Influence of rainfall-runoff on the spatial-temporal variation of Cr in Jiaozhou Bay

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Abstract. This paper analyzed the influence of rainfall-runoff on chromium (Cr) in Jiaozhou Bay using investigation data in April, July and October 1982. Results showed that Cr was strongly influenced by rainfall-runoff in different seasons. The wet season had not come in April, and there was a sediment process in the coastal waters in the southwest of the bay, while in waters far away from the coastal waters in the southwest the influence of rainfall-runoff was little and Cr contents in waters was homogeneous. The wet season had been coming in July, and there was a strong sediment process in the coastal waters in the southwest of the bay where the accumulation in bottom waters had been abundant. The wet season had come to an end in October, and there was also a sedimentation process in the coastal waters in the southwest of the bay, while in waters far away from the coastal waters in the southwest the influence of rainfall-runoff was little and Cr contents in waters was homogeneous again.

1. Introduction
Cr has been widely used heavy metal elements in industry and agriculture, and many marine bays have been polluted due to the lagging of waste treatment [1-3]. Rainfall-runoff is the major driving force of various pollutants from land to ocean, and therefore understanding the influence of rainfall-runoff on Cr contents in marine bay is essential to environmental protection and remediation [4-6]. This paper analyzed the influence of rainfall-runoff on chromium (Cr) in Jiaozhou Bay using investigation data in April, July and October 1982. The absolute horizontal loss amount and relative horizontal loss amount, the absolute vertical disputed amount and relative vertical disputed amount, and the absolute vertical sediment amount and relative vertical disputed sediment of Cr were calculated. Furthermore, we provided block diagram model to reveal the vertical and vertical migration process of Cr by means of the influence of rainfall-runoff.

2. Materials and method
2.1 Study area. 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 km\textsuperscript{2} and 7 m, respectively (Fig. 1). 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, and Loushan River etc., all of which are seasonal rivers [7-8].

Fig. 1 Geographic location and sampling sites of Jiaozhou Bay

2.2 Data collection. Dataset on Cr in Jiaozhou Bay was provided by North China Sea Environmental Monitoring Center. The investigations were carried on in April, July and October 1982. Cr in surface and bottom waters was monitored follow by National Specification for Marine Monitoring [9]. The sampling Sites were Site 122 in the coastal waters in the southwest and Site 084 in far away from the southwest, respectively (Fig. 1).

2.3 Calculation of the changing of substance content. We define that substance contents in surface waters in the coastal waters and in surface waters in the southwest (Site 122) and far away from the southwest (Site 084) are $A$ and $B$, respectively. From $A$ to $B$, the absolute horizontal loss amount ($D$) and the relative horizontal amount ($E$) in surface waters are calculated as Eq. (1).

$$
D = A - B \\
E = \frac{\text{abs}(A - B)}{\text{max}(A, B)}
$$

We define that substance contents in bottom waters in the coastal waters in the southwest and in bottom waters far away from the southwest are $a$ and $b$, respectively. From $A$ to $B$, the absolute horizontal loss amount ($d$) and the relative horizontal amount ($e$) in bottom waters are calculated as Eq. (2).

$$
d = a - b \\
e = \frac{\text{abs}(a - b)}{\text{max}(a, b)}
$$

From surface waters to bottom waters, in a certain sampling site, the absolute vertical loss amount...
$(V_{na})$ and the relative loss amount $(V_{nr})$ are calculated as Eq. (3).

$$
\begin{align*}
V_{na} &= A - a \\
V_{nr} &= \frac{\text{abs}(A - a)}{\max(A, a)}
\end{align*}
$$

$V_{na} > 0$ indicates absolute sediment amount from surface waters to bottom waters, while $V_{na} < 0$ indicates absolute disputed amount from surface waters to bottom waters.

### 3. Results and discussion

#### 3.1 Horizontal and vertical changing.

The horizontal loss of Cr in surface and bottom waters in Jiaozhou Bay 1982 were calculated by Eq. (1) and Eq. (2) and were listed in Table 1. The vertical loss of Cr in Jiaozhou Bay 1982 were calculated by Eq. (3) and were listed in Table 2. In April 1982, the relative horizontal loss amount in surface waters from the coastal waters in the southwest to waters far away from the southwest was 2.40%, compared to 14.73% in bottom waters (Fig. 2a). The relative vertical sediment amount in the coastal waters in the southwest was 14.73%, compared to 0.00% of relative disputed amount in waters far away from the southwest (Fig. 2a). In July 1982, the relative horizontal loss amount in surface waters from the coastal waters in the southwest to waters far away from the southwest was 25.54%, compared to 43.12% in bottom waters (Fig. 2b). The relative vertical disputed amount in the coastal waters in the southwest was 12.40%, compared to 51.65% of relative sediment amount in waters far away from the southwest (Fig. 2b). In October 1982, the relative horizontal loss amount in surface waters from the coastal waters in the southwest to waters far away from the southwest was 52.94%, compared to 39.21% in bottom waters (Fig. 2c). The relative vertical sediment amount in the coastal waters in the southwest was 52.94%, compared to 39.21% in bottom waters (Fig. 2c). Obviously, Cr contents in both surface and bottom waters were changing a lot during the migration process [10-11].

| Month | Surface waters | Bottom waters |
|-------|----------------|--------------|
| April | $D/\mu g \ L^{-1}$ | $E/%$ | $d/\mu g \ L^{-1}$ | $e/%$ |
| April | 0.02 | 2.40 | 0.14 | 14.73 |
| July | 0.35 | 25.54 | -0.91 | 43.12 |
| October | -0.27 | 52.94 | -0.20 | 39.21 |

| Month | Site | $V_{na}/\mu g \ L^{-1}$ | $V_{nr}/\%$ |
|-------|------|------------------|-------------|
| April | Site 122 | -0.12 | 12.63 |
| Site 084 | 0.00 | 0.00 |
| July | Site 122 | 0.17 | 12.40 |
| Site 084 | -1.09 | 51.65 |
| October | Site 122 | -0.07 | 22.58 |
| Site 084 | 0.00 | 0.00 |
3.2 Horizontal and vertical loss. The horizontal loss of Cr in surface waters from coastal waters in the southwest of the bay to waters far away of the bay were changing along with time within year. For instance, from April to July and to October, the relative horizontal loss amounts in surface waters were increasing from 2.40% to 25.54% and to 52.94% (Fig. 2). The horizontal loss of Cr in bottom waters from coastal waters in the southwest of the bay to waters far away of the bay were also changing along with time within year. From April to July and to October, the relative horizontal loss amounts in bottom waters were increasing from 14.73% to 43.12% and to 39.32% (Fig. 2). The vertical loss of Cr was also showing seasonal variations. For waters in the coastal in the southwest of the bay. In April, the absolute sediment amount and relative sediment amount were 0.12 μg L⁻¹ and 12.63%, respectively. In July, the absolute disputed amount and relative disputed amount were 0.17 μg L⁻¹ and 51.65%, respectively. In October, the absolute sediment amount and relative sediment amount were 0.07 μg L⁻¹ and 22.58%, respectively. It could be found that there were sediment and accumulation in April and October, yet there was only sediment. For waters far away from the southwest of the bay. In April, the absolute sediment amount and relative sediment amount were 0.00 μg L⁻¹ and 0.00%, respectively. In July, the absolute sediment amount and relative sediment amount were 1.09 μg L⁻¹ and 51.65%, respectively. In October, the absolute sediment amount and relative sediment amount were 0.00 μg L⁻¹ and 0.00%, respectively. The horizontal water’s effect [11-12] and vertical water’s effect [12-13] were two of the major reasons for these horizontal and vertical loss of Cr.
3.3 Influence of rainfall-runoff. Rainfall-runoff is the major driving force of various pollutants from land to ocean [4-6]. The influence of rainfall-runoff on Cr contents in study area could be defined in according to the spatial-temporal of horizontal and vertical change and loss of Cr. It could be seen from Fig. 2 that there were sediment and Cr contents in waters were homogeneous in April and October, yet there was strong sediment accumulation. In April, the wet season had not come, there was a sediment process in the coastal waters in the southwest of the bay where the accumulation in bottom waters was beginning. Meanwhile, in waters far away from the coastal waters in the southwest the influence of rainfall-runoff was little and Cr contents in waters was homogeneous. In July, the wet season was coming, there was a strong sediment process in the coastal waters in the southwest of the bay where the accumulation in bottom waters had been abundant. In October, the wet season had come to an end, there was also a sedimentation process in the coastal waters in the southwest of the bay. Meanwhile, in waters far away from the coastal waters in the southwest the influence of rainfall-runoff was little and Cr contents in waters was homogeneous again. In general, Cr in Jiaozhou Bay was strongly influenced by rainfall-runoff in different seasons.

4. Conclusions
Cr contents in both surface and bottom waters were changing a lot during the migration process. The vertical loss of Cr was also showing seasonal variations. In general, Cr in Jiaozhou Bay was strongly influencing by rainfall-runoff in different seasons. The block diagram model revealed the vertical and vertical migration process of Cr by means of the influence of rainfall-runoff. The influence of rainfall-runoff on Cr contents was strong, and was indicating that different pollution prevention and control measures should be applied in different seasons.

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