Spatiotemporal Variation of Pb Content Source Transportation in Jiaozhou Bay

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Abstract: Based on research data of the Jiaozhou Bay waters in May, August, and October 1992, the current transportation process and the various sources of Pb contents in the Jiaozhou Bay water body were studied. According to the Yang Dongfang migration law of the content, the results show that: after the ocean current with high levels of Pb content enters the Jiaozhou Bay, spatial change process of the sources carrying Pb content in May, August and October is shown with the transportation of the ocean current. Also, the model block diagram is used to reveal the change process of Pb content imported by ocean currents into the waters of Jiaozhou Bay. The location, magnitude, type, and time of the four sources of Pb content in the waters of Jiaozhou Bay were determined, which are the transportation of ships and terminals, surface runoffs, rivers, and offshore currents. Pb content of surface runoff transport is relatively low, and the transport time is short. Whereas Pb content of the ship terminal is increasing, and the time of transportation is also raising. And the content of Pb transported by rivers is the highest, and it has been transporting from land to sea nonstop throughout the year. Offshore currents carry a very high level of Pb content and constantly transporting it to the water body with low content of Pb. During the year, ships and terminals, land, and rivers were heavily polluted by Pb content, as well as the entire ocean. Among the rivers entering the sea around Jiaozhou Bay, there are four main ones: Haibo River, Licun River, Loushan River, and Dagou River. The sequence of Pb content transported by the rivers from high to low is listed as following: Licun River>Loushan River>Dagou River>Haibo River. The delivery time of Pb content in Licun River is the longer as delivery time in Haibo River, Loushan River and Dagou River is the same. Therefore, it is necessary to strictly control the Pb content from river transportation.

1 Introduction

With the continuous development of the economy, humans have continuously discharged Pb content to the continents, oceans, and the atmosphere in the production and use of various products containing heavy metal lead (Pb), ultimately bring a large amount of high content Pb to the ocean [1-6]. Therefore, the Pb content in the ocean has migrated everywhere with the currents and human emissions [1-6]. According to the 1992 data, the source, amount, and time of Pb content in ocean current transport and other sources in Jiaozhou Bay water body were studied, showing the source and degree of pollution of Pb content and the migration process. providing a scientific theoretical basis for Pb content variation process in ocean waters.

2 Waters and Methods of Investigation

2.1 Natural Environment of Jiaozhou Bay

Located in the south of Shandong Peninsula, Jiaozhou

Bay is between 120°04' - 120°23'E, 35°58' - 36°18'N. It is bounded by Tuan Island and Xuejia Island and connected with The Yellow Sea, with an area of about 446 km² and an average water depth of about 7 m. It is a typical semi-closed bay. More than ten rivers are flowing into the sea in Jiaozhou Bay, among which Dagou River, Yanghe River, and Haibo River, Licun River, and Loushan River in Qingdao City are the rivers with large runoff and sediment content. These rivers are seasonal rivers and their hydrological characteristics have obvious seasonal changes [7-8].

2.2 Waters, and Methods of Investigation

The Pb content data of the Jiaozhou Bay water body in May, August, and October 1992 used in this study were provided by the North Sea Monitoring Center of the State Oceanic Administration. Water samples were collected from 13 stations in the waters of Jiaozhou Bay: site 52, site 53, site 54, site 55, site 56, site 57, site 58, site 59, site 60, site 61, site 2014, site 2015 and site 2016 (Figure 1). Sampling was carried out on three occasions in May, August, and October 1992 respectively. Water samples were taken according to depth (Surface layer and bottom

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layer were taken when depth is more than 10 m; Only the surface layer is taken when depth is less than 10 m). The investigation of Pb in the Jiaozhou Bay water body was carried out according to the national standard method, which was included in the National Marine Monitoring Specification (1991) [9].

Figure.1. Investigation sites in Jiaozhou Bay

3 Results

3.1 Movement Track of Jiaozhou Bay Current

According to the author, the Yang Dongfang migration rule of material content proposes that the longer the migration path that the material content passes, the greater the amount of material is lost in the path. If the substance content originates from the same starting point and arrives at the same endpoint and the substance content at the starting point is the same value, then the longer the substance content traverses, the lower the value of the substance content when arriving at the end. This rule confirms that the ocean currents in the open sea enter the Jiaozhou Bay with a high level of Pb, and the current flow in the waters of the bay of Jiaozhou Bay as Pb content continues to decrease.

The offshore currents enter the bay through the bay mouth, carrying a high level of Pb content. In this way, the current leaves behind the flow trajectory in the waters of the bay of Jiaozhou Bay: in the bay, the currents flowed from the nearshore to the northeast, reaching the waters in the southeast of the bay at site 60. Then, the currents continued along the coast to the northeast, reaching the coastal waters in the east of Jiaozhou Bay, where the Pb content was from the ship terminal, detected by site 61. The currents further flowed along nearshore to the northeast, getting to the northeast waters of the bay, where the Pb content was imported from the Haibo River, where site 2106 stands. Afterward, the currents remained along near-shore to the northeast, reaching the near-shore waters of the inlet of Licun River in Jiaozhou Bay, where the Pb content is transported from the Licun River and detected by site 58. The current continued along northeast to the bottom of the bay in the northeast of the bay, where the Pb content is transported from the Loushan River, where data is collected from site

2104. Then, the current turned westward and reached the northern waters of the bay at site 57. Further, the current continued westward along the nearshore and reached the most western waters in the northwestern part of the bay, where the Pb content was transported from the Dagu River and the sampling site was 56. Then, the current turned to the south along nearshore and arrived at the waters in the southwest of the bay at 54. It is already very close to the bay mouth (Figure 2).

Figure.2. The movement track of the ocean current in August with high Pb content in Jiaozhou Bay ($\mu\text{g/L}$)

3.2 Spatial Changes in Source Transportation.

According to the Yang Dongfang migration rule of the material content proposed by the author, after ocean currents with a high content of Pb entered the Jiaozhou Bay, the spatial variation process of Pb content of the source importation was demonstrated through the transportation of the ocean current.

In May, the offshore currents were transported to the estuary of Jiaozhou Bay with a Pb content of $20.79 \mu\text{g/L}$. The currents flowed northeast along near shore and reached the southeast waters of the bay and Pb content carried is $5.54 \mu\text{g/L}$. Then, the offshore currents followed the northeast coastal waters to the eastern coastal waters of Jiaozhou Bay, where the Pb content from the ship terminal was $16.34 \mu\text{g/L}$. The currents continued to the northeast along the near shore, arriving reaches the northeast waters of the bay, carrying Pb content of $7.09 \mu\text{g/L}$. The offshore currents remained flowing to the northeast near-shore waters with a high content of Pb through the entrance of Licun River, where Pb content is $37.90 \mu\text{g/L}$. Afterwards, the ocean currents continued to the near-shore waters of the northeast and reached the northernmost waters in the northeastbay area. Here, the Pb content transported is $18.27 \mu\text{g/L}$. Then, the current turned westward along the nearshore and reached the northern waters of the bay. The Pb content transported by the current was $13.72 \mu\text{g/L}$. The current continues westward and reaches the westernmost waters of the northwestern part of the bay, with Pb content of $12.84 \mu\text{g/L}$. Further, the current turned southward along the nearshore and reached the southwestern waters of the bay, where Pb content transported by the current was

8.62 $\mu\text{g/L}$ (Figure 3). Therefore, in May, the ocean currents with a high content of Pb entered the Jiaozhou Bay, showing the spatial changes of the currents in the Jiaozhou Bay.

Figure.3. Spatial Variation Process of Pb content transportation in May ($\mu\text{g/L}$)

In August, the offshore currents were transported to the waters of Jiaozhou Bay mouth, with a Pb content of 37.53 $\mu\text{g/L}$. The currents reached northeast along the nearshore to the waters in the southeast of the bay and Pb content transported is 11.30 $\mu\text{g/L}$. Then, the offshore currents followed the northeastern coastal waters to the eastern coastal waters, where Pb content from the ship terminal was 13.91 $\mu\text{g/L}$. The currents remained to the northeast along the near shore, reaching the waters in the northeast of the bay. Here, Pb content from the Haibo River is 20.61 $\mu\text{g/L}$. Afterwards, The currents continued with a high content of Pb to the northeastern coastal waters, arriving the coastal waters of the entrance of Licun River, where Pb content transported from Licun River is 26.21 $\mu\text{g/L}$. Then, the currents flowed to the northeastern coastal waters, reaching the northernmost waters in the northeast of the bay, where Pb content from the Loushan River is 26.92 $\mu\text{g/L}$. Then, the current turned westward and reached the northern waters of the bay, carrying a Pb content of 20.42 $\mu\text{g/L}$. The current continued westward along the nearshore and reaches the westernmost waters of the northwestern part of the bay, where the Pb content from the Dagou River is 26.81 $\mu\text{g/L}$. Furthermore, the current turned to the south and destined the southwestern waters of the bay. Pb content contained by the current was 15.90 $\mu\text{g/L}$ (Figure 4). Therefore, in August, the ocean currents with a high content of Pb entered the Jiaozhou Bay, showing the spatial changes of the currents in the Jiaozhou Bay.

Figure.4. Spatial Variation Process of Pb content transportation in August ($\mu\text{g/L}$)

In October, the offshore currents were transported to the waters of Jiaozhou Bay mouth, with a Pb content of 13.25 $\mu\text{g/L}$. The currents flowed along the near shore to the northeast and reached the southeast waters of the bay, and The Pb content transported by the current is 9.67 $\mu\text{g/L}$. Then, the currents traveled along the northeastern coastal waters to the eastern coastal waters of Jiaozhou Bay, transporting Pb content of 4.21 $\mu\text{g/L}$. The current continued to the northeast along the near shore, arriving at waters in the northeast of the bay, where the Pb content from the Haibo River is 9.80 $\mu\text{g/L}$. The offshore currents then remained with high content of Pb to the near-shore waters of the northeast to the near-shore waters of the entrance of the Licun River, where the Pb content from the Licun River is 13.25 $\mu\text{g/L}$. The currents continued to the northeastern coastal waters with high content of Pb and reach the northernmost in the northeast of the bay, where Pb content is 7.11 $\mu\text{g/L}$. Then, the current turned westward along the near shore and reached the northern waters of the bay, where Pb content from surface runoff was 14.85 $\mu\text{g/L}$. The current continues westward along the near shore, reaching the westernmost waters of the northwestern part of the bay, importing Pb content from the Dagou River is 14.79 $\mu\text{g/L}$. Further, the current turned to the south along the near shore and reached the southwestern waters of the bay, with a Pb content of 6.41 $\mu\text{g/L}$ (Figure 5). Therefore, in October, the ocean currents with a high content of Pb entered the Jiaozhou Bay, demonstrating the spatial changes of the currents.

Figure.5. Spatial Variation Process of Pb content transportation in October ($\mu\text{g/L}$)

3.3 Time Variation of Source Delivery

In May, in the estuary of Jiaozhou Bay, Pb content transported from the offshore current was $20.79 \mu\text{g/L}$. In the eastern coastal waters of Jiaozhou Bay, Pb content from the ship terminal was $16.34 \mu\text{g/L}$. And in the waters near the estuary of the Licun River, Pb content from the Licun River was $37.90 \mu\text{g/L}$.

In August, in the waters of Jiaozhou Bay mouth, Pb content imported from the offshore current was $37.53 \mu\text{g/L}$. And in the coastal waters of the eastern Jiaozhou Bay, Pb content from the ship terminal was $13.91 \mu\text{g/L}$. In the waters in the northeast of the bay, Pb content from Haibo River was $20.61 \mu\text{g/L}$. Moreover, in the waters near the inlet of Licun River, Pb content f was $26.21 \mu\text{g/L}$. In the northernmost waters in the northeast of the bay, the Pb content from the Loushan River was $26.92 \mu\text{g/L}$. Further, in the westernmost waters of the northwestern part of the bay, Pb content transported from Dagū River was $26.81 \mu\text{g/L}$.

In October, in the waters of Jiaozhou Bay mouth, Pb content carried from the offshore current was $13.25 \mu\text{g/L}$. In the northeastern waters of the bay, Pb content from the Haibo River was $9.80 \mu\text{g/L}$. In addition, in the waters near the estuary of the Licun River, Pb content was $13.25 \mu\text{g/L}$ from the Licun River, and $14.85 \mu\text{g/L}$ from surface runoffs. In the westernmost waters of the northwestern part of the bay, the Pb content from the Dagū River is $14.79 \mu\text{g/L}$.

Four sources of Pb content were identified in the waters of Jiaozhou Bay, including transportation from ships and terminals, surface runoffs, rivers, and ocean currents. In addition, the transport of Pb content and transport time from these four sources to the Jiaozhou Bay marine water are shown in Table 1:

Table 1. The Pb contents and time scale from the different sources in Jiaozhou bay

Transportation Sources	Ships and terminals	Surface Runoffs	Rivers	Offshore Currents
Pb content/ $\mu\text{g}\cdot\text{L}^{-1}$	13.91-16.34	14.85	9.80-37.90	13.25-37.53

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Time	May, August	October	May, August, October	May, August, October

Pb content transported by the offshore current reached a maximum of $13.25 - 37.53 \mu\text{g/L}$. In May, August and October, transportation of Pb content from the offshore current to the Jiaozhou Bay marine water body was shown.

Pb content delivered by the ship terminal is relatively high from 13.91 to $16.34 \mu\text{g/L}$, which were discovered in May and August.

The content of Pb transported by river reaches the highest $9.80 - 37.90 \mu\text{g/L}$. In May, August, and October, rivers appeared to transport Pb content to the Jiaozhou Bay.

The Pb content of surface runoff transport is relatively low at $14.85 \mu\text{g/L}$ and only in October, surface runoff s transported Pb content.

There are four main rivers among the rivers entering the sea from around Jiaozhou Bay area, Haibo River, Licun River, Loushan River, and Dagū River; And delivery amount and time of Pb content of these rivers are shown in Table 2:

Table 2. The Pb contents and time scale from the different river sources in Jiaozhou bay

Sources	Haibo River	Licun River	Loushan River	Dagū River
Pb Content / $\mu\text{g}\cdot\text{L}^{-1}$	9.80-20.61	13.25-37.90	26.92	14.79-26.81
Time	August, October	May, August, October	August, October	August, October

Pb content transported from the Haibo River is $9.80 - 20.61 \mu\text{g/L}$, which only appeared in August and October.

Pb content from the Licun River is $13.25 - 37.90 \mu\text{g/L}$. And the importation was found in all May, August, and October.

Pb content carried by Loushan River was $26.92 \mu\text{g/L}$. In August and October, Loushan River appeared to transport Pb content to the Jiaozhou Bay marine water body.

The Pb content imported from Dagū River is $14.79 - 26.81 \mu\text{g/L}$ and was only detected in August and October.

4 Discussion

4.1 Pollution from Transportation Source

There are four sources of Pb content in the waters of Jiaozhou Bay, which are mainly from ships and terminals, surface runoffs, rivers, and ocean currents.

First and foremost, the Pb content of surface runoff transport relatively low at $14.85 \mu\text{g/L}$, which was only in October. Thus, it is concluded that the Pb content transported by surface runoff is relatively low, and the time of transportation within a year is also very short.

Pb content delivered by the ship terminal is quite high from 13.91 to $16.34 \mu\text{g/L}$, appearing in May and August

for human activities at sea are expanding and ships and terminals are in heavy traffic. In this way, the content of Pb transported to the ocean is increasing, and the time of transportation is also accelerating.

The content of Pb transported by rivers reaches the highest 9.80 - 37.90 µg/L and was detected in May, August, and October, indicating that the river is the main source of Pb content in the waters of Jiaozhou Bay and for the time span of a whole year. Therefore, Pb discharged by human beings on the land is brought together, resulting in the content of Pb transported by rivers on the land reaching the highest level throughout the year.

The Pb content transported by the offshore current reached a maximum of 13.25 - 37.53 µg / L in May, August, and October. This result indicates that with human activities bringing Pb content to the land and the ocean, Pb content is continuously transported to the ocean through three ways: surface runoffs, ships and terminals, and rivers. After years of transportation, Pb content has accumulated in the ocean, causing an increase of Pb in the ocean. Therefore, the Pb content transported by the ocean currents in the open sea is very high, transporting to the water body of low content of Pb throughout the year.

During the year, the Pb content delivered by the three sources of shipping terminal, surface runoff, and the rivers is greater than 9.80 µg/L, revealing that during this year, the shipping terminal, land and river are all heavily polluted. And Pb content carried by the ocean currents was greater than 13.25 µg/L, suggesting that the entire ocean was heavily polluted by the Pb content this year.

4.2 Pollution of Different Rivers

Among the rivers entering the sea around Jiaozhou Bay, there are four main ones: Haibo River, Licun River, Loushan River, and Dagū River. These rivers all import Pb to the waters of Jiaozhou Bay. According to the Pb content transported by the river, the sequence from high to low goes: Licun River>Loushan River>Dagū River>Haibo River. The time of Pb content delivery in Licun River is longer than the other rivers while delivery time in Haibo River, Loushan River, and Dagū River are all the same. As a result, among the inflow rivers around Jiaozhou Bay, Licun River transported the highest amount of Pb content at 13.25 - 37.90 µg / L for the longest time throughout the year. Therefore, control methods must be employed for the Pb content by rivers, especially the Licun River.

The Haibo River, Licun River, Loushan River, and Dagū River were all heavily polluted by Pb content. Among these four rivers, the Licun River is most polluted, and the Licun River has been carrying the highest levels of Pb throughout the year. The Haibo River, Loushan River, and Dagū River contains high levels of Pb two-thirds of the year. Therefore, it is necessary to rigidly control the discharge of Pb content in rivers, centralize management on the control of Pb content in rivers, and reduce the Pb content of rivers transported to the ocean.

5 Conclusion

Based on the Yang Dongfang migration law of material content, after the ocean currents with a high content of Pb entering the Jiaozhou Bay, the spatial changes of various sources transporting Pb content in May, August and October were displayed and model block diagram was used to study the changing process of Pb content transported by ocean currents in the waters of Jiaozhou Bay. The location, magnitude, type, and time of the source of Pb content in the waters of Jiaozhou Bay were determined, acquiring the four sources of Pb content in the waters of Jiaozhou Bay, which are ships and terminals, surface runoffs, rivers, and offshore currents. The amount of Pb transported by surface runoff to the waters of Jiaozhou Bay is relatively low and transport time in a year is also short. However, Pb content delivered by the ship terminal to the marine water body of Jiaozhou Bay is increasing due to heavy traffic of the ship terminal, and the delivery time is also increasing. Rivers take in all the Pb content discharged by humans onto the land, causing the highest content of Pb transported in terrestrial rivers, and transported from land to sea for the whole year. After years of transportation and accumulation, Pb content from the offshore currents is very high, which has also been carried to the water body of low content of Pb throughout the year.

During the year, the shipping terminal, surface runoff, and river, the Pb content delivered by these three sources is greater than 9.80 µg/L, indicating heavy pollution. Within the same year, the Pb content in the open sea was greater than 13.25 µg/L, which also revealed that the entire ocean was severely polluted by the Pb.

Among the rivers entering the sea around Jiaozhou Bay, the four main ones: Haibo River, Licun River, Loushan River, and Dagū River, import Pb to Jiaozhou Bay with the sequence of the following: Licun river>Loushan river>Dagū river>Haibo river. Meanwhile, the time of transportation of Pb content in Licun River is longer than other rivers as the time of Haibo River, Loushan River and Dagū River stays the same.

The Haibo River, Licun River, Loushan River, and Dagū River were all heavily polluted by Pb. Among these four rivers, the Licun River is most polluted by Pb content, and it has been carrying high levels of Pb throughout the year. Therefore, the Pb content discharged into rivers should be strictly controlled.

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