Fate of DDT-related compounds in Bohai Bay and its adjacent Haihe Basin, North China

Yi Wan, Jianying Hu*, Jinling Liu, Wei An, Su Tao, Zhenbang Jia

College of Environmental Sciences, Peking University, Beijing 100871, China

Abstract

Concentrations of ten DDTs (2,2-bis-(chlorophenyl)-1,1,1-trichloroethane) of which \( p,p' \)-DDA (2,2-bis(chlorophenyl)acetic acid), \( p,p' \)-DDM (bis(chlorophenyl)methane) and \( p,p' \)-DBP (dichlorobenzophenone) are often neglected, were measured in 25 water and 25 sedimentary samples from Bohai Bay and its adjacent Haihe Basin. The ratio of \( o,p' \)-DDX/\( p,p' \)-DDX in the upper reaches of Yongdingxin River ranged from 0.71 to 2.44, suggesting that the potential source of pollution would be the manufacturing or use of dicofol near this river. While DDA accounted for 52–93% of the \( \sum \) DDT concentration in water, DDA was only detected in three sedimentary samples. And DDM was found to be an important degradation product of DDT in water following DDA. It should be noted that DBP (0.60–3.30 ng/g) is a major metabolite comparable with DDE (2,2-bis(chlorophenyl)-1,1-dichloroethylene, non-detectable-1.80 ng/g) and DDD (2,2-bis-(chlorophenyl)-1,1-dichloroethane, nondetectable-2.86 ng/g) in sediment in Bohai Bay. Finally, the \( \sum \) DDT concentration in sedimentary sample from Bohai Bay was found to be dependant on the TOC (total organic carbon) value.

Keywords: DDTs; DDA; DBP; DDM; TOC; Bohai Bay

1. Introduction

As a well-known pesticide, DDT (2,2-bis-(chlorophenyl)-1,1,1-trichloroethane) came into use worldwide for pest control in agriculture and vector control of human hygiene following the discovery of its insecticidal properties at the end of the 1930s. In the 1960s, evidence was found showing that DDTs were highly persistent in the environment and accumulated in higher animals (World Health Organization, 1989; Korte, 1992; Heberer and Dunnbier, 1999). Recent study indicates that some DDT isomers can be categorized as endocrine disrupting chemicals, especially DDE (2,2-bis(chlorophenyl)-1,1-dichloroethylene), which has been identified as interfering with the transport of calcium across the egg-shell gland mucosa with subsequent thinning of the egg-shell and decreased breeding success (Connell et al., 2003; Walker et al., 1996). Additionally, Kelce et al. (1995) reported that abnormalities in male sex development induced by \( p,p' \)-DDE may be mediated at the level of the androgen receptor.

DDT is one of the major pollutants in organochlorine compounds (OCs), which are considered among the most dangerous pollutants because of their toxicity and persistence, long biological half-life and high lipophilicity (Serrano et al., 2003). As manufactured, DDT contains the byproducts DDD (2,2-bis-(chlorophenyl)-1,1-dichloroethane) and DDE, both of which can be formed by chemical and biological degradation of DDT. These three compounds are sometimes referred to as total DDTs (Quensen et al., 2001), to which the ratio of \( p,p' \)-DDT can be used as an indicator to identify a recent input of technical DDT (Lee et al., 2001). Besides
DDE and DDD, DDMU (2,2-bis(chlorophenyl)-1-chloroethylene) was also detected in samples of environmental sediment (Pereira et al., 1996), and a recent study has demonstrated it is mainly derived from DDE, not from DDD (Quensen et al., 1998). In 1999, Heberer et al. first reported that DDA (2,2-bis(chlorophenyl)acetic acid) is a major contaminant in environmental water and the concentration level was as high as one microgram per liter in the surface water of the Teltowkanal in Berlin (Heberer and Dunnbier, 1999), which supported the laboratory results reported in 1945 (Heberer and Dunnbier, 1999) and prediction published in 1980 (Ware et al., 1980). Heberer’s study concluded that DDA is formed from biodegradation of DDD. This conclusion was based on the fact that the levels of DDD and DDA were higher than those of DDE and DDMU in samples from the river (Heberer and Dunnbier, 1999). Nevertheless, for cases in which DDE is more dominant than DDD in the environment as exemplified by many reports about DDT residue in environmental water (Garcia-Repetto and Repetto, 1997; Hung and Thiemann, 2002; Castilhoo et al., 2000), mechanism behind DDA formation is unclear.

In addition, although DDA was proposed as a very persistent key metabolite in aquatic systems, other metabolites such as DBP (dichlorobenzophenone) and DDM (bis(chlorophenyl)methane) have also been detected in laboratory experiments. DDM and DBP were reported to form in microorganisms from DDA (Lal and Saxena, 1982), and the photodecomposition is another pathway in DBP formation from DDA (Ware et al., 1980). But only a few investigations of DDT residue in the environment included these three metabolites. Heberer and Dunnbier (1999) identified that DBP was at lower concentrations in the surface water in Berlin’s Teltowkanal, but did not provide its concentration; Schwarz Bauer et al. (2003) detected many kinds of DDT metabolites in four sediment samples in the same river and found that DDA, DBP and DDM existed mainly in nonextractable particulate. Thus, to really reflect the fate of DDT residues in aqueous environments, it is necessary to thoroughly investigate the occurrence of many metabolites including not only DDT, DDD, DDE and DDMU, but also metabolites such as DDA, DBP and DDM in both water and sediment.

After China banned the use of DDT as a pesticide in the 1980s, DDT was used as an intermediate in the production of the pesticide dicofol, an insecticide for crops such as cotton, fruit trees and tea. The composition of dicofol is about 3.54–10.78% DDT, with o,p′-DDT as the major DDT compound, followed by o,p′-DDE and p,p′-DDE (Mao, 1995). The production and use of dicofol in China has become a new source of DDT pollution. This paper focused on the occurrence of DDT and its metabolites in the surface water and sediment of Bohai Bay and its adjacent Haihe Basin in northern China, and to bring to light new aspects in the fate of DDT residues in aqueous environment.

2. Materials and methods

2.1. Sampling area

Bohai Bay is a typical inner sea located in the northeast region of China. There are a number of rivers along the east coast of Haihe Basin, through which a large amount of wastewater are being transported into Bohai Bay, causing marine pollution (Fig. 1). The Yongdingxun River, which is connected with the Beijingpaiwu River, the Beiyun River and the Jiyun River, flows directly into Bohai bay. It receives wastewater not only from many factories located in the vicinity, but also from the city of Beijing. As a major estuary, the Haihe River stretches from the lower Beiyun River to the Bohai bay, crossing the intensely industrialized area of Tianjin. Most of the land in this river basin is residential, commercial and industrial. In addition to these two rivers, the Nanpaiwu River and the Beipaiwu River are the main rivers that discharge wastewater from the industrial area into Bohai Bay directly. The sample sites spread from the Bohai bay to the rivers in the Haihe Basin nearby to investigate the level and fate of DDTs throughout these areas. Surface water (0–50 cm beneath the surface) and sediment samples (0–30 cm beneath the surface) were collected from 25 sites...
in September of 2002, and stored at −20 °C until extraction was carried out.

2.2. Chemical analysis

2.2.1. Reagent

- o,p′-DDD, p,p′-DDD, o,p′-DDT, p,p′-DDT, o,p′-DDE, p,p′-DDE were all purchased from Chemservice (Chester, England), and p,p′-DDMU was from Sigma. p,p′-DDA p,p′-DDM and p,p′-DBP were purchased from Accu Standard (Connecticut, USA). The structures of these chemicals were showed in Fig. 4.

- Dichloromethane (DCM), ethyl ester, acetonitrile, hexane and methanol were HPLC grade (Fisher Chemical Co., China). Ultra pure water was prepared using an Easypure UV Compact Ultrapure System (Fisher Chemical Co., China) with a conductivity of 18.3 Ω cm.

2.2.2. Nonpolar DDT derivatives

For each water sample, 21 were filtered using 0.45 mm glass fiber filter paper (Millipore Co., Bedford), and adjusted to a neutral pH before solid phase extraction (SPE) was conducted. Cartridges with a syringe of 6 ml (Waters Sep-Pak C-18, with a syringe volume of 6 ml), which were conditioned with 6 ml methanol and 6 ml deionized water, and then eluted with 10 ml methanol/dichloromethane (2:8 v/v). The eluate was dried and dissolved in 1 ml of methanol for liquid chromatograph-mass spectrometer (LC-MS) analysis.

- Sediment samples (10 g + 20 g of Na2SO4) were Soxlet extracted with 250 ml methanol (containing 0.1% KOH) for 24 h. Extracts were concentrated to about 2 ml by rotary evaporation, and 250 ml deionized water were then added to them. The extracts were concentrated by the SPE procedure similar to the one used for the water samples.

2.2.3. p,p′-DDA

SPE was also used for water sample preparation to detect p,p′-DDA. A 2 l water sample was passed through the cartridges (Waters Sep-Pak C-18, with a syringe volume of 6 ml), which were conditioned with 6 ml methanol and 6 ml deionized water, and then eluted with 10 ml methanol/dichloromethane (2:8 v/v). The eluate was dried and dissolved in 1 ml of methanol for liquid chromatograph-mass spectrometer (LC-MS) analysis.

- LC-ESI-MS was performed on an Alliance 2690 HPLC (Waters Corporation, USA) equipped with a quaternary gradient pump, an auto-sampler with a 100 ml injection loop and a C18 analytical column (2.1 mm in ID x 150 mm). The flow rate was kept at 0.2 ml/min, and a methanol and water containing 0.1% formate was used as the mobile phase. The composition of methanol in the mobile phase was changed to 90% methanol within 15 min, and then this percentage was maintained for 15 min. A platform ZMD (ZSpray Mass Detector) single-quadrupole mass spectrometer (Micromass, Manchester, UK) was used, with a Z-Spray ion source fitted with a pneumatically assisted electro-spray probe. In the positive mode, typical ion source parameters were used as follows: ESI capillary voltage of 3.5 kV; extractor voltage of 5 V; source block temperature of 120 °C; desolvation temperature of 180 °C; ion energy of 0.8 V; and multiplier voltage of 650 V. Nitrogen was used as the desolvation gas with a flow rate between 270 and 350 l/h, and as the cone gas with a rate of 70–100 l/h. The extraction cone voltage was ramped from 25 to 70 V for a dalton mass range of 0–300 for the full scan mass, and with a scan time of 1.2 s. The injection volume was 20 μl. In the LC-ESI-MS mass spectra of a standard DDA sample, no molecular ion [M-H]+ were found, and the base ion was m/z 235. For quantification of DDA, the selection ion mode was used, and the selected ions were m/z 235, 237 and 239.

2.2.4. Organic carbon analysis

Dry sediment (about 5 mg) was put into a small quartz sample boat, which had been heated at 600 °C for about 4 h. Then phosphoric acid (4%) was added...
into the boat to get rid of the total inorganic carbon (TIC) in the sample. Finally, the sample was analyzed using a Total Organic Carbon Analyzer (Apollo 9000, Tekmar-Dohrmann Co., USA).

3. Results and discussion

3.1. Determination of DDA in water and sediment

Fig. 2 shows the LC-ESI-MS chromatogram of a water sample collected from site E at the Haihe Basin. DDA was identified and quantified by its indicative ions at m/z 239, 237, 235. Applying LC-MS with SIM mode, the analytes could be detected and quantified in environmental water and sediment sample. Using this method, detection limits for analyzing DDA in water and sediment were 1 ng/l and 0.4 ng/g. And the recovery of DDA for water and sediment sample was 98% and 95%, respectively.

3.2. Occurrence of DDTs in the Haihe Basin

A chemical production plant (site K) that produces dicofol pesticide using DDT as a raw material is located in the upper reaches of the Yongdingxin River in the Haihe Basin. Due to the production and application of dicofol pesticide, the contaminants of o,p'-DDT, o,p'-DDE and o,p'-DDD in dicofol could contribute to the DDT residues in the Haihe Basin. Another chemical production plant producing DDT (site L) is located in the upper reaches of the Jiyun River (Fig. 1). Thus, there are two potential sources of DDT pollution in the Haihe Basin. In the study reported in this paper, a comprehensive assessment including DDT, DDD, DDE, DDMU, DDA, DDM and DBP in both water and sediment was carried out in the Haihe Basin.

In ten of the sites sampled, sites A-J, DDT residues were detected in 5 water and 9 sediment samples as shown in Tables 1 and 2. The concentration of ΣDDT in water samples ranged from 88.50 to 1964 ng/l and from 0.60 to 222 ng/g dry weight in sediment samples. At sites C, D and E, which were near the dicofol plant (Fig. 1), there were high concentrations in water samples ranged from 88.50 to 1964 ng/l and from 0.60 to 222 ng/g dry weight in sediment samples. Additionally, the ratios of o,p'-DDE/p,p'-DDE and o,p'-DDD/p,p'-DDD in the river ranged from 1.3 to 2.4 and 0.7 to 1.4, respectively, which were similar with the ratios in Hong Kong (Louie and Sin, 2003) and Taihu Lake (Qiu et al., 2004). But these observations contradict the fact that technical DDT contains less o,p'-DDT (15%) than p,p'-DDT (85%) suggesting that a new source of o,p'-DDE and o,p'-DDD would exist. It should be noted that a high ratio of o,p'-DDX/p,p'-DDX (DDE 0.89, DDD 1.34, DDT 2.0) was also found in the sample from the wastewater reservoir of a dicofol plant (site K) located at the upstream of the Site C in Fig. 1, which indicate that this new source is very likely the pesticide dicofol discharged from the dicofol plant as described in previous paper (Qiu et al., 2004). The disappearance of DDT from water and sediment in the Yongdingxin River indicated that DDT has not been used recently in this region. At the sites G and F (Fig. 1), DDT was the major component in sediment samples. Since the ratio of DDT/ DDE can be used as a rough estimate of the period of DDT use (Kale et al., 1999), the ratio of DDT/DDX (15.7–15.8) and low o,p'-DDT/p,p'-DDT (0.28) are evidences of the wastewater recently drained into the Jiyun River due to the production or use of DDT pesticides.

Table 1

<table>
<thead>
<tr>
<th>Site</th>
<th>p,p'-DDA</th>
<th>p,p'-DDM</th>
<th>p,p'-DBP</th>
<th>p,p'-DDMU</th>
<th>DDE</th>
<th>DDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>800</td>
<td>870</td>
</tr>
<tr>
<td>C</td>
<td>1799</td>
<td>20.59</td>
<td>122</td>
<td>2.29</td>
<td>13.70</td>
<td>70</td>
</tr>
<tr>
<td>D</td>
<td>868</td>
<td>27.60</td>
<td>120</td>
<td>10.40</td>
<td>16.88</td>
<td>650</td>
</tr>
<tr>
<td>E</td>
<td>1365</td>
<td>15.70</td>
<td>166</td>
<td>5.00</td>
<td>34.86</td>
<td>100</td>
</tr>
<tr>
<td>F</td>
<td>46</td>
<td>17.50</td>
<td>25.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>G</td>
<td>308</td>
<td>28.59</td>
<td>8.50</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

DDT concentrations at sites not listed in this table were all under the detection limit.
ND = nondetectable.
Of the 10 kinds of DDT metabolites, eight were detected in water samples, and nine were found in sediment samples collected mainly from the Yongdingxin River and the Jiyun River.

In the Yongdingxin River, the concentration of DDA in water samples from sites C, D, and E ranged from 869 to 1799 ng/l, accounting for 52–89% of the total DDTs concentration. DDA was also detected in sediment, and the concentration ranged from 1.0 to 9.7 ng/g dry weight. While these results are similar to those reported for the Teltowkanal (Heberer and Dunnbier, 1999), the profile of other DDT metabolites in the Haihe Basin is different from the profile for the Teltowkanal. In our investigation, \( p,p'\)-DDE is more dominant than \( o,o'\)-DDD, and \( p,p'\)-DDMU was detected in water samples from the Yongdingxin River (0.1–0.7%). Thus, it is difficult to determine whether DDA was formed from DDD only based on its concentration in water as described by Heberer and Dunnbier (1999). Laboratory experiments reported that DDM was converted from DDA or DDD by microorganisms (Lal and Saxena, 1982) and DBP was a photodegradation product of DDA (Ware et al., 1980) and DDM, or a degradation product formed together with DDE in microorganisms (Lal and Saxena, 1982). In the present study, DDM and DBP were also detected in the sediment and water samples from rivers.

It is interesting that while DDT, DDE, DDD and DDMU appeared only in sediment samples from sites F and G of the Jiyun River, only DDA, DDM and DBP were detected in water samples from the same sites. It should be noted that DDM was first detected in water samples, accounting for 0.8–19% of total DDTs. Our results indicated that DDM is another major DDT metabolite in aquatic systems following DDA, and is possibly a common degradation product in water.

### 3.3. DDT metabolites profile for the Bohai Bay

**Table 2**

<table>
<thead>
<tr>
<th>Site</th>
<th>( p,p')-DDA</th>
<th>( p,p')-DDM</th>
<th>( o,o')-DDM</th>
<th>( p,p')-DDMU</th>
<th>( o,o')-DDMU</th>
<th>( o,o')-DDD</th>
<th>( p,p')-DDD</th>
<th>( p,p')-DDT</th>
<th>( o,o')-DDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>B</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.90</td>
<td>3.60</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>C</td>
<td>8.0</td>
<td>ND</td>
<td>41.27</td>
<td>5.80</td>
<td>49.00</td>
<td>24.50</td>
<td>54.30</td>
<td>39.50</td>
<td>ND</td>
</tr>
<tr>
<td>D</td>
<td>1.0</td>
<td>ND</td>
<td>19.00</td>
<td>0.65</td>
<td>7.07</td>
<td>2.89</td>
<td>3.78</td>
<td>2.90</td>
<td>ND</td>
</tr>
<tr>
<td>E</td>
<td>9.7</td>
<td>ND</td>
<td>6.58</td>
<td>0.50</td>
<td>2.00</td>
<td>1.60</td>
<td>1.70</td>
<td>2.37</td>
<td>ND</td>
</tr>
<tr>
<td>F</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.48</td>
<td>0.59</td>
<td>1.10</td>
<td>1.80</td>
<td>4.70</td>
<td>6.18</td>
</tr>
<tr>
<td>G</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.79</td>
<td>0.58</td>
<td>1.10</td>
<td>1.89</td>
<td>4.60</td>
<td>5.80</td>
</tr>
<tr>
<td>H</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.88</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>I</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>6.60</td>
<td>7.80</td>
<td>22.70</td>
<td>ND</td>
</tr>
<tr>
<td>J</td>
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<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND = nondetectable.

**Fig. 3** shows DDT profiles for water and sediment samples from Bohai Bay, adjacent to the Haihe Basin.

Of ten kinds of DDT metabolites, six were detected in water samples, and the \( \sum \)DDT concentration ranged from 1.00 to 13.29 ng/l. The ratio of \( o,o'\)-DDE/\( p,p'\)-DDE ranged from 0 to 0.74 and the ratio of \( o,o'\)-DDD/\( p,p'\)-DDD ranged from 0 to 0.68, indicating that DDT pollution in Bohai Bay was mainly due to DDT production or use in the Haihe Basin. While \( p,p'\)-DDE concentrations (\(<0.25\) ng/l)–2.30 ng/l) were higher than \( p,p'\)-DDD concentrations (\(<0.25\) ng/l)–2.00 ng/l), DDA was still the primary pollutant in water samples from all the sites, except for the sites numbers 8, 9, 12, 13, 14, accounting for 59–93% of the total DDT concentration. The profile for DDT pollutants in the bay was similar to the pollution profile for the Haihe Basin. The levels of \( p,p'\)-DDM in water samples (\(<0.25\) ng/l)–2.66 ng/l) was similar to the \( p,p'\)-DDE levels even for sites where...
no DDA was detected, providing that DDM should not be overlooked as a potential pollutant in environmental water. In addition, \( p,p' \)-DDMU and \( p,p' \)-DBP were not detected in water samples from Bohai Bay.

Four kinds of DDT metabolites (DDD, DDE, DDMU and DBP) were detected in sediment samples collected from Bohai Bay, and the \( \Sigma \)DDT concentration ranged from 0.20 to 11.09 ng/g (Fig. 3(b)). DDA and DDM were lower than detection limit, possibly due to the fact that they would mainly be absorbed by non-extractable particulates as reported by Schwarzbauer et al. (2003), so they could not be extracted by the method used in the present study. \( p,p' \)-DBP was detected in the sediment samples from all of the sites except for sites 14 and 15. While \( p,p' \)-DBP was reported to also be absorbed by non-extractable particulates, it was still a major DDT metabolite in sediment (\(< 0.05 \text{ ng/g} \)– 3.30 ng/g dry weight), as it was detected in amounts comparable to \( p,p' \)-DDD measurements (\(< 0.05 \text{ ng/g} \)– 2.86 ng/g dry weight). So DBP is a metabolite which should not be overlooked as a possible pollutant in sediment. Even in some sites without DBP and DDD, trace amount of DDE and DDMU were still found, indicating the persistence of the two chemicals in sediment.

Fig. 4 shows the major metabolites detected in sediment and water from Bohai Bay and their proposed pathways reported in previous papers (Quensen et al., 1998; Pereira et al., 1996; Bumpus and Aust, 1987; Sayles et al., 1997; Heberer and Dunnbier, 1999; Ware et al., 1980). The concentrations of DDE were found to be higher than those of DDD in water samples, and vice versa in sediment, which can be explained by the well-known fact that DDT dechlorinates to DDD under anaerobic conditions and dehydrochlorinates to DDE under aerobic conditions (Heberer and Dunnbier, 1999). So, the results that DDA and DDM were mainly residual in water, and DBP and DDMU in sediment suggest that the formation of DDA and DDM would occurred at similar redox potential with DDE, DBP and DDMU at similar potential with DDD.

The spatial distribution of DDTs in both water and sediment from Bohai Bay indicate that \( \Sigma \)DDT concentrations decreased with increasing distance from the coast. However, \( \Sigma \)DDT concentration in water samples differed from those in sediment samples. While \( \Sigma \)DDT concentrations in sediment samples in Bohai Bay were only high near the estuary of the Yongdingxin River and the Jiyun River, \( \Sigma \)DDT concentrations in water samples were relatively high around both the estuary and coastal area. The difference between concentrations in water and sediment may be due to that water are fluid and easier influenced by many factors such as wind, tide etc. In addition, for the sediment samples, a close relationship between \( \Sigma \)DDT concentrations and TOC was obtained except for the sample at site 16 located in the dock (Fig. 5). It should be noted that while TOC is a major factor influencing the spatial distribution of total DDTs, no relationship between TOC and each metabolite of DDT was found. The difference of composition profiles of DDTs found in variable locations may be due to the variation of redox conditions in the environment, and further studies are needed.

This first comprehensive investigation of DDT-related compounds in the Haihe Basin and Bohai Bay showed that the main sources of DDT pollution were
the production and use of dicofol in the Haihe Basin and of DDT in the Bohai bay, on the basis of ratio of $o,p'-\text{DDX} / p,p'-\text{DDX}$ found in the environment. While DDA was the major metabolite in water samples both from the Haihe Basin and Bohai Bay, DDM content was also significant compared to DDD and DDE. On the other hand, DBP residue was found in sediment, indicating that this metabolite should not be overlooked. Heberer et al. proposed that DDA is formed by the biodegradation of DDD because DDD is a major metabolite of DDT following DDA (Heberer and Dunnbier, 1999). Nevertheless, further studies are necessary to clarify how DDA, DDM and DBP are formed in the environment because in this study, the residual DDE levels were higher than residual DDD levels in water.

Acknowledgments

Financial supports of National Basic Research Program of China [2003CB415004], Japan International Cooperation Agency, and the National Natural Science Foundation of China [40021101] are gratefully acknowledged.

References


