Mechanism of Cd Content Migration in Sea and Land

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Abstract: based on the survey data of Cd content in Jiaozhou Bay in May, August and October of 1992, the paper studies the process of ocean current transport and the source of Cd content in Jiaozhou Bay. The spatial variation of Cd content from source transport in May, August and October is shown according to Dongfang Yang’s matter content migration rule, which is revealed with the model block diagram. The location, size, type and time scale of source of Cd content transport are also determined. There were three main sources of Cd content in Jiaozhou Bay, from run-off transport, river transport and main sea current transport. Rivers carried Cd content in excess of 0.96 μg/L over the year, slightly polluting land and rivers. In addition, Cd content in run-off and main sea current was greater than 1.10 μg/L, which means the whole land and ocean were slightly polluted by Cd content. Among rivers flowing into Jiaozhou Bay, there are four major rivers which carried Cd content into the waters of Jiaozhou Bay: Haibo River, Licun River, Loushan River and Dagu River. According to Cd content in the river, from high to low was: Dagu River > Licun River > Loushan River > Haibo River. The Cd content transport time scale of Licun River, Loushan River and Dagu River was the same, while that of Haibo River was shorter. The mechanism of land transport and sea transport is put forward by authors, and the mechanism of alternating migration of Cd content between land and sea is revealed. In May, the land began transporting large quantities of Cd into the sea; from May to August, the land transported Cd content to the sea for three months; In August, the transport from land to sea ended, and the main sea current began to transport Cd content in large quantities; from August to October, the main sea current transported Cd content to the ocean for two months; In October, transport of the main sea current ended, and rivers began to carry Cd to the ocean again. The Cd content transported by northern run-off in May was 1.10 μg/L and the Cd content transported by main sea current in August was 1.11 μg/L, which further confirmed the authors’ theory of matter uniformity. It can be seen that the Cd content transported by land and by sea was the same. Thus land and sea had the consistency of matter content.

1. Introduction
With the continuous development of economy, cadmium (Cd) content is continuously discharged in the production and use of various products containing it. Cd content is transported to the ocean through run-off and rivers, bringing a large amount of high content Cd to the ocean [1-6]. Therefore, in the ocean, Cd content migrates from one water body to another with the transport of ocean current [1-6]. According to the survey data in 1992, sources, transport volume and time scale of Cd content in Jiaozhou Bay water body were studied, as well as the pollution sources, pollution levels and migration process of Cd content, which provides a scientific theoretical basis for studying the variation trend of Cd content in marine water bodies.
2. Water Area, Data and Methods

2.1. Natural Environments of Jiaozhou Bay. Jiaozhou Bay (120°04'-120°23'E, 35°58'-36°18'N) is a typical semi-closed bay. It is located in the south of Shandong Peninsula, bounded by Tuan Island and Xuejia Island, connected with the Yellow Sea, with an area of about 446km² and an average depth of about 7m. There are more than a dozen rivers entering Jiaozhou Bay, all of which are seasonal rivers — hydrological characteristics have obvious seasonal changes [7, 8]. Among them, Dagu River and Yang River, Haibo River, Licun River and Loushan River in Qingdao are the rivers with large run-off and sediment concentration.

2.2. Data and Methods. This paper uses the Cd survey data of Jiaozhou Bay in May, August and October 1992, provided by North China Sea Environmental Monitoring Center. There are altogether 13 water sample sites in Jiaozhou Bay: 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 2104, 2105 and 2106 (Figure 1). Three samples were taken for investigation in May, August and October 1992, respectively, according to the depth (When the depth > 10m, take samples of the surface and bottom. When the depth < 10m, only take samples of the surface layer). The investigation of Cd in Jiaozhou Bay was conducted according to the standard methods stipulated in the Specification for Marine Monitoring (1991) [9].

3. Results

3.1. Movement Track of Ocean Current in Jiaozhou Bay. According to Dongfang Yang’s matter content transfer rule proposed by the authors, the longer the matter content is transmitted, the more matter is lost in the transmission process. If the substance content comes from the same beginning and reaches the same end, and the substance content at the beginning is the same value, the longer the journey, the lower the value of the substance content at the end. This rule confirmed that the Cd content transported to Jiaozhou Bay by the main sea current was relatively high, and with the decrease of Cd content, the flow track of the main sea current was left in the waters of Jiaozhou Bay.

The main sea current carried Cd content from Jiaozhou Bay through the bay mouth. Thus it showed the flow trail in the waters of Jiaozhou Bay (Figure 2): In Jiaozhou Bay, the current moved northeast forward along the coast and reached the southeast waters of Jiaozhou Bay at site 60. Then it continued to flow to the northeast along the coast and reached the coastal waters near the estuary of Haibo River, where the Cd content was transported by Haibo River and the site is 59. The current continued to flow...
northeast along the shore and reached the coastal waters near the estuary of Licun River site 58, where Cd content was transported by Licun River. The current continued to flow to the northeast along the shore and reached the northermmost part of the northeastern bay site 2104. Cd content here came from Loushan River transportation. The current then flowed west along the coast to site 57, north of the bay. The current continued to the west along the shore and reached the western end northwest of the bay site 56, where Dagu River transported Cd content. The water then turned south along the coast to southwest of the bay site 54, which is very close to the bay mouth.

Figure 2 The flow path of the main sea current with a high content of Cd in Jiaozhou Bay in August (μg/L)

3.2. Spatial Variation of Source Transport. According to Dongfang Yang’s matter content migration rule proposed by the authors, the main sea current with Cd entered Jiaozhou Bay through the bay mouth and surrounded the coastal waters within the bay. Cd content from different sources was found in a circle of coastal waters in the bay under the action of main sea current transport. The spatial variation of Cd content during source transport is introduced.

In May, Cd content of 0.59 μg/L was transported by the main sea current to the bay mouth. The current carrying a Cd content of 0.23 μg/L flowed northeast along the coast to the waters southeast of the bay. The current then continued northeast along the inshore to the estuary inshore waters of the Haibo River, where Cd content of 1.07 μg/L was transported by the river. The main sea current continued to carry high Cd content to the northeastern coastal waters, reaching the estuary of the Licun River, where Cd content of 1.20 μg/L was transported by the river. The main sea current continued to carry high Cd content to the northeastern coastal waters, reaching the northermmost waters in the northeast of the bay, where Cd content ranged from 1.00 to 1.16 μg/L from the Loushan River. The current then moved westward along nearshore waters to the northern waters of the bay, where Cd content from run-off was higher at 1.10 μg/L. The current continued westward to the westernmost part of the northwestern bay, where 1.53 μg/L of Cd was transported by the Dagu River. The current then turned southward along the inshore waters to the southwest waters of the bay, carrying a Cd content of 0.91 μg/L. Therefore, in May, the main sea current carried Cd content into Jiaozhou Bay. Under the transport of the main sea currents, Cd content was transported by various river sources and run-off sources in a circle of nearshore waters within the bay, resulting in a high Cd content, which shows the spatial variation process of Cd content transported by sources.

In August, the Cd content in the main sea current flowing to the bay mouth was 1.11 μg/L. Cd content along a ring of nearshore waters around the bay was 0.11 μg/L-0.96 μg/L after the main sea current carried
Cd content into Jiaozhou Bay. The westernmost water body of the northwestern bay contained 0.96 μg/L Cd from Dagu River. As a result, the main sea current carried high content of Cd into Jiaozhou Bay in August. Under the action of the main sea current transport, only Dagu River transported the Cd content to the coastal waters of Jiaozhou Bay, which resulted in the lower Cd content in the coastal waters of Jiaozhou Bay, reflecting the spatial variation process of the high Cd content in the main sea current in Jiaozhou Bay.

In October, the main sea current brought Cd content of 0.39 μg/L to the bay mouth. The current flowed to the estuary of Licun River along the northeast coastal waters, and Cd content was 1.10 μg/L. The main sea current continued to carry high Cd content into the northeastern coastal waters of the bay to the northernmost end of northeastern bay, with Cd content of 1.04 μg/L transported by Loushan River. The current flowed westward along the coast to the westernmost part of the northwestern bay. The current then flowed south along the coast to the waters southwest of the bay. The current carried Cd content of 0.37-0.66 μg/L from the westernmost end of the northwestern bay to the southwest of the bay. Therefore, in October, the main sea current brought Cd into Jiaozhou Bay, and a ring of coastal waters in the bay were transported by various rivers. The Cd content was relatively high, which reflected the spatial variation process of Cd content in source transport.

3.3. Temporal Variation of Source Transport. In May, there was 1.07 μg/L of Cd transported by the Haibo River in the coastal waters near its estuary. Cd content of 1.20 μg/L was recorded near the estuary of Licun River. In the coastal waters of Loushan River estuary, Cd content of 1.16 μg/L was transported by Loushan River. In the northern waters of the bay, Cd content from run-off was 1.10 μg/L. Cd content of 1.53 μg/L was recorded near the estuary of the Dagu River.

In August, the Cd content of bay mouth transported by the main sea current was 1.11 μg/L. Near the estuary of Dagu River, Cd content was 0.96 μg/L.

In October, Cd content near the estuary of Licun River was 1.10 μg/L. The Cd content in the coastal waters of Loushan River estuary was 1.04 μg/L, which was transported by Loushan River.

The main sources of Cd content in Jiaozhou Bay were run-off transport, river transport and main sea current transport. The Cd content and transport time scale of the three sources to Jiaozhou Bay are as follows (Table 1):

| different sources | transported by run-off | transported by rivers | transported by the main sea current |
|-------------------|------------------------|----------------------|------------------------------------|
| Cd content/μg·L⁻¹ | 1.10                   | 0.96-1.53            | 1.11                               |
| time scale        | May                    | May, August and October | August                             |

3.4. Temporal and Spatial Variations of River Transport. Among rivers flowing into Jiaozhou Bay, there are four major rivers: Haibo River, Licun River, Loushan River and Dagu River. The Cd content and transport time scale of these rivers to Jiaozhou Bay are as follows (Table 2):

Cd content 1.07 μg/L was in the river transport of Haibo River. In May, the river transported Cd content to the waters of Jiaozhou Bay.

Cd content from Licun River was 1.10-1.20 μg/L. In May and October, the river brought Cd content into Jiaozhou Bay.

Cd content from Loushan River was 1.04-1.16 μg/L. In May and October, the river brought Cd content into Jiaozhou Bay.
Cd content from Dagu River was 0.96-1.53μg/L. In May and August, the river transported Cd content to Jiaozhou Bay.

Table 2 The Cd content and time scale from the different river sources in Jiaozhou bay

| different river sources | transported by Haibo River | transported by Licun River | transported by Loushan River | transported by Dagu River |
|-------------------------|---------------------------|---------------------------|-----------------------------|--------------------------|
| Cd content/μg·L⁻¹        | 1.07                      | 1.10-1.20                 | 1.04-1.16                   | 0.96-1.53                |
| time scale              | May                       | May and October           | May and October             | May and August           |

4. Discussion

4.1. Time Scale and Size of Transport Source. There are three main sources of Cd content in Jiaozhou Bay: run-off transport, river transport and main sea current transport.

First, the Cd content transported by run-off was relatively high 1.10μg/L. Only in May did run-off transported Cd content to Jiaozhou Bay. This indicates that the Cd content transported by run-off to Jiaozhou Bay water body was relatively high, but the transport time scale was also very short over a year.

Cd content from rivers was the highest, 0.96-1.53μg/L. In May, August and October, the rivers transported Cd content to Jiaozhou Bay. It shows that rivers were the main source of Cd content in Jiaozhou Bay, and they transported Cd content all year round. As a result, human activities on the land discharge large amounts of Cd. Rainwater collects Cd from human emissions on land, making rivers the most abundant source of Cd. In addition, Cd content was transported by rivers from land to sea throughout the year.

Relatively high Cd content 1.11μg/L transported by the main sea current. In August alone, the main sea current transported Cd content to Jiaozhou Bay. It indicates that Cd content produced by human activities was transported to land and sea through run-off transport and river transport. In particular, rivers continued to deliver Cd content to the ocean. Over many years of migration, Cd content in the ocean accumulated, leading to an increase in Cd content in the ocean. Therefore, the Cd content transported by the main sea current was relatively high. Moreover, water with high Cd content in the ocean was transported to water with low Cd content.

Over the course of a year, the river's Cd content was greater than 0.96μg/L. This suggests that land and rivers are slightly contaminated with Cd content during the year. During the year, Cd content in run-off and ocean current was greater than 1.10μg/L. The results showed that over the course of a year, the entire land and ocean were mildly contaminated with Cd content.

4.2. The Size and Time Scale of Transport of Different Rivers. Among the rivers around Jiaozhou Bay entering the sea, there are mainly four rivers: Haibo River, Licun River, Loushan River and Dagu River, all of which carried Cd content to the waters of Jiaozhou Bay (Figure 3). According to Cd content in the river, from high to low was: Dagu River > Licun River > Loushan River > Haibo River. The Cd content transport time scale of Licun River, Loushan River and Dagu River was the same, while that of Haibo River was shorter than that of other rivers. Among the rivers entering Jiaozhou Bay, Dagu River has the highest Cd content. However, Cd content transported by it declined rapidly over time. Cd content in Licun River and Loushan River was relatively stable. Although the time span was 5 months, the Cd content in transportation of two rivers did not exceed 0.10-0.12μg/L, so the Cd content in these two rivers transportation did not change with time. Therefore, Cd content in rivers, especially in Licun River, must be controlled.
4.3. The Mechanism of Land Transport. The production and use of products containing the heavy metal cadmium (Cd) continue to release Cd into the land, sea and atmosphere. As a result, a large number of Cd is stored on the ground. From the end of the first rainy season to the beginning of the second rainy season, that is, from November of the first year to May of the second year, after a long period of six months, whether the Cd content in the atmosphere sinks to the ground, or the Cd content is discharged to the ground by human activities, results in a large accumulation of Cd contents in the soil and on the ground.

In May, when the rainy season came, rainfall began to increase significantly. Cd deposited in the soil and on the surface was washed away by rain and discharged in large quantities into rivers. With the flood season of rivers beginning, Haibo River, Licun River, Loushan River and Dagu River and run-off in the north brought a lot of Cd content from Qingdao, Jimo Basin and Jiaolai Plain into the sea, leading to a great Cd content increase in the water bodies of Jiaozhou Bay. Cd content of inshore waters in Jiaozhou Bay reached 1.07-1.53 μg/L. It indicates that land and rivers around Jiaozhou Bay were slightly polluted with Cd content.

By August, after three months’ rainfall, Cd content in the soil and on the ground were very low. The Cd contents in Haibo River, Licun River, Loushan River and Dagu River were all less than 1.00 μg/L. This indicates that the coastal waters of Jiaozhou Bay reached high quality in Cd content. The water was clean and there was no pollution of the Cd content. In addition, the run-off in the north of Jiaozhou Bay transporting Cd content disappeared. So, after three months’ rainfall, the land will be clean.

4.4. Mechanism of Ocean Current Transport. In May, Haibo River, Licun River, Loushan River, Dagu River and run-off in the north carried a large number of Cd to the coastal waters of Jiaozhou Bay, with Cd content of 1.07-1.53 μg/L. In August, after three months’ transport of river and run-off, no large quantities of Cd were transported to the sea. At this time, the main sea current carried a large amount of Cd content of 1.11 μg/L into the waters of Jiaozhou Bay. In October, the transport of the main sea current ended and the rivers began to transport Cd to the ocean at a rate of 1.04-1.10 μg/L. As a result, during the three-month period from May to August, large quantities of Cd were transported from land to sea. After the end of land transportation in August, the Cd content in the ocean reached 1.11 μg/L. From
August to October for two months, Cd content was transported to Jiaozhou Bay by the main sea current. In October, the main sea current transport of Cd content ended, and the river began to transport it back to the sea.

In May, the Cd content transported by run-off from north was 1.10μg/L. In August, the main sea current carried 1.11μg/L of Cd. This proves that the Cd content transported by land and by sea was the same, meaning that land and sea had substance content consistency.

5. Conclusion
According to Dongfang Yang’s matter content migration rule, the spatial variation process of Cd content transported from source in May, August and October after the main sea current brought Cd content into Jiaozhou Bay is presented. The model block diagram is used to reveal the spatial variation process of Cd content in river transport. The location, size, type and time scale of Cd content in the waters of Jiaozhou Bay were determined. It was found that Cd content in the waters of Jiaozhou Bay mainly came from run-off transport, river transport and main sea current transport.

Rivers carried Cd content in excess of 0.96μg/L over the year, and land and rivers were slightly polluted. In addition, Cd content in run-off and main sea current was greater than 1.10μg/L, and the whole land and ocean were slightly polluted by Cd content.

Four major rivers—Haibo River, Licun River, Loushan River and Dagu River, carried Cd content into the waters of Jiaozhou Bay. The sequence of Cd content from high to low in the river is: Dagu River > Licun River > Loushan River > Haibo River. The Cd content transport time scale of Licun River, Loushan River and Dagu River was the same, while that of Haibo River was shorter than that of other rivers. Cd content in Licun River and Loushan River was relatively stable. Although the time span was 5 months, the Cd content of two rivers transport did not exceed 0.10-0.12μg/L. In this way, Cd content transported by the two rivers did not change over time. Therefore, Cd content in rivers must be controlled, especially in Licun River and Loushan River.

The authors propose a land transport mechanism: from the end of the rainy season in the first year to the beginning of the rainy season in the second year, namely from November in the first year to May in the second year, passing the long time of the six months, whether the Cd content in the atmosphere sinks to the ground, or the Cd content is discharged by human activities to the ground, it leads to a large amount of accumulation of Cd content in the soil and the ground. When the rainy season comes in May, rainfall begins to increase significantly and Cd content from the soil and ground is deposit in large quantities into the rivers. With the beginning of the flood season, Haibo River, Licun River, Loushan River and Dagu River, as well as run-off in the north, together bring a large amount of Cd content from Qingdao urban area, Jimo Basin and Jiaolai Plain to the sea, leading to a large increase of Cd content in the waters of Jiaozhou Bay.

The authors also suggest a mechanism for marine transport: in August, when land transport ended, Cd content in the ocean reached 1.11μg/L. Then, from August to October, the main sea current transported the Cd content to Jiaozhou Bay. The marine transport ended in October.

Through the land-sea migration mechanism proposed by the authors, the mechanism of Cd content alternating between land and sea is revealed. In May, the land began transporting large quantities of Cd into the sea; from May to August, the land transported Cd content to the sea for three months; In August, the transport from land to sea ended, and the main sea current began to transport Cd content in large quantities; from August to October, the main sea current transported Cd content to the ocean for two months; In October, transport of the main sea current ended, and rivers began to carry Cd to the ocean again.

In May, the Cd content transported by run-off in the north was 1.10μg/L. In August, the main sea current carried 1.11μg/L of Cd. This further confirms the authors’ matter uniformity theory, indicating that Cd content in land and sea transport was consistent, and land and sea also have the matter content consistency.
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