HCHs and DDTs in the Bohai Sea: Contamination, distribution and sources

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Abstract. Concentrations, distributions, and potential sources of DDTs and HCHs in seawater, sediments, soils, and atmosphere were collected to review their pollution statuses in the Bohai Sea and its coastal areas. In comparison to various sediment and seawater quality standards, DDTs and HCHs in sediments and seawater were at low levels in the entire Bohai Sea and might not cause adverse biological effects. However, DDTs and HCHs levels in various sea areas were closely associated with local pesticides production and application as well as hydrodynamic. DDTs and HCHs showed an obvious spatial distribution pattern. High levels were found in the Bohai Bay, Haihe River and Yellow River estuary. DDTs and HCHs concentrations in river and estuary sediments were higher than sea sediments and a seaward decreasing trend was observed. Although HCHs and DDTs residues in the Bohai Sea primarily originated from river runoffs (pesticide factory wastewater, historical applications and residues of technical HCH and DDT, etc.), additional sources of lindane and dicofol existed. Runoff from the demolished old pesticide factories might be another source. Further researches are highly recommended on pollution hotspots of DDTs and HCHs and investigate their migration and transformation at sediment-water interface and pollution history from sediment depth profiles.

1. Introduction
Organochlorine pesticides (OCPs) have been extensively applied worldwide in agriculture, forestry, and protection of livestock from pests in the last century; many OCPs produced in China were mainly dichlorodiphenyltrichloroethane (DDT) and its metabolites (DDD and DDE) and isomers of hexachlorocyclohexane (HCH)[1,2]. OCPs are of great concern to scientists and policy makers due to the toxic effects on human health and aquatic ecosystem[3, 4]. Two organochlorine compounds, HCH and DDT, were largely produced and widely used in China from 1951 to 1983. The total productions of HCHs and DDTs were up to 0.43 and 4.46 million tons, respectively[1]. Until now, DDTs and HCHs residues were still widespread in air, water, soils, sediments, and organisms all over the world [1, 5-8].

DDTs and HCHs usages in agriculture activities have been officially prohibited in 1983 in China, but high levels of DDTs and HCHs were still found in 2016 in the liver, muscle and egg of Kentish Plover from coastal wetland in western Bohai Bay, Northern China[9, 10]. Bohai Rim Region is one of the most developed areas in China. However, large quantities of treated or untreated wastewater from industrial, agricultural, and municipal activities have been discharged into the Bohai Sea. Rapid
economic development in past several decades has caused a severe environmental stress in the Bohai Sea and resulted in making the Bohai Sea one of the most polluted sea areas in China[11]. Many investigations on pesticides contamination in estuaries and marine environment in the Bohai Sea and its coastal rivers have been carried out since 20 years ago[12, 13]. However, those contaminants collected and measured in past two decades were not compared to show a trend in the levels of pesticides contamination. The spatial distribution patterns of DDTs and HCHs in seawater and surface sediments in the entire Bohai Sea and the relationships between their distributions and sedimentary environment or sources were still unclear. Therefore, DDTs and HCHs investigated in the period of 1998-2018 in the entire Bohai Sea were summarized to discuss their possible sources and the factors affecting DDTs and HCHs spatial distribution pattern.

2. Study area

Bohai Sea is the inland sea on the coast of Northeastern and North China, which has an area of approximately 7.8×10^4 km². Its proximity to Tianjin, Hebei (Qinhuangdao and Tangshan,), Liaoning (Jinzhou and Dalian), and Shandong (Dongying and Laizhou) makes it one of the busiest seaways in China. Bohai Sea consists of the Laizhou Bay to the south, the Liaodong Bay to the north, the Bohai Bay to the west, the Central Bohai, and the Bohai Strait. More than 40 coastal rivers (the Yellow River, the Haihe River, the Luanhe River, and the Liaohe River, etc.) flow into the Bohai Sea. Agricultural, industrial and municipal activities are highly developed in the Bohai Rim Region. The Bohai Rim Region accounts for 13.3% of total land area and 22.2% of total population of China, respectively. The large amount of effluent (household wastewaters and industrial wastewater) in the coastal area was discharged into the Bohai Sea[14,15].

The sediment of the Bohai Sea can be separated into eight fractions: sand, silt sandy, muddy sandy, sand silty, silt, sand muddy, mud, and gravel mud. Sand silty is widely distributed in the north and central areas of the Bohai Sea and the west area of the north Yellow Sea[16]. The sedimentation process in the Bohai Sea is obviously affected by the coastal rivers and oceanic circulation[16,17].

3. Results and discussion

3.1. Contamination and distribution

3.1.1. Sediments. The mean values and ranges of HCHs and DDTs in the surface sediments collected from the coastal rivers, estuaries, and the Bohai Sea were showed in Table 1 and Figure 1. The mean concentrations of DDTs and HCHs in the surface sediments collected during the period of 1996-2018 (summarized 432 samples) were 2.49 ng g⁻¹ DW (dry weight) and 4.85 ng g⁻¹ DW, respectively. The mean concentrations of HCHs and DDTs in the surface sediments met the first grade of China’s Marine Sediment Quality (GB18668-2002). As compared with the reference values of sediment quality standards the mean value of DDTs in the entire Bohai Sea was higher than the ERL value (Effects Range Low) but lower than the ERM value (Effects Range Median). The concentrations of DDTs and HCHs were below the ERL values, which indicate the adverse biological effects on marine organisms are rarely observed in sediments and the concentrations of DDTs and HCHs were above the ERM values, which indicate the adverse biological effects on marine organisms are frequently observed in sediments [18, 19]. In general, levels of DDTs and HCHs in the surface sediments collected from the Bohai Sea were low and the adverse biological effects of DDTs were minimal. However, further investigations and ecological risk assessments should be focused on several sea areas with high DDTs and HCHs levels in the sediments.

As seen from Figure 1, high HCHs concentrations in sediments were found in the Yellow River estuary, Liaohe River, Liaodong Bay and Haihe River. Meanwhile, high DDTs concentrations in sediments were found in the Jinzhou Bay, Haihe River, coastal rivers of Laizhou Bay, Bohai Bay and Yellow River estuary. The Yellow River is referred to as the Mother River of China, agricultural practices and industrial activities were highly developed in the Yellow River Delta. HCHs and DDTs...
were adsorbed on sediments in the deltalic depositional system and high concentrations of HCHs and DDTs were measured in the Yellow River estuary[27]. Among the various estuarine and coastal regions in China the highest HCHs concentrations in the old Yellow River estuary sediments core were reported in a previous study[29].

The concentrations of DDTs in Jinzhou Bay sediments were the highest among the various sea areas. DDTs in Jinzhou Bay were mainly originated from pesticides residues in the Wuli River basin. In the past, agricultural activities were highly developed in the upper reach in the Wuli River[12]. Meanwhile, the main form of tidal current in Jinzhou Bay is reversing current and high contents of DDTs were distributed in the Jinzhou Bay sediments[16].

The lowest HCHs and DDTs concentrations were found in the Laizhou Bay sediments among various sea areas. The results indicated low HCHs and DDTs residues in the Laizhou Bay due to strong hydrodynamic conditions and no pesticide factory located in the coastal region[16,28]. Laizhou Bay has the highest exchange ability among the three bays[17]. The depositional environment in Laizhou Bay was changed from river dominated to wave dominated environment[30].

There were high levels of DDTs in the lower reaches of the Haihe River and Bohai Bay sediments due to high residue of pesticides and low flow velocity. The distribution of OCPs were corresponded with the ocean current (wave and tide) of the Bohai Bay[31]. HCHs and DDTs residues in the surface sediments collected from the Dagu Drainage River (a tributary of the Haihe River) ranged from 2.30 to 124.61 ng g⁻¹ DW and from 11.28 to 237.30 ng g⁻¹ DW, respectively[6]. The mean concentration of HCHs and DDTs in the Haihe River sediments were up to 87.74 ng g⁻¹ DW and 35.52 ng g⁻¹ DW in

### Table 1. HCHs and DDTs (ng g⁻¹ DW) in the surface sediments in the Bohai Sea and its coastal estuaries.

| Site                  | Sampling Date | Sampling Size | HCHs       | DDTs       | Reference |
|-----------------------|---------------|---------------|------------|------------|-----------|
| Dalian Bay            | 1999          | 10            | 3.16 (1.11-7.96) | 2.31 (0.73-6.72) | [20]      |
| Liaohe River          | 2005          | 12            | 0.76 (1.86-21.48) | 5.87 (0.5-2.81) | [21]      |
| Liaohe River estuary  | 2007          | 35            | 3.8 (1.1-8.5) | 1.06 (0.8-12.6) | [22]      |
| Liaodong Bay          | 2014          | 8             | 1.21 (0.13-4.77) | 3.71 (0.11-3.54) | [23]      |
| Jinzhou Bay           | 1999          | 60            | 0.70 (0.07-7.25) | 0.66 (0.02-2.38) | [24]      |
| Haihe River           | 2003          | 26            | N/A        | 25.89 (0.97-154.87) | [12]      |
| Coastal rivers of     | 2006-2008     | 4             | 17.43 (1.88-18.76) | 15.94 (0.32-80.18) | [25]      |
| Laizhou Bay           | 2009          | 3.13 (2.08-10.07) | 7.77 (2.05-3.63) | 6.82 (4.81-11.35) | [26]      |
| Bohai Sea             | 2013          | 21            | 19.59 (1.06-3.17) | 7.20 (0.16-5.67) | [27]      |
| Mean value of Bohai Sea | 2013        | 342           | 2.49 (0.16-3.17) | 4.85 (0.24-5.67) | [19]      |
| Sediment Quality      |               |               |            |            |           |
| Standard, USNOAA      |               | 432           | 1.58 (N/A) | 46.1 (N/A) |           |
| The ERL value         |               | 1.85 (N/A)    | 1.58 (N/A) | 46.1 (N/A) |           |
| The ERM value         |               | 1.85 (N/A)    | 1.58 (N/A) | 46.1 (N/A) |           |
| The First Grade       |               | 1.85 (N/A)    | 1.58 (N/A) | 46.1 (N/A) |           |
| The Second Grade      |               | 1.85 (N/A)    | 1.58 (N/A) | 46.1 (N/A) |           |
| The Third Grade       |               | 1.85 (N/A)    | 1.58 (N/A) | 46.1 (N/A) |           |

*Data in bracket was the content range in sediments.
*N/A = Not Available, n.d. = Not Detected.*
another previous study[15]. Recently, high HCHs and DDTs residues were still detected in two estuary wetland sediments (Yongdingxinhe wetland and Binhai wetland) in the lower reaches of the Haihe River, which ranged from 69.81 to 379.28 ng g\(^{-1}\) DW (mean 224.55 ng g\(^{-1}\) DW) for HCHs, from 98.32 to 129.10 ng g\(^{-1}\) DW (mean 113.71 ng g\(^{-1}\) DW) for DDTs, respectively[13]. As compared with the mean concentration of HCHs (7.33 ng g\(^{-1}\) DW) in 2003, the mean concentration of HCHs (4.70 ng g\(^{-1}\) DW) decreased in the Haihe River sediments in 2008, which was due to the prohibition of production and application and biodegradation of DDTs and HCHs in sediments[15,25]. HCHs and DDTs were produced in Dagu Chemical Company near the Haihe River and applied for several decades in surrounding areas[14].

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Figure 1. Overview of ocean current and sediment type classification in the Bohai Sea[16,17]. Box plots of HCHs and DDTs concentrations from various sea areas. The lower and upper edges of the box represent the content ranges of HCHs and DDTs in the surface sediments, encompassing the mean value (line).

The distributions of HCHs and DDTs in the Bohai Sea were mainly affected by the hydrodynamic conditions (tidal current field) and river runoffs. The widespread of DDTs and HCHs mainly at the estuaries sites along the Bohai Sea coast was due to the emission into river of treated or untreated wastewater from industrial, agricultural and municipal activities in the past. DDTs and HCHs levels in
the surface sediments followed the order: rivers > estuaries > near-shore area[31]. The Haihe River flows seaward and empties into the Bohai Bay. Several decades ago large pesticide manufacturers (Dagu Chemical Company, Tianjin Chemical Company, etc.) were located near the lower reaches of the Haihe River. A tidal gate was built in the lower reaches of the Haihe River in 1958, the changed hydrodynamic conditions promoted the deposition of pollutants (heavy metals, HCHs and DDTs, etc.) with suspended particulate matter in river[15,32].

The concentrations of HCHs and DDTs in the sediments collected from the Liaohe River ranged from 1.86 to 21.48 ng g\(^{-1}\) DW (mean 6.82 ng g\(^{-1}\) DW) and 0.50 to 2.81 ng g\(^{-1}\) DW (mean 0.76 ng g\(^{-1}\) DW), respectively[21]. Agricultural activities were highly developed in the Liaohe River basin, HCHs and DDTs in surface sediments were mostly originated from the production of pesticides in the past and their residues[33]. HCHs and DDTs could be the most important contaminants in sediments due to their relatively higher usages in the past in northeastern Chinese river[34]. The mean concentrations in the Liaohe River estuary decreased from 4.20 ng g\(^{-1}\) DW in 2003 to 1.21 ng g\(^{-1}\) DW in 2014 for HCHs, and from 3.80 ng g\(^{-1}\) DW to 1.07 ng g\(^{-1}\) DW for DDTs, respectively[23]. This could be due to the decline of production and application and biodegradation of HCHs and DDTs in sediments.

Seawater HCHs and DDTs in seawater in the Bohai Sea were reviewed and shown in Table 2. The mean concentrations of DDTs and HCHs in seawater samples collected during the period of 1999-2007 (summarized 141 samples) were 72.59 ng L\(^{-1}\) and 12.43 ng L\(^{-1}\), respectively, which met the first grade of China’s Seawater Quality Standard (GB3097-1997). The results showed that risks associated with HCHs and DDTs in seawater in the entire Bohai Sea were relatively low. As seen from Table 2, lower DDTs and HCHs concentrations in seawater were found in Dalian Bay, Laohao River estuary and Laizhou Bay than other sea areas. High concentrations of HCHs and DDTs in Haihe River, Bohai Bay and Liaodong Bay were identified. The mean values in the Haihe River and Bohai Bay were up to 76 ng L\(^{-1}\) and 46 ng L\(^{-1}\) for DDTs, 660 ng L\(^{-1}\) and 160 ng L\(^{-1}\) for HCHs, respectively. DDTs concentrations in the Haihe River were higher than the first grade (50 ng L\(^{-1}\)) of China’s Seawater Quality Standard. DDTs and HCHs levels in seawater also followed the order: rivers > estuaries > near-shore area[14]. This could be related with several pesticide factories, which were located near the lower reaches of the Haihe River in the past. These factories have been dismantled, and runoff from ground in the demolished places (pesticide residue) would be a new input of HCHs and DDTs in the Haihe River[9,14]. Yet no new study on DDTs and HCHs in the Haihe River water was reported recently.

![Table 2. HCHs and DDTs (ng L\(^{-1}\)) in seawater in the Bohai Sea.](image)

| Site                  | Sampling Date | Sampling Size | HCHs (ng L\(^{-1}\)) | DDTs (ng L\(^{-1}\)) | Reference |
|-----------------------|---------------|---------------|----------------------|----------------------|-----------|
| Dalian Bay            | 1999          | 10            | 3.34                 | 1.01                 | [20]      |
|                       |               |               | (0.96-4.90)\(^{1}\) | (0.53-2.02)\(^{1}\) |           |
| Liaohe River Estuary  | 2007          | 35            | 10.2                 | 1.7                  | [22]      |
|                       |               |               | (3.4-23.8)           | (0.02-5.2)           |           |
| Liaodong Bay          | 1999          | 8             | 38.90                | 8.19                 | [20]      |
|                       |               |               | (26.81-47.10)        | (1.35-36.16)         |           |
| Haihe River           | 2004          | 11            | 660                  | 76                   | [14]      |
|                       |               |               | (30-1070)            | (9-152)              |           |
| Bohai Bay             | 2004          | 10            | 160                  | 46                   | [14]      |
|                       |               |               | (50-750)             | (n.d.-105)           |           |
| Yellow River Estuary  | 2013          | 24            | 18.57                | 9.79                 | [27]      |
|                       |               |               | (1.1-62.15)          | (1.46-35.52)         |           |
| Laizhou Bay           | 2005          | 43            | 5.3                  | 2.0                  | [35]      |
|                       |               |               | (n.d.-19.0)          | (n.d.-37)            |           |
| Mean value of Bohai Sea | 141          |               | 72.59                | 12.43                |           |
|                       | The First Grade|               | 1000                 | 50                   |           |
|                       | The Second Grade|             | 2000                 | 100                  |           |
|                       | The Third Grade|               | 3000                 | 100                  |           |
|                       | The Fourth Grade|             | 5000                 | 100                  |           |

\(^{1}\)Data in bracket was the content range in seawater.

\(^{n.d.}=\) Not Detected.

3.1.2. Coastal soils. HCHs and DDTs concentrations collected from coastal soils around the Bohai Sea (sampling size 889) were reviewed and shown in Table 3. DDT and HCH were found in all
analyzed sediments. The mean values of HCHs and DDTs in coastal soils around the Bohai Sea were 23.71 ng g⁻¹ DW and 40.01 ng g⁻¹ DW, respectively, which were lower than the risk screening values for soil contamination of agricultural land of China’s Soil Environmental Quality Standard (GB15618-2018). However, high concentration of HCHs (mean 93.9 ng g⁻¹ DW) was found in the soils near the Haihe River estuary and high concentration of DDTs (mean 63.6 ng g⁻¹ DW) was found in the soils in the western watershed of the Bohai Sea. The highest concentrations of OCPs in soils in Tianjin and Hebei Province were recorded among the urban and rural soils around the Yellow and Bohai seas in a previous study[36]. Dagu Chemical Company was located near the Haihe River estuary in the past. HCHs in soils in this region were originated from pesticide residue of agricultural activities and atmospheric deposition[37].

Pesticides were widely applied in the western watershed of the Bohai Sea in the past decades. Higher DDTs concentrations in soils were found in the western watershed of the Bohai Sea than other regions due to the pesticide residues. HCHs and DDTs residues were related to land use type. Higher pesticide residues were found in soils of vegetable lands than woodlands, cultivated lands and cotton fields[36,38]. HCHs and DDTs contamination were mainly occurred in the 0-30 cm surface soil layers, potential source analysis traced the occurrence of OCPs to both application in the past and application of lindane in recent years[39]. Despite OCPs did not show apparent adverse biological effects, contamination by pesticides residues still impacts on the quality of food, air, water, and soils[39-41].

| Site                                 | Sampling Date | Sampling Size | HCHs  | DDTs  | Reference |
|--------------------------------------|---------------|---------------|-------|-------|-----------|
| Haihe River estuary                  | 2007          | 186           | 93.9  | 34.4  | [37]      |
| Western Watershed of Bohai Sea       | 2006          | 302           | 3.87  | 63.6  | [38]      |
| Yellow River Estuary                 | 2013          | 54            | 9.66  | 8.39  | [27]      |
| Shenyang City                        | 2010          | 83            | 8.99  | 37.08 | [42]      |
| Offshore Area of Bohai Sea           | 2005-2008     | 264           | 4.45  | 24.35 | [43]      |
| Mean value in the coastal soils around Bohai Sea | 889          |               | 23.71 | 40.01 |           |

Table 3. HCHs and DDTs (ng g⁻¹ DW) in the coastal soils around the Bohai Sea.

- Data in bracket was the content range in seawater.
- n.d. = Not Detected.

3.1.3. Atmosphere. DDTs and HCHs atmospheric depositions were rarely studied in the Bohai Sea and coastal regions. DDTs and HCHs in atmosphere around the Bohai Sea were reviewed and summarized in Table 4; most of them were mainly focused on the atmosphere in the western watershed of the Bohai Sea. The results showed that the concentrations of HCHs and DDTs in Hangu and Tanggu were higher than urban areas in Tianjin, which might be due to that chemical industrial activities were concentrated in Hangu and Tanggu at that time. The median diameter and dispersion degree of HCHs and DDTs were at 2.1-2.5 μm and 3.1- 3.7 μm, respectively[44]. HCHs (0.32 ng m⁻³) and DDTs (0.21 ng m⁻³) concentrations were presented in Tianjin urban area atmosphere in 2018, which were lower than those in 2002[44,45].

| Site             | Sampling Date | Sampling Size | HCHs | DDTs | Reference |
|------------------|---------------|---------------|------|------|-----------|
| Tianjin          | 2002          | 0.581         | 1.874| 2.455| [44]      |
| Tianjin          | 2018          | 0.32          | 0.21 | N/A  | [45]      |
| Hangu, Tianjin   | 2006-2007     | 1.023         | 0.819| 1.842|           |
|                  | 2007-2008     | 1.019         | 1.928| 2.947|           |
| Tanggu, Tianjin  | 2006-2007     | 7.128         | 0.144| 7.272|           |
|                  | 2007-2008     | 5.242         | 0.215| 5.457|           |

- Data in bracket was the content range in seawater.
- n.d. = Not Detected.
3.2. Possible sources

The geochemical cycle of HCHs and DDTs in the Bohai Sea was significantly influenced by atmosphere deposition, volatilization, and river runoffs. The main sources of HCHs and DDTs in the Bohai Sea were shown in Figure 2. HCHs and DDTs atmospheric depositions and volatilization in the Bohai Sea have not been well studied. However, various OCPs in the Yellow Sea, East China Sea and South China Sea were monitored and the sea areas showed higher volatilization than deposition was reported in a previous study. Volatilization played an important role in the source of atmospheric OCPs[47]. A previous study in the East China Sea indicated that the highest particulate OCPs levels were originated from weathered agricultural soils and transported by continental outflow in winter. The lowest OCPs levels in the air found in summer, which were mainly come from illegal usage and net volatilization from the sea surface[48]. The new occurrences of DDTs and HCHs in atmosphere collected from the littoral cities of northern China were identified to the private or illegal applications of lindane and dicofol in small scale[45]. The possible new inputs in the surrounding provinces were also sources of DDTs and HCHs in the Bohai Sea[14].

There is no doubt that river runoffs were the most important sources for DDTs and HCHs in the Bohai Sea[22,26,37]. DDTs and HCHs in coastal rivers were originated from pesticide factory wastewater in the past, pesticide residues from agricultural activities, runoff from the demolished pesticide production facilities, and new use of small amount of lindane and dicofol until early 2000. Pesticide usage resulted in the residues of DDTs and HCHs in soils, the mean contents of HCHs in Chinese agricultural soils were 1.74 ng g\(^{-1}\) DW. Residues of HCHs were mainly originated from past application of technical HCHs[49]. Levels of HCHs and DDTs in soils were related with residues, volatilization, and atmospheric deposition[37,40,42]. Pesticide residues in soils could be an important reemission source of atmospheric OCPs via soil-air exchange processes[50]. OCPs in soils were also transported to coastal rivers by surface runoff and flowed into the Bohai Sea.

![Figure 2. Potential sources of HCHs and DDTs in the Bohai Sea.](image_url)

The ratios of \(\alpha\)-HCH to \(\gamma\)-HCH in soils and sediments were used to identify HCHs emission from lindane or technical HCH, and the ratios of (DDE+DDD) to DDTs were applied to judge DDTs sources from dicofol or technical DDT[1,29]. The high percentage of \(\gamma\)-HCHs may be from the later production of lindane (99% \(\gamma\)-HCH)[1]. Several recent investigations reported that a high percentage of \(\gamma\)-HCHs were recorded in the surface sediments collected from the Bohai Sea[9,13]. According to the analysis of the ratio, HCHs in the Bohai Sea sediments were originated mainly from historical
residue as well as fresh lindane. DDTs was come mainly from past residues in the Bohai Sea[14,51]. Dicofol was due to the recent input of DDTs usage[26]. The results indicated that lindane and dicofol might be new sources in marine environment in the Bohai Sea. The production of HCHs and DDT was officially banned in China in 1983, the small-scale production of lindane and HCH was not stopped until 2000 and 2003, respectively[9,23]. It should be noted that the potential environmental effects of lindane and dicofol are still worth attention.

4. Conclusions

HCHs and DDTs concentrations measured in seawater, surface sediments, soils, and atmospheres in the Bohai Sea and its coastal regions were reviewed. The mean concentrations in surface sediments were 4.85 ng g⁻¹ DW for DDTs and 2.49 ng g⁻¹ DW for HCHs, respectively, which were lower than the first grade of China’s Marine Sediment Quality. DDTs and HCHs in seawater were 12.43 ng L⁻¹ and 72.59 ng L⁻¹, respectively, which were lower than the first grade of China’s Seawater Quality Standard. DDTs were also below the ERL value of the proposed sediment quality standards, which represented a minimal-effects range and low ecological risk in the Bohai Sea.

DDTs concentrations in the Haihe River and Jinzhou Bay surface sediments were higher than other sea area. HCHs concentrations in the Yellow River estuary sediments were higher than other sea area. HCHs and DDTs concentrations in the sea sediments were lower than in the rivers and estuaries sediments, which showed that river runoffs were the most important sources for DDTs and HCHs in the Bohai Sea. HCHs and DDTs were mainly derived from pesticide factories wastewater, pesticide residue caused by agricultural activities, and runoff from the demolished old pesticide factories. Although continuous investigations of DDTs and HCHs in the Bohai Sea were not necessary, further investigations are highly recommended on tracing the pollution history in the pollution hotspots in the Bohai Sea through the analysis of sediment depth profiles and the desorption and migration at sediment-water interface.

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