

In September 1983, from H36 to H35 the horizontal loss of Cr in surface waters was 23.91%, while from H82 to H35 was 22.22%, respectively(Fig. 3). From H35 to H36 the horizontal loss of Cr in bottom waters was 19.14%, while from H35 to H82 was 58.92% (Fig. 3). The vertical accumulation of Cr in H35 was 37.50%, while the vertical dilutions of Cr in H36 and H82 were 2.17% and 48.88%, respectively(Fig. 3). It could be found that the horizontal and vertical changes of Cr in September 1983 were relatively high.

In October 1983, from H36 to H35 the horizontal loss of Cr in surface waters was 7.69%, while from H35 to H82 was 69.44%, respectively(Fig. 4). From H35 to H36 the horizontal loss of Cr in bottom waters was 43.03%, while from H35 to H82 was 60.12% (Fig.4). The vertical dilution of Cr in H35 was 42.30%, while the vertical accumulations of Cr in H36 and H82 were 8.86% and 30.18%, respectively(Fig. 4). It could be found that the horizontal and vertical changes of Cr in October 1983 were relatively low.

In general, the horizontal absolute loss and relative loss of Cr in 1983 were 0.12-0.95 $\mu\text{g L}^{-1}$ and 7.69-93.93%, the vertical absolute accumulation and relative accumulation were 0.14-0.86 $\mu\text{g L}^{-1}$ and 8.86-86.86%, and the vertical absolute dilution and relative dilution were 0.02-0.62 $\mu\text{g L}^{-1}$ and 2.17-80.00%, respectively. Substance contents were changing continuously during the migration process by means of horizontal and vertical water's effects [2].



Fig. 2 Block diagram model for horizontal-vertical changes of Cr in May 1983

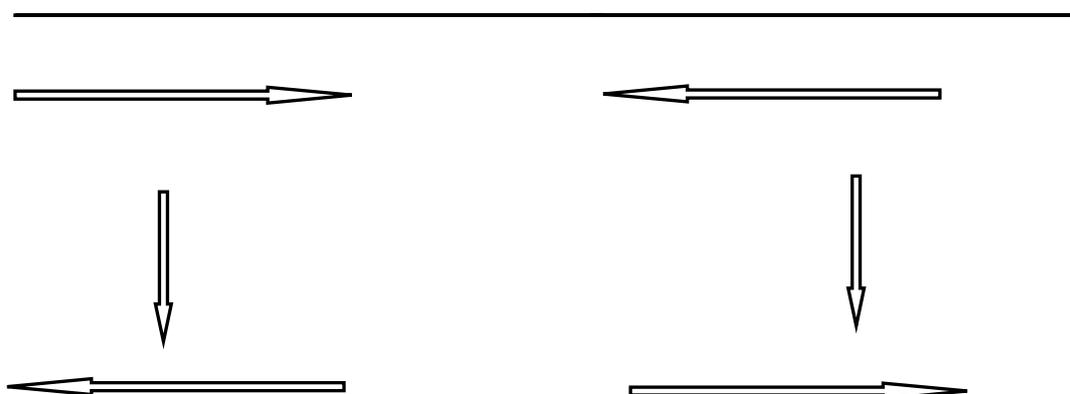


Fig. 3 Block diagram model for horizontal-vertical changes of Cr in September 1983

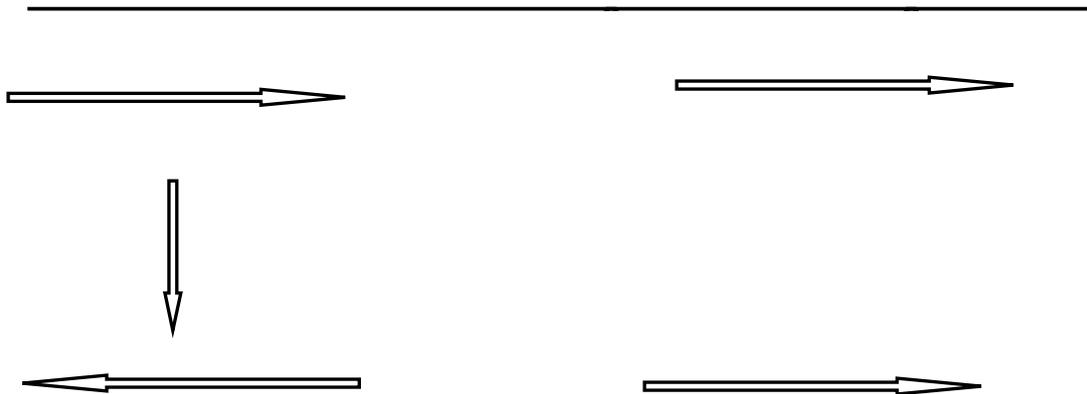


Fig. 4 Block diagram model for horizontal-vertical changes of Cr in October 1983

Spatial motion process of Cr. In May 1983, no matter from the inside of the bay mouth to the bay mouth, or from the outside of the bay mouth to the bay mouth, the horizontal loss of Cr in surface waters were relative high (5.17-56.66%), resulting in high vertical accumulation of Cr in waters in the bay mouth (86.86%). The reason was that Cr in river runoff and marine current was transporting to the bay mouth from the inside and outside of the bay mouth, respectively, and a big part of Cr was moving to bottom waters by means of vertical water's effect. Since there was high vertical accumulation in bottom waters in the bay mouth, there was high horizontal loss in bottom waters from the bay mouth to the inside of the bay mouth (93.93%), as well as the outside of the bay mouth (88.88%). Therefore, there were high diffusion and sedimentation processes from the bay mouth to the inside of the bay and to the outside of the bay (Fig. 5). Meanwhile, there were high vertical dilution processes in bottom waters in the inside of the bay mouth (80.00%) and the outside of the bay mouth (62.06%). These indicated that there were high sedimentation processes in waters in the inside and outside of the bay mouth, and high diffusion and sedimentation processes in waters in the bottom waters from the bay mouth to the inside and outside of the bay mouth (Fig. 6).

In September 1983, from the inside of the bay mouth to the bay mouth the horizontal loss of Cr in surface waters were relative high (22.22-23.91%), resulting in high vertical accumulation of Cr in waters in the bay mouth (37.50%). The reason was that Cr in river runoff and marine current was transporting to the bay mouth from the inside and outside of the bay mouth, respectively, and a big part of Cr was moving to bottom waters by means of vertical water's effect. Since there was high vertical accumulation in bottom waters in the bay mouth, there was low horizontal loss in bottom waters from the bay mouth to the inside of the bay mouth (19.64%), yet high in waters outside of the bay mouth (58.92%). Therefore, there were high diffusion and sedimentation processes from the bay mouth to the inside of the bay and to the outside of the bay (Fig. 5). Meanwhile, there were low vertical dilution process in bottom waters in the inside of the bay mouth (2.17%) and high vertical dilution process outside of the bay mouth (48.88%). These indicated that there were low sedimentation processes in waters in the inside of the bay mouth yet high in the outside of the bay mouth, and high diffusion and sedimentation processes in waters in the bottom waters from the bay mouth to the inside and outside of the bay mouth (Fig. 6).

In October 1983, from the inside of the bay mouth to the bay mouth the horizontal loss of Cr in surface and waters were relative low (7.69%), resulting in low vertical accumulation of Cr in waters in the bay mouth (8.86%). Hence, a small part of Cr sourced from river runoff was moving to bottom waters. From waters in the bay mouth to the outside of the bay mouth, the horizontal loss in surface was relative high (69.44%), resulting in high vertical accumulation of Cr in the outside of the bay mouth (30.15%). The horizontal loss in surface waters from the bay mouth to the inside of the bay mouth was 43.03%, compared to 60.12% from the bay mouth to the outside of the bay mouth. The

accumulation of Cr from river runoff was resulting in the diffusion and sedimentation processes from the bay mouth to the inside of the bay and to the outside of the bay (Fig. 5). Meanwhile, there were low vertical dilution process in bottom waters in the inside of the bay mouth (8.86%) and high vertical dilution process outside of the bay mouth (30.15%). These indicated that there were low sedimentation processes in waters in the inside of the bay mouth yet high in the outside of the bay mouth, and high diffusion and sedimentation processes in waters in the bottom waters from the bay mouth to the inside and outside of the bay mouth (Fig. 6).

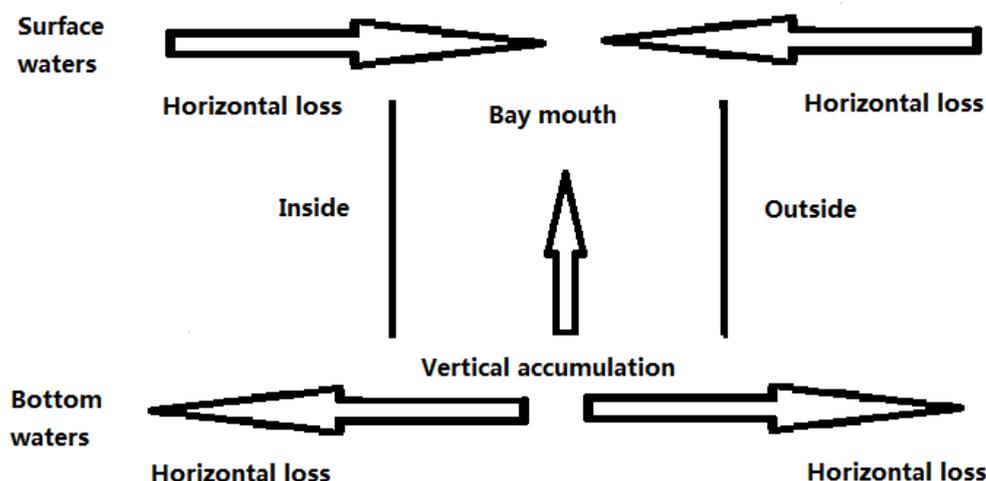


Fig. 5 Yang's theory for vertical sedimentation

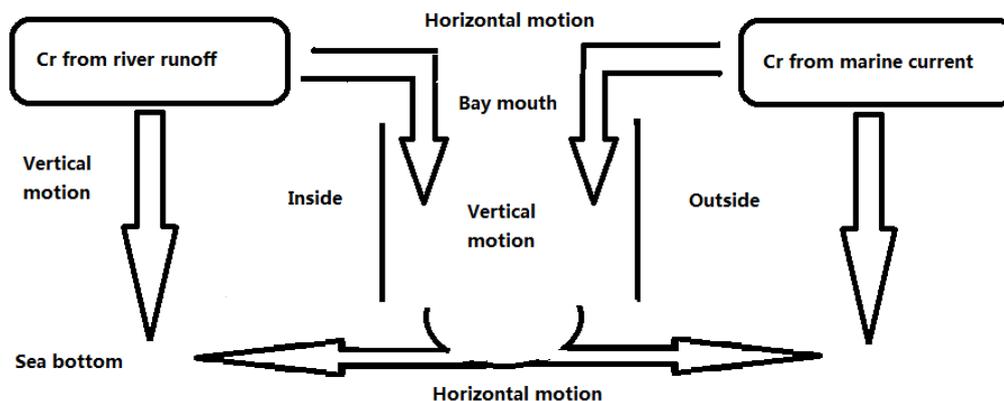


Fig. 6 Yang's phenomenon for spatial motion process

4. Conclusion

The horizontal absolute loss and relative loss of Cr in 1983 were $0.12-0.95\mu\text{g L}^{-1}$ and 7.69-93.93%, the vertical absolute accumulation and relative accumulation were $0.14-0.86\mu\text{g L}^{-1}$ and 8.86-86.86%, and the vertical absolute dilution and relative dilution were $0.02-0.62\mu\text{g L}^{-1}$ and 2.17-80.00%, respectively.

The bay mouth was playing a role of parclose. No matter from the inside of the bay mouth to the bay mouth, or from the outside of the bay mouth to the bay mouth, a big part of Cr was filtering by the parclose continuously. This phenomenon was named as Yang's Phenomenon.

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