Definition and formula of substance content change in marine bay and the application

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Abstract. We analyzed the substance content change in marine based on water exchange, and provided definitions and formulas for horizontal loss amount, vertical dilution amount and vertical sedimentation amount. A case study in analysis the change of Pb contents in Jiaozhou Bay was provided to exhibit the application of these definitions and formulas. Results showed that the vertical variation and model of Pb contents could be revealed by means of the definitions and formulas. The horizontal loss amount of Pb indicated the Pb was very difficult to be imported from the open sea to the bay via the bay channel. The vertical dilution and sedimentation loss amount of Pb indicated that Pb was diluted greatly in the bay mouth due to the marine current, and the sedimentation rate was relative high in the open waters outside the bay mouth.

Introduction

Pb has been widely used in instrumentation, electrolysis and smelting etc. A large amount of Pb-containing wastes were generated and discharged to the environment since industrial revolution. However, Pb is high toxicity and long persistent, and many marine bays have been polluted by Pb finally due to ocean is the sink of various pollutants [1-6]. Therefore, understanding of the transfer process of various pollutants in marine bay is essential to environmental protection.

In this paper, we analyzed the substance content change in marine based on water exchange, and provided definitions and formulas for horizontal loss amount, vertical dilution amount and vertical sedimentation amount. Jiaozhou Bay is a semi-closed bay located in Shandong Province, China. A case study in analysis the change of Pb contents in Jiaozhou Bay was provided to exhibit the application of these definitions and formulas.

Materials and method

Basic definition. Along with the water exchange, the contents of the substances in marine bay are decreasing continuously [10-12]. Once the substances are mainly from point-source, the contents are very high. By means of water exchange, it is necessary to define the horizontal loss amount of the substance, including absolute horizontal loss amount and relative horizontal loss amount. By means of gravity force and marine current, the substances were settling to sea bottom continuously, and it is necessary to define the vertical dilution amount and vertical sedimentation amount, including absolute vertical dilution amount and vertical sedimentation amount, as well as relative vertical dilution amount and vertical sedimentation amount.

Definition and formula of horizontal loss. In surface waters, suppose that the content of

certain substance (*M*) outside the bay mouth is *A*, in the bay mouth is *B*, and inside the bay mouth is *C*. From the open waters to the inside of the bay, the absolute horizontal loss amount is *D*, and the relative horizontal loss amount is *E*. If $D<0$, the absolute horizontal loss amount is $-D$ (Eq. 1). From inside of the bay to the open waters, the absolute horizontal loss amount is *F*, and the relative horizontal loss amount is *G*. If $G<0$, the absolute horizontal loss amount is $-F$ (Eq. 2).

$$D=A-B, \qquad E=|A-B|/\max(A,B) \tag{1}$$

$$F=B-C, \qquad G=|B-C|/\max(B,C) \tag{2}$$

In bottom waters, suppose that the content of certain substance (*M*) outside the bay mouth is *a*, in the bay mouth is *b*, and inside the bay mouth is c. From the open waters to the inside of the bay, the absolute horizontal loss amount is *d*, and the relative horizontal loss amount is *e*. If $d<0$, the absolute horizontal loss amount is $-d$ (Eq. 3). From inside of the bay to the open waters, the absolute horizontal loss amount is *f*, and the relative horizontal loss amount is *g*. If $f<0$, the absolute horizontal loss amount is $-f$ (Eq. 4).

$$d=a-b, \qquad e=|a-b|/\max(a,b) \tag{3}$$

$$f=b-c, \qquad g=|b-c|/\max(b,c) \tag{4}$$

Definition and formula of vertical loss. In waters outside the bay, suppose that the content of certain substance (*M*) in surface waters is *A*, while in bottom waters is *a*. For a sampling site *n*, the absolute vertical dilution amount is V_{na}, and the relative vertical dilution amount is V_{nr}. If $V_{na}<0$, the absolute vertical sedimentation amount is $-V_{na}$. If $V_{na}>0$, the relative vertical dilution amount is V_{nr} (Eq. 5).

$$V_{na}=A-a, \qquad V_{nr}=|A-a|/\max(A,a) \tag{5}$$

Case study. Jiaozhou Bay is located in the south of Shandong Province, eastern China (35°55′-36°18′ N, 120°04′-120°23′ E), which is connected to the Yellow Sea in the south. This bay is a typical of semi-closed bay, and the total area, average water depth and bay mouth width are 446 km^2, 7 m and 3 km, respectively. There are a dozen of rivers, and the majors are Dagu River, Haibo Rriver, Licun Rriver, and Loushan Rriver etc., all of which are seasonal rivers [7-8]. The investigation on Cd in Jiaozhou Bay was carried on in April, July and Pctober 1986 in three investigation sites namely 2031, 2032 and 2033, respectively (Fig. 1). Pb in waters was sampled and monitored follow by National Specification for Marine Monitoring [9].

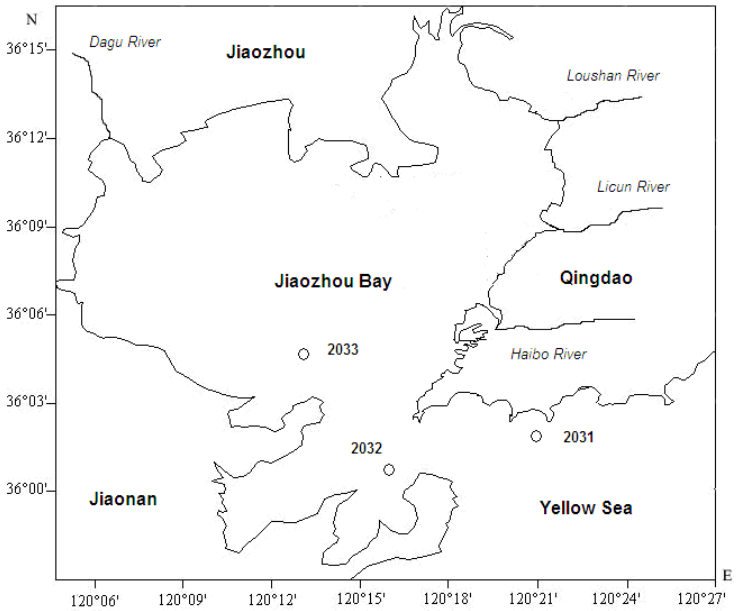

Fig. 1 Geographic location and sampling sites in Jiaozhou Bay

Results

Horizontal loss. Suppose that waters from the open waters to the bay mouth is from *A* to *B*, and waters from the bay mouth to the inside of the bay is from *B* to *C*. Pb contents in surface waters were changing a lot along with time, and the horizontal losses in surface waters could be calculated by Eq. 1 and Eq. 2, and were listed in Table 1. Similarly, the horizontal losses in bottom waters could be calculated by Eq. 3 and Eq. 4, and were listed in Table 2.

Table 1 Horizontal losses of Pb in surface waters

A to *B*	*D*	*E*	*E*
April	12.97	0.50664	50.66%
July	-7.35	0.21054	21.05%
October	0.1	0.00365	0.36%
B to *C*	*F*	*G*	*G*
April	-2.45	0.16247	16.25%
July	4.82	0.16018	16.02%
October	6.93	0.25384	25.38%

Table 2 Horizontal losses of Pb in bottom waters

A to *B*	*d*	*e*	*e*
April	2.15	0.11832	11.83%
July	-0.66	0.02887	2.89%
October	2.36	0.06662	6.66%
B to *C*	*f*	*g*	*g*
April	4.72	0.29463	29.46%
July	-11.47	0.50175	50.17%
October	10.58	0.32002	32.00%

Vertical dilution amount and sedimentation amount. Pb contents in surface waters were changing a lot along with time, and the vertical dilution amount and sedimentation amount could be calculated by Eq. 5, and were listed in Table 3. For the three sampling sites (Site 2031, 2032 and 2033), Pb contents in surfaces were subtracting by which in bottom waters in different months. The subtractions in April, July and October were ranging from -2.88 to 17.10 μg L^{-1}, -3.39 to 7.43μg L^{-1} and -8.02 to -2.11μg L^{-1}, respectively. In April, the subtraction in Site 2032 was negative, yet in the other sampling sites was positive (Table 4). In July, the subtraction in Site 2033 was negative, yet the subtractions in the other two sampling sites were positive (Table 4). In October, the subtractions in all of the three sampling sites were negative (Table 4).

Table 3 Vertical dilution amount and sedimentation amount of Pb

Time	Waters	V_{na}	V_{nr}	V_{nr}
April	Outside the bay	7.43	0.29023	29.02%
	Bay mouth	-3.39	0.21161	21.16%
	Inside the bay	3.78	0.25066	25.06%
July	Outside the bay	5.36	0.19448	19.44%
	Bay mouth	12.05	0.34517	34.51%
	Inside the bay	-4.24	0.12351	12.35%
October	Outside the bay	-8.02	0.22643	22.64%
	Bay mouth	-5.76	-0.17423	17.42%
	Inside the bay	-2.11	-0.09386	9.38%

Table 4 Pb contents in surface minus which in bottom waters

Time	Site 2033	Site 2032	Site 2031
April	Positive	Negative	Positive
July	Negative	Positive	Positive
October	Negative	Negative	Negative

Discussion

Substance content's change. The contents of the substances were changing greatly during the migration processes. Based on the vertical water's effect and horizontal water's effect [11-12], the horizontal changes were revealing the loss effect of horizontal water body, and the changes of surface and bottom waters were revealing the dilution effect and sedimentation effect. Hence, based on the water's effect, we further provided the definitions and formulas of substances, as well as the vertical changes. Therefore, the migration processes of the substances were quantified.

Horizontal and vertical change. In open waters outside the bay mouth, Pb was mainly sourced from marine current. In waters inside the bay mouth, Pb was mainly sources from stream flow. In waters in the bay mouth, Pb contents were decreasing from the high value region to low value region by tide and marine current. In April, from the open waters to the bay mouth, the horizontal loss of Pb in surface waters was biggest as 50.66%, yet in bottom waters as smallest as 11.83% (Fig. 2). The vertical dilution amounts of Pb were relative big in waters outside the bay mouth and waters inside the bay mouth, while in waters in the bay mouth the vertical sedimentation amount was relative small. In July, from the bay mouth to the inside of the bay, the horizontal loss of Pb in bottom waters was biggest as 50.17%. From the open water s to the bay mouth the horizontal loss of Pb in bottom waters as smallest as 2.89% (Fig. 3). In waters outside the bay mouth and waters inthe bay mouth, the vertical dilution amounts of Pb were relative big, while in waters inside the bay mouth, the vertical sedimentation amount was relative small. In October, from the waters inside the bay mouth to the bay mouth, the horizontal loss of Pb in surface waters was biggest as 32.00 %, yet in bottom waters as smallest as 11.83% (Fig. 4). In waters outside the bay mouth, waters inside the bay mouth and waters in the bay mouth, there were vertical sedimentations.

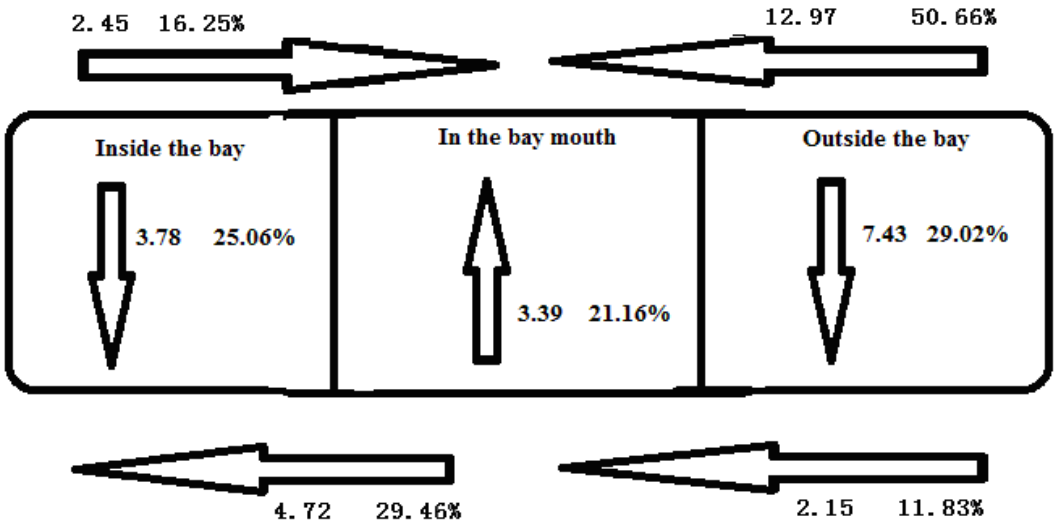

Fig. 2 The model of the horizontal and vertical changing of Pb in April

In generally, the absolute horizontal loss of Pb in April, July and October 1986 was from 0.10-12.97μg L^{-1}, while the relative horizontal loss was 0.36-50.66%. The absolute vertical sedimentation of Pb was 3.39-8.02 μg L^{-1}, while the relative horizontal sedimentation was 9.38-22.64%. The absolute vertical dilution of Pb was 3.78-12.05 μg L^{-1}, while the relative horizontal dilution was 19.44-34.51%. In according to the horizontal loss of Pb, it could be found that from the open waters to the bay mouth and from the bay mouth to the inside of the bay, the horizontal loss amount was biggest during the extension process. In surface waters, the horizontal loss of Pb was almost 50% during the extension process from the open waters to the bay mouth. In bottom waters, the horizontal loss of Pb was almost 50% during the extension process from the bay mouth to the inside of the bay. Hence, Pb was very difficult to be imported form the open waters to the inner bay via bay channel. The Pb source strength of marine current was 25.60-27.40 μg L^{-1}, which was very stable yet relative low. The vertical dilution amount and vertical sedimentation

amount of Pb were revealing that the relative vertical dilution amount of Pb was biggest in the bay mouth, while the relative vertical sedimentation amount of Pb was biggest in waters outside the bay mouth. In waters in the bay mouth, Pb was diluted greatly by means of tide and marine current, while the sedimentation of Pb was relative great in waters outside the bay mouth.

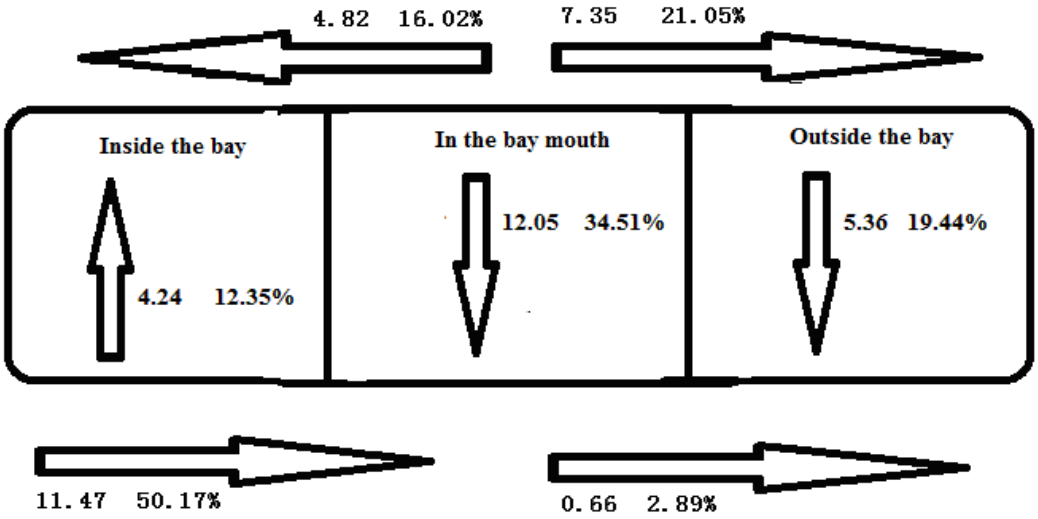

Fig. 3 The model of the horizontal and vertical changing of Pb in July

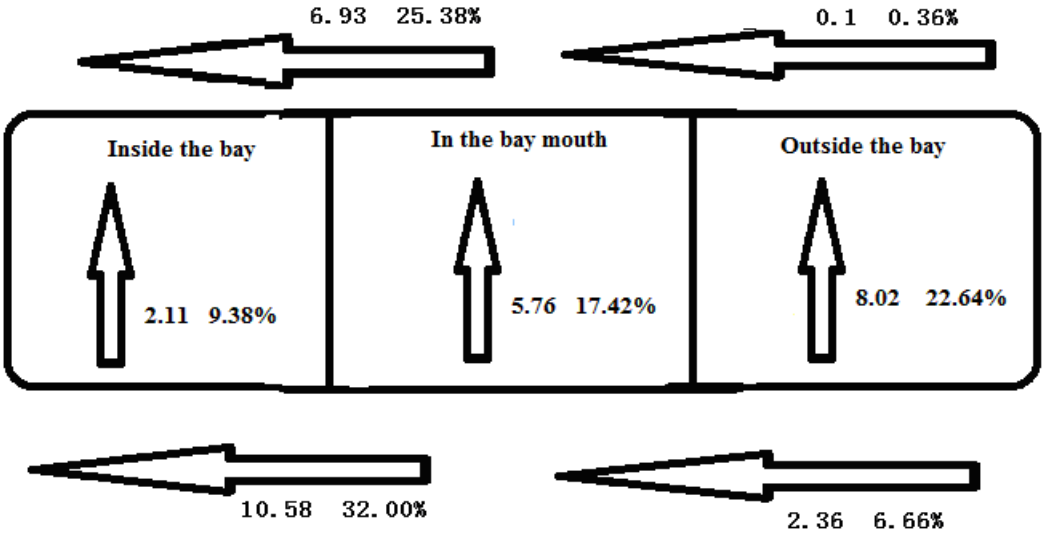

Fig. 4 The model of the horizontal and vertical changing of Pb in October

Regional settling. At regional scale, for the three sampling sites (Site 2031, 2032 and 2033), Pb contents in surfaces were subtracting by which in bottom waters in different months, and the subtractions were changing along with time, and were indicating the changing of Pb contents in surface and bottom waters. Once Pb was imported to the bay, it was originally arrived at surface waters, and was settling to sea bottom rapidly and continuously, and was exhibiting the changing of Pb contents in surface and bottom waters. In April, Pb was mainly sourced from marine current, and Pb contents in surface waters were higher than which in bottom waters in waters inside and outside the bay mouth, yet Pb contents in surface waters were lower than which in bottom waters in waters in the bay mouth. It was revealing that the relative high Pb contents were extending from the inside and outside of the bay mouth to the bay mouth. In July, Pb was mainly sourced from stream flow, and the source strength was relative high. Hence, the was a large sedimentation amount in waters inside the bay mouth, resulting in Pb contents in surface waters were lower than which in bottom waters. However, in waters in the bay mouth and outside the bay mouth, Pb contents in surface

waters were high than which in bottom waters. It was revealing that the relative high Pb contents were extending along with the surface waters and there was high sedimentation in waters inside the bay mouth. In October, Pb was mainly sourced from stream flow and marine current, and the source strength was relative high. Hence, Pb contents in surface waters were lower than which in bottom waters in waters inside and outside the bay mouth, as well as in the bay mouth. It was revealing that the relative high Pb contents were extending and there were high sedimentations in waters inside and outside the bay mouth, as well as in the bay mouth. In generally, in April, July and October, the continuously sedimentation of Pb was resulting in the great accumulation of Pb in sea bottom. Hence, in October, Pb contents in surface waters were lower than which in bottom waters in waters inside and outside the bay mouth, as well as in the bay mouth.

Conclusions

We analyzed the substance content change in marine based on water exchange, and provided definitions and formulas for horizontal loss amount, vertical dilution amount and vertical sedimentation amount. A case study in analysis the change of Pb contents in Jiaozhou Bay was provided to exhibit the application of these definitions and formulas.

From the open waters to the bay mouth and from the bay mouth to the inside of the bay, the horizontal loss amount was biggest during the extension process. In surface waters, the horizontal loss of Pb was almost 50% during the extension process from the open waters to the bay mouth. In bottom waters, the horizontal loss of Pb was almost 50% during the extension process from the bay mouth to the inside of the bay. Hence, Pb was very difficult to be imported form the open waters to the inner bay via bay channel.

The vertical dilution amount and vertical sedimentation amount of Pb were revealing that the relative vertical dilution amount of Pb was biggest in the bay mouth, while the relative vertical sedimentation amount of Pb was biggest in waters outside the bay mouth. In waters in the bay mouth, Pb was diluted greatly by means of tide and marine current, while the sedimentation of Pb was relative great in waters outside the bay mouth.

In April, July and October, the continuously sedimentation of Pb was resulting in the great accumulation of Pb. Hence, in October, Pb contents in surface waters were lower than which in bottom waters in waters inside and outside the bay mouth, as well as in the bay mouth.

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