Spatial distribution characters of petroleum hydrocarbon in Jiaozhou Bay 1989

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Abstract. This paper analyzed the spatial distribution characters of petroleum hydrocarbon (PHC) in Jiaozhou Bay using investigation data in surface waters in April, July and October in 1989. Results showed that PHC contents in surface waters in the whole year ranged from 0.020-0.474 mg L⁻¹, and in April, July and October were 0.020-0.100 mg L⁻¹, 0.010-0.474 mg L⁻¹ and 0.006-0.082 mg L⁻¹, respectively. River discharge and marine current were the two major PHC sources, whose source strengths were 0.010-0.474 mg L⁻¹ and 0.082 mg L⁻¹, respectively. In general, the source strengths of river discharge and marine current were moderate and slight in 1989. The input sources of PHC were changing with season, resulted in different spatial distribution characters in surface waters. By means of the influences of the major sources, the spatial distribution characters of PHC in surface waters in Jiaozhou Bay have three modes of semi-circle/parallel, semi-circle and parallel, respectively. These findings implied that the source control of anthropogenic sources is essential to pollution control and environmental remediation.

1. Introduction
PHC pollution has been one of the critical environmental issues in many marine bays along with the rapid development of economic and population size [1-3]. Understanding the pollution level, distribution and source of pollutants in marine bay is essential to marine environmental protection. Jiaozhou Bay is a semi-closed bay located in south of Shandong Peninsula, eastern China. This bay has been polluted by various pollutants due to the rapid increasing of industry since China’s Reform and Opening-up [4-7]. This paper analyzed the spatial distribution characters of PHC in Jiaozhou Bay using investigation data in surface waters in April, July and October 1989. Results showed that river discharge and marine current were the two major PHC sources, whose source strengths were moderate and slight, respectively. The spatial distribution characters of PHC in surface waters were mainly impacted by the source inputs. These results were useful to provide scientific basis for the research on the source, pollution level and transfer process, and for the sustainable development of study area [8-11].

2. Study area and data collection
Jiaozhou Bay (120°04′-120°23′ E, 35°55′-36°18′ N) is located in the south of Shandong Province, eastern China (Fig. 1). It is a semi-closed bay with the total area, average water depth and bay mouth width of 446 km², 7 m and 3 km, respectively. There are more than ten inflow rivers such as Haibo River, Licun River, Dagu River, and Loushan River etc., most of which have seasonal features [12-13].
Data on PHC contents in surface waters in Jiaozhou Bay was provided by North China Sea Environmental Monitoring Center. The survey was conducted in April, July and October 1989. There were 10 sampling sites (04, 05, 06, 84, 85, 86, 87, 88, 89 and 90) in April and July compared to 7 sampling sites (84, 85, 86, 87, 88, 89 and 90) in October (Fig. 1). Surface water samples were collected and measured followed by National Specification for Marine Monitoring [14].

![Fig.1 Geographic location and monitoring sites in Jiaozhou Bay](image)

### 3. Results

#### 3.1. Contents of PHC.

In Chinese Sea Water Quality Standard (GB 3097-1997), there are 4 classes of water quality, and for PHC the guide lines of Class I (include II), III and IV are 0.05 mg L\(^{-1}\), 0.30 mg L\(^{-1}\) and 0.50 mg L\(^{-1}\), respectively. In April 1989, PHC contents were 0.020-0.100 mg L\(^{-1}\), and were Class I to III. In July 1989, PHC contents were 0.010-0.474 mg L\(^{-1}\), and were Class I to IV. In October 1989, PHC contents were 0.006-0.082 mg L\(^{-1}\), and were Class I to III. PHC contents in surface waters in the whole year ranged from 0.020-0.474 mg L\(^{-1}\), and were Class I to IV, and could be considered as moderate polluted in general.

#### 3.2. Horizontal distribution of PHC.

In April 1989, high value region occurred in Site 88 in the estuary of Licun River in the northeast of the bay, and the contour lines were forming a series of semi-circle/parallel lines that were decreasing from the high value center (0.100 mg L\(^{-1}\)) to the bay mouth in the south of the bay (0.020 mg L\(^{-1}\)) (Fig. 2). In July 1989, high value region occurred in Site 89 in the estuary of Haibo River in the northeast of the bay, and the contour lines were forming a series of semi-circle lines that were decreasing from the high value center (0.474 mg L\(^{-1}\)) to the bay center (0.010 mg L\(^{-1}\)), bay mouth (0.042mg L\(^{-1}\)), and the coastal waters in the northeast of the bay (0.042mg L\(^{-1}\)), respectively (Fig. 3). In October1989, high value region occurred in Site 90 in the bay mouth, and the contour lines were forming a series of parallel lines that were decreasing from the high value center (0.100 mg L\(^{-1}\)) to the bay mouth in the south of the bay (0.020 mg L\(^{-1}\)) (Fig. 4). In general, the spatial distribution characters of PHC in surface waters in Jiaozhou Bay have three modes of semi-circle/parallel, semi-circle and parallel, respectively.
Fig. 2 Distributions of PHC in surface waters in Jiaozhou Bay in April 1989/mg L$^{-1}$

Fig. 3 Distributions of PHC in surface waters in Jiaozhou Bay in July 1989/mg L$^{-1}$
Fig. 4 Distributions of PHC in surface waters in Jiaozhou Bay in October 1989/mg L\(^{-1}\)

4. Discussion

4.1. Spatial distribution of water quality.
In April 1989, PHC contents were 0.020-0.100 mg L\(^{-1}\) as a whole, yet there was a triangular high value region (between Site 87, 88 and 89) in where PHC contents were 0.054-0.100 mg L\(^{-1}\) and the water quality was moderately polluted as Class III (Fig. 5). In the other regions in April 1989 water quality of PHC was slightly polluted in Class I and II. In July 1989, PHC contents in the whole study area were 0.010-0.474 mg L\(^{-1}\), and there was a rectangular high value region (between Site 05, 06, 88 and 89) in where PHC contents were 0.121-0.474 mg L\(^{-1}\) and the water quality was moderate polluted as Class IV (Fig. 6). In the other regions in July 1989 water quality of PHC were slight polluted in Class I and II. In October 1989, PHC contents in the whole study area were 0.006-0.082 mg L\(^{-1}\), and the was a high value region around Site 90 in where PHC contents were about 0.082 mg L\(^{-1}\) and the water quality was moderate polluted as Class III, while in the other regions was slightly polluted in Class I and II. In general, the moderate polluted regions in April and July were in waters closed to estuaries of the major inflow river in the northeast of the bay, while in October was in the bay mouth.
4.2. Influences of sources of PHC.

In general, there might be different sources in different seasons that resulted in horizontal variations of water quality. In accordance with the spatial distributions of PHC in surface waters (Fig. 2 to Fig. 4) and the horizontal variations of water quality (Fig. 5 to Fig. 6), it could be found that river discharge was the major source in April and July 1989, while marine current was responsible in October 1989. In general, the source strengths of river discharge and marine current were 0.010-0.474 mg L\(^{-1}\) and 0.082 mg L\(^{-1}\), respectively (Table 1). In accordance with Chinese Sea Water Quality Standard (GB 3097-1997), the source strengths of river discharge and marine current were moderate and slight in 1989. It could be concluded that by means of the influences of the major sources, the spatial distribution characters of PHC in surface waters in Jiaozhou Bay have three modes of semi-circle/parallel (Fig. 7a), semi-circle (Fig. 7b) and parallel (Fig. 7c), respectively (Table 2). Furthermore, block diagram models were provided to demonstrate the spatial distribution characters that changing along with the changes of major source inputs (Fig. 7).
Table 1 Source and source strengths of PHC in Jiaozhou Bay 1989

| Source          | Licun River | Haibon River | Marine current |
|-----------------|-------------|--------------|----------------|
| Strength/mg L\(^{-1}\) | 0.100       | 0.474        | 0.082          |
| Class           | III         | IV           | III            |

Table 2 Source input and distribution modes of PHC in Jiaozhou Bay 1989

| Month          | April | July | October |
|----------------|-------|------|---------|
| Source input   | Licun River | Haibon River | Marine current |
| Distribution mode | Semi-circle/parallel | Semi-circle | Parallel |
| Pollution level | Slight | Moderate | Slight |

Fig. 7 Block diagram models of the spatial distribution modes of PHC in Jiaozhou Bay

5. Conclusion
PHC contents in surface waters in the whole year ranged from 0.020-0.474 mg L\(^{-1}\) that could be considered as moderately polluted in general, yet the seasonal and spatial variations were considerable. The moderately polluted regions in April and July were in waters closed to estuaries of the major inflow river in the northeast of the bay, while in October was in the bay mouth. River discharge and marine current were the major PHC sources and the source strengths were 0.010-0.474 mg L\(^{-1}\) and 0.082 mg L\(^{-1}\), respectively. By means of the influences of the major sources, the spatial distribution characters of PHC in surface waters in Jiaozhou Bay have three modes of semi-circle/parallel, semi-circle and parallel, respectively. Source control of anthropogenic sources is essential to pollution control and environmental remediation.

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