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The Migration Rule of Pb Content Transported from Different Sources

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Abstract

According to the survey materials of the waters of Jiaozhou Bay in May, September and October 1993, this article studied the content of Pb and its horizontal distribution in the surface water bodies. The results showed that the Pb content in the waters of Jiaozhou Bay ranged within 0.62 - 3.05 μg/L, which conformed to the seawater standard of Class I and II. And it also indicated that in terms of the Pb content, the water bodies of Jiaozhou bay were mildly contaminated by Pb content in May, September and October. The Pb content in Jiaozhou bay mainly had three sources, the transportation of rivers, surface runoff and offshore ocean currents. The Pb content was 2.13 μg/L transported from the rivers, 2.74 μg/L from the surface runoff and 3.05 μg/L from the offshore ocean currents. It demonstrated that the transportation of rivers, surface runoff and offshore ocean currents had been moderated polluted by Pb content. Three different migration paths of Pb content, from land, ocean to Jiaozhou Bay water bodies, have been expressed in model block diagram. In the migration process of Pb content transported from different sources, the author found out the migration rules: 1) the Pb content was continuously decreased with the extension of migration distance; 2) the Pb content in the ocean water body was very high with the accumulation of Pb content in the ocean.

Keywords

Pb Content, Sources, Process, Rules, Jiaozhou Bay

1. Introduction

Humans continually emit Pb content to land, ocean and atmosphere which brings the Pb pollution to global environment and ecology. The Pb content is transported to the ocean and is gradually accumulated in the ocean in the final (Yang, Su, & Gao, 2008; Yang, Guo, Zhang, Ding, & Bu, 2011; Yang, Zhu, Wang, He, & Yang, 2014; Yang, Geng, Chen, Xu, & Cui, 2014; Yang, Ge, Sun, Li, & Yang, 2014; Yang, Zhu, Wang, Yang, & Wu, 2014). Therefore, the pollution degree, sources of pollution, and the migration process of Pb content in the coastal waters have attracted much attention. Based on the survey data in 1993, this article discussed the Pb content, horizontal distribution, and its sources in the waters of Jiaozhou Bay, and determined the water quality, sources background, volume of sources, and migration paths and process, providing scientific and theoretical basis for the study of sources of Pb, pollution degree and migration process.

2. Survey Waters, Materials and Methods

2.1. Natural Environment of Jiaozhou Bay

Jiaozhou Bay is located in the southern part of Shandong Peninsula. Its geographical position is between 120˚04' E - 120˚23'E and 35˚58' N - 36˚18'N. It is bounded by the line connecting Tuan Island and Xuejia Island, and is connected to the Yellow Sea. With an area of about 446 km^2 and an average water depth of about 7 m, it is a typical semi-enclosed bay. There are more than a dozen rivers entering the sea in Jiaozhou Bay, among which the Dagu River, Yang River and the Haibo River, Licun River and Loushan River in Qingdao City with larger runoff and sand content. These rivers are all seasonal rivers, and the river hydrological characteristics have obvious seasonal changes (Yang, Chen, & Gao, 2005; Yang, Wang, & Gao, 2004).

2.2. Materials and Methods

The survey data of Cd content in Jiaozhou Bay in May, September and October 1993 used in this study are provided by the North Sea Monitoring Center of the State Oceanic Administration. Seven stations were set up in the waters of Jiaozhou Bay to take water samples: stations H3101, H3102, H3103, H3104, H3105, H3106 and H3107 (**Figure 1**). Sampling was conducted three times in May, September and October 1993, respectively. Water samples were taken according to the water depth (surface and bottom layers were taken when the depth > 10 m, and only the surface layer was taken when the depth < 10 m) for investigation and sampling. The survey of PHC content in Jiaozhou Bay water body was carried out according to the national standard method, which was recorded in the national "Marine Monitoring Code" (SOA, 1991).

3. Results

3.1. Pb Content

The nation has put forward the national seawater standards of Class I (1.00 μg/L), Class I (5.00 μg/L), Class III (10.00 μg/L) and Class IV (50.00 μg/L). In May, September and October, the content of Pb in the waters of Jiaozhou Bay

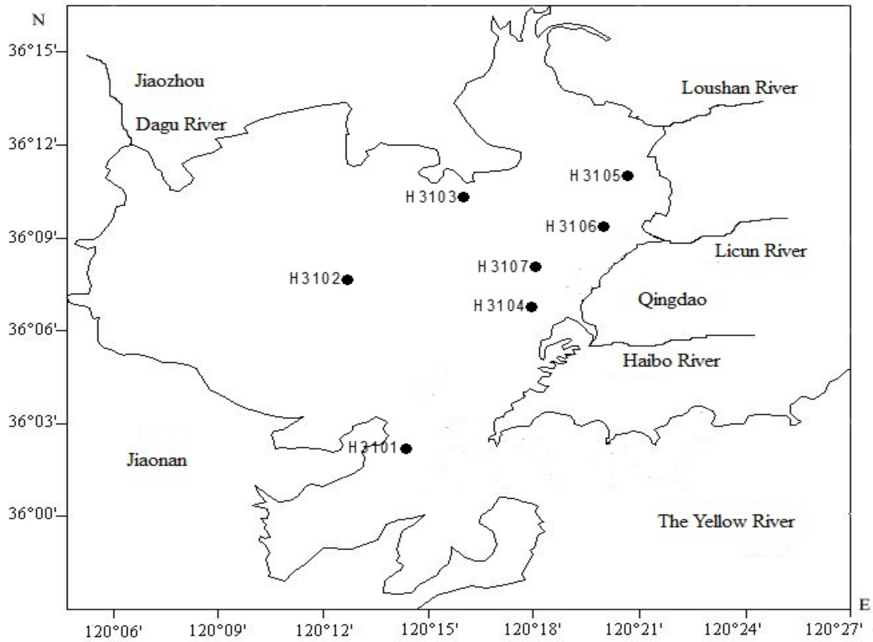

Figure 1. Investigation sites in Jiaozhou Bay.

ranged within 0.62 - 3.05 μg/L, which met the seawater standards of Class I and II.

In May, the Pb content in the waters of Jiaozhou Bay ranged within 0.84 - 2.13 μg/L (**Table 1**). The high value area appeared in the estuary of nearshore waters of Haibo River, station H3104 and H3107, where the range of Pb content was 2.02 - 2.13 μg/L that met the national seawater standard of Class II (5.00 μg/L). The low value area appeared in the northern and northeastern waters of Jiaozhou Bay, station H3103 and H3105, where the range of Pb content was relatively low, 0.84 - 0.97 μg/L, met the national seawater standard of Class I (1.00 μg/L). In other water areas of Jiaozhou Bay, the Pb content was relatively high, which exceeded the national seawater standard of Class I (1.00 μg/L) but lower than the national seawater standard of Class II (5.00 μg/L). In May, the Pb content in the entire waters of Jiaozhou Bay was relatively high, and the variation range of Pb content was 0.84 - 2.13 μg/L, met the national seawater standards of Class I and Class II.

In September, the Pb content in the waters of Jiaozhou Bay ranged within 0.78 - 2.74 μg/L (**Table 1**). The high value area appeared in the northern nearshore waters and the central waters of Jiaozhou Bay, station H3103 and H3102, where the range of Pb content was 2.05 - 2.74 μg/L that met the national seawater standard of Class II (5.00 μg/L). The low value area appeared in the eastern waters of Jiaozhou Bay, station H3104, H3107 and H3106, where the range of Pb content was relatively low, 0.78 - 0.84 μg/L, met the national seawater standard of Class I (1.00 μg/L). In other water areas of Jiaozhou Bay, the Pb content was relatively high, which exceeded the national seawater standard of Class I (1.00 μg/L) but lower than the national seawater standard of Class II (5.00 μg/L). In

Table 1. The surface water quality in Jiaozhou bay in May, September and October.

	May	September	October
Pb content/μg·L^{-1} in the seawater	0.84 - 2.13	0.78- 2.74	0.62 - 3.05
National Seawater Standards	Class I & II	Class I & II	Class I & II

September, the Pb content in the entire waters of Jiaozhou Bay was relatively high, and the variation range of Pb content was 0.78 - 2.74 μg/L, met the national seawater standards of Class I and Class II.

In October, the Pb content in the waters of Jiaozhou Bay ranged within 0.62 - 3.05 μg/L (**Table 1**). The high value area appeared in the mouth waters of the bay, station H3101, where the highest value of Pb content was 3.05 μg/L that met the national seawater standard of Class II (5.00 μg/L). The low value area appeared in the northern waters of Jiaozhou Bay, station H3103, and H3105, where the range of Pb content was relatively low, 0.62 - 0.79 μg/L, met the national seawater standard of Class I (1.00 μg/L). In other water areas of Jiaozhou Bay, the Pb content was relatively high, which exceeded the national seawater standard of Class I (1.00 μg/L) but lower than the national seawater standard of Class II (5.00 μg/L). In October, the Pb content in the entire waters of Jiaozhou Bay was relatively high, and the variation range of Pb content was 0.78 - 2.74 μg/L, met the national seawater standards of Class I and Class II.

Therefore, the variation range of Pb content in the waters of Jiaozhou Bay was 0.62 - 3.05 μg/L in May, September and October, which met the seawater standards of Class II, III and IV. It indicated that the entire water body of Jiaozhou Bay was mildly polluted by Pb content (**Table 1**).

3.2. Horizontal Distribution in the Surface Layer

In May, in the estuary coastal waters of Haibo River, station H3107, the Pb content was the highest, 2.13 μg/L. A high Pb content area was formed centered on the coastal waters of the estuary of Haibo River, and there appeared a series of semi-circles with different gradients. The Pb content decreased from the high content of 2.13 μg/L in the center to the surroundings along the gradient, to 0.97 μg/L in the northeastern waters of the bay, to 0.84 μg/L in the northern waters of the bay, and to 1.14 μg/L in the central waters of the bay (**Figure 2**).

In September, in the northern waters of Jiaozhou bay, station H3103, the highest Pb content was 2.74 μg/L. A high Pb content area was formed centered on the northern waters of the bay, forming a series of semi-circles with different gradients. The Pb content decreased from the high content of 2.74 μg/L in the center to the surroundings along the gradient, to 0.84 μg/L in the eastern waters of the bay, to 0.80 μg/L in the southeastern waters of the bay, and to 1.14 μg/L in the central waters of the bay (**Figure 3**).

In October, in the mouth waters of Jiaozhou bay, station H3101, the highest Pb content was 3.05 μg/L. A high Pb content area was formed centered on the mouth waters of the bay, forming a series of semi-circles with different gradients.

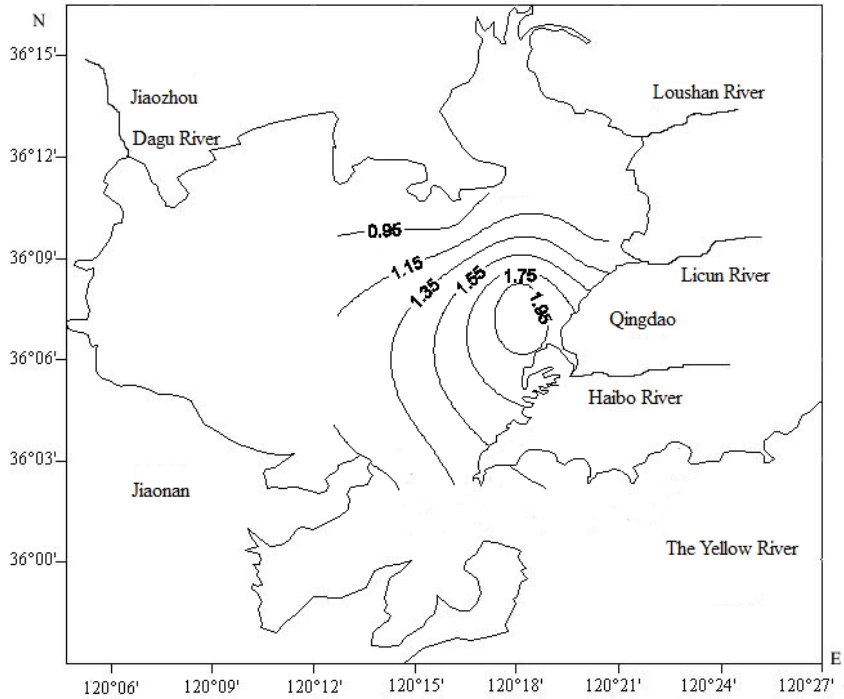

Figure 2. Pb content distribution at the surface in Jiaozhou Bay in May (μg/L).

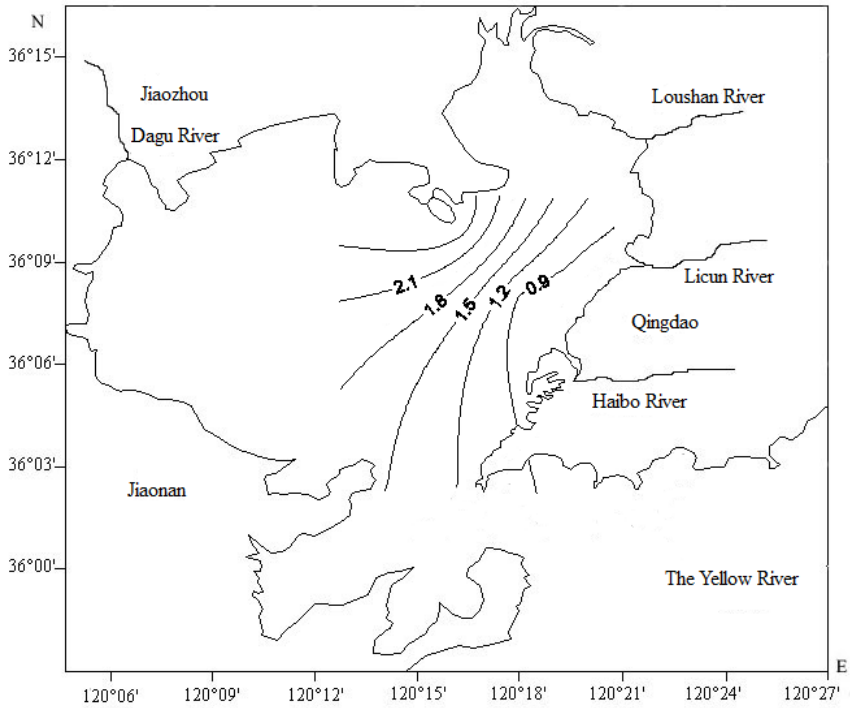

Figure 3. Pb content distribution at the surface in Jiaozhou Bay in September (μg/L).

The Pb content decreased from the high content of 3.05 μg/L in the center to the surroundings along the gradient, to 0.90 μg/L in the southwestern waters of the bay, to 1.28 μg/L in the central waters of the bay, and to 0.62 μg/L in the northern waters of the bay (**Figure 4**).

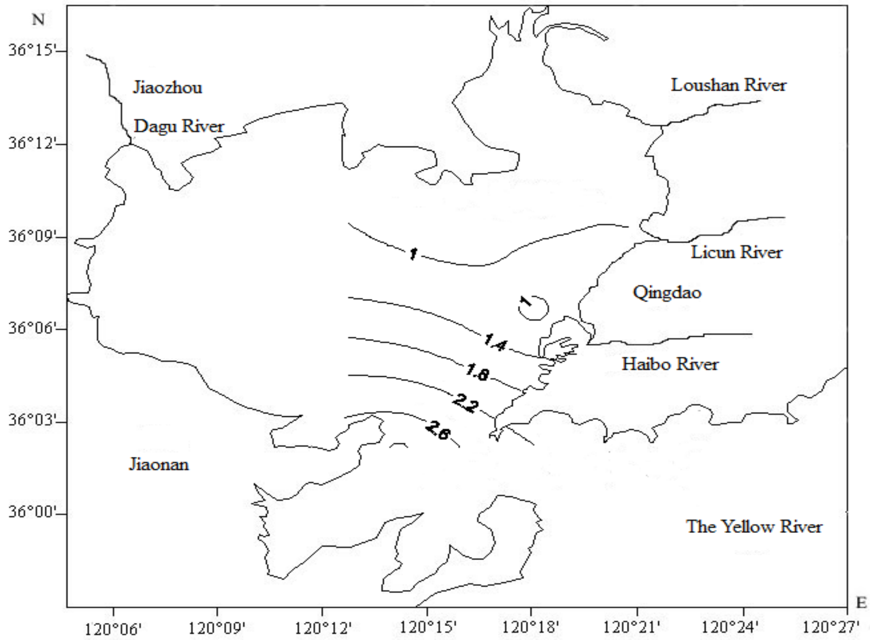

Figure 4. Pb content distribution at the surface in Jiaozhou Bay in October (μg/L).

4. Discussion

4.1. Water Quality

In May, September and October, the Pb content in the waters of Jiaozhou Bay was 0.62 - 3.05 μg/L, which conformed to the national seawater standards of Class I and II. It indicated that in terms of Pb content, in May, September and October, the entire water body of Jiaozhou Bay was mildly polluted by Pb.

In May, the variation range of Pb content in the waters of Jiaozhou Bay was 0.84 - 2.13 μg/L, indicating that the water body of Jiaozhou Bay was mildly polluted by Pb. In the estuary of coastal waters of Haibo River, the Pb content ranged within 2.02 - 2.13 μg/L, which indicated that the water quality in this area achieved the seawater quality standard of Class II and the water was mildly polluted by Pb. In the northern waters and the northeastern waters of Jiaozhou Bay, the Pb content was relatively low, ranging within 0.84 - 0.97 μg/L. It indicated that in terms of Pb content, the water quality reached the seawater standard of Class I, so the water did not get any contamination of Pb. In other water areas of Jiaozhou Bay, the Pb content was relatively high, exceeding the national seawater standard of Class I (1.00 μg/L) but conforming to the national seawater standard of Class II (5.00 μg/L). Therefore, the water was slightly polluted by Pb content.

In September, the variation range of Pb content in the waters of Jiaozhou Bay was 0.78 - 2.74 μg/L, indicating that the water body of Jiaozhou Bay was mildly polluted by Pb. In the northern coastal waters and the central waters of Jiaozhou Bay, the Pb content ranged within 2.05 - 2.74 μg/L, which indicated that the water quality in this area achieved the seawater quality standard of Class II and the water was mildly polluted by Pb. In the eastern waters of the bay, the Pb content was relatively low, ranging within 0.78 - 0.84 μg/L. It indicated that in terms of

Pb content, the water quality reached the seawater standard of Class I, so the water did not get any contamination of Pb. In other water areas of Jiaozhou Bay, the Pb content was relatively high, exceeding the national seawater standard of Class I (1.00 μg/L) but conforming to the national seawater standard of Class II (5.00 μg/L). Therefore, the water was slightly polluted by Pb content.

In October, the variation range of Pb content in the waters of Jiaozhou Bay was 0.62 - 3.05 μg/L, indicating that the water body of Jiaozhou Bay was mildly polluted by Pb. In the mouth waters of the bay, the Pb content was 3.05 μg/L, which indicated that the water quality in this area achieved the seawater quality standard of Class II and the water was mildly polluted by Pb. In the northern waters and northeastern of the bay, the Pb content ranged within 0.62 - 0.79 μg/L. It indicated that in terms of Pb content, the water quality reached the seawater standard of Class I, so the water did not get any contamination of Pb. In other water areas of Jiaozhou Bay, the Pb content was relatively high, exceeding the national seawater standard of Class I (1.00 μg/L) but conforming to the national seawater standard of Class II (5.00 μg/L). Therefore, the water was slightly polluted by Pb content.

4.2. Sources

In May, it formed a high Pb content area in the estuary of coastal waters of Haibo River, which indicated that the Pb was sourced from the transportation of Haibo River with a relatively high content of 2.13 μg/L.

In September, it formed a high Hg content area in the northern waters of the bay, which indicated that the Pb was sourced from the transportation of land surface runoff, and the Pb content was 2.74 μg/L.

In October, it formed a high Hg content area in the mouth waters of the bay, which indicated that the Pb was sourced from the offshore currents with a relatively high content of 3.05 μg/L.

The Pb content in the waters of Jiaozhou Bay mainly transported from three sources, rivers, surface runoff and offshore currents. The Pb content transported from rivers was 2.13 μg/L, from surface runoff was 2.74 μg/L and from offshore currents was 3.05 μg/L.

The Pb content transported from rivers, surface runoff and offshore currents all exceeded the national seawater standard of Class I (1.00 μg/L) but conformed the national seawater standards of Class II (5.00 μg/L). It indicated that the transportation of rivers, surface runoff and offshore currents had slightly polluted by Pb content (**Table 2**). Therefore, the source of Pb pollution in the waters of Jiaozhou Bay was a non-point pollution source, which mainly came from

Table 2. The surface water quality in Jiaozhou bay in May, September and October.

Different Sources	Transportation of rivers	Transportation of surface runoff	Transportation of offshore currents
Pb content/μg·L^{-1}	2.13	2.74	3.05

the transportation of rivers, the transportation of surface runoff, and the transportation of offshore currents.

4.3. Transportation Paths of Pb Content

The Pb content mainly had three sources, the transportation of rivers, surface runoff and offshore currents. Thus, human activities took Pb content to the land and ocean and the Pb content was transported to the ocean water body through these three paths.

From land, ocean to the water body of Jiaozhou Bay, three different migration paths of Pb content are shown in the following: 1) Human activities directly discharged Pb content on land. Through rainwater, the Pb content transported from surface runoff directly to the water body of Jiaozhou Bay was 2.13 μg/L. 2) Humans discharged Pb content to land, and then transported the Pb content to the ocean through rivers. The Pb content transported by rivers to the water body of Jiaozhou Bay was 2.74 μg/L. 3) Humans discharged Pb content to land and oceans, and then transported Pb content to the ocean through the above paths. Over time, the accumulation of transported Pb content in the ocean resulted in an increase in the Pb content of the ocean. And through the transportation of ocean currents, Pb content was transported from high content areas to low content areas. The Pb content of the offshore ocean currents transported to the water body of Jiaozhou Bay was 3.05 μg/L. This reveals how the Pb content from human emissions reached the waters of Jiaozhou Bay through three paths (**Figure 5**).

The order of Pb content transported by different paths to the waters of Jiaozhou Bay from large to small is: Pb content transported by offshore ocean currents > Pb content transported by surface runoff > Pb content transported by rivers. Therefore, the Pb content in the ocean water was very high, and the ocean was slightly polluted by the Pb content. In terms of Pb content, the slight pollution of the ocean has aroused human attention.

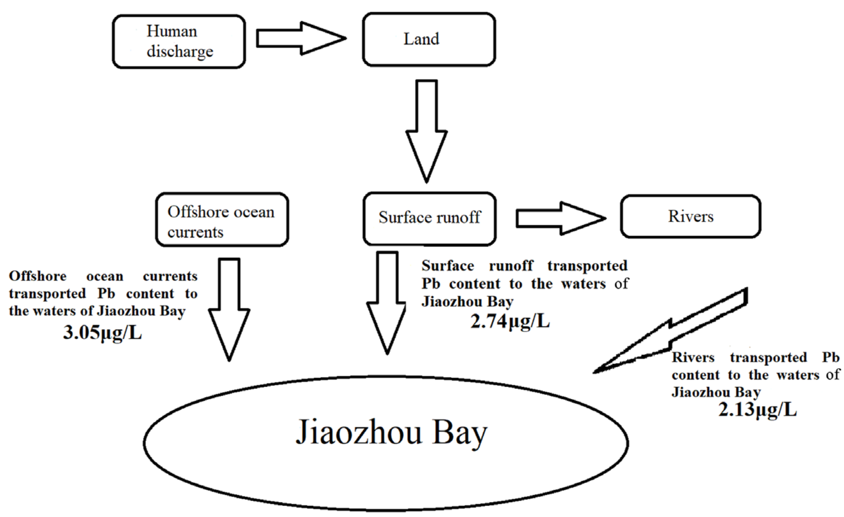

Figure 5. The transportation paths of Pb content into ocean.

4.4. Migration Deposition of Pb Content

With the rapid development of industry, humans have discharged a large amount of waste water, waste gas and solid waste containing Pb into the atmosphere, land and ocean during various activities. The Pb content in the atmosphere sinks to land and oceans, and then is transported to ocean waters.

In the waters of Jiaozhou Bay, there were three main sources of Pb content: river transportation, surface runoff transportation and offshore ocean currents transportation, showing three different migration paths for Pb content. The Pb content followed the migration paths, revealing the migration and changing process of the Pb content:

1) The content of Pb discharged by humans to the land was relatively high, so the content of Pb transported by surface runoff directly to the ocean through the surface was relatively high, which was 2.74 μg/L.

2) The content of Pb discharged by humans to the land was relatively high. The surface runoff of the land gathered the Pb content on the land, and then transported the Pb content to rivers. During the transportation process of rivers, the Pb content continued to sink, and when the river flowed to the coastal waters of the bay, the Pb content became relatively low. The content of Pb transported by rivers to the ocean was relatively low, which was 2.13 μg/L.

3) Human activities brought Pb content to the land and ocean. Through surface runoff and rivers, Pb content was continuously transported to the ocean. After years of transportation, the Pb content in the ocean continued to settle and accumulate, resulting in the increase of Pb content in the ocean. This revealed that the Pb content of ocean water bodies was very high, and the Pb content transported by the offshore ocean current was very high, 3.05 μg/L (**Figure 5**).

With three different migration paths of Pb content, this paper established a model block diagram of Pb content along the migration paths, revealing the migration and changing process of Pb content. In the migration process of Pb content from different sources, the author discovered the migration rules of Pb content: 1) As the migration distance increased, the Pb content continued to decrease. 2) Pb content continued to accumulate in the ocean, resulting in the high Pb content in the ocean waters.

5. Conclusion

In May, September and October, the Pb content in the waters of Jiaozhou Bay was 0.62 - 3.05 μg/L, which conformed to the national seawater standards of Class I and II. It indicated that in terms of Pb content, in May, September and October, the entire water body of Jiaozhou Bay was mildly polluted by Pb.

In May, the variation range of Pb content in the waters of Jiaozhou Bay was 0.84 - 2.13 μg/L, indicating that the water body of Jiaozhou Bay was mildly polluted by Pb. In the estuary of coastal waters of Haibo River, the Pb content was relatively high, which indicated that the water was mildly polluted by Pb. In the northern waters and the northeastern waters of Jiaozhou Bay, the Pb content was relatively low, indicating that the water did not get any contamination of Pb. In other water areas of Jiaozhou Bay, the Pb content was relatively high, and the water was slightly polluted by Pb content.

In September, the variation range of Pb content in the waters of Jiaozhou Bay was 0.78 - 2.74 μg/L, indicating that the water body of Jiaozhou Bay was mildly polluted by Pb. In the northern coastal waters and central waters of the bay, the Pb content was relatively high, which indicated that the water was mildly polluted by Pb. In the eastern waters of Jiaozhou Bay, the Pb content was relatively low, indicating that the water did not get any contamination of Pb. In other water areas of Jiaozhou Bay, the Pb content was relatively high, and the water was slightly polluted by Pb content.

In October, the variation range of Pb content in the waters of Jiaozhou Bay was 0.62 - 3.05 μg/L, indicating that the water body of Jiaozhou Bay was mildly polluted by Pb. In the mouth waters of the bay, the Pb content was relatively high, which indicated that the water was mildly polluted by Pb. In the northern waters and the northeastern waters of Jiaozhou Bay, the Pb content was relatively low, indicating that the water did not get any contamination of Pb. In other water areas of Jiaozhou Bay, the Pb content was relatively high, and the water was slightly polluted by Pb content.

The Pb content in Jiaozhou bay mainly had three sources, the transportation of rivers, surface runoff and offshore ocean currents. The Pb content was 2.13 μg/L transported from the rivers, 2.74 μg/L from the surface runoff and 3.05 μg/L from the offshore ocean currents. It demonstrated that the transportation of rivers, surface runoff and offshore ocean currents had been moderated polluted by Pb content.

From land, ocean to Jiaozhou Bay water bodies, there are three different migration paths of Pb content: 1) The Pb content transported by surface runoff from land directly to the ocean; 2) The Pb content transported by rivers to the ocean; 3) The Pb content transported by ocean currents from high content area to low content area. In addition, this article applied model block diagram to reveal the change of Pb content transported by three paths to the ocean.

The order of Pb content transported by different paths to the waters of Jiaozhou Bay from large to small is: Pb content transported by offshore ocean currents > Pb content transported by surface runoff > Pb content transported by rivers. Therefore, the Pb content in the ocean water was very high, and the ocean was slightly polluted by the Pb content. In terms of Pb content, the slight pollution of the ocean has aroused human attention.

In the migration process of Pb content transported from different sources, the author found out the migration rules: 1) the Pb content was continuously decreased with the extension of migration distance; 2) the Pb content in the ocean water body was very high with the accumulation of Pb content in the ocean.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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